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Transportation of Materials Under Fuzzy Environment Using Expected Monetary Value Strategy

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ABSTRACT

There are many circumstances in real-word situations where multiple objectives were taken into account and optimized simultaneously. Developing an acceptable solution for a multi-objective optimizing problem might be done in various ways. The multi-objective optimization problems include assignment problem, transport problem, travelling salesman problem and many more. To better tackle real-world scenarios, a fuzzy set theory-based multi-objective transportation problem (MOTP) is examined. An understandable and direct method is intended to find the fully fuzzy multi objective transportation problems where the parameters are triangular fuzzy numbers. By applying a new ranking method and a new type of arithmetic operations on the parametric representation of triangular fuzzy numbers, we have obtained a non-dominated solution of the fully fuzzy multi objective transportation problems. The new ranking method preserves the fuzzy nature of the problem. The Expected Monetary Value (EMV) strategy is applied to deal with the multi-objective optimization circumstances and a numerical example is provided to illustrate the strategy.

1. INTRODUCTION

The task of moving goods from a set of origins to a set of destinations while lessening the overall cost of transportation is commonly referred to as a transportation problem. Moving goods from one source to another while considering with regard to their respective supply and demand is the main objective of this particular type of linear programming problem (LPP). In order to deal with the increasing demands of the customers, different ideas and methods are to be implemented to fulfill their demands with minimum cost and within the stipulated time period.

Though there are different methods available to deal with the transportation problems, in real life situations, the demands, supply and availabilities are not known exactly. Fuzzy set theory proposed by Zadeh [1] is the main tool to tackle these kinds of situations.

Many authors have put in their efforts to solve single objective fuzzy transportation problems. However, we do not deal with a single objective at all circumstances, it is necessary to satisfy the other objectives like time and profit which play a major role in fuzzy transportation problems. To save time and money, the majority of the authors provided their solutions for numerous fuzzy transportation model problems. Some authors focused on the crucial aspect of the transportation problem with multiple objectives: the limitations on product blending while transferring raw materials with various levels of purity. In a realistic sense, the model's parameters are fuzzy because of various uncontrollable variables that exist.

Bit [2] was one of the mathematicians who worked on multi-objective fuzzy transportation problems. Abd El-Wahed, and Lee [3] presented a dynamic goal programming method for multi-objective transportation problem. An innovative approach for resolving linear multi-objective transportation problems utilizing fuzzy parameters was reported by Gupta and Kumar [4]. To deal with the objectives which are conflict in nature, Khan and Das [5] examined multi-objective transportation problems and presented a review to connect between the shortcomings of the problem and the fuzzy multiobjective optimization techniques. The optimal compromise approach to a multi-objective transportation problem (MOTP) was discovered by Abd El-Wahed [6]. Khoshnava and Mozaffarib [7] dealt with fully fuzzy transportation problems with multi objectives using weighted average method.

Uddin et al. [8] have used fuzzy goal programming approach to solve multi objective transportation problems. Bhageri et al. [9] is one of the authors who dealt with fuzzy multi-objective transportation problem using a system of weights. Ammar and Khalifa [10] solved multi-objective transportation problems using parametric analysis. Krishnaveni and Ganesan [11] proposed an effective approach for solving fuzzy transportation problem. Midya et al. [12] recommended multiobjective fractional fixed charge transportation problem using the fuzzy chance-constrained rough approximation method, which led to the most preferable optimal solution. Goal programming was used by Anukokila and Radhakrishnan [13] to analyse a fully fuzzy fractional multi-objective transportation problem. An example was also given to demonstrate the effectiveness of the multi-objective suggested strategy.

Fathy and Hassanien's work [14] shows how multilevel multiobjective fuzzy linear programming problems can be effectively solved using the harmonic mean technique. They have applied the crisp linear approach which is then split into three crisp multiobjective linear programming problems at each level. Then, each crisp problem's multiobjective is combined into a single objective using the fuzzy harmonic mean technique. Secondly, the harmonic mean for each level is used to generate the resulting final, single-objective problem. A fuzzy harmonic mean approach was used by Kache and Singh [15] to address the fuzzy multi-objective transportation problem (FMOTP). Initially, the problem was mathematically formulated followed by the division into three levels of multi-objective LPPs using fuzzy arithmetic. The multi-objective LPPs are then reduced to single-objective linear programming problems utilizing the fuzzy harmonic mean as a technique. Such single objective linear programming problems for any of the three levels are subsequently addressed in order to yield the combined fuzzy optimal solution. To address the multi-objective transportation problem, an innovative approach based on nearest interval approximation was suggested by Niksirat [16] in 2022.

