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Solving the trapezoidal fuzzy assignment problem using the novel Dhouib-Matrix-AP1 heuristic

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ABSTRACT

The assignment problem is a famous problem in combinatorial optimization where several objects (tasks) are assigned to different entities (workers) with the goal of minimizing the total assignment cost. In real life, this problem often arises in many practical applications with uncertain data. Hence, this data (the assignment cost) is usually presented as fuzzy numbers. In this paper, the assignment problem is considered with trapezoidal fuzzy parameters and solved using the novel Dhouib-Matrix-AP1 (DM-AP1) heuristic. In fact, this research work presents the first application of the DM-AP1 heuristic to the fuzzy assignment problem, and a step-by-step application of DM-AP1 is detailed for more clarity. DM-AP1 is composed of three simple steps and repeated only once in n iterations. Moreover, DM-AP1 is enhanced with two techniques: a ranking function to order the trapezoidal fuzzy numbers and the min descriptive statistical metric to navigate through the research space. DM-AP1 is developed under the Python programming language and generates a convivial assignment network diagram plan.

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1. INTRODUCTION

The assignment problem deals with the allocation of n objects (i activities) to n other objects (j resources) depending upon their efficiency to do the job (the assignment cost C_{ij}). The basic assumption in the assignment problem is that one activity can be allocated to exactly one resource, and the main objective is to generate the minimal assignment network plan such that the total cost is minimal. Mathematically, the problem is formulated as in (1).

$$Min(Z) = \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}$$

Subject to:

$$\sum_{i=1}^{n} x_{ij} = 1, \sum_{j=1}^{n} x_{ij} = 1,$$

$$x_{ij} = \begin{cases} 1, \text{ if the } i^{\text{th}} \text{ job is assigned to the } j^{\text{th}} \text{ worker} \\ 0, \text{ otherwise} \end{cases} \quad (1)$$

Various methods have been developed in order to optimize the assignment problem, such as the ant colony optimization [1]–[14], the tabu search method [15]–[20], the red deer algorithm [21]–[28], the genetic algorithm [29]–[35], the neural network [36]–[39], the linear programming [37]–[41] and the Hungarian algorithm [42]–[47]. In this field, we invented a new column row heuristic entitled Dhouib-Matrix-AP1 (DM-AP1) in order to solve the assignment problem in certain environments [48]. DM-AP1 is composed of one iterative structure gathering three simple steps (see Figure 1) and presenting a time complexity of *O(n)*.

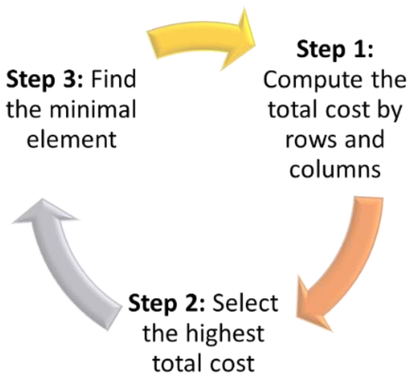

Figure 1. Flowchart of the novel DM-AP1 heuristic

The assignment problem is said to be a fuzzy assignment problem if the allocation cost parameter $\tilde{C}_{ij}$ is imprecise. The assignment problem with an imprecise cost matrix is considered and solved by the labeling algorithm in [49]. The bottleneck assignment problem with non-deterministic matrix cost is studied in [50]. A new ranking for generalized interval-valued pentagonal fuzzy numbers is introduced in [51]. An original level effect function with a genetic algorithm is considered for the fuzzy assignment problem in [52]. A robust ranking technique and a fuzzy Hungarian method are studied for the triangular assignment problem in [53]. A novel technique to obtain the optimal assignment under triangular fuzzy numbers is described in [54]. The centroid ranking method combined with genetic algorithms is presented in [55]. A trapezoidal fuzzy assignment problem is unraveled in [56]. A sensitive analysis of the fuzzy assignment problem is introduced in [57]. The flight-gate assignment problem is solved via the fuzzy bee colony optimization method in [58].

