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Comparison of Existing Methods of Solving Linear Transportation Problems with a New Approach

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***Abstract* – This study examined comparatively the existing methods of solving linear transportation problems with a new approach proposed by Mollah [6]. The existing methods known as North West Corner Method, Least Cost Method, and Vogel's Approximation Method were compared to a new proposed algorithm known as Allocation Table Method. A real life data were collected from Dangote Flour Mills Plc, Calabar Cross River State Nigerian, and two numerical examples were collected from the exercise of Inyama [5]. The Allocation Table Method was solved using the stated algorithm, while the other three existing methods were solved via TORA software. From the analysis carried out in this study, it has been observed that the allocation table method did not yield comparatively a better result. We then conclude that the inefficiency of allocation table method has been tested by solving several number of cost minimizing transportation problems and it is found that the allocation table method did not yield a better result compare to the existing methods. It is therefore recommended that Mollah [6] should re-visit their proposed algorithm to probably know the lacuna in it, and future researchers should also look into a similar study to make their comments as regards to this contradiction.**

***Keywords* – North West Corner Method, Least Cost Method, Vogel's Approximation Method, Allocation Table Method, Initial Basic Feasible Solution.**

I. Introduction

Transportation problem deals with determination of a minimum-cost schedule for transporting a single commodity from a number of sources (warehouses) to a number of destinations (markets). This class of problem which is basically a linear programming problem can be extended to some practical applications such as inventory control, staff assignment, job scheduling, cash flow etc. Transportation problem is a well known problem of operations research that can be formulated and solved as a linear programme. The classical Transportation Problem (TP) refers to a special class of linear programming problems. Transportation problem was first introduced by Hitchcock [4], though transportation problems can be solved using the Simplex method. The work of Gass [3] described the history of Transportation Problem (TP) from simplex method implementation to Dantzig's adaptation of the Simplex method to the TP as the primal simplex transportation method. The work went further to Ramakrishnan [9] who explained a variation of Vogel's Approximation Method (VAM)[10], for finding a first feasible solution to the TP. Studies of Shafaat and Goyal [11] and Arsham and Kahn [2] for solving degenerate TPs.VAM was considered to give a better IBFS among all the existing techniques, with a unique penalty technique approach which gives a better convergence rate for getting optimal solution.

Transportation problem assumes that the transportation cost on a given route is directly proportional to the number of units of the commodity transported. Although the formation of a transportation problem can be used to represent more general assignment and scheduling problems as well as transportation and distribution problems. The two common objectives of such problems are either (1) minimize the cost of shipping m units to n destinations or (2) maximize the profit of shipping m units to n destinations. In this study, a new algorithm proposed by Mollah [6] shall be used to compare comparatively to other existing heuristics available to find an efficient initial basic feasible solution for a transportation problem. We shall achieve this objective by solving three numerical problems, using existing methods known as North West Corner Method, Least Cost Method, and Vogel's Approximation Method.

II. Related Literature Review

Mollah [6] carried out a research on a New Approach to Solve Transportation Problems. Solution of transportation problems was proposed. Efficiency of allocation table method was tested by solving several number of cost minimizing transportation problems and it was found that the allocation table method yields comparatively a better result. Finally it can be claimed that the allocation table method may provided a remarkable Initial Basic Feasible Solution by ensuring minimum transportation cost. According to the researcher, it will help to achieve the goal to those who want to maximize their profit by minimizing the transportation cost.

Parra [8] worked on a Survey of Transportation Problems. The study aimed at being a guide to understand the different types of transportation problems by presenting a survey of mathematical models and algorithms used to solve different types of transportation modes (ship, plane, train, bus, truck, Motorcycle, Cars, and others) by air, water, space, cables, tubes, and road. Some problems are as follows: bus scheduling problem, delivery problem, combining truck trip problem, open vehicle routing problem, helicopter routing problem, truck

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loading problem, truck dispatching problem, truck routing problem, truck transportation problem, vehicle routing problem and variants, convoy routing problem, railroad blocking problem (RBP), inventory routing problem (IRP), air traffic flow management problem (TFMP), cash transportation vehicle routing problem, and so forth.