Taking all these methods into consideration, our focus has been on a FTP that has two goals: fuzzy time and fuzzy cost. The EMV analysis is performed to transform it to a single objective transportation problem. The ranking function and the arithmetic operations play the major role to preserve the fuzziness of the problem.

Using the location index and fuzziness index concepts to describe the decision parameters (fuzzy numbers) in their parametric form, we minimize the transportation cost and time in this work in the simplest possible manner.

2. PRELIMINARIES

Definition 2.1

A fuzzy number $\tilde{f}$ is a triangular fuzzy number (TFN) denoted by $\tilde{f} = (f_1, f_2, f_3)$ where, f_1, f_2 and f_3 are real numbers and its membership function is given by:

$$\mu_{\tilde{f}(x)} = \begin{cases} \dfrac{x - f_1}{f_2 - f_1}, & f_1 \le x \le f_2 \\ \dfrac{f_3 - x}{f_3 - f_2}, & f_2 \le x \le f_3 \\ 0, & \text{otherwise} \end{cases}$$

The diagrammatic representation of TFN is given in Figure 1.

Definition 2.2

An alternative representation of a triangular fuzzy number $\tilde{f} = (f_1, f_2, f_3)$ is $\tilde{f} = (f_0, f_*, f^*)$, here $f_* = (f_0 - \underline{f})$, $f^* = (\overline{f} - f_0)$ are left and right fuzziness index functions. f_0 is the average of the monotonic increasing left and right continuous functions $\underline{f}$ & $\overline{f}$ at r=1.

2.1 Ranking of triangular fuzzy numbers

The ranking of $\tilde{f} = (f_1, f_2, f_3)$ by the concept of graded mean is defined by $R(\tilde{f}) = \left(\frac{f^* + 4f_0 - f_*}{4}\right) = \left(\frac{\underline{f} + \overline{f} + f_0}{4}\right)$. Hence for any two fuzzy numbers $\tilde{f}$ and $\tilde{g}$:

(i) $\tilde{f} \succeq \tilde{g} \Leftrightarrow R(\tilde{f}) \ge R(\tilde{g})$;
(ii) $\tilde{f} \preceq \tilde{g} \Leftrightarrow R(\tilde{f}) \le R(\tilde{g})$;
(iii) $\tilde{f} \approx \tilde{g} \Leftrightarrow R(\tilde{f}) = R(\tilde{g})$.

2.2 Arithmetic operations on triangular fuzzy numbers

With reference to Vinoliah and Ganesan [17], Balaganesan, and Ganesan [18], for any two fuzzy numbers $\tilde{f}$ and $\tilde{g}$, we define the arithmetic operations as follows: $\tilde{f} \vee \tilde{g} = max\{\tilde{f}, \tilde{g}\}$ and $\tilde{f} \wedge \tilde{g} = min\{\tilde{f}, \tilde{g}\}$. Consider $\tilde{f} = (f_0, f_*, f^*)$, $\tilde{g} = (g_0, g_*, g^*)$ then, $\tilde{f} * \tilde{g} = (f_0, f_*, f^*) * (g_0, g_*, g^*) = (f_0 * g_0, max\{f_*, g_*\}, max\{f^*, g^*\})$.

