

Mixed Constraints Cost Minimization Transportation Problem: An Effective Algorithmic Approach

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Abstract In the literature, there are several methods for finding an initial basic feasible solution to the cost-minimizing transportation problem with equality constraints. In this paper, we proposed an efficient algorithm for solving transportation problems in which the origin and destination constraints consist not only of equality but also inequality. The proposed method is easy to understand and to apply for finding an initial basic feasible solution to transportation problems happening in real-life situations.

Keywords Transportation problem (TP), Cost Minimization Transportation Problem with Mixed Constraints (CMTP-MC), Initial Basic Feasible Solution (IBFS)

1. Introduction

The transportation problem (TP) is a special class of linear programming problems, which deals with shipping commodities from sources to destinations. The transportation problem is to find the amount of commodity which should be transported from each source to each destination satisfying all the supply and demand limits of sources and destinations respectively so that the overall transporting cost is minimum which the objective of the TP. If the total supply and demand limits are equal, then the problem is said to be a balanced transportation problem with equality constraints.

The transportation problem was formalized by the French Mathematician Monge, [1]. Major advances were made in the field during World War II by the Russian Mathematician and Economist Leonid Vitaliyevich Kantorovich [2]. The standard form of the transportation problem was first presented by Frank Lauren Hitchcock [3]. Efficient methods of solution were derived by T. C. Koopman [4], Dantzig, G.B., [5], and then by Charnes A. et al. [6-8].

Many researchers developed a lot of methods to solve the Transportation problem. Some recent research work I mentioned here. Babu et al. [9] demonstrate that Vogel's Approximation Method (VAM) has some limitations and computational blunders. To overcome these limitations, they developed an Improved Vogel's Approximation Method (IVAM) by correcting these blunders.

Baidya [10] develop the stochastic solid transportation models to minimize the total transport time and ensuring safety with the safety and time objective functions. Dash and Mohanty et al. [11] inspect the TP where unit transportation cost, supplies, and demands are measured as uncertain normal variables. They develop the conceptual uncertain programming model for TP which is converted to a deterministic linear programming model. Sometimes per unit transport cost is uncertain due to the unstable condition of the fuel market. Gupta and Arora [12] provide an algorithm for determining the minimum unit transportation cost in a capacitated transportation problem with bounds on rim conditions. Ahmad and Adhami [13] develop a couple of mathematical optimization models to obtain the lower and upper bounds of the TP, where the supplies and demands quantities vary in an interval. Some transport systems impose a certain charge to use their routes along with the transport cost. Khurana and Adlakha [14] propose an algorithm for solving a multi-index fixed charge bi-criterion TP which minimizes the variable and fixed costs simultaneously to yield an optimal basic feasible solution. They also offer an algorithm to obtain an initial basic feasible solution of the multi-index TP.

If the capability of a supply is appreciably expanded/reduced and the requirement of a destination is also appreciably expanded/decreased, then the usual transportation system transformed to unequal transportation problem with mixed constraints. The special type of transportation problem with mixed constraints was meticulously studied firstly by Brigden [15]. He solved this problem by considering a related standard transportation problem having two additional sources and two additional

