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BI-OBJECTIVE ASSIGNMENT PROBLEM WITH A MINOR MINIMUM METHOD AND GENERALIZED INTERVAL ARITHMETIC

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ABSTRACT

The assignment problem is a well-known topic that is frequently used in engineering and management science difficulties. In this paper we presented a minor minimum method with generalized interval arithmetic (MMMWGIA) for Bi-Objective Interval Assignment Problem (BOIAP). We present a new algorithm for solving interval assignment problems. This method provides the efficient/non - efficient solution and best compremise solution than minor minimum method (MMM) for BOIAP. This technique helps us decision makers working with BOIAP.A numerical example is provided to illustrate the BOIAP.

Keywords: bi - objective interval assignment problem, minor - minimum method, generalized interval arithmetic, efficient solution and non - efficient solution.

1. INTRODUCTION

Assignment problem (AP) is a special type of transportation problem which deals with production and service system. The aim of Assignment Problem (AP) is to allocate a number of jobs to an equal number of machines, also minimize the total assignment cost or to reduce the total consumed time for implementation of all the jobs. Assignment problem solved by Hungarian method, which is developed by Kuhn, who is acknowledged as the first practical method to solve the (AP). Some authors worked on multi - objective assignment problem, but in real life Assignment Problem (AP) mostly considered as single objective problem. An Assignment Problem is called a multi - objective function if it has a more than one objective function. Bao *et al* [8] studied for the multi - objective Assignment Problem. Bi - Objective Assignment problem was solved by Przybylski [20] using two - phase method. Bufardi [9], worked with BOIAP for all efficient solutions. Adiche *et al.*, [1] applied a hybrid method for finding an efficient solution to Multi - Objective Assignment Problem (MOAP). Medvedeva and Medvedev [17] worked in MOAP. Ahmed and Hammed [4] proposed a Bi - level multi - objective optimization model. Typically cost and time are not always in a crisp form, in real life situation problems, so we deal with uncertain parameters which are called intervals. Sarangam Majumdar [25] was presented an interval linear assignment problem. G. Ramesh and K. Ganesan [22] considered an Assignment problem with generalised interval arithmetic. Ramesh kumar A *et al.*, [21] offered the application of assignment problem and converting Crisp Assignment Problem (CAP) into Interval Assignment Problem (IAP). Jayalakshmi [13] founded computation of intervals without using arithmetic operations, as converted Fully Interval Assignment Problem (FIAP) into Crisp Assignment Problem (AP) using midpoint technique. Kagade and Balaji; Salehi [14, 24] answered multi - objective AP with interval entries by using fuzzy method and weighted min - max method. Amutha [2] gave the solution for both maximization and minimization of Hungarian method by using its extension of intervals. Khalifa and AI - Shabi [15] studied multi objective assignment problem under fuzzy environment by using an interactive approach. Sobana and Anuradha [26] solving all efficient solution for BOIAP by Minor Minimum Method (MMM). Anuradha and Pandian [5] originated new method for finding all efficient solution for Bi - objective Assignment Problem. Humayra DilAfroz *et al* [12] proposed a new assignment method comparative with existing method.

This article focusing to finding the set of all appropriate solution sets for BOIAP. Section (2) we recall the preliminaries concept of intervals and their arithmetic operations. Section (3) presents the mathematical model for BOIAP. Section (4) Deals with minor minimum method with generalised interval arithmetic. Section (5) to illustrate the numerical example. Section (6) concludes the article.

