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Research Article

Solution to Fuzzy Multi-Objective Assignment Problems using Diagonal Optimal Method

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Abstract. In this paper a new algorithm diagonal optimal method is proposed to obtain optimal solution to fuzzy multi-objective assignment problem with several fuzzy parameters. The method is illustrated with a numerical example.

Keywords. Fuzzy multi-objective assignment problem, Trapezoidal fuzzy number, Ranking of fuzzy numbers, Diagonal optimal method

Mathematics Subject Classification (2020). 62A86, 62B86, 62C86

1. Introduction

Assigning various tasks to an equal number of people while keeping project costs as low as possible is known as the "*Assignment Problem*". The fuzzy set notion was first presented by Zadeh (1965) [12] to account for the uncertainty and imprecision inherent in real-world situations. They worked together on a multi-objective optimization problem in 2004 [7] Marler and Arora, fuzzy multi-objective undertakings were addressed in 2006 by Feng and Yang [3].

Using their fuzzy ranking approach, Thorani and Shankar [10] submitted and resolved a fuzzy assignment problem in 2017. It's a three-parameter challenge, and the parameters are as follows. The fuzzy undertaking hassle is extra sensible than classical venture trouble because most actual environments are uncertain. Several authors have mentioned fuzzy assignment problem the use of extraordinary techniques. Kar *et al*. [5] discussed fuzzy ranking and fuzzy regulations to solve fuzzy project issues.

Trapezoidal fuzzy numbers and a three-parameter fuzzy assignment problem: fuzzy value, fuzzy time, and fuzzy inefficiency are discussed in this article. By using a weighted average, a single objective fuzzy assignment problem may be addressed without having to transform the problem into a crisp one. The most up-to-date inspiration processes result in the most precise and best answer. The diagonal optimum approach given herein yields the answer in Trapezoidal fuzzy quantity form. Here we have to avoid the Trapezoidal fuzzy numbers into crisp.

2. Preliminaries

Definition 2.1 (Fuzzy set [12])**.** A fuzzy set A is distinguished by a membership function that maps items of a domain, space, or universe of discourse X to the unit interval $[0,1]$. $\widetilde{A} = \{(x, \mu_{\widetilde{A}}(x)) : x \in X\}$ here $\mu_{\widetilde{A}} : X \to [0,1]$ is a mapping called the degree of membership function of the fuzzy set A and $\mu_{\widetilde{A}}(x)$ called the membership function value of $x \in X$ in the fuzzy set $\widetilde{A}$. The real numbers may be used to symbolise the various levels of membership $[0,1]$.

Definition 2.2 (Fuzzy number [12])**.** A fuzzy number is a subset of the universal real number set R that is defined as a fuzzy set, with the membership function $\mu_{\widetilde{A}}(x)$ if it satisfies the properties given below:

(i) $\widetilde{A}$ is convex.

(ii) $\widetilde{A}$ is normal i.e., there is a $x_0 \in \widetilde{A}$ such that $\mu_{\widetilde{A}}(x_0) = 1$.

(iii) $\mu_{\widetilde{A}}(x)$ is a piecewise continuous in its domain.

(iv) $\widetilde{A}$ is convex i.e., $\mu_{\widetilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_{\widetilde{A}}(x_1), \mu_{\widetilde{A}}(x_2))$, for all $x_1, x_2 \in X$.