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destinations. Klingman, D., et al. [16-18] in transportation problem with mixed constraints interpret generalization of standard transportation problem having only one additional origin and destination. They accommodate the mixed transportation model by showing that it is equivalent to a standard transportation problem having only one additional origin and destination whereas Isermann, H. [19] in his paper show that to each transportation problem with mixed constraints a standard transportation problem with two additional costs can be related. Very few researchers published their research work on transportation problems with mixed constraints. Some well-known and existing methods are- LBP (least bound problem) proposed by Veena Adlakha, et al. [20] state that LBP is obtained by changing all inequalities to equalities with the lowest possible feasible right-hand side values. Then balanced it by using VAM and solve it with any transportation algorithm. Place the load(s) of the dummy row(s)/ column(s) of the balanced LBP at the lowest cost feasible cells of the given TP to obtain a solution for the TP with mixed constraints. Then Pandian, P. et al. [21-23] introduced a method named Zero Point Method, Fourier method, more for solution for fuzzy transportation problem for finding an optimal solution of mixed constraints transportation problem. Mondal R.N. et al. [24] developed new algorithms to find an optimal solution by using computer programming for TPs with mixed constraints. Also Arora and Khurana [25-26], Adlakha et al. [27-32], Pandian, P. et al. [33] Arsham, Gani, A. et al. [34], Akilbasha, A. et al. [35] Rayan, M. [36] proposed some algorithm has demonstrated the identifying cases where MFL paradoxical situation exists and also has provided various methods for finding MFL solution for transportation problems. Gupta, S. et al. [37] explain multi-objective capacitated transportation problem with mixed constraints. Agarwal et al. [38]. developed minimax method for Time minimizing transportation problem with mixed constrain. P. Rajarajeswari and D. Maheswari [39] presented Transportation problem with mixed constraints having all parameters as integer intervals is considered. Here we solve the fully integer interval transportation problem without converting it to the crisp transportation problem. Three Dimensional Bounded Transportation Problem by Kavita Gupta and Ritu Arora [40] presents a methodology to solve a three dimensional bounded transportation problem. Bounded transportation problem is expounded by defining a parallel bounded transportation problem. Equivalence between the two problems is established. A method has been developed for finding an optimal more-for-less solution in transportation problem by Nikky Kumari [41]. Khoso, A. M. et al. [42] proposed Modified LCM's Approximation Algorithm for Solving Transportation Problems has been developed in order to gain foremost fundamental capable solution of transportation issues where entity cut down the transportation expensive. The proposed algorithm is correlate with popular presenting methods corraling NWCM, LCM. Gupta, G., Rani, D., & Singh, S. [43]

considered transportation problems with uncertainty in transportation costs and proposed an alternate algorithm to find its initial basic feasible solution. The grade value for the zero costs is defined and is used to find the initial solution. Numerical examples with transportation costs represented by different kinds of fuzzy numbers have been added to illustrate the proposed methodology. The paper discussed a solution procedure of a multi-objective capacitated transportation problem (MOCTP) in an uncertain environment by Gupta, S., Ali, I., & Chaudhary, S. [44].

A literature search uncovered that much effort has been focused on classical transportation problem with equality constraints which is computationally easy to solve. Very few numbers of papers observed in the literature address the transportation problem with mixed constraints. In our proposed method we solve the transportation problem with mixed constraints by adding one additional row and a column. Then step by step complete the total procedure. Our method is easy to understand gives a better result than another existing method. Then we provide a table showing the comparison of some existing methods and the proposed method. we proposed only the solution procedure of transportation problem with mixed constraints without touching MFL paradoxical situation.

2. Formulation of a General Transportation Problem

A set of m supply points (origins) $O_1, O_2, \dots, O_i, \dots, O_m$ from which a good is shipped. The supply point i can supply at most a_i units. A set of n demand points (destinations) $D_1, D_2, \dots, D_j, \dots, D_n$ to which the good is shipped. Demand point j must receive at least b_j units of shipped goods. c_{ij} is the unit transportation cost and x_{ij} is the amount of product transported from sources i destinations j .

Using the above notation, the general transportation problem can be represented by the network diagram shown in Fig-1:

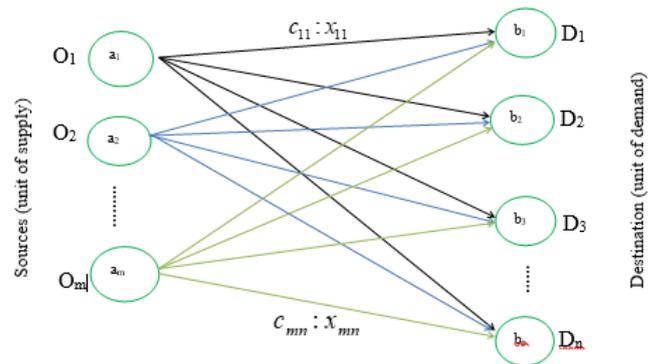


Figure 1. Network Representation of Transportation Problem

We can also represent the TP by using matrix form as follows:

