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Implementation of BCM for Solving the Fuzzy Assignment Problem with Various Ranking Techniques

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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Abstract

Allocations and job scheduling are mainly solved with the help of Assignment Problems. By choosing the best element from set of available alternative elements the optimization processes in mathematics, computer science and economics are solved effectively. The key idea of best candidate method (BCM) is to minimize the combinations of the solution by choosing the best candidates to reach the optimal solution. Triangular Fuzzy Assignment Problem is used and Method of magnitude is used for ranking of Triangular fuzzy numbers.

Keywords: Magnitude of fuzzy number; method of promoter operator; parametric form of fuzzy number; Ranking of fuzzy numbers; Triangular fuzzy number.

Mathematics Subject Classification: 90C05, 90C08, 90C10, 90C90, 03E72.

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1 Introduction

An Assignment problem concerns as to what happens to the effectiveness function when we associate each of a number of origin with each of the same number of destinations. The objective of Assignment Problems is to assign n number of jobs to n number of machines (persons) at a minimum cost. Solving problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variables from within an allowed set refers to choosing the best element from some set of available alternatives. Assignment problems have various applications in the real world because of their wide applicability in industry, commerce, management science etc. Traditional classical assignment problems cannot be successfully used hence the use of fuzzy assignment problems is more appropriate. To deal with situations, involving imprecision in the data the concept of fuzziness proposed by Zadeh [1] is employed. Over the past 50 years, many variations of the classical assignment problems are proposed. Problems on production and work force assignment in a firm using interactive fuzzy programming for two level linear and linear fractional programming models was proposed by Sakawa et al. [2].

Fuzzy assignment model that considers all persons to have same skills have been discussed by Chen [3]. The procedure for resolving assignments problem with multiple inadequate inputs and outputs in crisp form for each possible assignment using linear programming model to determine the assignments with the maximum efficiency was developed by Chen Liang-Hsuan and Lu Hai-Wen [4]. Solution method for fuzzy assignment problem with Restriction of Qualification was proposed by Long-Sheng Huang, Li-pu Zhang [5]. Ones Assignment Method for Solving Assignment Problems was introduced by Hadi Basirzadeh [6]. Ranking of fuzzy utilities with triangular membership functions was proposed by Chang [7]. Ordering fuzzy subsets of the unit interval is introduced by Yager R. R [8], A new approach for ranking of trapezoidal fuzzy numbers has been discussed by Abbasbandy and Hajjari [9]. Ranking fuzzy subsets over the unit interval was introduced by Yager [10]. Hajjari and Abbasbandy [11] have derived a Promoter Operator for Defuzzification Methods. Assignment Problems with Fuzzy Costs under Robust Ranking Techniques have been proposed by Nagarajan and Solairaju [12]. Mohanaselvi and Ganesan [13] have devised a new approach to Fuzzy Transportation Problem. Solution of a Fuzzy Assignment Problem by Using a New Ranking Method was developed by Nagoor Gani and Mohamed [14].

Abdullah A. Hlayel, Mohammad A. Alia [15,16] has proposed the BCM for solving optimization problems. Annie Christi and Malini [17,18] have solved the transportation problems with hexagonal and octagonal fuzzy numbers using best candidates method and centriod ranking techniques. A new approach namely BCM for fuzzy assignment problems with yager's and method of magnitude ranking has been introduced.

Some elementary concepts and operations of fuzzy set theory, Yager's ranking and Method of magnitude has been defined for ranking fuzzy numbers in section 2. Formation of Assignment Problem has been explained in section 3. BCM method has been proposed for Fuzzy Assignment Problem in section 4. The proposed method is illustrated by a numerical example in section 5.