Definition 2.3 (Trapezoidal fuzzy number [10])**.** A fuzzy member $\widetilde{A} = (a,b,c,d)$ is said to be trapezoidal fuzzy member if its membership function is given by

$$\mu_{\widetilde{A}}(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}, & a \leq x \leq b, \\ 1, & b \leq x \leq c, \\ \dfrac{(x-d)}{(d-c)}, & c \leq x \leq d. \end{cases}$$

2.1 Arithmetic Operations on Trapezoidal Fuzzy Number

Fuzzy arithmetic procedures on two trapezoidal fuzzy numbers $\widetilde{A}_1 = (a_1, b_1, c_1, d_1)$, $\widetilde{A}_2 = (a_2, b_2, c_2, d_2)$ are defined as follows:

Fuzzy addition: $(a_1,b_1,c_1,d_1)+(a_2,b_2,c_2,d_2)=(a_1+a_2,b_1+b_2,c_1+c_2,d_1+d_2)$

Fuzzy Subtraction: $(a_1,b_1,c_1,d_1)-(a_2,b_2,c_2,d_2)=(a_1-d_2,b_1-c_2,c_1-b_2,d_1-a_2)$

3. Model of Fuzzy Multi-Objective Assignment

It is a fuzzy multi-objective assignment paradigm described in this part, which includes fuzzy time, fuzzy cost, and fuzzy inefficiency, and so on, as well as its mathematical formulation.

In a common *assignment problem*, n tasks must be completed with the assistance of n individuals, in order to keep costs down or up depending on their ability to execute the work on a one-to-one basis. When the purpose of a job is to keep fuzzy costs and fuzzy time to a minimum, then, fuzzy inefficiency and so forth, then this type of fuzzy venture trouble with numerous parameters inside the following form of $n\times n$ fuzzy matrix in which every cell having a fuzzy cost ($\widetilde{c}_{ij}$), fuzzy time ($\widetilde{t}_{ij}$), fuzzy inefficiency ($\widetilde{q}_{ij}$) and so forth is proven in Table 1.

Table 1. General fuzzy multi-objective assignment model

$\widetilde{c}_{11},\widetilde{t}_{11},\widetilde{q}_{11},\dots$	$\widetilde{c}_{12},\widetilde{t}_{12},\widetilde{q}_{12},\dots$	$\dots$	$\widetilde{c}_{1j},\widetilde{t}_{1j},\widetilde{q}_{1j},\dots$	$\dots$	$\widetilde{c}_{1n},\widetilde{t}_{1n},\widetilde{q}_{1n},\dots$
$\widetilde{c}_{21},\widetilde{t}_{21},\widetilde{q}_{21},\dots$	$\widetilde{c}_{22},\widetilde{t}_{22},\widetilde{q}_{22},\dots$	$\dots$	$\widetilde{c}_{2j},\widetilde{t}_{2j},\widetilde{q}_{2j},\dots$	$\dots$	$\widetilde{c}_{2n},\widetilde{t}_{2n},\widetilde{q}_{2n},\dots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\widetilde{c}_{i1},\widetilde{t}_{i1},\widetilde{q}_{i1},\dots$	$\widetilde{c}_{i2},\widetilde{t}_{i2},\widetilde{q}_{i2},\dots$	$\dots$	$\widetilde{c}_{ij},\widetilde{t}_{ij},\widetilde{q}_{ij},\dots$	$\dots$	$\widetilde{c}_{in},\widetilde{t}_{in},\widetilde{q}_{in},\dots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\widetilde{c}_{n1},\widetilde{t}_{n1},\widetilde{q}_{n1},\dots$	$\widetilde{c}_{n2},\widetilde{t}_{n2},\widetilde{q}_{n2},\dots$	$\dots$	$\widetilde{c}_{nj},\widetilde{t}_{nj},\widetilde{q}_{nj},\dots$	$\dots$	$\widetilde{c}_{nn},\widetilde{t}_{nn},\widetilde{q}_{nn},\dots$