Table 1. Matrix Representation of Transportation Problem

Factory	Warehouse				Supply
	1	2	...	n	
1	x_{11} c_{11}	x_{12} c_{12}	...	x_{1n} c_{1n}	a_1
2	x_{21} c_{21}	x_{22} c_{22}	...	x_{2n} c_{2n}	a_2
⋮	⋮	⋮	...	⋮	⋮
m	x_{m1} c_{m1}	x_{m2} c_{m2}	...	x_{mn} c_{mn}	a_m
Demand	b_1	b_2	...	b_n	

Mathematically (For General case):

x_{ij} = number of units shipped from supply point i to demand point j .

Then the general formulation of a transportation problem is:

$$\text{Minimize } z = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij}$$

$$\text{subject to } \sum_{j=1}^n x_{ij} \leq a_i ;$$

$i=1,2,\dots,m$ (Supply constraints)

$$\sum_{i=1}^m x_{ij} \geq b_j ;$$

$j=1,2,\dots,n$ (Demand constraints)

$x_{ij} \geq 0$, for all $i=1,2,\dots,m$ and $j=1,2,\dots,n$.

In the case of Balanced TP may be written as

$$\text{Minimize } z = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} .$$

$$\text{subject to } \sum_{j=1}^n x_{ij} = a_i ; i=1,2,\dots,m \text{ (Supply constraints)}$$

constraints)

$$\sum_{i=1}^m x_{ij} = b_j ; j=1,2,\dots,n \text{ (Demand constraints)}$$

$x_{ij} \geq 0$; for all $i=1,2,\dots,m$ and $j=1,2,\dots,n$.

3. Formulation of Transportation Problem with Mixed Constraints

Transportation problem with mixed constraints can be described as follows:

Suppose there are m origins O_i ($i \in S = \{1,2,3,\dots,m\}$) and we partitioned them into three sets S_1, S_2, S_3 . The set S_1 must distribute exactly a_i units of supply, S_2 must distribute at least a_i units of supply and S_3 must distribute at most a_i units of supply. Also, there are n destinations D_j ($j \in T = \{1,2,3,\dots,n\}$) and we partitioned them into three sets T_1, T_2, T_3 . The set T_1 must receive exactly b_j units, the set T_2 must receive at least b_j units and the set T_3 must receive at

most b_j units of demand. The objective is to determine the amount x_{ij} transported from source i to destination j while minimizing the total transport cost when satisfying mixed type supply and demand constraints.

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij}$$

Subject to

$$\sum_{j \in T} x_{ij} = a_i, \quad i \in S_1$$

$$\sum_{j \in T} x_{ij} \geq a_i, \quad i \in S_2$$

$$\sum_{j \in T} x_{ij} \leq a_i, \quad i \in S_3$$

and

$$\sum_{i \in S} x_{ij} = b_j, \quad j \in T_1$$

$$\sum_{i \in S} x_{ij} \geq b_j, \quad j \in T_2$$

$$\sum_{i \in S} x_{ij} \leq b_j, \quad j \in T_3$$

$$x_{ij} \geq 0, \quad i \in S, j \in T$$

We can also represent the above Transportation Problem with Mixed Constraints (TP-MC) by matrix form as follows:

Table 2. Matrix Representation of Transportation Problem with mixed constraints

Factory	Warehouse				Supply
	1	2	...	n	
1	x_{11} c_{11}	x_{12} c_{12}	...	x_{1n} c_{1n}	$\geq/\leq a_1$
2	x_{21} c_{21}	x_{22} c_{22}	...	x_{2n} c_{2n}	$\geq/\leq a_2$
⋮	⋮	⋮	...	⋮	⋮
m	x_{m1} c_{m1}	x_{m2} c_{m2}	...	x_{mn} c_{mn}	$\geq/\leq a_m$
Demand	$\geq/\leq b_1$	$\geq/\leq b_2$...	$\geq/\leq b_n$	

4. Proposed Algorithm

The proposed algorithm for determining the initial solution consists of the following steps:

Step 1: Construct the transportation table with mixed constraints for the given problem.