2 Preliminaries

2.1 Fuzzy set

The characteristic function μ_A of a crisp set $A \subseteq X$ assigns a value either 0 or 1 to each member in X .A function $\mu_{\tilde{a}}$ such that the value assigned to the element of the universal set X fall within a specified range i.e. $\mu_{\tilde{a}}\ : X \to [0,1]$. The assigned value indicates the membership grade of the element in the set A . The function $\mu_{\tilde{a}(x)}$ is called the membership function and the set $\hat{A} = \{(x,\ \ \mu_{\tilde{a}(x)}; x \in X\ )\}$ defined by $\mu_{\tilde{a}(x)}$ for each $x \in X$ is called a fuzzy set.

2.2 Triangular fuzzy number (TFNs)

A fuzzy number ậ on R is said to be a triangular fuzzy number (TFN) or linear fuzzy number if its membership function ậ : R →[0,1] has the following characteristics

$$\mu_{ậ(x)} = \begin{cases} (x - a_1) / (a_2 - a_1) \text{ if } a_1 \leq x \leq a_2 \\ (a_3 - x) / (a_3 - a_2) \text{ if } a_2 \leq x \leq a_3 \\ 0 \quad \text{otherwise} \end{cases}$$

We denote this triangular fuzzy number by ậ = (a_{1}, a_2, a_3) .We use F(R) to denote the set of all triangular fuzzy numbers.

Also if m = a_2, represents the modal value or midpoint, α = $(a_2 - a_1)$ represents the left spread and β = $(a_3 - a_2)$ represents the right spread of the triangular fuzzy number ậ = (a_1, a_2, a_3), then the triangular fuzzy number ậ can be represented by the triplet ậ = (α, m, β) i.e. ậ = $(a_1, a_2, a_3) = (\alpha, m, \beta)$.

2.3 Operations of TFNs

Let $a = [a_1, a_2, a_3,]$ and $b = [b_{1,2}, b_3]$ be two triangular fuzzy numbers then the arithmetic operations on a and b as follows.

Addition: $a + b = (a_1+b_1, a_2+b_2, a_3+b_3$

Subtraction: $a - b = (a_1-b_1, a_2-b_2, a_3-b_3)$

Multiplication:

$a.\, b = \frac{a_1}{3}(b_1+b_2+b_3), \frac{a_2}{3}(b_1+b_2+b_3), \frac{a_3}{3}(b_1+b_2+b_3)$ $if\ R(a) > 0$
$a\,.\, b = \frac{a_3}{3}(b_1+b_2+b_3), \frac{a_2}{3}(b_1+b_2+b_3), \frac{a_1}{3}(b_1+b_2+b_3)$ if $R(a) < 0$

2.4 Defuzzification

Defuzzification is the process of finding singleton value (crisp value) which represents the average value of the TFNs. Here use Yager's ranking and Method of magnitude to defuzzify the TFNs because of its simplicity and accuracy.

2.4.1 Yager's ranking technique [10,12]

Yager's ranking technique which satisfies compensation, linearity, additivity properties and provides results which consists of human intuition. For a convex fuzzy number ã, the Robust's Ranking Index is defined by,

$$R(ã) = \int_0^1 (0.5)(a^L{}_\alpha, a^U{}_\alpha)\, d\alpha \quad (1)$$

Where $(a^L{}_\alpha, a^U{}_\alpha) = \{(b-a)\alpha + a, c - (c-b)\alpha\}$ which is the α – level cut of the fuzzy number ã.

2.4.2 Method of magnitude [11,13]

A triangular fuzzy number $\breve{\alpha} \in$ F(R) can also be represented as a pair $\breve{\alpha} = (\underline{a}, \overline{a})$ of functions $(\underline{a}(r), \overline{a}(r))$ for $0 \leq r \leq 1$ which satisfies the following requirements:

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

2.4.2.1 Definition

For an arbitrary triangular fuzzy number, $\breve{a} = (\underline{a}, \overline{a})$, the number

$a_0 = \left(\frac{\underline{a}\,(1)+\overline{a}\,(1)}{2}\right)$ is said to be a location index number of $\breve{a}$. The two non-decreasing left continuous functions $a_*= (a_0 - \underline{a})$ and $a^* = (\overline{a} - a_0)$ are called the left fuzziness index function and the right fuzziness index function respectively. Hence every triangular fuzzy number $\breve{a} = (a_{1\,,}a_{2\,,}a_3)$ can also be represented by $\breve{a} = (a_{0\,,}a_*\,, a^*)$.