3.1 Mathematical Formulation of the Multipurpose Ambiguous Assignment Problem

The mathematical formulation of a fuzzy multi-objective assignment problem in Table 1 can be stated as,

$$\text{Minimize } \widetilde{z}_K=\sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{P}_{ij}^{K})X_{ij},\quad K=1,2,\dots,n$$

subject to

$$\sum_{i=1}^{n}X_{ij}=1,\quad j=1,2,\dots,n,$$

$$\sum_{j=1}^{n}X_{ij}=1,\quad i=1,2,\dots,n,$$

$$X_{ij}=0 \text{ or } 1,\quad \text{for all } i=1,2,\dots,n \text{ and } j=1,2,\dots,n,$$

$$X_{ij}=\begin{cases}1, & \text{if } i\text{the person is assigned } j\text{th work,}\\ 0, & \text{otherwise,}\end{cases}$$

where $\widetilde{Z}_K=\{\widetilde{Z}_1,\widetilde{Z}_2,\widetilde{Z}_3,\dots,\widetilde{Z}_k\}$ is a vector of K-objective functions.

There is no longer a fuzzy multi-objective assignment issue, but just one objective assignment problem by taking into account the weights associated with the goal's priority in the sort of way that $W_1 + W_2 + \cdots + = 1$.

$$\text{Minimize } \widetilde{Z} = W_1 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{c}_{ij})X_{ij} + W_2 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{t}_{ij})X_{ij} + W_3 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{q}_{ij})X_{ij} + \cdots$$

subject to

$$\sum_{i=1}^{n} X_{ij} = 1, \quad j = 1,2,\dots,n,$$

$$\sum_{j=1}^{n} X_{ij} = 1, \quad i = 1,2,\dots,n,$$

and $W_1 + W_2 + W_3 + \cdots + = 1$,

$X_{ij} = 0$ or 1, for all $i = 1,2,\dots,n$ and $j = 1,2,\dots,n$,

$$X_{ij} = \begin{cases} 1, & \text{if } i\text{th person is assigned } j\text{th work,} \\ 0, & \text{otherwise.} \end{cases}$$

$\widetilde{Z}_1$ denotes the fuzzy cost function is defined as follows:

$$\text{Minimize } \widetilde{Z}_1 = \sum_{i=1}^{n}\sum_{j=1}^{n} \widetilde{c}_{ij} X_{ij}.$$

$\widetilde{Z}_2$ denotes the fuzzy time function is defined as follows:

$$\text{Minimize } \widetilde{Z}_2 = \sum_{i=1}^{n}\sum_{j=1}^{n} \widetilde{t}_{ij} X_{ij}$$

$\widetilde{Z}_3$ denotes the fuzzy inefficiency function is defined as follows:

$$\text{Minimize } \widetilde{Z}_3 = \sum_{i=1}^{n}\sum_{j=1}^{n} \widetilde{q}_{ij} X_{ij}$$

$\widetilde{Z}_1$, $\widetilde{Z}_2$, $\widetilde{Z}_3$ are called three objective fuzzy assignment problems.

By normalising the fuzzy cost, the three-objective fuzzy assignment issue is reduced to a single-objective fuzzy assignment problem $(\widetilde{c}_{ij})$ fuzzy time $(\widetilde{t}_{ij})$ and fuzzy inefficiency $(\widetilde{q}_{ij})$ and by considering the weights W_1, W_2 and W_3 in light of the needs of the goal.

The assignment problem is not affect by normalized data.

$$\text{Minimize } \widetilde{Z} = W_1 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{c}_{ij})X_{ij} + W_2 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{c}_{ij})t_{ij} + W_3 \sum_{i=1}^{n}\sum_{j=1}^{n}(\widetilde{c}_{ij})q_{ij}$$

subject to

$$\sum_{i=1}^{n} X_{ij} = 1, \quad j = 1,2,\dots,n,$$

$$\sum_{j=1}^{n} X_{ij} = 1, \quad i = 1,2,\dots,n,$$

$X_{ij} = 0$ or 1, for all $i = 1,2,\dots,n$ and $j = 1,2,\dots,n$,

$$X_{ij} = \begin{cases} 1, & \text{if } i\text{th person is assigned } j\text{th work,} \\ 0, & \text{otherwise,} \end{cases}$$

and $W_1 + W_2 + W_3 + \cdots = 1$.

