

# Modified matrix minima method for subset constrained transportation problem and its performance evaluation with respect to the optimal solution by mathematical model

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Transportation Problem, Subset Constraint, Matrix Minima Method, Least Cost Method, Mathematical Modeling.

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## Abstract

**Purpose of the study:** The transportation problem has a huge application in logistics. Therefore, dealing a transportation problem with permissible constraints is always an interesting area. In the present paper, we have tried a version of transportation problem which is constrained in nature. We have explored strategies for dealing the subset constrained transportation problem.

**Methodology:** An updated version of matrix minima method is proposed in this paper. This version is used for subset constrained transportation problem only. We have also applied the mathematical model for solving the same subset constrained transportation problem.

**Main Findings:** The mathematical model gives an optimal solution of the constrained transportation problem with the help of software. It is found that the proposed updated matrix minima method does not guarantee the optimality. However, we use the matrix minima approach for having an idea of the closer feasible solution. It is found that the mathematical model is always a superior way to find an optimal solution.

**Applications of this study:** The study has a huge application in logistics.

**Novelty/Originality of this study:** An updated version of matrix minima method is proposed. The method is applied on constrained transportation problem and the results are compared with the optimal solution.

## INTRODUCTION

Operations research consists of a lot of problems which are to be dealt with the help of mathematical modeling. Some well known problems which could be processed are knapsack problem, graph coloring problem, packing problem, assignment problem and transportation problem etc. Each problem could further be categorized into several sub-categories which is must for a better analysis. For example, the packing problem consists of ball packing problems in three dimensional spaces, circle packing problem in two dimensional space or even rectangle packing in two dimensional spaces. Each of these categories creates a unique field which needs to be dealt separately. In addition to these, the literature is filled up of various problems where mathematical model plays a vital role for the search of optimal value of the variable(s), which is/are to be optimized.

The transportation problem is always an interesting field when operations research comes into the picture. It has a huge application in logistics. Trans-shipment problem is an extension of transportation problem, which needs a separate attention. Further, we have a plenty of transportation problems which needs to be dealt separately. Some of the categories coming under transportation problem may include constrained transportation problem, red-blue transportation problem etc. The constrained transportation problem analysis is further a huge area dealing the various types of constrained problems such as constraints in terms of supply/demand, limitation on the path etc.

The present paper consists of a problem based analysis of constrained transportation problem. The paper is inspired from an idea of subset constraints, which already exists in the literature (Prajapati, R., Pal, J., & Dubey, O. P. (2022)). We are willing to deal only those transportation problems which have some constraints, which are in terms of subset constraints.

The originality of this paper is the application of the above idea (mathematical model of the subset constrained transportation problem in (Prajapati, R., Pal, J., & Dubey, O. P. (2022)) on some problems, the performance evaluation of the same and comparison of the results with the updated version of an existing method (for dealing the subset constrained transportation problem), which is matrix minima method. Therefore, we are proposing the matrix minima method for the subset constrained transportation problem. In this regard, we can also say that the idea presented here for dealing such constrained transportation problem by an updated matrix minima method is also the originality of this paper. We can find the feasible solution by updated matrix minima method while the mathematical model for

constrained transportation problem guarantees the optimal solution while solved by software. We have used LINDO software for solving the mathematical model here.

Before going in the detailed study of the problem under consideration, we'd like to have a survey of the literature dealing transportation problem, the constrained transportation problem or similar areas.