2.4.2.2 Ranking of triangular Fuzzy Numbers

Many different approaches for the ranking of fuzzy numbers have been proposed in the literature. Abbasbandy and Hajjari [1] proposed a new ranking method based on the left and the right spreads at some α -levels of fuzzy numbers.

For an arbitrary triangular fuzzy number $\breve{a} = \left(a_{1\,,}a_{2\,,}a_3\right) = (a_{0\,,}a_*\,, a^*)$ with parametric form

$\breve{a} = (\ \underline{a}\,(r), \overline{a}$ (r)) we define the magnitude of the triangular fuzzy number by $\breve{a}$ by

$$\text{Mag}(\breve{a}) = \frac{1}{2}\left(\int_0^1 \left(\overline{a} + \underline{a} + \text{a}_0\right) f(r)dr\right)$$
$$= = \frac{1}{2}\left(\int_0^1 \left(a^* + 4\text{a}_0 - a_*\right) f(r)dr\right)$$

where the function f (r) is a non-negative and increasing function on [0,1] with f (0) = 0, f (1) = 1 and $\int_0^1 f(r)dr = \frac{1}{2}$. The function f (r) can be considered as a weighting function. In real life applications, f (r) can be chosen by the decision maker according to the situation. In this paper, for convenience we use f (r) = r.

$$\text{Hence Mag}\ (\breve{a}) = \left(\frac{a^*+4\text{a}_0-a_*}{4}\right) = \left(\frac{\overline{a}+\underline{a}+\text{a}_0}{4}\right) \tag{2}$$

The magnitude of a triangular fuzzy number $\breve{a}$ synthetically reflects the information on every membership degree, and meaning of this magnitude is visual and natural. Mag ($\breve{a}$) is used to rank fuzzy numbers. The larger Mag($\breve{a}$), the larger fuzzy number.

For any two triangular fuzzy numbers $\breve{a} = (a_{0\,,}a_*\,, a^*)$ and $\breve{b} = (b_{0\,,}b_*\,, b^*)$

1. Mag($\breve{a}$) ≥ Mag($\breve{b}$) if and only if $\breve{a} \geq \breve{b}$,
2. Mag($\breve{a}$) ≤ Mag($\breve{b}$) if and only if $\breve{a} \leq \breve{b}$,
3. Mag($\breve{a}$) = Mag($\breve{b}$) if and only if $\breve{a} \approx \breve{b}$,.

3 Assignment Method

The assignment problem can be stated in the form of n x n cost matrix [c_{ij}] of real numbers as given in the following table

Jobs→ Persons ↓	**1**	**2**	**3**	**---j---**	**n**
1	C_{11}	C_{12}	C_{13}	-- C_{1j}--	C_{1n}
2	C_{21}	C_{22}	C_{23}	-- C_{2j}--	C_{2n}
-	-	-	-	-	-
-	-	-	-	-	-
I	C_{i1}	C_{i2}	C_{i3}	-- C_{ij}--	C_{in}
-					
N	C_{n1}	C_{n2}	C_{n3}	-- C_{nj}--	C_{nn}

Mathematically assignment problem can be stated as

Minimize $z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \quad x_{ij}$ where i = 1,2,3….n , j = 1,2,3….n

Subject to

$$\sum_{i=1}^{n} x_{ij} = 1, \quad i = 1,2,3\ldots. \tag{3}$$
$$\sum_{j=1}^{n} x_{ij} = 1 \quad j = 1,2,3\ldots.n \qquad x_{ij} \in \{0,1\}$$

$$\text{where } x_{ij} = \begin{cases} 1 & \text{if the } i^{th} \text{person is assigned the } j^{th} \text{job} \\ 0 & otherwise \end{cases}$$

is the decision variable denoting the assignment of the person i to job j, Cij is the cost of assigning the j^{th} job to the i^{th} person.