Step 2:

We convert the TP with mixed constraints into Equivalence Standard Balance Transportation Problem (ESBTP) by introducing dummy row and column with cost

1 against the equal (=) and at least (\geq) type constraints and cost 0 against the at most (\leq) type constraints.

Also setting

$$c_{m+1,n+1} = 0$$

$$a_{m+1} = \sum b_j, j = 1,2,3 \dots \dots n$$

$$b_{n+1} = \sum a_i, i = 1,2,3 \dots \dots m$$

Finally, we get balance TP with equality constraints.

Step 3:

Solve the ESBTP can be solved by using Vogel’s approximation method (VAM).

Step 4:

Shift the allocation from dummy cell to original cell by using the transformation:

$$\bar{x}_{ij} = \begin{cases} x'_{ij} + x'_{i,n+1}, & \text{If } \sum x_{ij} \text{ satisfying} \\ & \text{the condition } T_1 \cup T_2 \cup T_3, \text{ where} \\ & i \in S_1 \cup S \\ x'_{i,n+1}, & \text{otherwise select} \\ c_{ij} = \min c_{ij}, & i \in S_1 \cup S_2, \\ j \in T_1 \cup T_2 \cup T_3 \end{cases}$$

And Continue this process until all allocations are satisfied for all row and similarly for a column that is

$$\bar{x}_{ij} = \begin{cases} x'_{ij} + x'_{m+1,j}, & \text{If } \sum x_{ij} \text{ satisfying} \\ & \text{the condition } S_1 \cup S_2 \cup S_3 \\ & \text{where } j \in T_1 \cup T_2 \\ x'_{m+1,j}, & \text{otherwise} \\ \text{select } c_{ij} = \min c_{ij}, \\ j \in T_1 \cup T_2, i \in S_1 \cup S_2 \cup S_3 \end{cases}$$

\bar{x}_{ij} = optimal solution of the original problem,

x'_{ij} = optimal solution of ESBTP.

Step 5:

Finally, compute the total transportation cost for the feasible allocations as the sum of the product of cost and corresponding allocated value of the transportation matrix and total unit of flow.

Remarks:

We consider Problem TP is bounded. Necessary and sufficient conditions for the existence of a feasible solution are found in *Brigden (1974)*. Problem TP will be unbounded if there exists $c_{ij} < 0, (i,j) \in S_2 \times T_2$.

5. Numerical Illustration

Example 1

There are three factories and four warehouses and the factory produces a homogeneous product. Factory A has a

production capacity of exactly 20 units, Factory B has a production capacity of at least 16 units and Factory C has a production capacity at most 25 units. Likewise, Warehouse 1 having a capacity of demands at least 11 units, Warehouse 2 having a capacity of demands at most 13 units, warehouse 3 having a capacity of demands at least 17 units. Warehouse 4 having a capacity of demands exact 14 units. If per unit shipping cost from each factory to each warehouse is c_{ij} which are given. Then this type of TP is called Transportation problem with mixed constraints and we conclude the minimum transportation cost with shipping units (flow) using our proposed method:

Step-1: Formulation –

Factory	Warehouse				Supply
	1	2	3	4	
A	1	6	3	5	=20
B	7	3	1	6	≥ 16
C	9	4	5	4	≤ 25
Demand	≥ 11	≤ 13	≥ 17	=14	

		Warehouse				Supply
		D ₁	D ₂	D ₃	D ₄	
Factory	O ₁	1	6	3	5	=20
	O ₂	7	3	1	6	≥ 16
	O ₃	9	4	5	4	≤ 25
Demand		≥ 11	≤ 13	≥ 17	=14	

Step-2: Convert TP-MC to Equivalence Standard Balance Transportation (ESBTP) Problem:

		Warehouse					Supply
		D ₁	D ₂	D ₃	D ₄	D ₄₊₁	
Factory	O ₁	1	6	3	5	1	20
	O ₂	7	3	1	6	1	16
	O ₃	9	4	5	4	0	25
O ₃₊₁		1	0	1	1	0	55
Demand		11	13	17	14	61	116