The conventional transportation problem is well familiar to most of us. However, the transportation problem with some constraints is a matter of interest in a large number of literatures. The fixed-charged transportation problem is introduced in [Adlakha, V. and Kowalski, K. \(2003\)](#) in which the transportation problem incurs some fixed charge in addition to the variable cost involved in the transportation process. A network augmented path basis algorithm for transportation problem is introduced in [Barr, R., Elam, J., Glover, F. and Klingman, D. \(1980\)](#). A new type of simplex algorithm is introduced in this paper for solving the capacitated network transportation problem. The concept of transit time restriction is introduced in [Brouer, B.D. et al. \(2015\)](#). They introduced a meta-heuristic for linear shipping network design problem. Heuristic approach for dealing the transportation problem is also a matter of interest in various literatures. Genetic algorithm for solving transportation problem is introduced in ([Deep, K., Dubey, O.P. and Nagar, A. \(2012\)](#)) with a case study taken from coal transportation sector. Further, the genetic algorithm used for bi-objective stochastic model for transportation is introduced in [Ardjmand, E. Et al. \(2016\)](#). Goal programming approach for transportation problem is introduced in [Dubey, O.P., Deep, K. and Nagar, A.K. \(2014\)](#). They applied the method on a transshipment problem which is an extension of transportation problem. The transshipment problem is converted to a transportation problem and further modified as a suitable goal programming problem. In [Dwivedi, R.K., Mehta, N.N. and Dubey, O.P. \(2009\)](#), the authors deal with an unbalanced transportation problem. They have used the example of coal transportation from four sources points to three destination points for illustrating their ideas. The idea of fractional capacitated transportation problem is introduced in [Gupta, K. and Arora, S.R. \(2012\)](#). The authors deal with the transportation problem with bounds on total availability at sources and total destination requirements. A similar linear plus fractional capacitated transportation problem with restricted flow is introduced in ([Kavita, G. and Shri Ram, A. \(2013\)](#)). A paper dealing the scheduling problem of blocked transportation with delivery restriction is given by [Joo, C.M. and Kim, B.S. \(2014\)](#). They dealt with the scheduling of transporter and their timing so that each block could be delivered from its source points to its destination points. Capacitated two stage time minimization transportation problem is introduced in ([Sharma, V., Dahiya, K. and Verma, V. \(2010\)](#), [Kaur, P., Verma, V. and Dahiya, K. \(2017\)](#)). In such problem, the total availability of a homogeneous product at various sources is more than the total requirement of the same at destinations. There are several articles which deal with the variants of transportation/transshipment problems. Some of them are ([Khurana, A. \(2015\)](#), [Agadaga, G.O. and Akpan, N.P. \(2017\)](#)). The impaired flow transportation problem, enhanced flow transportation problem, unbalanced capacitated transportation problem, Bi-criterion multi stage transshipment problem are some of them. The optimization of transportation problem with multiple objectives is introduced in [Lee, S.M. and Moore, L.J. \(1973\)](#). A three dimensional transportation problem is introduced in [Misra, S. and Das, C. \(1981\)](#). They dealt the transportation problem with capacity restriction. A general discussion on transfer of masses from one location to other is introduced in [Rachev, S.T. and Rüschemdorf, L. \(1998\)](#). The application of the same is introduced in [Rachev, S.T. and Rüschemdorf, L. \(2006\)](#). A time minimizing transportation problem is introduced in [Singh, P. and Saxena, P.K. \(1998\)](#). The trade-off between the total shipping cost and shipping time is analyzed by solving the transportation problem with additional restriction. A red-blue transportation problem is introduced in ([Vancroonenburg, W. et al.\(2014\)](#)), where the supply nodes are classified into two categories and exclusionary constraints are imposed. The present paper, which is dealing the subset constraint transportation problem, is inspired from this. Solution of the multi-commodity transportation problem is introduced in ([Staniec, C.J. \(1987\)](#)). A new method named ASM-method for dealing the transportation problem is introduced by [Quddoos, A., Javaid, S. and Khalid, M.M. \(2012\)](#). The ASM-method is completely a new method which works on the reduced cost matrix, which is obtained from the transportation matrix. A revised version of the same method is introduced by the same authors in ([Quddoos, A., Javaid, S. and Khalid, M.M. \(2016\)](#)). This version helps to deal with the unbalanced transportation problem. Some conventional well known methods for dealing the transportation problem are North-west corner rule (NWCR), Matrix minima method (Least cost method) and Vogel's Approximation Method (VAM). They are used to find the feasible solution. Some literatures discuss about the modifications in these methods. For instance, modified Vogel's approximation for fuzzy transportation is introduced in ([Samuel, A.E. and Venkatachalapathy, M. \(2011\)](#)). Improvement in least cost method for finding the better feasible solution is given introduced in ([Uddin, M.S. et al.\(2016\)](#)). A computational analysis on number of iteration is done by [Loch, G.V. and da Silva, A.C.L., \(2014\)](#), the paper analyses the iterations coming during the application of these various methods. In addition to these, reduced cost iterated heuristic approach is done in ([Buson, E., Roberti, R. and Toth, P. \(2014\)](#)), which is there for fixed charged transportation problem. In this model additional fixed cost is paid for sending the goods from origin to destination. A new method called Lowest allocation method (LAM) is introduced in ([Babu, M.A. et al.\(2013\)](#)) for finding the feasible solution of transportation problem. The paper discusses an algorithm which takes the minimum iteration among some of the existing conventional methods. A paper discusses about the modified Vogel's approximation method ([Balakrishnan, N. \(1990\)](#)). This paper uses a modified way for the calculation of penalties. A similar modification of VAM as VAM-TOC (Vogel's