Osuji [7] worked on Paradox Algorithm in Application of a Linear Transportation Problem. Two numerical examples were used for the study. In the study, an efficient algorithm for solving a linear programming problem was explicitly discussed, and it was concluded that paradox does not exist in the first set of data, while paradox existed in the second set of data. The Vogel's Approximation Method (VAM) was used to obtain the initial basic feasible solution via the Statistical Software Package known as TORA. The first set of data revealed that paradox does not exist, while the second set of data showed that paradox existed. The method however gave a step by step development of the solution procedure for finding all the paradoxical pair in the second set of data.

Anubhav [1] worked on Row-Column (RC) method for Transportation Problem for finding an Initial Basic Feasible Solution (IBFS). Transportation Problem (TP) deals with finding an Initial basic Feasible Solution (IBFS) and then checking its optimality so that the goods can be deliver from corresponding supply stations to the corresponding demanding points/destinations. The study presented another possible model for getting the IBFS for TP. The presented models do not require balancing the TP. Subsequently, the model was capable of delivering the IBFS with lesser number of steps, and two significant insights were shown.

III. Linear Transportation Problem

3.1. Transportation Model Problem

Transportation is an example of network optimization problem. It deals with the efficient distribution (transportation) of product (goods) and services from several supply locations (sources) with limited supply, to several demand locations (destinations) with a specified demand with the objective of minimizing total distribution cost; a typical example of which this thesis represents (in analogy).

This objective is achieved under the following constraints;

1. Each demand point receives its requirement.
2. Distributions from supply points do not exceed its available capacity.

This goal is achieved contingent on availability and requirements constraints. Transportation problem therefore assumes that the transportation cost on a given route is directly proportional to the number of units of the commodity transported[5].

IV. Model Formulation

The formulation of the transportation model employs double – subscripted variables of the form x_{ij}. Thus, the general formulation of the transportation problem with n sources and m destinations, is given by

$$\left.\begin{aligned} &\text{Minimize} \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} x_{ij} \\ &\text{Subject to} \sum_{i=1}^{n} s_i = s \quad i = 1,2,3,\ldots,n \\ &\sum_{j=1}^{m} d_j = d \quad j = 1,2,3,\ldots,m \end{aligned}\right\}$$

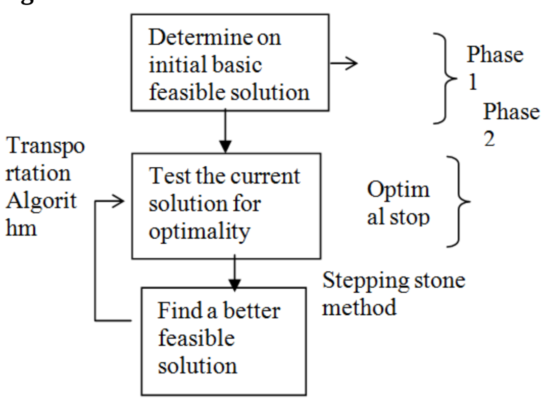
V. Finding Initial Feasible Solution to Transportation Problem

The general formulation of the transportation problem reveals that m supply constraints and n demand constraints translate into m + n total constraints. In the transportation problem however, one of the constraints is redundant resulting in the fact that if, in a balance condition,

$$\sum_{i=1}^{n} s_i \geq \sum_{j=1}^{m} d_j$$

m + n constraints are met then m + n equations will also be met. Only m + n – 1 independent equation, thus, exist and so the initial solution will have only m+ n -1 basic variables. The flow chart below illustrates the various phases leading to the optional solution of a transportation problem

Fig. 1



5.1. *Transportation Tableau*

The transportation tableau is a unique tabular representation of the transportation problem. The x_{ij} variable gives the number of units transported from source i to destination j (which is to be solved for) while the unit cost for the transportation from i to j, denoted by C_{ij}, is recorded in a small box in the upper – right – hand corner of each cell. Below is the form of the general transportation tableau.