4. Optimal Solution to the Fuzzy Multi-Objective Assignment problem

In this segment, a functioning principle to get ideal arrangement, utilizing diagonal optimal algorithm. By normalising the fuzzy cost, the three-objective fuzzy assignment issue is reduced to a Problem of single-objective fuzzy assignment.

The Average Method of Weighing

The weighted normal approach incorporates all multi-objective capabilities into a single scalar composite goal function. Prior to the streamlining system, the weights are calculated and normalised to one, i.e.,

$$\sum_{i=1}^{k} W_i = 1.$$

Diagonal Optimal Algorithm

The suggested algorithm is discussed in further detail below,

Step 1: Each row's least trapezoidal fuzzy cost must be subtracted from the next-lowest trapezoidal fuzzy cost. On a row-by-row basis, we get the trapezoidal fuzzy penalty.

Step 2: The difference between the first and second lowest trapezoidal fuzzy costs should be entered as the value for each column. Column by column, we get the trapezoidal fuzzy penalty.

Step 3: Determine the smallest trapezoidal fuzzy number that corresponds to the largest trapezoidal fuzzy penalty row or column.

Step 4: Select the most severe maximum penalty fuzzy number and continue down this column/row to get the smallest trapezoidal fuzzy number. Assign that cell and delete the corresponding row and column.

Step 5: Repeat steps 3 and 4 until each row/column has a unique assignment. This is referred to as the first solution.

Step 6: Find the $\widetilde{a}_j - \widetilde{c}_j$ where $\widetilde{a}_j$ is the allocated cost and $\widetilde{c}_j$ the cost of the jth column of the cost matrix.

Step 7: In order to create a rectangle with a negative trapezoidal fuzzy penalty for one of the crossing lines, each corner is allocated a cell.

Step 8: The sum of the cells on the unassigned diagonal $\widetilde{d}_j$ is: In this case, all the $\widetilde{d}_j \geq \widetilde{o}$ of the assignments are the best they could be, so they are all the best. If not, choose the most negative $\widetilde{d}_j$. Then, change the diagonals of the grid. Repeat this until all the $\widetilde{d}_j \geq \widetilde{o}$ are done.

5. Numerical Example for Fuzzy Multi-Objective Assignment problem

Three personas (A, B, and C) and three tasks (I, II, and III) are used to exemplify the proposed model, with the goal of reducing the fuzzy costs, fuzzy time, and fuzzy inefficiency associated with trapezoidal fuzzy numbers as a Fuzzy multi-objective assignment problem.

Table 2. Three-objective trapezoidal fuzzy assignment problem

Person	I	II	III
A	(4,7,9,15) (7,11,15,19) (1,6 9,11)	(3,5,7,8) (5,7,9,12) (1,3,5,7)	(10,12,14,17) (13,15,18,21) (7,9,10,13)
B	(3,4,7,8) (4,5,8,9) (2,3,6,7)	(5,7,10,13) (6,9,11,15) (4,5,9,11)	(7,8,10,12) (9,12,14,16) (5,7,9,11)
C	(7,9,12,14) (8,11,13,15) (3,4,5,7)	(2,3,4,6) (3,4,5,7) (1,2,3,5)	(5,7,8,11) (6,8,9,13) (4,6,7,9)

5.1 Solution

A well-balanced assignment issue is the multifunctional ambiguous assignment problem.

The weighted average method may be used to reduce the complexity of the problem of fuzzy multi-objective assignment and allocating equal weights to the three goals $W_i = \frac{1}{3}$, $i = 1,2,3$ and they are reduced to a single goal. The next table illustrates the same thing.