The objective is to minimize the total cost of assigning all the jobs to the available persons. (one job to one person). When the costs $\tilde{c}_{ij}$ are fuzzy numbers, then the fuzzy assignment problem becomes

$$Y(\tilde{z}) = \sum_{i=1}^{n} \sum_{j=1}^{n} Y(\tilde{c}_{ij}) \quad x_{ij} \tag{4}$$

Subject to the same conditions (3)

For an unbalanced problem add dummy rows/ columns then follow the same procedure.

4 Algorithm for Best Candidates Method (BCM) has the following Solution Steps

Step1: From the matrix with the Fuzzy Assignment Costs. Balance the unbalanced matrix and don't use the added row or column candidates in our solution procedure.

Step2: The best candidates are selected by choosing minimum cost for minimization problems and maximum cost for maximization problems. Select the best two candidates in each row, if the candidate is repeated more than two times select it also. Check the columns that not have candidates and select one candidate for them, if the candidate is repeated more than one time select it also.

Step3: The combinations are found by determining only one candidate for each row and column starting from the row that have least candidates and delete that row and column if there is situation that has no candidate for some rows or columns, select directly the best available candidate. Repeat step 3 (1,2) by determining the next candidate in the row that started from. The total sum of candidates for each combination is computed and compared to determine the best combinations that give the optimal solution.

4.1 Algorithm to solve fuzzy assignment problem with BCM

Step 1: First test whether the given fuzzy cost matrix of an fuzzy assignment problem is a balanced one or not If not change this unbalanced assignment problem by adding the number of dummy row (s) / column(s) and the values for the entries are zero. If it is a balanced one (i.e, number of persons are equal to the number of works) then go to step 2. If it is an unbalanced one then convert it into a balanced one and then go to step 2.

Step 2: Replace the cost matrix C_{ij} with linguistic variables by triangular or trapezoidal fuzzy numbers.

Step 3: Defuzzify the fuzzy cost by using various ranking methods like Yagers ranking, Method of maginitude method etc.

Step 4: Replace Triangular or Trapezoidal numbers by their respective ranking indices.

Step 5: Apply BCM to determine the best combination to produce the lowest total weight of the costs, where is one candidate for each row and column.

Step 6: Select the row with the smallest cost candidate from the chosen combination. Then allocate the demand and the supply as much as possible to the variable with the least unit cost in the selected row or column. Also, we should adjust the supply and demand by crossing out the row/column to be then assigned to zero. If the row or column is not assigned to zero, then we check the selected row if it has an element with lowest cost comparing to the determined element in the chosen combination, then we select it.

5 Numerical Example

5.1 Consider the following assignment problem with triangular fuzzy numbers

A factory has five machines and employed five workers to work on the given five machines. Based on the workers experience and their personal efficiency, the workers have assigned to work on five machines. Following the times (minutes) taken by workers in completion of that work in the respective machines. The times are as follow. Obtain optimal assignment of the workers.

	1	**2**	**3**	**4**	**5**
A	(6,8,10)	(2,4,6)	(0,2,4)	(4,6,8)	(0,1,2)
B	(0,2,4)	(7,9,11)	(3,5,7)	(3,5,7)	(2,4,6)
C	(1,3,5)	(6,8,10)	(7,9,11)	(0,2,4)	(4,6,8,)
D	(2,4,6)	(1,3,5)	(0,1,2)	(0,2,4)	(1,3,5)
E	(7,9,11)	(3,5,7)	(6,8,10)	(7,9,11)	(3,5,7)

5.2 Deffuzzification by Yager's Ranking Technique using (1)

The α –cut of the fuzzy number (6, 8, 10) is R (ã) $= \int_0^1 (0.5)(a^L{}_\propto , a^U{}_\propto) d\propto$