Table 1. Transportation Tableau

To (i) From (j)	DESTINATIONS							
SOURCES		1	2	…	j	…	m	Supply
	1	C_{11} x_{11}	C_{12} x_{12}	…	C_{1j} x_{1j}	…	C_{1m} x_{1m}	S_1
	2	C_{21} x_{21}	C_{22} x_{22}	…	C_{2j} x_{2j}	…	C_{2m} x_{2m}	S_2
	…	…	…	…	…	…	…	…
	i	C_{i1} x_{i1}	C_{i2} x_{i2}	…	C_{ij} x_{ij}	…	C_{im} x_{im}	S_i
	…	…	…	…	…	…	…	…
	n	C_{n1} x_{n1}	C_{n2} x_{n2}	…	C_{nj} x_{nj}	…	C_{nm} x_{mn}	S_n
Demand		d_1	d_2	…	d_j	…	d_m	$\sum S_i = \sum d_j$

VI. Methods for Finding Initial Basic Feasible Solutions

The first phase of the solving a transportation problem for optimal solution involves finding the initial basic feasible solution. An initial feasible solution is a set of arc flows that satisfies each demand requirement without supplying more from any origin node than the supply available. Heuristic, a common – sense procedure for quickly finding a solution to a problem is a producer most employed to find an initial feasible solution to a transportation problem. This paper examines three of the more popular heuristics for developing an initial solution to transportation problem.

i. The Northwest corner method
ii. The Least Cost Method
iii. The Vogel's Approximation Method

In this study, we shall compare the three popular heuristics for developing an initial solution to transportation problem to Allocation Table Method (ATM) proposed by Mollah [6] using real life examples. Thus, the algorithm for determining the initial basic feasible solution to transportation problem according Mollah [6] is stated below.

Step 1: Construct a Transportation Table (TT) from the given transportation problem.

Step 2: Ensure whether the TP is balanced or not, if not, make it balanced.

Step 3: Select Minimum Odd Cost (MOC) from all the cost cells of TT. If there is no odd cost in the cost cells of the TT, keep on dividing all the cost cells by 2 (two) till you obtain at least an odd value in the cost cells.

Step 4: Form a new table which is to be known as Allocation Table (AT) by keeping the MOC in the respective cost cell/cells as it was/were, and subtract selected MOC only from each of the odd cost valued cells of the TT. Now all the cell values are to be called as Allocation Cell Value (ACV) in AT.

Step 5: At first, start the allocation from minimum of supply/demand. Allocate this minimum of supply/demand in the place of odd valued ACVs at first in the AT formed in **Step 4**. If demand is satisfied, delete the column. If it is supply, delete the row.

Step 6: Now identify the minimum ACV and allocate minimum of supply/demand at the place of selected ACV in the AT. In case of same ACVs, select the ACV where minimum allocation can be made. Again in case of same allocation in the ACVs, choose the minimum cost cell which is corresponding to the cost cells of TT formed in **Step 1** (*i.e.* this minimum cost cell is to be found out from the TT which is constructed in **Step 1**). Again if the cost cells and the allocations are equal, in such case choose the nearer cell to the minimum of demand/supply which is to be allocated. Now if demand is satisfied delete the column and if it is supply delete the row.

Step 7: Repeat **Step 6** until the demand and supply are exhausted.

Step 8: Now transfer this allocation to the original TT.

Step 9: Finally calculate the total transportation cost of the TT. This calculation is the sum of the product of cost and corresponding allocated value of the TT.

VII. Data Analysis

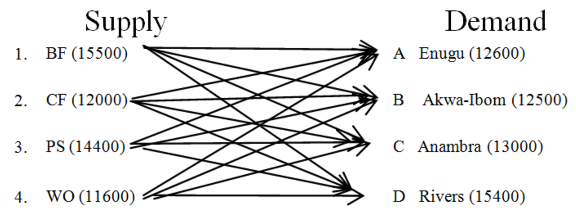
Dangote Flour Mills Plc is a manufacturing company located in Calabar. The company produces Bread Flour (BF), Confectionery Flour (CF), Penny Semolina (PS) and Wheat Offals (WO). These products are supplied to the following states (locations) Bayelsa, Anambra, Rivers, Kano, Abia, Enugu, Akwa Ibom etc. For the purpose of this study, only four (4) of these demand points shall be considered; Enugu, Akwa-Ibom, Anambra and Rivers. The estimated supply capacities of the four products, the demand requirements at the four sites (states) and the transportation cost per bag of each product are given below:

Table 2. Data Collected for the Transportation Problem

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	45	52	63	57	15500
CF	58	48	56	54	12000
PS	52	55	62	58	14400
WO	65	48	44	54	11600
Demand	12600	12500	13000	15400	53500

The problem is to determine how many bags of each product to be transported from the source to each destination in order to minimize the total transportation cost.