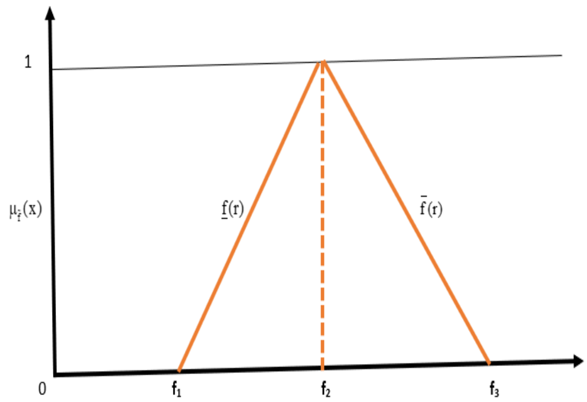

Figure 1. Triangular fuzzy number $\tilde{f} = (f_1, f_2, f_3)$

3. FUZZY TRANSPORTATION PROBLEM (FTP)

The mathematical formulation of Multi-Objective Fuzzy Transportation Problem (MOFTP) is defined as follows:

Let $\tilde{Z}_k = \{\tilde{Z}_1, \tilde{Z}_2, \ldots\ldots, \tilde{Z}_k\}$ be a vector of k objective functions, $\tilde{c}_{ij}^k$ denotes the fuzzy cost (fuzzy time); $\tilde{a}_i$ be the amount available at the source; $\tilde{b}_j$ be the amount available at the destination and $\tilde{x}_{ij}$ denotes the decision variable, then the mathematical formulation of the transportation problem is given below:

$$\begin{aligned} &\text{Minimize } \tilde{Z}_k = \sum_{i=1}^{m}\sum_{j=1}^{n} \tilde{c}_{ij}\tilde{x}_{ij} \\ &\text{subject to } \sum_{i=1}^{n} \tilde{x}_{ij} = \tilde{a}_i, \; i = 1, 2, \ldots\ldots m \\ &\qquad\qquad \sum_{i=1}^{m} \tilde{x}_{ij} = \tilde{b}_j, \; j = 1, 2, \ldots\ldots n \\ &\text{and } \tilde{x}_{ij} \succeq \tilde{0} \end{aligned} \tag{1}$$

This multi-objective fuzzy transportation problem can also be represented as an (m×n) cost matrix given in Table 1.

Table 1. Generalized multi-objective fuzzy transportation table

Sources \ Destinations	**D_1**	**D_2**	**….**	**D_n**	**Supply**
S_1	$\tilde{c}_{11}, \tilde{t}_{11}$	$\tilde{c}_{12}, \tilde{t}_{12}$	….	$\tilde{c}_{1n}, \tilde{t}_{1n}$	$\tilde{a}_1$
….	…….	….	….	….	….
S_i	$\tilde{c}_{i1}, \tilde{t}_{i1}$	$\tilde{c}_{i2}, \tilde{t}_{i2}$	….	$\tilde{c}_{in}, \tilde{t}_{in}$	$\tilde{a}_i$
…	…	…	….	….	….
S_m	$\tilde{c}_{m1}, \tilde{t}_{m1}$	$\tilde{c}_{m2}, \tilde{t}_{m2}$	….	$\tilde{c}_{mn}, \tilde{t}_{mn}$	$\tilde{a}_m$
Demand	$\tilde{b}_1$	$\tilde{b}_2$	….	$\tilde{b}_n$	Total

Definition 3.1

A feasible solution $\tilde{\boldsymbol{x}} = \{\tilde{x}_{ij}\}$ is said to be non-dominated solution (an efficient solution or fuzzy Pareto efficiency or fuzzy Pareto optimality) of the problem (1) if there exists no other solution $\tilde{\boldsymbol{x}} = \{\tilde{x}_{ij}\} \in X$ such that:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\bar{\tilde{c}}_{ij}^{\,t}\tilde{x}_{ij} \preceq \sum_{i=1}^{m}\sum_{j=1}^{n}\tilde{c}_{ij}\tilde{x}_{ij}^{*} \text{ for all r and}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\bar{\tilde{c}}_{ij}^{\,t}\tilde{x}_{ij} \neq \sum_{i=1}^{m}\sum_{j=1}^{n}\tilde{c}_{ij}\tilde{x}_{ij}^{*} \text{ for some r.}$$

3.1 Expected Monetary Value (EMV) analysis

When there are circumstances that may or may not occur, EMV analysis aids in computing the average results. It assists in calculating the sum required to control the identified risks and also enables us to select the task that will cost less money.