approximation method total opportunity cost) is introduced in (Hakim, M.A. (2012)), which yield a very efficient initial solution. A new type of technique is used to find the solution of transportation problem (Kousalya, P. and Malarvizhi, P. (2016)). The solution obtained by this new technique is compared with the least cost method and the transportation cost found to be either less than or equal to the one found by the least cost method.

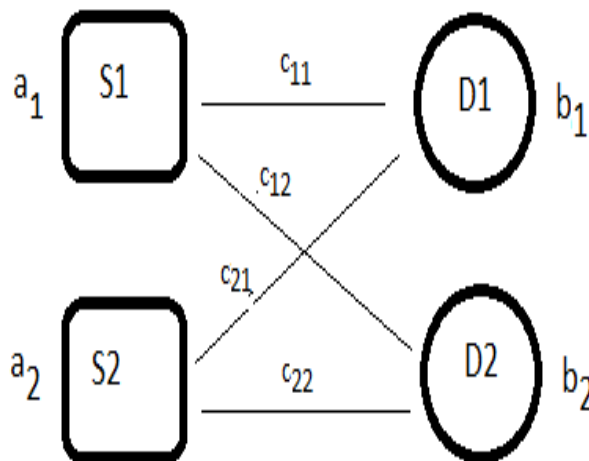
In the present paper, we are dealing the subset constrained transportation problem. The problem can be stated as follows.

A balanced transportation problem with  $m$  sources and  $n$  destinations along with the availabilities at different sources  $a_i, i=1,2,3,4\dots m$  and demand at different destinations  $b_j, j=1,2,3,4\dots n$  is given. The cost of transportation  $c_{ij}, i=1,2,3,4\dots m, j=1,2,3,4\dots n$  is also given from each source to each destination. Now, the subset constraints should come into the picture. A subset constraint tells that a subset of sources and a subset of destinations are given and demand of these given destinations must be fulfilled by the given sources at the priority level. After meeting this criterion first, we move for the remaining solution of the entire transportation problem. The remaining transportation problem could be dealt at usual level after that.

We'd like to understand the above on the basis of a simple example first. Suppose we have a transportation problem with two sources and two destinations, which is as per figure 1. The availability at different sources and demand at different destinations are given. In addition to that, the costs of transportation from different sources to different destinations are also given.

We need to find the optimal transportation cost subject to one more priority constraint stating that demand at destination 2 must be fulfilled by sources 1 and 2 together first. We say such constraint as source-destination subset constraint or simply source destination constraint in the entire paper.

We'll solve the above in two ways. The first as the transportation problem alone, whereas the second as transportation problem with source-destination constraint.