A diagram of the different transportation routes with supply and demand figures is shown below.



To form the transportation tableau, let:
i = product to be shipped
j = destination of each product
S_i = the capacity of source node i,
d_j = the demand of destination j,
x_{ij} = the total capacity from source i to destination
c_{ij} = the per unit cost of transporting commodity from source i to destination j.

If we suppose that discount is given on each bag transported from i to j, then the non linear transportation problem can be formulated as:

$$\min \sum_{i=1}^{4} \sum_{j=1}^{4} c_{ij} x_{ij}$$

S.t.
$$x_{11} + x_{12} + x_{13} + x_{14} = 15500$$
$$x_{21} + x_{22} + x_{23} + x_{24} = 12000$$
$$x_{31} + x_{32} + x_{33} + x_{34} = 14400$$
$$x_{41} + x_{42} + x_{43} + x_{44} = 11600$$
$$x_{11} + x_{21} + x_{31} + x_{41} = 12600$$
$$x_{12} + x_{22} + x_{32} + x_{42} = 12500$$
$$x_{13} + x_{23} + x_{33} + x_{43} = 13000$$
$$x_{14} + x_{24} + x_{34} + x_{44} = 15400$$
$$x_{ij} \ (i = 1,2,3,4;\ j = 1,2,3,4) \geq 0$$

Here we shall use the algorithm stated above to implement the Allocation Table Method, and use the TORA Software to handle the three popular heuristics method stated in this study.

Using the ATM, the solution follows this way;

According to **Step 2**, it is found that the given problem is balanced because of the sum of supplies is equal to the sum of the demands which is 53500.

Using **Step 3**, minimum odd cost is 45 in cost cell (1, 1) among all the cost cells of the Transportation **Table 2**.

Allocation in **Table 3** is formed according to **Step 4**, where minimum odd cost is in cell (1, 1) remains same, but this odd cost is subtracted from all other odd valued cost cells of the transportation **Table 1**. Like in cost cell (1, 3) it is 57 in Transportation **Table 2**, but in allocation table this cell value is 12 (57-45).

Based on **Step 5**, minimum supply/demand is 12600 which is allocated in cell (1, 1). After allocating this value it is observed that the demand is satisfied. This means that Enugu column is exhausted. The adjusted table is shown in below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**	52	18	12	**2900**
CF		48	56	54	**12000**
PS		10	62	58	**14400**
WO		48	44	54	**11600**
Demand	0	**12500**	**13000**	**15400**	**40900**

Here, only the cells of Akwa-Ibom, Anambra and Rivers columns are to be considered. 10 is the lowest cell value in the cell (3, 2) with the demand value of 12500. Hence, Akwa-Ibom column is exhausted. The adjusted table is shown below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**		18	12	**2900**
CF			56	54	**12000**
PS			62	58	**1900**
WO		**(12500)**	44	54	**11600**
Demand	0	0	**13000**	**15400**	**28400**

Here, only the cells of Anambra and Rivers columns are to be considered. 12 is the lowest cell value in the cell (1, 4) with the supply value of 2900. Hence, BF row is exhausted. The adjusted table is shown below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**			**(2900)**	0
CF			56	54	**12000**
PS		**(12500)**	62	58	**1900**
WO			44	54	**11600**
Demand	0	0	**13000**	**12500**	**25500**

At this point, only the cells (2,3), (2,4), (3,3), (3,4), (4,3), and (4,4) of Anambra and Rivers columns are to be considered. 44 is the lowest cell value in the cell (4, 3) with the supply value of 11600. Hence, WO row is exhausted. The adjusted table is shown below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**			**(2900)**	0
CF			56	54	**12000**
PS		**(12500)**	62	58	**1900**
WO			**(11600)**		0
Demand	0	0	**1400**	**12500**	**13900**

At this point, only the cells (2,3), (2,4), (3,3), and (3,4) of Anambra and Rivers columns are to be considered. 54 is the lowest cell value in the cell (2, 4) with the supply value of 12000. Hence, CF row is exhausted. The adjusted table is shown below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**			**(2900)**	0
CF				**(12000)**	0
PS		**(12500)**	62	58	**1900**
WO			**(11600)**		0
Demand	0	0	**1400**	**500**	**1900**

At this point, only the cells (3,3), and (3,4) of PS row is to be considered. 58 is the lowest cell value in the cell (3, 4) with the demand value of 500. Hence, Rivers Column is exhausted. The adjusted table is shown below.