Table 3. Three-objective trapezoidal fuzzy assignment problem

Person	I	II	III
A	(4,8,11,15)	(3,5,7,9)	(10,12,14,17)
B	(3,4,7,8)	(5,7,10,13)	(7,9,11,13)
C	(6,8,10,12)	(2,3,4,6)	(5,7,8,11)

Applying proposed algorithm (diagonal optimal method) in matrix form

$$\begin{array}{l} \\ \text{Person A} \\ \text{Person B} \\ \text{Person C} \\ \text{Fuzzy penalty} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Task I} & \text{Task II} & \text{Task III} \end{array} \\ \begin{bmatrix} (4,8,11,15) & (3,5,7,9) & (10,12,14,17) \\ (3,4,7,8) & (5,7,10,13) & (7,9,11,13) \\ (6,8,10,12) & (2,3,4,6) & (5,7,8,11) \\ (-2,1,6,9) & (-3,1,4,7) & (-4,1,4,8) \end{bmatrix} \end{array} \begin{array}{c} \text{Fuzzy penalty} \\ (-5,1,6,12) \\ (-3,0,6,10) \\ (-1,3,5,9) \\ \\ \end{array}$$

When all trapezoidal fuzzy penalty figures are compared, the highest penalty is associated with the first row trapezoidal fuzzy. Choose and assign the row's smallest trapezoidal fuzzy number. In this instance, the cell is (1,2). As a result, the matching first row and second column are omitted.

The reduced matrix is,

$$\begin{pmatrix} (3,4,7,8) & (7,9,11,13) \\ (6,8,10,12) & (5,7,8,11) \end{pmatrix}$$

Applying the first two steps, we get

$$\begin{array}{r} \\ \\ \\ \text{Fuzzy Penalty} \end{array} \begin{pmatrix} (3,4,7,8) & (7,9,11,13) \\ (6,8,10,12) & (5,7,8,11) \\ (-2,1,6,9) & (-4,1,4,8) \end{pmatrix} \begin{array}{c} \text{Fuzzy penalty} \\ (-1,2,7,10) \\ (-5,0,3,7) \\ \\ \end{array}$$

The second row fuzzy penalty is currently the highest of all fuzzy penalties. Select the least number in the second row $(5,7,8,11)$ for the $(3,3)$ cell. Crossing the 3rd row and 3rd column, finally left with cell $(2,1)$.

As a result, the allocations are $(1,2)$, $(2,1)$, and $(3,3)$.

The assignment matrix is (initial solution)

$$\begin{array}{r} \\ \text{Person A} \\ \text{Person B} \\ \text{Person C} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Task I} & \text{Task II} & \text{Task III} \end{array} \\ \begin{bmatrix} (4,8,11,15) & (\mathbf{3},\mathbf{5},\mathbf{7},\mathbf{9}) & (10,12,14,17) \\ (\mathbf{3},\mathbf{4},\mathbf{7},\mathbf{8}) & (5,7,10,13) & (7,9,11,13) \\ (6,8,10,12) & (2,3,4,6) & (\mathbf{5},\mathbf{7},\mathbf{8},\mathbf{11}) \end{bmatrix} \end{array}$$

Checking for optimality

$$\begin{array}{r} \\ \text{Person A} \\ \text{Person B} \\ \text{Person C} \end{array} \begin{array}{c} \begin{array}{ccc} (3,4,7,8) & (3,5,7,9) & (5,7,8,11) \end{array} \\ \begin{bmatrix} (4,8,11,15) & (3,5,7,9) & (10,12,14,17) \\ (3,4,7,8) & (5,7,10,13) & (7,9,11,13) \\ (6,8,10,12) & (2,3,4,6) & (5,7,8,11) \end{bmatrix} \end{array}$$

By subtracting each column element from its associated assignment, we get

$$\begin{bmatrix} (-4,1,7,12) & (-\mathbf{6},-\mathbf{2},\mathbf{2},\mathbf{6}) & (-1,4,7,12) \\ (-\mathbf{5},-\mathbf{3},\mathbf{3},\mathbf{5}) & (-4,0,5,10) & (-4,1,4,8) \\ (-2,1,6,9) & (-7,-4,-1,3) & (-\mathbf{6},-\mathbf{1},\mathbf{1},\mathbf{6}) \end{bmatrix}$$