Here the risk identified is the fuzzy time and this EMV analysis helps us to select the optimal allocation that will reduce the fuzzy cost as well.

In the fuzzy MOTP (with fuzzy cost $\tilde{c}_{ij}$ and fuzzy time $\tilde{t}_{ij}$) which we have considered, the Expected Monetary Value for each source S_i and destination D_j are given by:

$$EMV(S_i) = \sum_{j=1}^{n}\left(\tilde{c}_{ij} \times memebershipvalue(\tilde{t}_{ij})\right),\quad i = 1,2,3,\ldots,m$$

$$EMV(D_j) = \sum_{i=1}^{m}\left(\tilde{c}_{ij} \times memebershipvalue(\tilde{t}_{ij})\right),\quad j = 1,2,3,\ldots,n$$

where, the membership value of $\tilde{t}_{ij}$ is $\frac{U-\tilde{t}_{ij}}{U-L}$, U is the maximum of all $\tilde{t}_{ij}$'s and L is the minimum of all $\tilde{t}_{ij}$'s.

4. ALGORITHM

Figure 2 represents the flow chart of the given algorithm.

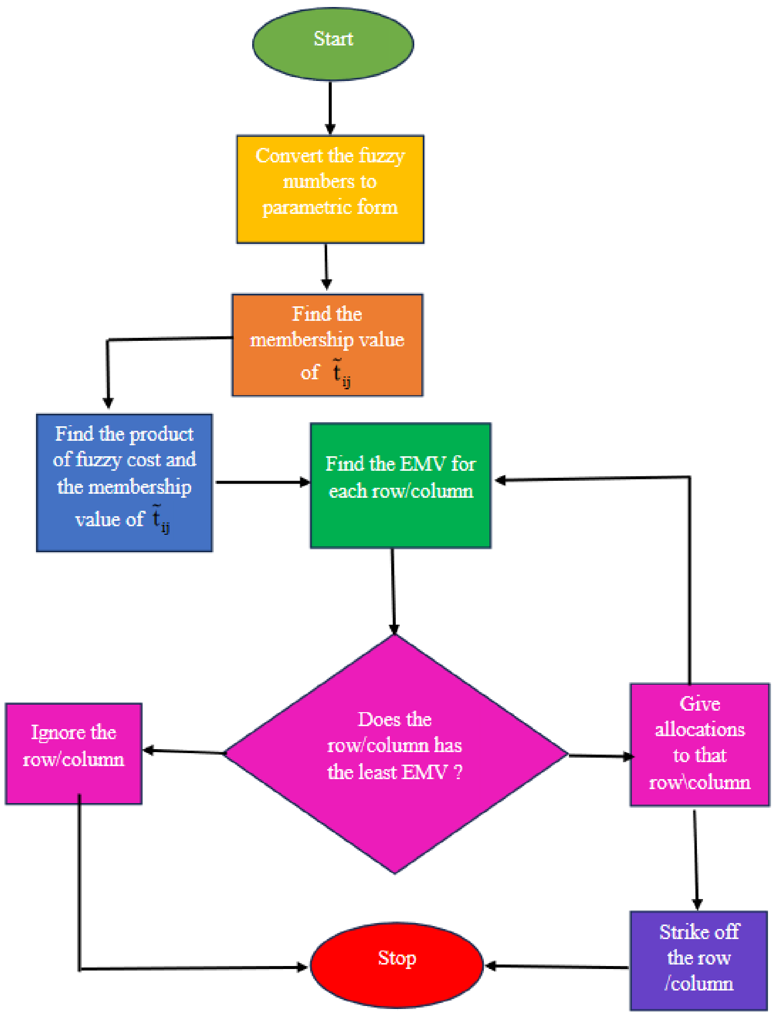

Figure 2. Flowchart of the algorithm

Step 1. Convert the given fuzzy transportation problem as a balanced one by adding a dummy source or a dummy destination.

Step 2. Develop a parametric representation of all the fuzzy numbers according to Definition 2.2.

Step 3. The membership value for $\tilde{t}_{ij}$ in each cell except for the fuzzy cost entries is computed.

