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Column Allocation Method for the Transportation Problem

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Method Article

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Abstract

The transportation problem deals with determining the optimal distribution plan for a single product. An optimal distribution plan helps a company achieve maximum profit while minimising product distribution costs. In this paper, the Column Allocation Method (CAM) is presented for finding the Initial Basic Feasible Solution (IBFS) to the transportation problem. A numerical example and comparative analyses were used to justify the performance of the proposed algorithm. The algorithm was capable of computing near-optimal solutions, and in some cases, the IBFS was the optimal solution.

1. Introduction

Transportation problem (TP) arises when there is a set, S, of source nodes and set D of destination nodes, and there are links called the arcs that link the elements of set S and D. The links have weights such as cost per unit transported. The elements of set S have supply capacity, whereas the elements of set D have demand requirements that are supposed to be satisfied. The problem is determining a mapping from set S to set D that minimizes total arc weights thus minimizing the transportation cost. TP can be classified as balanced or unbalanced. When total supply is equal to total demand, the problem is said to be a Balanced Transportation problem (BTP) and an Unbalanced Transportation problem (UTP) otherwise. Transportation problem has similarities with the maximum flow problem (Munapo et al. 2022, Tawanda et al. 2023) in that some variants of the TP have capacity restrictions in terms of the units that can be moved between two points. Generally, the TP is solved in two phases, thus the 1st and 2nd phases. The 1st phase is for determining the IBFS using well-known methods or algorithms such as the North West Corner Method (NWCM), Least Cost Method (LCM), and Vogel's Approximation Method (VAM). The 2nd phase is for optimization of the IBFS found in 1st phase using well-known TP methods and algorithms such as the U-V Method, among others. TP model can be applied in areas such as personnel management, inventory control and employment scheduling, among others.

2. Transportation problem

The following notations are associated with the transportation problem:

p – Number of sources

q – Number of destinations

μ_i – supply capacity at source i

α_j – Total demand at destination j

φ_{ij} – Unit transportation cost from source i to destination j

$\varnothing_{ij}$ - Amount to be shipped from source i to destination j

Transportation problem can be modelled as a network problem as shown below in **Fig. 1**. The nodes on the far right represent the source locations where as the ones on the far left represent the destination locations. The arcs connecting the source nodes and destination nodes show all possible routes that can be used to transport products.

Figure 1: Generalized transportation network

Transportation problem can be formulated mathematical as a linear programing model as shown below. The objective is to minimize overall transportation cost and the constraints gives restrictions on possible transportation routes (Tawanda 2018, Tawanda et al. 2022), demand requirement, and supply capacity.

2.1 Mathematical model

$$Mimimise\,\pi = \sum_{i=1}^{p} \sum_{j=1}^{q} \varphi_{ij} \varnothing_{ij}$$

Subjected to:

$$\sum_{j=1}^{q} \varnothing_{ij} \leq \mu_i,\ for\, i = 1,\ 2,\ \ldots,\ p$$

$$\sum_{i=1}^{p} \varnothing_{ij} \geq \alpha_j, \; for\, j = 1, 2, \; \ldots, q$$

$$\varvec{\varnothing}_{\varvec{i}\varvec{j}} \geq 0, \; \forall \; i \; and \; j$$