**Figure 1:** A simple example of the transportation problem

Consider the Figure 1. Suppose the value of  $a_1=100, a_2=150$  and  $b_1=200$  and  $b_2=50$ . Also  $c_{11}=5, c_{12}=15, c_{21}=10, c_{22}=12$ . The solution of this problem, when solved by LINDO is given by  $x_{11}=100, x_{21}=100, x_{22}=50, x_{ij}$  represents the amount of goods to be shipped from source  $i$  to destination  $j$ . The overall transportation cost is given by  $c_{11}x_{11} + c_{21}x_{21} + c_{22}x_{22} = 5(100) + 10(100) + 12(50) = 2100$ .

Now, we are willing to apply the source-destination subset constraint as follows: The source S1 must satisfy the destination D2 first then the remaining transportation should be adjusted after that minimizing the total cost of transportation. An additional source-destination subset constraint is coming in the picture this way. We need to apply an update in the LINDO program. The additional constraint coming this way is  $x_{12} = 50$ . If we apply that in the model, the solution gets altered. The solution is given by  $x_{11}=50, x_{12}=50, x_{21}=150$ . The overall transportation cost is given by  $c_{11}x_{11} + c_{12}x_{12} + c_{21}x_{21} = 5(50) + 15(50) + 10(150) = 2500$ . Therefore, the source-destination subset constraint changes the optimality and must be studied on some advanced problems.

The mathematical model for the general transportation problems is given in (Sharma, J.K. (2009)). However, the mathematical model for source-destination constrained transportation problem is stated later in this paper.

### A PROBLEM UNDER CONSIDERATION

Consider the following example with 6 sources and 5 destination points. The figure 2 illustrates the situation. The availability at different sources and demand at different destinations are listed in the figure.

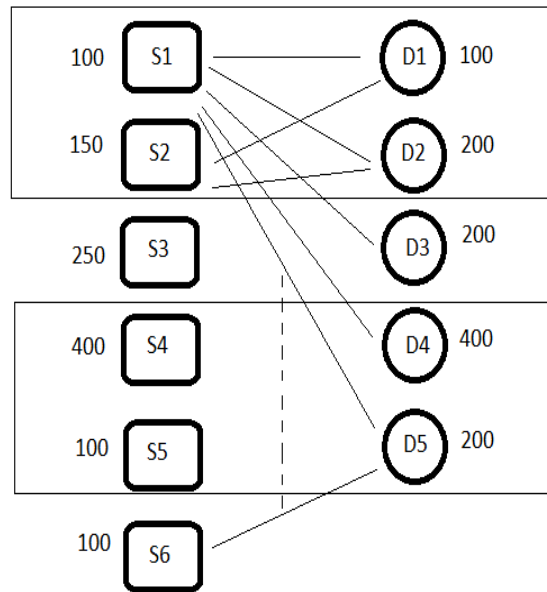


Figure 2: The problem under consideration.

All the sources are connected by each destination by an arc (which is not possible to show in the picture). The unit cost of transportation on each arc is directly given in the table 1. The two additional boxes in the picture show the source-destination subset constraints.

We also consider the following tabular representation of the problem under consideration.

**Table 1:** The transportation problem under consideration

Sources/Destination	D1	D2	D3	D4	D5	Availability
<b>S1</b>	2	5	6	8	10	100
<b>S2</b>	12	4	6	8	1	150
<b>S3</b>	7	8	10	2	6	250
<b>S4</b>	20	5	6	9	2	400
<b>S5</b>	7	8	5	4	2	100
<b>S6</b>	15	6	7	8	5	100
<b>Demand</b>	100	200	200	400	200	1100

We define the two additional subset constraints as follows:

Source-destination subset constraint 1: The demand at D1 and D2 must be fulfilled by S1 and S2 at priority.

Source-destination subset constraint 2: The demand at D4 and D5 must be fulfilled by S4 and S5 at priority.