Step 4. In each cell, the product of fuzzy cost and the membership value of $\tilde{t}_{ij}$ is calculated using $\frac{U-\tilde{t}_{ij}}{U-L}$, as explained in the Expected Monetary Value analysis and a new table is constructed.

Step 5. The expected monetary values are then calculated for each row and each column using EMV(S_i) and EMV(D_j) that is by adding the products row-wise as well as column-wise.

Step 6. The row or column with the least Expected Monetary Value is then identified using our ranking technique explained above. The ranking technique applied here expresses the fuzzy number in terms of location index and fuzziness index functions respectively. The ties are broken arbitrarily by choosing the cell with minimum cost.

Step 7. Depending on the situation at hand, the cell in the selected row or column that has the largest membership value at the lowest cost is chosen. This cell is provided with the maximum attainable quantity in order to completely satisfy both supply and demand. Next, the exhausted row or column is dropped.

Step 8. Steps 4 through 7 should be repeated until all resources and demands have been met.

5. NUMERICAL EXAMPLE

A multi-objective fuzzy transportation problem in which the information for the fuzzy cost, time, supply, and demand are displayed in Table 2.

Table 2. Multi-objective fuzzy transportation problem (MOFTP)

$S_i \backslash D_j$	D_1	D_2	D_3	Supply
S_1	(14,16,18) (8,9,10)	(15,19,23) (11,14,17)	(8,12,16) (10,12,14)	(8,14,20)
S_2	(20,22,24) (12,16,20)	(9,13,17) (8,10,12)	(18,19,20) (10,14,18)	(14,16,18)
S_3	(9,14,19) (3,8,13)	(24,28,32) (18,20,22)	(6,8,10) (5,6,7)	(9,12,15)
Dem-and	(5,10,15)	(12,15,18)	(14,17,20)	**(31,42,53)**

Each of the fuzzy number in Table 2 is observed to be a symmetric fuzzy number. The Table 3 is obtained by converting all fuzzy numbers into parametric form defined in Definition 2.2.

Table 3. Parametric form of MOFTP

$S_i \backslash D_j$	D_1	D_2	D_3	Supply
S_1	(16,2-2δ,2-2δ) (9,1-δ,1-δ)	(19,4-4δ,4-4δ) (14,3-3δ,3-3δ)	(12, ,4-4δ,4-4δ) (12, 2-2δ,2-2δ)	(14,6-6δ,6-6δ)
S_2	(22, 2-2δ,2-2δ) (16,4-4δ,4-4δ)	(13, 4-4δ,4-4δ) (10, 2-2δ,2-2δ)	(19,1-δ,1-δ) (14, 4-4δ,4-4δ)	(16,2-2δ,2-2δ)
S_3	(14,5-5δ,5-5δ) (8, 5-5δ,5-5δ)	(28, 4-4δ,4-4δ) (20 ,2-2δ,2-2δ)	(8,2-2δ,2-2δ) (6,1-δ,1-δ)	(12,3-3δ,3-3δ)
Demand	(10,5-5δ,5-5δ)	(15,3-3δ,3-3δ)	(17,3-3δ,3-3δ)	

Table 4. Fuzzy transportation table with membership values of fuzzy time

$S_i \backslash D_j$	D_1	D_2	D_3	Supply
S_1	(0.6,4-4δ,4-4δ) (9,1-δ,1-δ)	(0.45,4-4δ,4-4δ) (14,3-3δ,3-3δ)	(0.8,4-4δ,4-4δ) (12, 2-2δ,2-2δ)	(14,6-6δ,6-6δ)
S_2	(0.3, 4-4δ,4-4δ) (16,4-4δ,4-4δ)	(0.75, 4-4δ,4-4δ) (10, 2-2δ,2-2δ)	(0.45,4-4δ,4-4δ) (14, 4-4δ,4-4δ)	(16,2-2δ,2-2δ)
S_3	(0.7,5-5δ,5-5δ) (8, 5-5δ,5-5δ)	(0, 4-4δ,4-4δ) (20 ,2-2δ,2-2δ)	(1,4-4δ,4-4δ) (6,1-δ,1-δ)	(12,3-3δ,3-3δ)
Demand	(10,5-5δ,5-5δ)	(15,3-3δ,3-3δ)	(17,3-3δ,3-3δ)	