Step-3 This is a balanced transportation problem. We solve it by using Vogel’s approximation method (VAM) and we get the allocation below:

	D ₁	D ₂	D ₃	D ₄	D ₄₊₁	Sup.
O ₁	11		1		8	20
O ₂		6	3	5	1	16
O ₃		3	1	6	1	25
O ₃₊₁		4	5	4	25	0
O ₃₊₁		13		14	28	0
	1	0	1	1	0	55
Dem.	11	13	17	14	61	116

Step-4: Now using transformation we get our required solution. Which is:

	D ₁	D ₂	D ₃	D ₄	Sup.
O ₁	19		1		=20
	1	6	3	5	
O ₂			16		≥16
	7	3	1	6	
O ₃				14	≤25
	9	4	5	4	
Dem.	≥11	≤13	≥17	=14	

Step-5: So required allocations are:

$x_{11} = 19, x_{13} = 1, x_{23} = 16, x_{34} = 14$, Total unit of flow-50

Total Cost = $x_{11} \times c_{11} + x_{13} \times c_{13} + x_{23} \times c_{23} + x_{34} \times c_{34} = 94$.

The rest of the three examples are given below for making a comparison.

Example 2: [Ref: Klingman, D. et al., (1974)]

1	6	3	5	=20
7	3	1	6	≥16
9	4	5	4	≤25
≥11	≤13	≥17	=14	

Example 3: Ref: Mondal, R.N. et al., (2015)

12	4	9	5	=55
8	1	6	6	≥40
1	2	4	7	≤30
=40	=20	≤45	≤20	

Example 4: Ref: Panadian, P. et al., (2010)]

10	1	7	=5
5	7	1	≥6
8	9	2	≤9
=8	≤10	≤5	

6. Comparative Study

The accompanying Table-3 demonstrates an examination for expense alongside the total unit of flow. Arrangements got by our proposed calculation and the other well-known existing calculations and Table-4 speak to the per-unit cost from where we effortlessly distinguish the best calculation.

Table 3. A Comparative Study of Different Solutions Shows cost and flow of the unit

	Methods Name ↓	Examples			
		1. Mondal, R.N. et al. (2015) (3×3)	2. Klingman, D. et al. (1974) (3×4)	3. Mondal, R.N. et al. (2015) (3×4)	4. Panadian, P. et al. (2010) (3×3)
1.	Proposed method	Cost-63 Flow-23	Cost-94 Flow-50	Cost-605 Flow-125	Cost-85 Flow-23
2.	Least Bound Problem (LBP)	Cost-58 Flow-18	Cost-94 Flow-42	Cost-655 Flow-95	Cost-80 Flow-18
3.	Zero point Method	Cost-80 Flow-18	Cost-132 Flow-64	Cost-755 Flow-95	Cost-80 Flow-18
4.	Mondal, R.N., et al.	Cost-58 Flow-18	Cost-93 Flow-51	Cost-605 Flow-125	Cost-74 Flow-18
5.	Klingman, D. et al.	Cost-58 Flow-18	Cost-93 Flow-51	Failed	Cost-85 Flow-23

Table 4. Comparative study shows per unit cost

	Methods Name ↓	Examples			
		1. Mondal, R.N. et al. (2015) (3×3)	2. Klingman, D. et al. (1974) (3×4)	3. Mondal, R.N. et al. (2015) (3×4)	4. Panadian, P. et al. (2010) (3×3)
1.	Proposed method	2.7	1.8	4.8	3.7
2.	Least Bound Problem (LBP)	3.2	2.2	6.9	4.4
3.	Zero point Method	4.4	2.1	7.9	4.4
4.	Mondal, R.N., et al.	3.2	1.8	4.8	4.1
5.	Klingman, D. et al.	3.2	1.8	Failed	3.7

7. Conclusions

In this paper, we have developed an effective algorithm for solving transportation problems with mixed constraints. A comparative study is carried out here on twenty randomly selected problems of a different order from some reputed journals. This comparison shows that our proposed method gives a better outcome over other existing calculations and we trust this new idea will help individuals who are working in this field. Still, there exists a rich opportunity for further research in this subject.