In this paper, the assignment problem is considered in the trapezoidal fuzzy domain and the novel DM-AP1 heuristic is enhanced to solve it. In fact, this paper introduces the first application of the DM-AP1 heuristic to the fuzzy assignment problem. Hence, the fuzzy numbers are converted to Haar tuples, which satisfy the properties of compensation, and the Min metric is used to handle the movement through the Haar tuple assignment cost matrix. The rest of the paper is organized as follows: in section 2, the basic definitions and the arithmetic operations of fuzzy numbers are introduced. In section 3, the novel DM-AP1 heuristic is reviewed. In section 4, a numerical example is presented to show the applications of the proposed heuristic and the total optimal fuzzy costs for the proposed algorithms are shown. Finally, the conclusion is given in section 5.

2. METHOD

Very recently, a new optimization concept entitled DM has been designed where several heuristics, metaheuristics and exact methods have been invented using the Python programming language: the DM-AP1 method for the balanced assignment problem with the linear sum function is developed in [48]. Moreover, for the travelling salesman problem, two heuristics are proposed: the DM-TSP1 and the DM-TSP2 in [59]. Furthermore, a novel heuristic named DM-TP1 is introduced for the transportation problem in [60]. In addition, an iterated stochastic metaheuristic named Dhouib-Matrix-3 (DM3) is intended in [61], a local search metaheuristic entitled Far-to-Near (FtN) is presented in [61] and a multi-start metaheuristic (based on several differential statistical metrics) entitled Dhouib-Matrix-4 (DM4) is studied in [62].

The novel column-row DM-AP1 method is applied to the classical assignment problem in this paper, where all input data are presented as trapezoidal fuzzy sets with a membership function formulated as in (2). Figure 2 depicts the three major steps (repeated in a structure with n iterations) of the proposed DM-AP1. For more clarity, a step-by-step application of DM-AP1 will be given in the next section.

$$\mu_{\tilde{F}}(x) = \begin{cases} \frac{x-f_1}{f_2-f_1} & f_1 \le x \le f_2 \\ 1 & f_2 \le x < f_3 \\ \frac{f_4-x}{f_4-f_3} & f_3 \le x < f_4 \\ 0 & otherwise \end{cases} \quad (2)$$

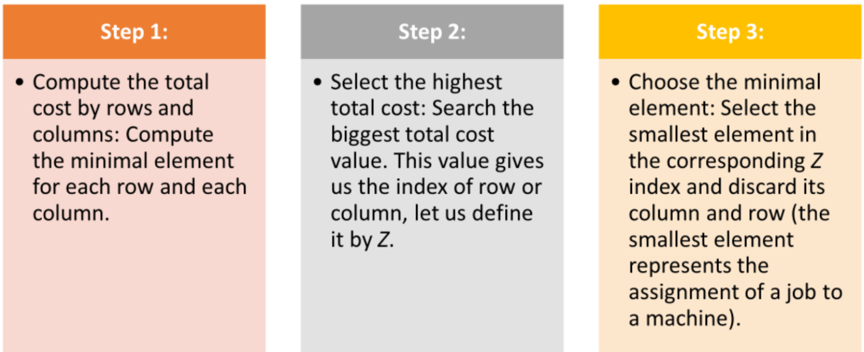

Figure 2. The three steps of the DM-AP1 heuristic

Moreover, the Haar ranking function is used for defuzzification. Thus, from any trapezoidal fuzzy number $\tilde{F} = (f_1, f_2, f_3, f_4)$ a new tuple $R(\tilde{F}) = (\alpha, \beta, \gamma, \delta)$ can be calculated using the Haar ranking function [63] which is characterized by its scaling and wavelet coefficient: $\alpha = ((f_1 + f_2 + f_3 + f_4)/4)$, $\gamma = ((f_1 - f_2)/2)$, $\beta = ((f_1 + f_2) - (f_3 + f_4)/4)$, $\delta = ((f_3 - f_4)/2)$. Let us consider two trapezoidal fuzzy numbers $\tilde{F} = (f_1, f_2, f_3, f_4)$ and $\tilde{E} = (e_1, e_2, e_3, e_4)$ then:
- $\tilde{F} \prec \tilde{E}$ only if the first element $(\alpha_{\tilde{F}})$ of $R(\tilde{F})$ is less than the first element $(\alpha_{\tilde{E}})$ of $R(\tilde{E})$
- $\tilde{F} \approx \tilde{E}$ only if the all elements of $R(\tilde{F})$ and $R(\tilde{E})$ are term wise equal.
- $\tilde{F} \succ \tilde{E}$ only if the first *element* $(\alpha_{\tilde{F}})$ of $R(\tilde{F})$ is greater than the first element $(\alpha_{\tilde{E}})$ of $R(\tilde{E})$