2. PRELIMINARIES

This section includes some notation which results in our further consideration. Let $\tilde{a} = [a_1, a_2] = \{x: a_1 \leq x \leq a_2, x \epsilon R\}$. If $\tilde{a} = a_1 = a_2 = a$, then $\tilde{a} = [a_1, a_2] = a$ is a real number (or a degenerate interval). Let IR $= \{ \tilde{a} = [a_1, a_2]: a_1 \leq a_2$ and $a_1, a_2 \epsilon R\}$ be the set of all proper intervals and IR $= \{ \tilde{a} = [a_1, a_2]: a_1 > a_2$ and $a_1, a_2 \epsilon R\}$ be the set of all improper interval and interval number interchangeably. The midpoint and width of an interval number$\tilde{a} = [a_1, a_2]$ are defined as $m(\tilde{a}) = \left(\frac{a_1+a_2}{2}\right)$ and $w(\tilde{a}) = \left(\frac{a_2-a_1}{2}\right)$. The interval number $\tilde{a}$ can be also be expressed interms of its midpoint and width as:$\tilde{a} = [a_1, a_2] = \langle m(\tilde{a}), w(\tilde{a}) \rangle$.

2.1 A New Interval Arithmetic

Ming ma *et al* [18] have proposed a new fuzzy arithmetic based upon both fuzziness index and location index function. The fuzziness index functions are in use to follow the lattice rules then they are the least upper bound and greatest lower bound in the lattice L. That is for $a, b \epsilon L$. We define $a \vee b = \max\{a, b\}$ *and* $a \wedge b = \min\{a, b\}$. Whereas the location index number is considered as the ordinary arithmetic which includes basic concepts. For two intervals $\tilde{a} = [a_1, a_2]$, $\tilde{b} = [b_1, b_2] \epsilon IR$ and $* \epsilon \{+, -, \cdot, \div\}$ the arithmetic operations on $\tilde{a}$ and $\tilde{b}$ are defined as:

$\tilde{a} * \tilde{b} = [a_1, a_2] * [b_1, b_2] =$
$\langle m(\tilde{a}), w(\tilde{a}) \rangle * \langle m(\tilde{b}), w(\tilde{b}) \rangle =$
$\langle m(\tilde{a}) * m(\tilde{b}), \max\{ w(\tilde{a}), w(\tilde{b})\} \rangle$.

In particular

(i) Addition: $\tilde{a} + \tilde{b} = \langle m(\tilde{a}), w(\tilde{a}) \rangle + \langle m(\tilde{b}), w(\tilde{b}) \rangle = \langle m(\tilde{a}) + m(\tilde{b}), \max\{ w(\tilde{a}), w(\tilde{b})\} \rangle$.

(ii) Subtraction: $\tilde{a} - \tilde{b} = \langle m(\tilde{a}), w(\tilde{a}) \rangle - \langle m(\tilde{b}), w(\tilde{b}) \rangle = \langle m(\tilde{a}) - m(\tilde{b}), \max\{ w(\tilde{a}), w(\tilde{b})\} \rangle$.

(iii) Multiplication: $\tilde{a} \times \tilde{b} = \langle m(\tilde{a}), w(\tilde{a}) \rangle \times \langle m(\tilde{b}), w(\tilde{b}) \rangle = \langle m(\tilde{a}) \times m(\tilde{b}), \max\{ w(\tilde{a}), w(\tilde{b})\} \rangle$.

(iv) Division: $\tilde{a} \div \tilde{b} = \langle m(\tilde{a}), w(\tilde{a}) \rangle \div \langle m(\tilde{b}), w(\tilde{b}) \rangle = \langle m(\tilde{a}) \div m(\tilde{b}), \max\{ w(\tilde{a}), w(\tilde{b})\} \rangle$.

Provided $m(\tilde{b}) \neq 0$.

2.2 Ranking of Interval Numbers

Sengupta and pal [6] proposed a simple and efficient index for comparing any two intervals on interval ranking (IR) through decision makers satisfaction.

2.2.1 Definition: Let $\preccurlyeq$ be an extended order relation between the interval numbers $\tilde{a} = [a_1, a_2]$, $b = [b_1, b_2]$ in IR, then for $m(a) < m(b)$, we construct to $\tilde{b}$ (or $\tilde{b}$ is superior to $\tilde{a}$).