$\left(a^L{}_\propto, a^U{}_\propto\right)$=$\{(b-a)\propto + a, c-(c-b)\propto\}$

$(a^L{}_\propto , a^U{}_\propto)$ =$\{(8\text{-}6)\propto + 6 , 10\text{-}(10\text{-}8)\propto\}$ =$(2\propto+6, 10-2\propto)$ for which

$R(\tilde{a}_{11})$ = R (6, 8, 10) = $\int_0^1 (0.5)(a^L{}_\propto , a^U{}_\propto) d\propto = \int_0^1 (0.5)(2\propto+6 , 10-2\propto) d\propto$

$= \int_0^1 (0.5)\ 16\ d\propto = 8$

Proceeding similarly, the Robust's ranking indices for the fuzzy costs ãij are calculated as:

$R(\tilde{a}_{12}) = 4$, $R(\tilde{a}_{13}) = 2$, $R(\tilde{a}_{14}) = 6$,$R(\tilde{a}_{15}) = 1$.
$R(\tilde{a}_{21}) = 2$, $R(\tilde{a}_{22}) = 9$, $R(\tilde{a}_{23}) = 5$, $R(\tilde{a}_{24}) = 5$, $R(\tilde{a}_{25})= 4$.
$R(\tilde{a}_{31}) = 3$, $R(\tilde{a}_{32}) = 8$, $R(\tilde{a}_{33}) = 9$, $R(\tilde{a}_{34}) = 2$, $R(\tilde{a}_{35})= 6$.
$R(\tilde{a}_{41}) = 4$, $R(\tilde{a}_{42}) = 3$, $R(\tilde{a}_{43}) = 1$, $R(\tilde{a}_{44}) = 2$, $R(\tilde{a}_{45}) = 3$.
$R(\tilde{a}_{51}) = 9$, $R(\tilde{a}_{52}) = 5$, $R(\tilde{a}_{53}) = 8$, $R(\tilde{a}_{54}) = 9$, $R(\tilde{a}_{55}) = 5$.

Defuzzifying the triangular fuzzy numbers by using Yager's ranking technique, we have

Table 1. Defuzzifying by Yager's ranking technique

	1	**2**	**3**	**4**	**5**
A	8	4	2	6	1
B	2	9	5	5	4
C	3	8	9	2	6
D	4	3	1	2	3
E	9	5	8	9	5

Select the best candidates by step 2.

Table 2. Selection of the best candidates

	1	**2**	**3**	**4**	**5**
A	8	4	(2)	6	(1)
B	(2)	9	5	5	(4)
C	(3)	8	9	(2)	6
D	4	3	(1)	(2)	3
E	9	(5)	8	9	(5)

Find the combination 1 by step 3.

Table 3. combination 1

	1	**2**	**3**	**4**	**5**
A	8	4	(2)	6	1
B	2	9	5	5	(4)
C	(3)	8	9	2	6
D	4	3	1	(2)	3
E	9	(5)	8	9	5

Find the combination 2 by step 3.

Table 4. Combination 2

	1	**2**	**3**	**4**	**5**
A	8	4	2	6	1
B	2	9	5	5	4
C	3	8	9	2	6
D	4	3	1	2	3
E	9	5	8	9	5

Combination 1: (A3, B5, C1, D4, E2): 2 + 4 + 3 + 2 + 5 =16

Combination 2: (A5, B1, C4, D3, E2): 1 + 2 + 2 + 1 + 5 = 11 this is the optimal one.