Table 5. Fuzzy transportation problem with single objective

$S_i \backslash D_j$	D_1	D_2	D_3	Supply
S_1	(5.4,4-4δ,4-4δ)	(6.3,4-4δ,4-4δ)	(9.6, 4-4δ,4-4δ)	(14,6-6δ,6-6δ)
S_2	(4.8,4-4δ,4-4δ)	(7.5, 2-2δ,2-2δ)	(6.3, 4-4δ,4-4δ)	(16,2-2δ,2-2δ)
S_3	(5.6,5-5δ,5-5δ)	(0 ,4-4δ,4-4δ)	(6,4-4δ,4-4δ)	(12,3-3δ,3-3δ)
Demand	(10,5-5δ,5-5δ)	(15 ,3-3δ,3-3δ)	(17,3-3δ,3-3δ)	

After shifting that problem to its parametric form, we cannot solve it directly. The multi-objective problem must be reduced to a single objective problem before any strategy can be used to attain the desired answer. The membership value of the fuzzy quantities excluding the fuzzy cost is calculated. Later the EMV is obtained for each cell. The next step is to find the EMV for each row first and then for each column. The Table 4 depicts a single objective transportation problem that is ready to be dealt with.

The row or the column which has the least Expected Monetary Value is identified according to Step 6 of the algorithm. The column or the row which is so selected will be given priority and then from that row (column), the cell with largest EMV is selected. The cell which is chosen is given the maximum allocation. The process from step 4 till step 7 goes on and the Table 5 is obtained.

Table 6. Fuzzy transportation problem after giving the allocation

$S_i \backslash D_j$	D_1	D_2	D_3	Supply
S_1	(16,2-2δ,2-2δ) (9,1-δ,1-δ) **(10,5-5δ,5-5δ)**	(19,4-4δ,4-4δ) (14,3-3δ,3-3δ)	(12, ,4-4δ,4-4δ) (12, 2-2δ,2-2δ) **(4,2-2δ,2-2δ)**	(14,6-6δ,6-6δ)
S_2	(22, 2-2δ,2-2δ) (16,4-4δ,4-4δ)	(13, 4-4δ,4-4δ) (10, 2-2δ,2-2δ) **(15,3-3δ,3-3δ)**	(19,1-δ,1-δ) (14, 4-4δ,4-4δ) **(1,2-2δ,2-2δ)**	(16,2-2δ,2-2δ)
S_3	(14,5-5δ,5-5δ) (8, 5-5δ,5-5δ)	(28, 4-4δ,4-4δ) (20 ,2-2δ,2-2δ)	(8,2-2δ,2-2δ) (6,1-δ,1-δ) **(12,3-3δ,3-3δ)**	(12,3-3δ,3-3δ)
Demand	(10,5-5δ,5-5δ)	(15 ,3-3δ,3-3δ)	(17,3-3δ,3-3δ)	

According to Table 6, the optimum fuzzy transportation cost is:

=(9, 1-δ, 1-δ)**(10, 5-5δ, 5-5δ)**+(12, 2-2δ, 2-2δ)**(4, 2-2δ, 2-2δ)**+(10, 2-2δ, 2-2δ)**(15, 3-3δ, 3-3δ)**+(14, 4-4δ, 4-4δ)**(1, 2-2δ, 2-2δ)**+(6, 1-δ, 1-δ)**(12, 3-3δ, 3-3δ)**=(90, 5-5δ, 5-5δ)+(48, 2-2δ, 2-2δ)+(150, 3-3δ, 3-3δ)+(14, 4-4δ, 4-4δ)+(72, 3-3δ, 3-3δ)=(374, 5-5δ, 5-5δ)=(513+5δ, 518, 523-5δ)

Optimum fuzzy transportation time is:

=(16, 2-2δ, 2-2δ)**(10, 5-5δ, 5-5δ)**+(12, 4-4δ, 4-4δ)**(4, 2-2δ, 2-2δ)**+(13, 4-4δ, 44δ) **(15, 3-3δ, 3-3δ)**+(19, 1-δ, 1-δ) **(1, 2-2δ, 2-2δ)**+(8, 2-2δ, 2-2δ)**(12, 3-3δ, 33δ)**=(160, 5-5δ, 5-5δ)+(48, 4-4δ, 4-4δ)+(195, 4-4δ, 4-4δ)+(19, 22δ, 2-2δ)+(96, 3-3δ, 3-3δ)=(518, 5-5δ, 5-5δ)=(369+5δ, 374,379-5δ).