3. RESULTS AND DISCUSSION

In this section, a trapezoidal fuzzy assignment problem with 5 jobs (J_1, J_2, J_3, J_4, J_5) to be allocated to 5 workers (W_1, W_2, W_3, W_4, W_5) in such a way that the total assignment cost is minimized (see Figure 3). Before applying the DM-AP1 heuristic, the Haar ranking function is used to convert the trapezoidal fuzzy numbers to Haar tuples (see Figure 4). DM-AP1 will generate an optimal solution after just 5 iterations (n=5).
- Iteration 1: the first step resides in computing for each row and column the minimal value. The second consists in selecting the highest Haar tuple element (8,-1.5,-5,-5) at row 3 (see Figure 5). The last step is to select the minimal element in row 3 which is at position C_{32}. Thus, Job 3 is allocated to worker 2 and their corresponding row and column are discarded.
- Iteration 2: compute the minimal value for each row and column. Then, select the highest element (7.25,-4.75,-5,-2) which is in row 5 (see Figure 6). Now, choose the minimal element in row 5 which is at position C_{53}. Thus, Job 5 is allocated to worker 3 and their corresponding row and column are discarded.
- Iteration 3: again, compute the minimal value for each row and column and select the highest element (6.25,-1.75,-5,-1) in row 4 (see Figure 7). Choose the minimal element in row 4 which is at position C_{41}. Thus, Job 4 is allocated to worker 1 and their corresponding row and column are discarded.
- Iteration 4: hence, compute the minimal value for each row and column, select the highest element (5.5,-2,-5,-1.5) in row 1 (see Figure 8) and the minimal element in row 1 is at position C_{14}. Thus, Job 1 is allocated to worker 4 and their corresponding row and column are discarded.

- Iteration 5: finally, compute the minimal value for each row and column, select the highest element (5.5,-2,-5,-1.5) at row 1 (see Figure 9) and the minimal element in row 1 which is at position C_{14}. Thus, Job 1 is allocated to worker 4 and their corresponding row and column are discarded.

	W1	W2	W3	W4	W5
J1	(4,6,7,9)	(3,5,7,9)	(5,7,10,12)	(3,4,6,9)	(4,5,7,10)
J2	(2,3,5,9)	(5,7,9,13)	(4,6,9,12)	(5,6,7,10)	(2,3,5,7)
J3	(7,9,10,12)	(6,7,9,10)	(7,9,10,13)	(6,7,10,13)	(7,10,13,14)
J4	(4,5,7,9)	(5,7,12,15)	(7,9,13,15)	(2,9,10,13)	(5,7,10,14)
J5	(4,10,13,15)	(3,7,9,13)	(2,3,10,14)	(3,7,10,13)	(4,7,10,14)

Figure 3. Trapezoidal fuzzy cost assignment matrix

	W1	W2	W3	W4	W5
J1	(6.5,-1.5,-1,-1)	(6,-2,-1,-1)	(8.5,-2.5,-1,-1)	(5,5,-2,-5,-1.5)	(6.5,-2,-5,-1.5)
J2	(4.75,-2.5,-5,-2)	(8.5,-2.25,-1,-2)	(7.75,-2.75,-1,-1.5)	(7,-1.5,-5,-1.5)	(4.25,-1.75,-5,-1)
J3	(9.5,-1.5,-1,-1)	(8,-1.5,-5,-5)	(9.75,-1.75,-1,-1.5)	(9,-2.5,-5,-1.5)	(11,-2.5,-1.5,-5)
J4	(6.25,-1.75,-5,-1)	(9.75,-3.75,-1,-1.5)	(11,-3,-1,-1)	(8.5,-3,-3.5,-1.5)	(9,-3,-1,-2)
J5	(10.5,-3.5,-3,-1)	(7.75,-2.75,-2,-2)	(7.25,-4.75,-5,-2)	(8.25,-3.25,-2,-1.5)	(8.75,-2.25,-1.5,-2)