5.3 Deffuzzification by Method of Magnitude (2)

Mag ($\breve{a}$) =$\left(\frac{a^{*}+4a_0-a_{*}}{4}\right) = \left(\frac{\overline{a}+\underline{a}+a_0}{4}\right)$ where $\breve{a} = \left(a_{1\,,}a_{2\,,}a_3\right) = (a_{0\,,}a_{*}\,,a^{*})$

R($\tilde{a}_{11}$) = R (6, 8, 10) =$\frac{10+4*6-8}{4}$ = $\frac{10+24-8}{4}$=$\frac{26}{4}$ =6.5

Proceeding similarly, the Robust’s ranking indices for the fuzzy costs ãij are calculated as:

R($\tilde{a}_{12}$) = 2.5 , R($\tilde{a}_{13}$) = 0.5, R($\tilde{a}_{14}$) = 4 ,R($\tilde{a}_{15}$) = 0.25 .
R($\tilde{a}_{21}$) = 0.5 , R($\tilde{a}_{22}$) = 7.5, R($\tilde{a}_{23}$) =3.5, R($\tilde{a}_{24}$) = 3.5, R($\tilde{a}_{25}$)= 2.5.
R($\tilde{a}_{31}$) = 1.5 , R($\tilde{a}_{32}$) = 6.5, R($\tilde{a}_{33}$) = 7.5, R($\tilde{a}_{34}$) = 0.5, R($\tilde{a}_{35}$)= 4.5.
R($\tilde{a}_{41}$) = 2.5 , R($\tilde{a}_{42}$) = 1.5, R($\tilde{a}_{43}$) =0.25, R($\tilde{a}_{44}$) = 0.5 , R($\tilde{a}_{45}$) = 1.5 .
R($\tilde{a}_{51}$) = 7.5, R($\tilde{a}_{52}$) = 3.5, R($\tilde{a}_{53}$) = 6.5 , R($\tilde{a}_{54}$) = 7.5, R($\tilde{a}_{55}$) = 3.5.

Defuzzifying the triangular fuzzy numbers by using Method of magnitude ranking technique, we have

Table 5. Defuzzifying by Method of Magnitude technique

	1	**2**	**3**	**4**	**5**
A	6.5	2.5	0.5	4	0.25
B	0.5	7.5	3.5	3.5	2.5
C	1.5	6.5	7.5	0.5	4.5
D	2.5	1.5	0.25	0.5	1.5
E	7.5	3.5	6.5	7.5	3.5

Select the best candidates

Table 6. Selection of the best candidates

	1	2	3	4	5
A	6.5	2.5	0.5	4	0.25
B	0.5	7.5	3.5	3.5	2.5
C	1.5	6.5	7.5	0.5	4.5
D	2.5	1. 5	0.25	0.5	1.5
E	7.5	3. 5	6.5	7.5	3.5

Find the combinations 1

Table 7. Combination 1

	1	2	3	4	5
A	6.5	2.5	0.5	4	0.25
B	0.5	7.5	3.5	3.5	2.5
C	1.5	6.5	7.5	0.5	4.5
D	2.5	1.5	0.25	0.5	1.5
E	7.5	3.5	6.5	7.5	3.5

Find the combinations 2

Table 8. Combination 2

	1	2	3	4	5
A	6.5	2.5	0.5	4	0.25
B	0.5	7.5	3.5	3.5	2.5
C	1.5	6.5	7.5	0.55	4.5
D	2.5	1.5	0.25	0.5	1.5
E	7.5	3. 5	6.5	7.5	3.5

Combination1: (A3, B5, C1, D4, E2): 0.5 +2.5 + 1.5+ 0.5 +3.5 =8.5

Combination2: (A5, B1, C4, D3, E2): 0.25+ 0.5 +0.5 + 0.25 + 3. 5=**5** this is the optimal one.

By comparing the the application of BCM with the Fuzzy Assignment Problems using Yagers ranking technique and Method of Maginitude ranking the combination 2 in method of Maginitude gives a better approximation.

6 Conclusion

Various ranking techniques have been applied with triangular fuzzy assignment problem along with BCM method. The best combinations are sSelected without any complication. Optimal solution or closest to optimal solution can be obtained using BCM with less computation time. This method is very easy to solve and it can be applied to wide range of applications in real day life with uncertain fuzzy costs.

Competing Interests

Authors have declared that no competing interests exist.

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