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	**(12600)**			**(2900)**	0
CF				**(12000)**	0
PS		**(12500)**	62	**(500)**	**1400**
WO			**(11600)**		0
Demand	0	0	**1400**	0	**1400**

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At this point, only the cell (3, 3) is to be considered with demand/supply value of 62. All these allocations are made according to **Step 6** and **Step 7** of the proposed algorithm by Mollah [6]. Now according to **Step 8**, all these allocations are transferred to the Transportation **Table 2**, which is shown in the Final Allocation **Table 3**

Table 3. Initial Basic Feasible Solution according to ATM

	Enugu	Akwa-Ibom	Anambra	Rivers	Supply
BF	45(12600)	52	63	57(2900)	**15500**
CF	58	48	56	54(12000)	**12000**
PS	52	55(12500)	62(1400)	58(500)	**14400**
WO	65	48	44(11600)	54	**11600**
Demand	**12600**	**12500**	**13000**	**15400**	**53500**

Using **Step 9**, total transportation cost is (12600× 45 + 12500 × 55 + 1400 × 62 + 11600 × 44 + 2900 × 57 + 12000 × 54 + 500× 58) = **2,694,000**

Now solving for the three existing methods stated in this study using TORA software, the output is shown below.

Table 4. Output for North-West Corner Method

Iteration 1	**ObjVal**	**2817000.00**	**D1 Enugu**	**D2 Akwa-Ibom**	**D3 Anambra**	**D4 Rivers**	**Supply**
	Name		v1=45.00	v2=52.00	v3=60.00	v4=56.00	
S1	BF	u1=0.00	45.00 **12600** 0.00	52.00 **2900** 0.00	63.00 -3.00	57.00 -1.00	**15500**
S2	CF	u2= -4.00	58.00 -17.00	48.00 **9600** 0.00	56.00 **2400** 0.00	54.00 -2.00	**12000**
S3	PS	u3=2.00	52.00 -5.00	55.00 -1.00	A2.00 **10600** 0.00	8.00 **3800** 0.00	**14400**
S4	WO	U4=-2.00	5.00 -22.00	48.00 2.00	4.00 14.00	54.00 **11600** 0.00	**11600**
	Demand		**12600**	**12500**	**13000**	**15400**	

Table 5. Output for Vogel's Method

Iteration 1	**ObjVal**	**2657000.00**	**D1 Enugu**	**D2 Akwa-Ibom**	**D3 Anambra**	**D4 Rivers**	**Supply**
	Name		v1=45.00	v2=52.00	v3=61.00	v4=57.00	
S1	BF	u1=0.00	45.00 **12600** 0.00	52.00 **500** 0.00	63.00 -2.00	57.00 **2400** -1.00	**15500**
S2	CF	u2= -4.00	58.00 -17.00	48.00 **12000** 0.00	56.00 1.00	54.00 -1.00	**12000**
S3	PS	u3=1.00	52.00 -6.00	55.00 -2.00	62.00 **1400** 0.00	58.00 **13000** 0.00	**14400**
S4	WO	U4=-17.00	65.00 -37.00	48.00 -13.00	44.00 **11600** 0.00	54.00 -14.00	**11600**
	Demand		**12600**	**12500**	**13000**	**15400**	