### MATRIX MINIMA APPROACH FOR SUBSET CONSTRAINED PROBLEMS

If we deal the above problem (the subset constrained transportation problem) by the matrix minima approach, we need to follow the following steps, which may be treated as modified matrix minima method. Therefore, we are willing to propose a modified matrix minima method for the above problem, which is as under.

- i) We first satisfy the sub-matrix, which are obtained from the subset constraints
  - a. From the sub-matrix obtained from subset constraints, we choose the cell with minimum possible entry, and allocate the maximum possible value there.
  - b. We cancel the saturated row/column and again search for the next cell with minimum possible entry until the entire sub-matrix gets cancelled.
  - c. Once a sub-matrix is cancelled, we move on to the next sub-matrix.
  - d. We repeat the process until all sub-matrixes gets cancelled.
- ii) We then apply the usual matrix minima method on the remaining transportation problem.

We apply the modified matrix minima method on the above subset-constrained problem.

**Table 2:** The problem under consideration with subset constraints

Sources/Destination	D1	D2	D3	D4	D5	Availability
S1	2	5	6	8	10	100
S2	12	4	6	8	1	150
S3	7	8	10	2	6	250
S4	20	5	6	9	2	400
S5	7	8	5	4	2	100
S6	15	6	7	8	5	100
<b>Demand</b>	100	200	200	400	200	1100

We first operate on the sub matrices obtained due to the two subset constraints. As per our modified algorithm written above, we have the following allocations:

**Table 3:** Dealing with the sub matrices obtained due to subset constraints

Sources/Destination	D1	D2	D3	D4	D5	Availability
S1	2 <sub>100</sub>	5	6	8	10	100
S2	12	4 <sub>150</sub>	6	8	1	150
S3	7	8	10	2	6	250
S4	20	5	6	9 <sub>200</sub>	2 <sub>200</sub>	400
S5	7	8	5	4 <sub>100</sub>	2	100
S6	15	6	7	8	5	100
<b>Demand</b>	100	200	200	400	200	1100

The remaining allocations for satisfying the sources and demands are to be done after dealing with the sub matrices.

**Table 4:** The complete feasible solution obtained by the modified matrix minima method

Sources/Destination	D1	D2	D3	D4	D5	Availability
S1	2 <sub>100</sub>	5	6	8	10	100
S2	12	4 <sub>150</sub>	6	8	1	150
S3	7	8	10 <sub>150</sub>	2 <sub>100</sub>	6	250
S4	20	5	6	9 <sub>200</sub>	2 <sub>200</sub>	400
S5	7	8	5	4 <sub>100</sub>	2	100
S6	15	6 <sub>50</sub>	7 <sub>50</sub>	8	5	100
<b>Demand</b>	100	200	200	400	200	1100

The feasible allocation obtained in this way is given by  $x_{11}=100, x_{22}=150, x_{33}=150, x_{34}=100, x_{44}=200, x_{45}=200, x_{62}=50, x_{63}=50$ . Correspondingly, the total cost of transportation is given by  $z=5750$ .

The above problem could also be dealt with the help of mathematical model. We need to minimize the overall cost of transportation considering these two constraints to be fulfilled first.

### MATHEMATICAL MODEL FOR SUBSET CONSTRAINED TRANSPORTATION PROBLEMS

In addition to the general mathematical model of a transportation problem described earlier, the newer thing coming into the picture are two additional constraints. For the above particular example, the constraints are as follows:

$$x_{11} + x_{12} + x_{21} + x_{22} = 250 \tag{1}$$

$$x_{44} + x_{45} + x_{54} + x_{55} = 500.$$

We add these two subset constraints as constraints with priority in the mathematical model.