Figure 4. Haar tuples assignment cost matrix

	W1	W2	W3	W4	W5	
J1	(6.5,-1.5,-1,-1)	(6,-2,-1,-1)	(8.5,-2.5,-1,-1)	(5,5,-2,-5,-1.5)	(6.5,-2,-5,-1.5)	(5,5,-2,-5,-1.5)
J2	(4.75,-2.5,-5,-2)	(8.5,-2.25,-1,-2)	(7.75,-2.75,-1,-1.5)	(7,-1.5,-5,-1.5)	(4.25,-1.75,-5,-1)	(4.25,-1.75,-5,-1)
J3	(9.5,-1.5,-1,-1)	(8,-1.5,-5,-5)	(9.75,-1.75,-1,-1.5)	(9,-2.5,-5,-1.5)	(11,-2.5,-1.5,-5)	(8,-1.5,-5,-5)
J4	(6.25,-1.75,-5,-1)	(9.75,-3.75,-1,-1.5)	(11,-3,-1,-1)	(8.5,-3,-3.5,-1.5)	(9,-3,-1,-2)	(6.25,-1.75,-5,-1)
J5	(10.5,-3.5,-3,-1)	(7.75,-2.75,-2,-2)	(7.25,-4.75,-5,-2)	(8.25,-3.25,-2,-1.5)	(8.75,-2.25,-1.5,-2)	(7.25,-4.75,-5,-2)
	(4.75,-2.5,-5,-2)	(6,-2,-1,-1)	(7.25,-4.75,-5,-2)	(5,5,-2,-5,-1.5)	(4.25,-1.75,-5,-1)	

Figure 5. The job 3 is assigned to worker 2

	W1	W2	W3	W4	W5	
J1	(6.5,-1.5,-1,-1)		(8.5,-2.5,-1,-1)	(5,5,-2,-5,-1.5)	(6.5,-2,-5,-1.5)	(5,5,-2,-5,-1.5)
J2	(4.75,-2.5,-5,-2)		(7.75,-2.75,-1,-1.5)	(7,-1.5,-5,-1.5)	(4.25,-1.75,-5,-1)	(4.25,-1.75,-5,-1)
J3						
J4	(6.25,-1.75,-5,-1)		(11,-3,-1,-1)	(8.5,-3,-3.5,-1.5)	(9,-3,-1,-2)	(6.25,-1.75,-5,-1)
J5	(10.5,-3.5,-3,-1)		(7.25,-4.75,-5,-2)	(8.25,-3.25,-2,-1.5)	(8.75,-2.25,-1.5,-2)	(7.25,-4.75,-5,-2)
	(4.75,-2.5,-5,-2)		(7.25,-4.75,-5,-2)	(5,5,-2,-5,-1.5)	(4.25,-1.75,-5,-1)	

Figure 6. The job 5 is assigned to worker 3

	W1	W2	W3	W4	W5	
J1	(6.5,-1.5,-1,-1)			(5,5,-2,-5,-1.5)	(6.5,-2,-5,-1.5)	(5,5,-2,-5,-1.5)
J2	(4.75,-2.5,-5,-2)			(7,-1.5,-5,-1.5)	(4.25,-1.75,-5,-1)	(4.25,-1.75,-5,-1)
J3						
J4	(6.25,-1.75,-5,-1)			(8.5,-3,-3.5,-1.5)	(9,-3,-1,-2)	(6.25,-1.75,-5,-1)
J5						
	(4.75,-2.5,-5,-2)			(5,5,-2,-5,-1.5)	(4.25,-1.75,-5,-1)	