3. Literature review

Munapo et al. (2015) proposed the use of transportation branch and bound algorithm to solve the generalized assignment problem. Tawanda (2015) developed a node merging approach to solve the transshipment problem as a transportation problem. The approach converts the transshipment problem to TP and solve it using the well-known TP methods. Ahmed et al. (2016a) solved the TP using a new approach named the Table allocation method. A fixed charge TP with multi-route and different capacities was addressed by (Fakhrzad et al., 2019), using novel hybrid meta-heuristics. Ahmed et al. (2016b) developed incessant allocation method. The Vogel's approximation method was modified by (Ullah et al., 2016). Fuzzy TP algorithm (Rash et al., 2020). Pythagorean fuzzy approach to TP (Kumar et al., 2019). Chen et al (2017) considered uncertain goal programming models for bacteria solid TPs. TP with uncertain costs and random supplies (Guo, 2015). A two stage solution method for annual dairy TPs (Masson, 2016). Juman et al. (2015) presented an efficient heuristic to obtain a better initial feasible solution to the TP. Maity et al. (2019) Solved dual –hesitant fuzzy TP with restrictions. Multi-objective TP using genetic algorithm approach (Karthy and Ganesan, 2018). Two –level hierarchical time minimization TP (Kaur et al., 2020). Multi-lateral TP (Li et al., 2019). Assignment and loading TP considered by (Homsi et al., 2021). Shen and Zhu (2020) presented uncertainty two-echelon fixed charge TP. Kumar et al (2023) unified the transportation and assignment problems by solving the transportation problem using the modified Hungarian method. Prasad and Sigh (2020) modified the LCM for solving TP. Palsu's Favorable Cost Method presented by (Mohanta, 2018), this is a direct TP method. Ahmed et al (2017) proposed an innovative approach for computing the IBFS for the transportation problem. The proposed method is capable of computing IBFSs to both balanced and unbalanced transportation problems. A comparative study was used to justify the proposed approach, thus the performance of the proposed algorithm requires less effort to compute near or optimal solutions. Ahmed et al (2016c) developed a customized Vogel's approximation method (CVAM). A number of problems were solved using CVAM to demonstrate its efficiency, better results were obtained and it can also be stated that the algorithm requires minimum number of iterations to obtain IBFS as compared to existing methods. Uddin et al (2018) solved multi-objective transportation problem using genetic and fuzzy goal programming. Numerical examples were used to justify their approach. Das et al (2014) proposed the advanced Vogel's approximation method (AVAM). The IBFS computed by AVAM are more close to the optimal solution as compared to VAM, and in some instances AVAM computes optimal solutions. Badu et al (2014a) proposed a new approach to allocate zero supply or zero demand for all transportation algorithms so as to resolve degeneracy problems. Das et al (2014) identified limitations of VAM and developed an improved algorithm called Logical development of Vogel's approximation method (LD-VAM). The proposed method can compute better IBFS as compared to VAM and in other cases IBFS of LD-VAM are equal to the optimal solutions. Gatha and Anandhi (2018) developed a Standard deviation method (SDM) for solving unbalanced transportation problems. It is worth to mention that SDM provides better IBFS within minimum number of iterations to unbalance transportations problems. Badu et al (2014b) developed the implied cost method (ICM). This method can obtain optimal or near optimal solutions, however a couple of iterations are required to obtain IBFS. Numerical illustrations were used to justify the efficiency of the algorithm. Badu et al (2013) discussed the lowest allocation method (LAM). The method finds feasible solutions to the transportation problem within minimum number of iterations. Badu et al (2020) developed a heuristic called improved Vogel's approximation method (IVAM) that can be used to compute IBFS to the transportation problems. Computational experiments are conducted on 1500 randomly generated instances and it can be concluded that the proposed heuristic reduces transportation costs by 71.8%. Computational experiments have also revealed that IVAM is more efficient than VAM and other VAM related approaches. This literature review reveals there is still need to develop better TP algorithms that can give us better basic initial feasible solutions

4. Column Allocation Method

In this section we introduce the proposed method. The layout of the steps to be followed when computing the IBFS is given below. A flow chart to show the logic behind the method during IBFS computations. The method chooses columns for allocation using the least cost cell value criteria. Every chosen column should be satisfied in terms of its demand requirements before selecting the next column to be considered for allocation. The computations stops if and only if all columns are satisfied.

Steps

Step 1: Convert the given TP to Transportation table

Step 2: Check whether the TP is balanced or not, if not balanced then balance it by introducing dummy column, If Supply > Demand, Else introduce dummy row.

Step 3: Find the minimum cell value in the Transportation table

Step 4: Go to the column corresponding to the minimum value cell and do the following procedures.

1. Allocate the least value by comparing supply and demand, Min {Supply, Demand}
2. If the column is not satisfied, thus Min {Supply, Demand} < Total Column Demand, consider the next least cell value in the same column and allocate Min {Supply, Demand}
3. Repeat (b) until the column demands are met

Step 5: Find the next minimum cell value in the Transportation table.

Step 6: Go to Step 4

Step 7: Calculate the Total Transportation Cost (TTC) by adding products of all allocated cells in the transportation table.

Start

5. Numerical example

A company manufactures motor cars and it has three factories F1, F2 and F3 whose weekly production capacities are 300, 400 and 500 pieces of cars respectively. The company supplies motor cars to its four showrooms located at D1, D2, D3 and D4 whose weekly demands are 250, 350, 400 and 200 pieces of cars respectively. Table 1 below shows transportation costs per piece of motor cars are given in the transportation. Find out the schedule of shifting of motor cars from factories to showrooms with minimum cost.