An acceptability function is defined as:

$A_{\preccurlyeq}: IR \times IR \to [0, \infty)$

$A_{\preccurlyeq}(\tilde{a}, \tilde{b}) = A(\tilde{a} \preccurlyeq \tilde{b}) = \frac{m(\tilde{b}) - m(\tilde{a})}{m(\tilde{b}) + m(\tilde{a})}$

Where $m(\tilde{b}) + m(\tilde{a}) \neq 0$. May be interpreted as the grade of acceptability of the first interval number to be inferior to the second interval number. For any two interval numbers $\tilde{a}$ and $\tilde{b}$ in IR either $A(\tilde{a} \preccurlyeq \tilde{b}) \geq 0$ (or) $A(\tilde{b} \succcurlyeq \tilde{a})$ (or) $A(\tilde{a} \preccurlyeq \tilde{b}) = 0$ (or) $A(\tilde{a} \preccurlyeq \tilde{b}) + A(\tilde{b} \succcurlyeq \tilde{a}) = 0$. If $A(\tilde{b} \preccurlyeq \tilde{a}) = 0$ and $A(\tilde{b} \succcurlyeq \tilde{a}) = 0$, then we say that the interval numbers $\tilde{a}$ and $\tilde{b}$ are equivalent (non – interior to each other) and we denote it by $\tilde{a} \approx \tilde{b}$, also $A(\tilde{a} \preccurlyeq \tilde{b}) \geq 0$, then $\tilde{a} \preccurlyeq \tilde{b}$ and if $A(\tilde{b} \preccurlyeq \tilde{a}) \geq 0$, then $\tilde{b} \preccurlyeq \tilde{a}$.

3. MATHEMATICAL STRUCTURE

We consider n cars in a company and the company has n drivers to process the cars. Each car has to be associated with one and only one driver. A penalty c_{ij} and d_{ij} is the cost of execution and u_{ij} and v_{ij} deviation in route, time and so on, which is incurred when a car $j = (1,2,\dots,n)$ is processed by the driver $i = (1,2,\dots,n)$. Let x_{ij} denote the assignment of j^{th} car to i^{th} driver. Our aim is to determine the assignment of cars to the drivers at minimum assignment cost and deviation in route. Now, the mathematical model of the above BOIAP is given as follows:

(R) Minimize $[z_1 z_2] = \sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}]\, x_{ij}$

Minimize $[z_3 z_4] = \sum_{i=1}^{m} \sum_{j=1}^{n} [u_{ij}, v_{ij}] x_{ij}$

Subject to

$$\sum_{j=1}^{n} x_{ij} = 1, \ \ i = 1,2,\dots,n \qquad (1)$$

$$\sum_{i=1}^{n} x_{ij} = 1, \ \ j = 1,2,\dots,n \qquad (2)$$

$$x_{ij} = \begin{cases} 1, \ if\ i^{th}\ driver\ is\ assigned\ to\ j^{th}\ car, \\ 0, \ otherwise \end{cases} \qquad (3)$$

We construct two interval assignment problem (IAP) from the given (R), namely, first objective IAP (R_1) and second objective IAP (R_2) which is shown given below.

(R_1) Minimize $[z_1 z_2] = \sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}]\, x_{ij}$.

Subject to (1), (2) and (3) are satisfied.

(R_2) Minimize $[z_3 z_4] = \sum_{i=1}^{m} \sum_{j=1}^{n} [u_{ij}, v_{ij}]\, x_{ij}$.

Subject to (1) (2) and (3) are satisfied.

The fundamental concepts of the arithmetic operators, partial ordering of closed bounded intervals, feasible and optimal solutions of the interval can be obtained in [16, 19].

Definition 3.1 A set $X^0 = \{x_{ij}^0, i = 1,2,\dots,m,$ $j = 1,2,\dots n\}$ is said to be feasible to the problem (R) if X^0 satisfies the conditions from (1) to (3).