Figure 7. The job 4 is assigned to worker 2

	W1	W2	W3	W4	W5	
J1				(5,5,-2,-5,-1.5)	(6.5,-2,-5,-1.5)	(5,5,-2,-5,-1.5)
J2				(7,-1.5,-5,-1.5)	(4.25,-1.75,-5,-1)	(4.25,-1.75,-5,-1)
J3						
J4						
J5						
				(5,5,-2,-5,-1.5)	(4.25,-1.75,-5,-1)	

Figure 8. The job 1 is assigned to worker 4

	W1	W2	W3	W4	W5	
J1						
J2					(4.25,-1.75,-5,-1)	(4.25,-1.75,-5,-1)
J3						
J4						
J5						
					(4.25,-1.75,-5,-1)	

Figure 9. The job 2 is assigned to worker 5

Then, the optimal assignment network diagram plan is: *J3->W2*, *J5->W3*, *J4->W1*, *J1->W4* and *J2->W5*. Figure 10 depicts the generated solution using Python programming language. The total trapezoidal fuzzy assignment cost is $\tilde{F} = (17,22,37,49)$. This solution is computed by:

$$\tilde{F} = (3,4,6,9) + (2,3,5,7) + (6,7,9,10) + (4,5,7,9) + (2,3,10,14) = (17,22,37,49)$$

Thus, for the decision maker, the total allocation cost will lie at [56] with a 100% level of satisfaction (lying at [61]. Also, increasing and decreasing levels for the remaining values of the minimal cost as shown in (3).

$$\mu_{\tilde{F}}(x) = \begin{cases} \frac{x-17}{5} & 17 \leq x \leq 22 \\ 1 & 22 \leq x < 37 \\ \frac{49-x}{12} & 37 \leq x < 49 \\ 0 & otherwise \end{cases} \quad (3)$$

Figure 11 shows a picture of the membership function of the generated trapezoidal fuzzy solution.

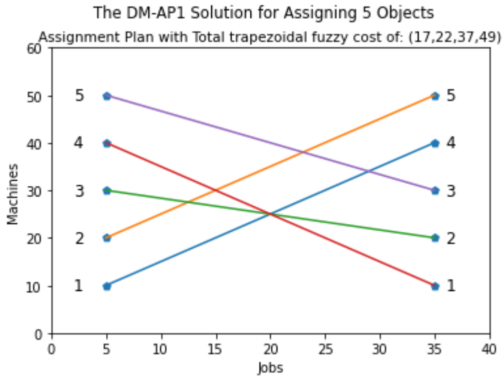

Figure 10. The assignment network diagram plan for 5 jobs

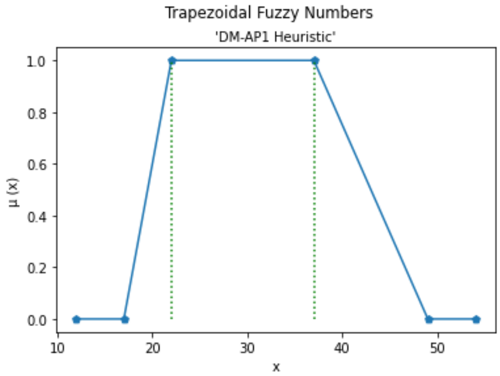

Figure 11. The graphical representation of the generated trapezoidal fuzzy solution

4. CONCLUSION

The assignment problem is frequently used to find solutions to problems that occur in the real world; however, in the real world, data is typically imprecise. In this study, the assignment problem is analyzed using a trapezoidal fuzzy cost, and a novel constructive column-row heuristic called DM-AP1 is used to find a solution to the problem. In the first step of the process, the trapezoidal fuzzy numbers are converted to the Haar tuples. After that, the DM-AP1 is applied, and its one-of-a-kind repetitive structure, which is made up of three straightforward steps, is utilized. It only takes n iterations to complete DM-AP1, where n is the total number of objects that need to be assigned. This algorithm is very efficient. An illustration of the novel DM-AP1 heuristic being applied in a step-by-step fashion is provided for the purpose of increasing clarity. In a future extension, the unorthodox DM-AP1 method will be utilized to find solutions for problems involving single-valued neutrosophic assignments.

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