Table 6. Output for Least-Cost Method

Iteration 1	**ObjVal**	**2657000.00**	**D1 Enugu**	**D2 Akwa-Ibom**	**D3 Anambra**	**D4 Rivers**	**Supply**
	Name		v1=45.00	v2=52.00	v3=61.00	v4=57.00	
S1	BF	u1=0.00	45.00 **12600** 0.00	52.00 **500** 0.00	63.00 -2.00	57.00 **2400** -1.00	**15500**
S2	CF	u2= -4.00	58.00 -17.00	48.00 **12000** 0.00	56.00 1.00	54.00 -1.00	**12000**
S3	PS	u3=1.00	52.00 -6.00	55.00 -2.00	62.00 **1400** 0.00	58.00 **13000** 0.00	**14400**
S4	WO	U4=-17.00	65.00 -37.00	48.00 -13.00	44.00 **11600** 14.00	54.00 -14.00	**11600**
	Demand		**12600**	**12500**	**13000**	**15400**	

Example 2

Consider a Transportation problem with four markets and three warehouses. The market demands are 10, 6, 8, and 12 while the warehouse capacities are 12, 14, and 10. The cell entries represent unit cost of transportation, and the table is shown below {Exercise 9, Number 5 of Inyama [6]}

Table 7. Data of Example 2

	Markets				Supply
Warehouses	M_1	M_2	M_3	M_4	
W_1	5	7	9	6	**12**
W_2	6	7	10	5	**14**
W_3	7	6	8	1	**10**
Demand	**10**	**6**	**8**	**12**	**36**

Using the proposed algorithm to obtain the initial basic feasible solution, the final allocation table is presented in Table 8.

Table 8. Initial basic feasible solution using ATM

	Markets				
Warehouses	M_1	M_2	M_3	M_4	Supply
W_1	5(10)	7(2)	9	6	**12**
W_2	6	7(4)	10(8)	5(2)	**14**
W_3	7	6	8	1(10)	**10**
Demand	**10**	**6**	**8**	**12**	**36**

Total transportation cost is $(5\times 10 + 7 \times 2 + 7 \times 4 + 10 \times 8 + 5 \times 2 + 1 \times 10)$ = **192**

Example 3

Consider a Transportation problem with four markets and four warehouses. The market demands are 10, 4, 6, and 14 while the warehouse capacities are 6, 9, 7, and 12. The cell entries represent unit cost of transportation, and the table is shown below {Exercise 9, Number 4 of Inyama[5]}

Table 9. Data of Example 3

	Markets				Supply
Warehouses	M_1	M_2	M_3	M_4	
W_1	2	5	6	3	**6**
W_2	9	6	2	1	**9**
W_3	5	2	3	6	**7**
W_4	7	7	2	4	**12**
Demand	**10**	**4**	**6**	**14**	**34**

Using the proposed algorithm to obtain the initial basic feasible solution, the final allocation table is presented in Table 10.

Table 10. Initial basic feasible solution using ATM

	Markets				Supply
Warehouses	M_1	M_2	M_3	M_4	
W_1	2(1)	5	6	3(5)	**6**
W_2	9	6	2	1(9)	**9**
W_3	5	2(4)	3(3)	6	**7**
W_4	7(9)	7	2(3)	4	**12**
Demand	**10**	**4**	**6**	**14**	**34**

Total transportation cost is $(2\times 1 + 3 \times 5 + 1 \times 9 + 2 \times 4 + 3 \times 3 + 7 \times 9 + 2 \times 3)$ = **112**

Having completed the analysis using the three existing result and the new on proposed by Mollah [3], the summary shall be presented in Table 11.

Table 11. Comparison of the results obtained by various methods with the proposed one

Method	Total Transportation Cost		
	Example 1	**Example 2**	**Example 3**
North West Corner Method	**2,817,000**	**192**	**149**
Least Cost Method	**2,657,000**	**192**	**83**
Vogel's Approximation Method	**2,657,000**	**190**	**92**
Proposed Approach (ATM)	**2,694,000**	**192**	**112**

VIII. Conclusion

In this study, the primary aim is to confirm the authenticity of the efficiency of the new approach proposed by Mollah [6] according to their findings using numerical examples to the existing methods to obtain the initial basic feasible solution. Hence, from the analysis carried out in this study, it has been observed that the allocation table method did not yield comparatively a better result. We can conclude that the inefficiency of allocation table method has been tested by solving several number of cost minimizing transportation problems and it is found that the allocation table method did not yield a better result compare to the existing methods. It is therefore recommended that Mollah [6] should re-visit their proposed algorithm to probably know the lacuna in it, and future researchers should also look into a similar study to make their comments as regards to this contradiction.

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