Definition 3.2 A feasible solution X^0 is said to be an efficient solution to the problem (R) if there exists no other feasible solution X of (R) such that $[z_1(X), z_2(X)] \leq [z_1(X)^0, z_2(X)^0]$ and $[z_3(X), z_4(X)] \leq [z_3(X)^0, z_4(X)^0]$ (or) $[z_3(X), z_4(X)] < [z_3(X)^0, z_4(X)^0]$ and $[z_1(X), z_2(X)] < [z_1(X)^0, z_2(X)^0]$, otherwise , it is called non – efficient solution to the problem (R). The Minor Minimum Method with generalised interval arithmetic method proceeds as given below:

4. MINOR MINIMUM METHOD WITH GENERALISED INTERVAL ARITHMETIC

Algorithm.

Step 1: Very firstly to make the Assignment interval cost as (R_1) and (R_2) form (R).

Step 2: Find the midpoint and width value form (R_1) and (R_2).

Step 3: Obtain optimal solution from (R_1) by HM.

Step 4: Find optimal solution from (R_2) by HM.

Step 5: Take the optimal solution of (R_2) in (R_1) as a feasible solution which is efficient / non - efficient solution to (R).

Step 6: Find the minor of the highest assignment cost, say in the i^{th} row from (R_2) and find an optimal solution by HM. Then go to the next highest cost cell of the i^{th} row to obtain optimum solution. Repeat this process to find efficient / non efficient solutions until all the highest cost cells of the i^{th}row are considered.

Step 7: Now we begin with the optimal solution of (R_2) as a feasible solution of (R_1) which is efficient / non efficient solution to (R).

Step 8: Repeat step 6 for (R_1) to obtain the optimal solution.

Step 9: Combine all the efficient /non - efficient solutions of (R) found using the optimal solutions of (R_1) and (R_2). A set of efficient / non - efficient solutions to the (R) can be obtain from $P = P_1 \cup P_2$.

5. NUMERICAL EXAMPLE

A company has to work out the assignment of three different cars on three different drivers. Assume that there are two objectives in consideration: (i) the minimization of the total allocation costs that are used in the allocation (ii) the minimization of the total deviation in route that is used in the allocation. Because the allocation plan has been prepared in advance, we are generally unable to get this information precisely. For this condition, the usual way to obtain the interval data is through experience evaluation. The corresponding interval data is shown in Combined Assignment Cost Table. This problem adopted from Sobana and Anuradha BOIAP [26].

Table-1. Combined interval assignment cost.

		Cars		
		B_1	B_2	B_3
Drivers	D_1	[1, 3] [3, 5]	[5, 9] [2, 4]	[4, 8] [1, 5]
	D_2	[7,10] [4, 6]	[2, 6] [7, 10]	[3, 5] [9, 11]
	D_3	[7, 11] [4, 8]	[3, 5] [3, 6]	[5,7] [1,2]

Now, using step 1 the (R_1) and (R_2) to the given (R) is given below:

Table-2. Separation interval assignment cost.

	(R_1)			(R_2)		
	B_1	B_2	B_3	B_1	B_2	B_3
D_1	[1,3]	[5, 9]	[4,8]	[3, 5]	[2, 4]	[1,5]
D_2	[7,10]	[2, 6]	[3,5]	[4, 6]	[7,10]	[9,11]
D_3	[7,11]	[3, 5]	[5,7]	[4, 8]	[3,6]	[1,2]

Using step 2 to find midpoint and width from (R_1) and (R_2).

Table-3. Midpoint and width.

	(R_1)			(R_2)		
	B_1	B_2	B_3	B_1	B_2	B_3
D_1	$\langle 2,1\rangle$	$\langle 7,2\rangle$	$\langle 6,2\rangle$	$\langle 4,1\rangle$	$\langle 3,1\rangle$	$\langle 3,2\rangle$
D_2	$\langle 8.5,1.5\rangle$	$\langle 4,2\rangle$	$\langle 4,1\rangle$	$\langle 5,1\rangle$	$\langle 8.5,1.5$	$\langle 10,1\rangle$
D_3	$\langle 9,2\rangle$	$\langle 4,1\rangle$	$\langle 6,1\rangle$	$\langle 6,2\rangle$	$\langle 4{,}5,1.5$	$\langle 1.5,0.5\rangle$

Now using step 3 to find optimal solution of $(R_1)$by HM.