Table 1
Transportation table

Factory	Showrooms				Capacity
	D1	D2	D3	D4	
F1	3	1	7	4	300
F2	2	6	5	9	400
F3	8	3	3	2	500
Demand	250	350	400	200	1200*

Solution

The solution to the numerical example is given in Table 2 below.

Solution explanation

In this section, all the iterations involved when computing the IBFS are given and explained as follows:

Iteration 1

The minimum cell value in in the Transportation table is Cell (F1, D2) = 1, this cell corresponds to column D2. Consider column D2 and allocate Min {300, 350} = 300 in cell (F1, D2). The production capacity of F2 is now 0 units and F2 may be deleted from the Transportation table. Column D2 requires (350 − 300) = 50 units to be satisfied. Consider the next minimum cell value in this column D2, thus Cell (F3, D2) = 3. Allocate Min {500, 50} = 50. After this allocation D2 is satisfied and may be deleted from the Transportation table. The production capacity of F3 is now reduced to (500 − 50) = 450 units.

Iteration 2

Next, consider the next minimum cell value in the transportation table thus Cell (F2, D1) = 2 and Cell (F3, D4) = 2. In this case we can randomly choose any cell between two cells. Cell (F2, D1) corresponds to column D1, Consider column D1 and allocate Min {400, 250} =

250 in cell (F2, D1). Column D1 is satisfied and may be deleted from the Transportation table. Production capacity of F2 is reduced from 400 units to 150 units.

Iteration 3

Next, consider the next minimum cell value in the transportation table thus Cell (F3, D4) = 2 corresponds to column D4, consider column D4 and allocate Min {450, 200} =200 in Cell (F3, D4). Column D4 is satisfied and the production capacity of F3 is now (450–200) = 250 units. Column D4 may be deleted from the Transportation table.

Iteration 4

Next, consider the next minimum cell value in the transportation table thus Cell (F3, D3) = 3, this cell corresponds to column D3. Go to column D3 and allocate Min {250, 400} =250, after this allocation column D3 is not yet satisfied it requires (400 – 250) = 150 units. Also note that production capacity of F3 is now reduced to 0 units. F3 may be deleted from the Transportation table. Since demand of D3 is not yet satisfied, consider the next minimum cell value in this column D3 thus Cell (F2, D3) = 5. Allocate Min {150, 150} = 150. After this allocation D3 is satisfied and all other columns are satisfied as well.

Total Transportation Cost = $((1×300) + (2×250) + (5×150) + (3×50) + (3×250) + (2×200))

= $(300 + 500 + 750 + 150 + 750 + 400)

= $ 2850

6. Comparative study and analysis

To justify the proposed method, we have solved 10 examples presented by (Ahmed et al., 2016c). The IBFS computed by the proposed algorithm (Column Allocation Method) are compared with the solutions found by NWCM, LCM, VAM, and CVAM as shown in Table 3 below. Computational gap is also being considered, thus how far the solution is from the optimal solution. Computational gap is given as a percentage from the optimal solution obtained after optimizing the IBFS. The more closer the IBFS is to the optimal solution the less computational effort, and less iterations required by IBFS optimizing algorithms such as the U-V Method to reach the optimal solution.

Table 3
Performance comparisons

Example	Size	INITIAL BASIC FEASIBLE SOLUTION					Optimal	OPTIMALITY GAP				
		NWCM	LCM	VAM	CVAM	CAM	Solution	NWCM	LCM	VAM	CVAM	CAM
EX-01	3×3	730	**555***	**555***	**555***	**555***	**555**	31.53%	00.00%	00.00%	00.00%	00.00%
EX-02	3×3	1500	1450	1500	**1390***	**1390***	**1390**	07.91%	04.32%	07.91%	00.00%	00.00%
EX-03	3×4	273	231	204	**200***	231	**200**	36.50%	15.50%	02.00%	00.00%	15.50%
EX-04	3×4	4400	2900	**2850***	**2850***	**2850***	**2850**	54.39%	01.75%	00.00%	00.00%	00.00%
EX-05	4×4	425	310	**285***	**285***	310	**285**	49.12%	08.77%	00.00%	00.00%	08.77%
EX-06	3×5	234	191	187	**183***	**183***	**183**	27.87%	04.37%	02.19%	00.00%	00.00%
EX-07	3×5	363	305	**290***	**290***	305	**290**	25.17%	05.17%	00.00%	00.00%	05.17%
EX-08	4×3	102	83	80	80	80	**76**	34.21%	09.21%	05.26%	05.26%	05.26%
EX-09	5×5	4284	2223	2224	2224	2224	**2202**	94.55%	00.95%	01.00%	01.00%	01.00%
EX-10	5×7	3180	2080	1930	1920	**1900***	**1900**	67.37%	09.47%	01.58%	01.05%	00.00%
AVERAGE OPTIMALITY GAP								**42.86%**	**05.95%**	**01.99%**	**00.73%**	**03.57%**