The following table (Table 7) gives the fuzzy optimum solution to multi-objective fuzzy transportation problem for different values of δ.

Table 7. Fuzzy optimum solution to multi-objective fuzzy transportation problem

Value of $\boldsymbol{\delta} \in [\mathbf{0}, \mathbf{1}]$	**Proposed Method**	
	Transportation cost	Transportation time
δ=0	(513, 518, 523)	(369, 374,379)
δ=0.5	(515.5, 518,520.5)	(371.5, 374,376.5)
δ=1	(518, 518,518)	(374, 374,374)

On the other hand, we convert this multi-objective fuzzy transportation problem in to an equivalent crisp transportation problem using the proposed ranking method.

Table 8. Multi-objective crisp transportation problem

	D_1	D_2	D_3	Supply
S_1	16 9	19 14	12 12	14
S_2	22 16	13 10	19 14	16
S_3	14 8	13 10	19 14	12
Demand	10	20	17	

Converting this multi-objective crisp transportation problem (Table 8) in to a single objective crisp transportation problem (Table 9) using weighted mean, we have:

Table 10 gives the optimum allocation for the given multi-objective fuzzy transportation problem by converting to an equivalent crisp multi-objective transportation problem and which is given by x_{11}=9, x_{13}=5, x_{21}=1, x_{22}=15, x_{33}=12.

The corresponding Transportation cost is 518 cost units and the transportation time is 374-time units. Here we got only the crisp solution for the fuzzy problem. We are not sure that how far this crisp solution (outputs) is suitable when the inputs are fuzzy parameters.

Table 9. Single objective crisp transportation problem

	D_1	D_2	D_3	Supply
S_1	13.2	17	12	14
S_2	19.6	11.8	17	16
S_3	11.6	24.8	7.2	12
Demand	10	20	17	

Table 10. Optimum allocation for the single objective crisp transportation problem

	D_1	D_2	D_3
S_1	13.2 **9**	17	12 **5**
S_2	19.6 **1**	11.8 **15**	17
S_3	11.6	24.8	7.2 **12**

6. RESULT AND DISCUSSION

In majority of the papers, the model parameters (fuzzy numbers) are converted into equivalent crisp numbers through some defuzzification methods and then apply the existing traditional classical methods to solve the real life problems. The defuzzification process has a significant drawback, according to Kaufmann and Gupta [17]. Although this method is mathematically sound, we should avoid it because it reduces the amount of information that is available in the original data. By applying the ranking function (section 2.1), the problem has been solved and obtained a crisp solution. The minimum time is 374 units and the corresponding minimum transportation cost is 518 units whereas for the same problem we have obtained (513+5δ, 518,523-5δ) as the minimum fuzzy transportation cost and (369+5δ, 374,379-5δ) as the minimum fuzzy time respectively. It can be seen that the location indices of the fuzzy cost and time are the crisp solutions.

7. CONCLUSIONS

In this article, we have put forth a straightforward strategy for an optimal solution of transportation-related problems with multiple, fully fuzzy objectives. By operating a new ranking algorithm and new fuzzy arithmetic on the parametric form of triangular fuzzy numbers, we were able to solve a fully fuzzy multi-objective transportation problem with (without) converting in its crisp version. The aforementioned example clearly demonstrates how flexible the suggested method is to the choice maker in terms of selecting a good value for δ.

This article also points out the shortcomings of the other methods where those methods have their solution to be in crisp form alone. This way of solving the given fuzzy transportation problem has more advantages than the existing ones. Moreover, fuzzy transportation problems occur frequently in this business world and this article would be of real value to deal with such problems.

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