Table-4. Optimal solution of(R_1).

	$(\mathbf{R_1})$		
	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$
D_1	$\langle 2,1\rangle$	$\langle 7,2\rangle$	$\langle 6,2\rangle$
D_2	$\langle 8.5,1.5\rangle$	$\langle 4,2\rangle$	$\langle 4,1\rangle$
D_3	$\langle 9,2\rangle$	$\langle 4,1\rangle$	$\langle 6,1\rangle$

Now the optimal allocation of (R_1) by Hungarian method is $D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2 = \langle 2,1\rangle + \langle 4,1\rangle + \langle 4,1\rangle = \langle 10,1\rangle = [9,11]$

It is noted that our solution [9, 11] is very much sharper than the solution [7, 13] obtained by Sobana and Anuradha [26].

Now using step 4 to finding optimal solution of (R_2) by Hungarian Method (HM).

Table-5. Optimal solution of(R_2).

	(R_2)		
	B_1	B_2	B_3
D_1	$\langle 4,1\rangle$	$\langle 3,1\rangle$	$\langle 3,2\rangle$
D_2	$\langle 5,1\rangle$	$\langle 8.5,1.5\rangle$	$\langle 10,1\rangle$
D_3	$\langle 6,2\rangle$	$\langle 4.5,1.5\rangle$	$\langle 1.5,0.5\rangle$

Here the optimal allocation of (R_2) by HM is $D_1 \to B_2 + D_2 \to B_1 + D_3 \to B_3 = \langle 3,1\rangle + \langle 5,1\rangle + \langle 1.5,0.5\rangle = \langle 9.5,1\rangle = [8.5,10.5]$.

It is noted that our solution $[8.5, 10.5]$ is very much sharper than the solution [7, 12] obtained by Sobana and Anuradha [26]

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Table-6. Assignment cost from $(R_1) \to (R_2)$.

	$(\boldsymbol{R_1})$			$(\boldsymbol{R_2})$		
	$\boldsymbol{B_1}$	$\boldsymbol{B_2}$	$\boldsymbol{B_3}$	$\boldsymbol{B_1}$	$\boldsymbol{B_2}$	$\boldsymbol{B_3}$
D_1	$\langle 2, 1\rangle$	$\langle 7, 2\rangle$	$\langle 6, 2\rangle$	$\langle 4, 1\rangle$	$\langle 3, 1\rangle$	$\langle 3, 2\rangle$
D_2	$\langle 8.5, 1.5\rangle$	$\langle 4, 2\rangle$	$\langle 4, 1\rangle$	$\langle 5, 1\rangle$	$\langle 8.5, 1.5\rangle$	$\langle 10, 1\rangle$
D_3	$\langle 9, 2\rangle$	$\langle 4, 1\rangle$	$\langle 6, 1\rangle$	$\langle 6, 2\rangle$	$\langle 4{,}5, 1.5\rangle$	$\langle 1.5, 0.5\rangle$

In the above, table by using step 5, consider the optimal solution of (R_1) in the (R_2) as a feasible solution, the assignment cost of (R_2) is $D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2 = \langle 4, 1\rangle + \langle 10, 1\rangle + \langle 4.5, 1.5\rangle = \langle 18.5, 1.5\rangle = [17,\ 20]$ and the assignment cost of (R_1) is $\langle 10, 1\rangle = [9, 11]$ for the allotment of $D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2$.

Now, using step 6, we find the set of all solutions P_1 of the (R) obtain form (R_1) to (R_2) is given in below.

Table-7. Assignment interval cost allocation for$P_1$of R from (R_1) to (R_2).