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REFERENCES

- [1] Monge, Gaspard.: Mémoires sur la théorie des déblais et des remblais. Histoire de l'Académie Royale des Sciences de Paris 666-704 (1781).

- [2] Kantorovich, Leonid V.: On the translocation of masses. Dokl.Akad.Nauk. USSR (NS). 37, 7-8 (1942).
- [3] Hitchcock, F.L.: The distribution of a product from several sources to numerous localities. Journal of Mathematics & Physics. 20, 224-230 (1941).
- [4] Koopmans, T. C.: Optimum utilization of the transportation system. Econometrica. Journal of the Econometric Society. 136-146 (1949).
- [5] Dantzig G.B.: Linear Programming and Extensions. Princeton University Press, Princeton, NJ, (1963).
- [6] Charnes A., Cooper W.W, Henderson A.: An Introduction to Linear Programming. John Wiley & Sons, New York. (1953).
- [7] Charnes A., Cooper W.W.: The Steepest Descent Method of Explaining Linear Programming Calculations in Transportation Problems. Management Science. 1(1) 49–69 (1954).
- [8] Charnes, A. and Klingman, D.: The more-for-less paradox in the distribution models. Cahiers du Centre d'Etudes Recherche Operationnelle. 13 11-22 (1977).
- [9] Babu, M. A., Hoque, M. A., & Uddin, M. S. A heuristic for obtaining better initial feasible solution to the transportation problem. OPSEARCH, 1-25 (2019).
- [10] Baidya, A.: Stochastic supply chain, transportation models: implementations and benefits. OPSEARCH, 56(2), 432-476 (2019).
- [11] Dash, S., Mohanty, S. P. Uncertain transportation model with rough unit cost, demand and supply. Opsearch, 55(1), 1-13 (2018).
- [12] Gupta, K., Arora, R. More for less method to minimize the unit transportation cost of a capacitated transportation problem with bounds on rim conditions. Opsearch. 54(3), 460-474 (2017).
- [13] Ahmad, F., Adhami, A. Y.: Total cost measures with probabilistic cost function under varying supply and demand in transportation problem. OPSEARCH. 56(2), 583-602 (2019).
- [14] Khurana, A., Adlakha, V.: On multi-index fixed charge bi-criterion transportation problem. Opsearch, 52(4), 733-745 (2015).
- [15] Brigden, M. E. B.: A variant of the transportation problem in which the constraints are of mixed type. Journal of the Operational Research Society 25(3), 437-445 (1974).
- [16] Klingman, D., Russell R.: The transportation problem with mixed constraints. Journal of the Operational Research Society 25(3) 447-455 (1974).
- [17] Klingman, D., Russell R.: Solving Constrained Transportation Problems. Institute for Operations Research and the Management Sciences (INFORMS) 23(1) 91-106 (1975a).
- [18] Klingman, D., Russell R.: Solving constrained transportation problems. Operations Research 23(1), 91-106 (1975b).
- [19] Heinz, I.: Solving the transportation problem with mixed constraints. Zeitschrift für Operations Research 26(1) (1982): 251-257.
- [20] Adlakha, V., Kowalski, K., Lev, B.: Solving transportation problems with mixed constraints. International Journal of Management Science and Engineering Management, 1(1), 47–52 (2006).
- [21] Pandian, P., Natarajan, G.: A new method for finding an optimal more-for-less solution of transportation problems with mixed constraints. Int. J. Contemp. Math. Sciences, 5(19), 931-942 (2010).
- [22] Pandian, P., Natarajan, G.: Fourier method for solving transportation problems with mixed constraints. Int. J. Contemp. Math. Sciences 5(28) 1385-1395 (2010b).
- [23] Pandian, P., and Natarajan, G.: An optimal more-for-less solution to fuzzy transportation problems with mixed constraints. Applied Mathematical Sciences 4(29) 1405-1415 (2010c).
- [24] Mondal, R. N., Rashid, F., Shaha, P. R., Roy.: An Innovative Method for Unraveling Transportation Problems with Mixed Constraints. American Journal of Mathematics and Statistics 5(4) 190-195 (2015).
- [25] Arora, S., Khurana, A.: A paradox in an indefinite quadratic transportation problem with mixed constraints, International Journal of Management and Systems, 18(3), 301-318 (2002).
- [26] Khurana, A., Arora, S. R.: Solving transshipment problems with mixed constraints. International Journal of Management Science and Engineering Management, 6(4), 292-297 (2011).
- [27] Adlakha, V., Kowalski, K.: A heuristic method for more-for-less in distribution related problems. International Journal of Mathematical Education in Science and Technology, 32, 61-71 (2001).
- [28] Adlakha, V., Kowalski, K., Lev, B., Vemuganti, R.R.: More-for-less algorithm for fixed-charge transportation problems. The International Journal of Management Science, 35(1), 1–20 (2007a).
- [29] Adlakha, V., Kowalski, K., Lev, B., Vemuganti, R.R.: More-for-less algorithm for fixed charge transportation problems. Omega. 35, 116-127 (2007b).
- [30] Adlakha, V., Kowalski, K., & Vemuganti, R. R.: Heuristic algorithms for the fixed-charge transportation problem. Opsearch. 43(2) 132-151 (2006).
- [31] Adlakha, V., Kowalski, K. (1998). "A quick sufficient solution to the more-for-less paradox in transportation problems", Omega, 26, 541-547.
- [32] Adlakha, V., Kowalski, K.: A note on the procedure MFL for a more-for-less solution in transportation problems. Omega. 28, 481-483(2000).
- [33] Pandian, P., Anuradha, D.: Path Method for Finding a More-For-Less Optimal Solution to Transportation Problems. In International Conference on Mathematical Computer Engineering. 1, 331-337 (2013).
- [34] Gani, A. N., Assarudeen, S. M.: A new operation on triangular fuzzy number for solving fuzzy linear programming problem. Applied Mathematical Sciences. 6(11), 525-532 (2012).
- [35] Akilbasha, A., Natarajan, G., & Pandian, P.: Solving Transportation Problems with Mixed Constraints In Rough