Finding the $\widetilde{d}_{ij}$ for all the unallocated cells. For $\widetilde{d}_{11}$

$$\begin{pmatrix} (-4,1,7,12) & \left[\begin{array}{c} (-\mathbf{6},-\mathbf{2},\mathbf{2},\mathbf{6}) \\ (-4,0,5,10) \end{array}\right] & \begin{array}{c} (-1,4,7,12) \\ (-4,1,4,8) \end{array} \\ (-\mathbf{5},-\mathbf{3},\mathbf{3},\mathbf{5}) & & \\ (-2,1,6,9) & (-7,-4,-1,3) & (-\mathbf{6},-\mathbf{1},\mathbf{1},\mathbf{6}) \end{pmatrix},$$

$$\widetilde{d}_{11} \approx \begin{pmatrix} (-4,1,7,12) & (-\mathbf{6},-\mathbf{2},\mathbf{2},\mathbf{6}) \\ (-\mathbf{5},-\mathbf{3},\mathbf{3},\mathbf{5}) & (-4,0,5,10) \end{pmatrix} \approx (-8,1,12,22) \geq 0,$$

$$\widetilde{d}_{13} \approx \begin{pmatrix} (-6,-2,2,6) & (-1,4,7,12) \\ (-7,-4,-1,3) & (-6,-1,1,6) \end{pmatrix} \approx (-8,0,6,15) \geq 0,$$

$$\widetilde{d}_{23} \approx \begin{pmatrix} (-5,-3,3,5) & (-4,1,4,8) \\ (-2,1,6,9) & (-6,-1,1,6) \end{pmatrix} \approx (-6,2,10,17) \geq 0,$$

$\widetilde{d}_{22} \approx \widetilde{d}_{11} \geq 0$, $\widetilde{d}_{31} \approx \widetilde{d}_{23} \geq 0$, $\widetilde{d}_{32} \approx \widetilde{d}_{13} \geq 0$.

Hence all $\tilde{d}_{ij} \geq 0$.

Therefore the solution is optimal

$$\begin{array}{c} \\ \text{Person A} \\ \text{Person B} \\ \text{Person C} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Task I} & \text{Task II} & \text{Task III} \end{array} \\ \begin{bmatrix} (4,8,11,15) & (\mathbf{3},\mathbf{5},\mathbf{7},\mathbf{9}) & (10,12,14,17) \\ (\mathbf{3},\mathbf{4},\mathbf{7},\mathbf{8}) & (5,7,10,13) & (7,9,11,13) \\ (6,8,10,12) & (2,3,4,6) & (\mathbf{5},\mathbf{7},\mathbf{8},\mathbf{11}) \end{bmatrix} \end{array}$$

The optimum assignment schedule is

$$\text{Person A} \to \text{Task II}, \quad \text{Person B} \to \text{Task I}, \quad \text{Person C} \to \text{Task III}.$$

The trapezoidal fuzzy assignment cost is

$$\begin{aligned} \tilde{Z} &\approx (3,5,7,9)+(3,4,7,8)+(5,7,8,11) \\ &\approx (11,16,22,28). \end{aligned}$$

The assignment cost's membership function is

- The optimal assignment cost will be between 11 and 28.
- The cost of the most satisfactory option is between 16 and 22.
- The decision maker's satisfaction level is

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-11}{5}, & 11 \leq x \leq 16, \\ 1, & 16 \leq x \leq 22, \\ \dfrac{x-28}{6}, & 22 \leq x \leq 28. \end{cases}$$

6. Conclusion

The weighted average approach was used to handle a fuzzy assignment issue using trapezoidal numbers. An optimal solution was found without having to convert it into an exact answer. The converted single objective fuzzy trapezoidal problem was solved using diagonal optimal model. This method gives the solution to membership function instead of crisp one so as to get the better choice of assignment cost.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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