Initial basic feasible solutions obtained by different methods are presented in Table 3 above. Out of 10 problems solved the percentages of optimal solutions obtained is as follows NWCM (00.00%), LCM (10.00%), VAM (40.00%), CVAM (70.00%) and CAM (50%). Average optimality gap is given as follows NWCM (42.86%), LCM (05.95%), VAM (01.99%), CVAM (00.73%) and CAM (03.57%). In terms of finding the IBFS that is equal to optimal solutions, the proposed method (CAM) is the second best algorithm and third best algorithm on average optimality gap.

7. Conclusions

In this research, a new method for finding the IBFS is presented. The method is capable of computing near optimal solutions and in some cases the IBFS computed by the method are actual optimal solutions. Near optimal solutions computed by the proposed method reduce computational effort needed by 2nd phase algorithms to optimize IBFS. The proposed method is designed is such a way that it is less complex and this implies that it can be used for teaching purposed so as to usher the upcoming optimization scientists into the world of methodology development. Considering all these, the proposed method can be used by delivering companies to minimize total transportation cost when doing their day to day business.

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Figures

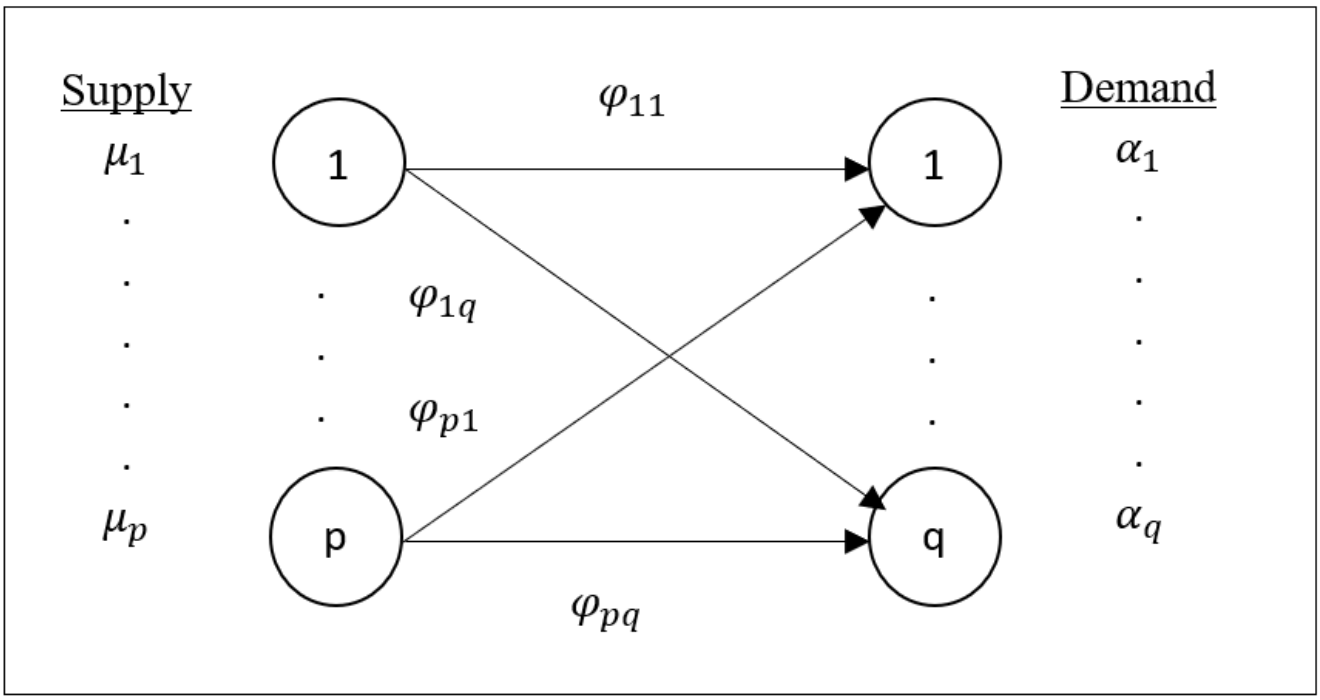


Figure 1

Generalized transportation network

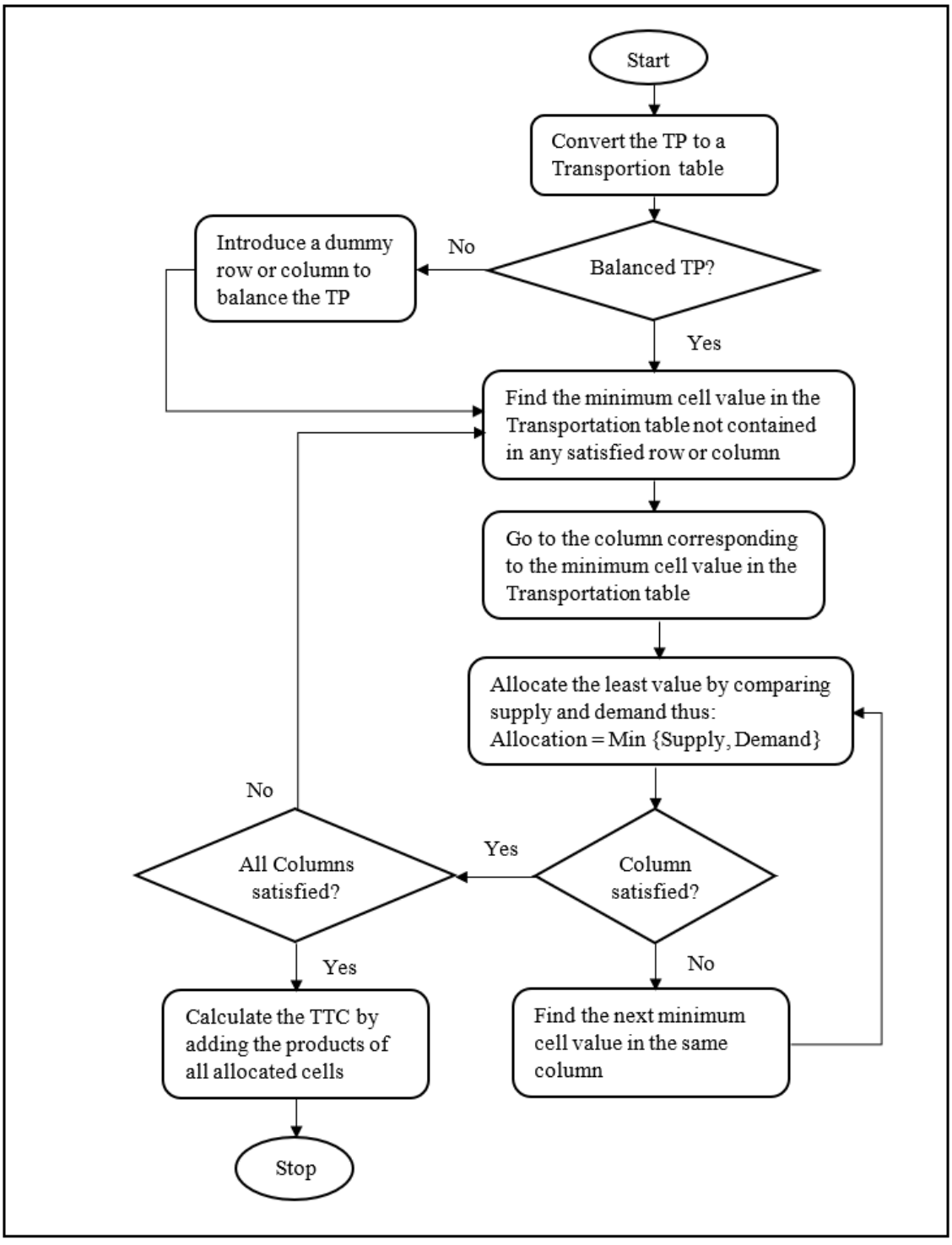


Figure 2

Column allocation method flow chart

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- Table2.docx