- Environment. *International Journal of Pure and Applied Mathematics* 113(9), 130 -138 (2017).
- [36] M.Rayan,: More- for- less paradox in distribution model, *Extremal methods and systems analysis*. Springer, New York, (1978).
- [37] Gupta, S., Ali, I., & Ahmed, A.: Multi-objective capacitated transportation problem with mixed constraint: a case study of certain and uncertain environment. *Opsearch*. 55(2), 447-477 (2018).
- [38] Agarwal, S., & Sharma, S.: A Minimax Method for Time Minimizing Transportation Problem with Mixed Constraints. *International Journal of Computer & Mathematical Sciences*. 7(3), 1-6 (2018).
- [39] Rajarajeswari, P., & Maheswari, D.: Solving Integer Interval Transportation Problem with Mixed Constraints. *IOSR Journal of Mathematics*. 16 (3), 35-39 (2020).
- [40] Gupta, K., & Arora, R.: Three dimensional bounded transportation problem. *Yugoslav Journal of Operations Research* 31(1), 121–137 (2021).
- [41] Kumari, N.: Zero Accomplishment Method for Finding an Optimal More-For-Less Solution of Transportation Problem with Mixed Constraints. *International Journal of Mathematics Trends and Technology (IJMTT)*. 66(8) 143-149 (2020).
- [42] Khoso, A. M., Shaikh, A. A., & Qureshi, A. S.: Modified LCM'S Approximation Algorithm for Solving Transportation Problems. *Journal of Information Engineering and Applications*. 10(3), 7-15(2020).
- [43] Gupta, G., Rani, D., & Singh, S.: An Alternate for the Initial Basic Feasible Solution of Category 1 Uncertain Transportation Problems. *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences*, 90(1), 157-167(2020).
- [44] Gupta, S., Ali, I., & Chaudhary, S. (2020). Multi-objective capacitated transportation: a problem of parameters estimation, goodness of fit and optimization. *Granular Computing*, 5(1), 119-134 (2020).