S. No	Assignment	Efficient/ non – efficient solutions
1	$D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2$	$\langle 10, 1\rangle = [9, 11], \langle 18.5, 1.5\rangle = [17, 20]$
2	$D_1 \to B_1 + D_2 \to B_2 + D_3 \to B_3$	$\langle 12, 2\rangle = [10, 14], \langle 14, 1.5\rangle = [12.5, 15.5]$

Similarly, by step 7 and 8, we will obtain the set of all solutions of (P_2) of the (R) find from (R_2) to (R_1) is given in Assignment Cost Table for P_2.

Table-8. Assignment cost allocation for $P_2$of R from (R_2) to (R_1).

S. No	Assignment	Efficient/ non – efficient solutions
1	$D_1 \to B_2 + D_2 \to B_1 + D_3 \to B_3$	$\langle 21.5, 2\rangle = [19.5, 23.5], \langle 9.5, 1\rangle = [8.5, 10.5]$,
2	$D_1 \to B_3 + D_2 \to B_1 + D_3 \to B_2$	$\langle 18.5, 2\rangle = [16.5, 20.5]$,$\langle 12.5, 2\rangle = [10.5, 14.5]$
3	$D_1 \to B_1 + D_2 \to B_2 + D_3 \to B_3$	$\langle 12, 2\rangle = [10, 14], \langle 14, 1.5\rangle = [12.5, 15.5]$
4	$D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2$	$\langle 10, 1\rangle = [9, 11], \langle 18.5, 1.5\rangle = [17, 20]$

The following table reveal the set of all solutions for (R) by using MMMWGIA obtained.

Table-9. Solution set of P.

S. No	Assignment	$\boldsymbol{P = P_1 \cup P_2}$
1	$D_1 \to B_1 + D_2 \to B_3 + D_3 \to B_2$	$\langle 10, 1\rangle = [9, 11], \langle 18.5, 1.5\rangle = [17, 20]$
2	$D_1 \to B_1 + D_2 \to B_2 + D_3 \to B_3$	$\langle 12, 2\rangle = [10, 14], \langle 14, 1.5\rangle = [12.5, 15.5]$
3	$D_1 \to B_2 + D_2 \to B_1 + D_3 \to B_3$	$\langle 21.5, 2\rangle = [19.5, 23.5], \langle 9.5, 1\rangle = [8.5, 10.5]$
4	$D_1 \to B_3 + D_2 \to B_1 + D_3 \to B_2$	$\langle 18.5, 2\rangle = [16.5, 20.5]$,$\langle 12.5, 2\rangle = [10.5, 14.5]$

From the Solution Set Table, we find the Types of solutions which are exhibit below:

Table-10. Types of solution set of (R).

Type of solutions	Interval value
Ideal Solution	([9,11], [8.5, 10.5])
Efficient Solution	([10, 14], [12.5, 15.5]), ([19.5, 23.5], [8.5, 10.5]) ([9 ,11], [17, 20])
Best compromise Solution	([10, 14], [12.5, 15.5])

We see that the proposed method can be find the ideal and set of efficient/ non - efficient solutions. Sobana and anuradha [26] applied Minor Minimum Method (MMM) method for this example and obtained the best compromise solution as [8, 16], [11, 17]. It is to be noted that the optimal solution obtained by our method is sharper than the solution obtained by others.

Table-11. Comparison table.

Our proposed method Intervals (MMMWGIA)	Sobana and Anuradha Proposed method [26] Intervals (MMM)
$[10, 14], [12.5, 15.5]$	[8, 16], [11, 17]

6. CONCLUSIONS

To acquire the set of all solutions for the bi-objective interval assignment issue, the minor minimum technique with generalised interval arithmetic is proposed. Using a new type of arithmetic operations to solve interval assignment problems without converting them to classical assignment problems. The interval optimal assignment as well as the interval optimal total cost may be obtained using the aforementioned method, as demonstrated by numerical examples. It should be emphasised that the optimal solution obtained by our method is sharper than that obtained by other methods. These set of solutions will help when the decision makers work with this type of problem, and he managed the economic behaviour and make perfect decision in administrative decisions.

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