The mathematical model of the subset constraint transportation problem is given as follows ([Prajapati, R., Pal, J., & Dubey, O. P. \(2022\)](#)).

$$\begin{aligned} \text{Minimize} \quad & \sum_{i=1}^m \sum_{j=1}^n c_{ij} x_{ij} \tag{2} \\ \text{Subject to} \quad & \sum_{j=1}^n x_{ij} = a_i, i = 1, 2, 3, 4, \dots, m \end{aligned}$$



$$\sum_{i=1}^m x_{ij} = b_j, j = 1, 2, 3, 4, \dots, n$$
$$x_{ij} \geq 0, \sum_{i=1}^m a_i = \sum_{j=1}^n b_j$$
$$\sum_{i \in s_k} \sum_{j \in d_k} x_{ij} = \theta_k, k = 1, 2, 3, 4, \dots, \eta.$$

Where  $\theta_k = \text{minimum of } \sum_{i \in s_k} a_i \text{ or } \sum_{j \in d_k} b_j \text{ (for a given } k \text{)}.$

Here,  $\eta$  is representing the number of subset constraints. We say the additional constraint coming this way as source-destination constraint of the given transportation problem. The number of constraints having this type of structure may be equal to or more than one i.e.,  $k \geq 1$  in a given model. A model may consist of number of such source-demand constraint ranging from  $k = 1$  to  $k = \eta = (2^m - 1)(2^n - 1) - 1$ . In this analysis, we have left the null set as a subset of source and destination constraints. Also, we have left the constraint which consists of all the sources and destinations nodes.

The above model is directly imposed on the problem under consideration. We solve the model in LINDO software and stated the results.

### DISCUSSION OF THE SOLUTION

If we simply solve the above model (with subset constraints) using LINDO software, we have the following results:  
 $z = 5700$ , with  $x_{11}=100$ ,  $x_{22}=150$ ,  $x_{32}=50$ ,  $x_{33}=100$ ,  $x_{34}=100$ ,  $x_{44}=200$ ,  $x_{45}=200$ ,  $x_{54}=100$ ,  $x_{63}=100$ .

The general transportation result when subset constraints are not applied is as follows: Optimal cost  $z = 4000$ , with  $x_{11}=100$ ,  $x_{22}=150$ ,  $x_{34}=250$ ,  $x_{42}=50$ ,  $x_{43}=150$ ,  $x_{45}=200$ ,  $x_{54}=100$ ,  $x_{63}=50$ ,  $x_{64}=50$ . This only result may also be considered under degenerate solution case of the transportation problem.

From the solution, we can see that the subset constraints, which are used at priority level, need extra cost to give an optimal solution.

### CONCLUSION

We have proposed an updated matrix minima method in this paper. There are conventional methods for dealing the transportation problem. Many of them (like matrix minima etc.) do not guarantee the optimality. However, some of them (like stepping stone method) guarantee the optimality but involves a lot of calculations. Even we need a starting feasible solution for the start of the method. When the number of sources and destinations are larger, applying the calculation involves in finding the optimal solution also gets larger. It becomes further tedious when we get a degenerate feasible solution. Optimality of a transportation problem could be found by its mathematical model. We need software for this purpose. In a subset constrained transportation problem, we find the corresponding updated mathematical model and obtained the optimal solution using LINDO software. We have compared this solution with the one obtained by proposed modified matrix minima method. The solution obtained from the mathematical model is always optimal. However, the modified matrix minima method matters as it gives the nearby feasible solution in some small steps of manual calculations. A mathematical model for any type of constrained transportation problem could always be used for finding an optimal solution. We escape from a lot of manual calculation while applying these strategies.

### LIMITATION AND STUDY FORWARD

The present research explores the matrix minima method for transportation problem and compares the solution with the one obtained by mathematical model. The problem under consideration is constrained transportation problems only. The sources-destination constraints are considered in the paper where the subsets of sources and destination points are taken and should be satisfied on priority basis. Proper examples are given/ solved to justify the idea.

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### AUTHORS CONTRIBUTION

The authors confirm contribution to the manuscript as follows: study conception and design: RP, data analysis: RP; analysis and interpretation of results: RP; draft manuscript preparation: JP, OPD. All authors reviewed the results and JP and OPD approved the final version of the manuscript.

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