
An Effective Approach for Solving Multi-objective Transportation Problem

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Abstract

In this present study, a transportation problem is considered such that the total cost and time of transportation are minimized without taking into account their priorities. In literature, there are less techniques available for finding the efficient solutions of multi-objective transportation problem. So, we developed a heuristic algorithm to find most efficient solution of multi-objective transportation problem, which gives efficient solution with minimum difference from ideal solution. Firstly, we aim at formulating a multi-objective transportation problems along with a novel algorithm to find efficient solutions. The proposed algorithm gives optimal solution faster in comparison to other available techniques in literature for the given multi-objective transportation problem. Moreover, it avoids the degeneracy

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as well as requires low computational effort. Furthermore, an illustrative example is provided to show the feasibility and applicability of the proposed approach and compare the results with the existing approaches to show the effectiveness of it.

Keywords: Efficient solution, ideal solution, multi-objective transportation problem, simple heuristic.

1 Introduction

Practical applications give rise to a large class of mathematical programming problems frequently. For instance, a product may be transported from factories (sources) to retail stores (destinations). One must know the amount of the product available as well as the demand of the product. So, the difficulty is that the different ways of the network joining the sources to the destinations have different costs linked with them. Therefore, we aim at calculating the minimum cost routing of products from point of supply to point of destination and this problem is named as cost minimizing Transport Problems. Generally, the classical transportation problems are associated with single objective, which can be transportation cost or time and are developed by Hitchcock (1941) and Koopmans (1947). But competition between organizations is increasing day to day very quickly. So it is not sufficient to achieve only one objective at time, when transportation of goods from organizations is made. Therefore it is necessary to proceed with multi-objectives simultaneously so that firms can get maximum profit. Many researchers have developed efficient techniques for solving two or more objectives simultaneously, which are by Lee et al. (1973), Zeleny (1974), Diaz (1978; 1979), Isermann (1979), Aneja et al. (1979), Gupta et al. (1983), Ringuest et al. (1987), Reeves et al. (1985), Kasana et al. (2000), Chang (2007; 2008), Bai et al. (2011), Pandian et al. (2011), Quddoos et al. (2013a) and Nomani et al. (2017) etc. All techniques developed by these researchers are very difficult to apply and more time consuming.

In literature, we find that there are many transportation models where linear programming has been applied or approaches to solve multi-objective transportation problems. From this idea, Chanas (1984) developed multi-objective linear programming by using parametric approach. Further, Zimmerman (1978) makes use of intersection of all constraints and goals by proposing a multi-criteria decision making (MCDM) set and multi-objective

linear programming problems that taking all parameters, along with a triangular possibility distribution. Prakash (1981) considered linear programming approach to multi criteria decision making where the constraints are of equality type. Also, various authors worked on developing different models for solving multi-objective transportation problems.

In this paper, an novel algorithm has been developed to find optimal value of multi-objective Transportation Problem. The proposed algorithm gives optimal solution faster in comparison to other available techniques in literature for the given Transportation Problems. Moreover, it avoids the degeneracy as well as demands low computational effort.

2 Model Representation

For m sources P_1, P_2, \dots, P_m and n destinations Q_1, Q_2, \dots, Q_n , multi-objective transportation problems are represented mathematically as follows:

$$\text{Min } Z = \sum_{i=1}^m \sum_{j=1}^n c_{ij}^r x_{ij}, \quad r = 1, 2, \dots, l$$

subject to

$$\sum_{i=1}^m x_{ij} = a_i, a_i \geq 0, \quad i = 1, 2, \dots, m$$

$$\sum_{j=1}^n x_{ij} = b_j, b_j \geq 0, \quad j = 1, 2, \dots, n$$

$$x_{ij} \geq 0, \forall (i, j)$$

where

x_{ij} Quantity of goods transported from source P_i to destination Q_j .

c_{ij}^r Cost of transportation of goods from source P_i to destination Q_j of r^{th} objective.

a_i Availability at source P_i .

b_j Demand at destination Q_j .

and are non-negative numbers.

Because of the special structure of the multi-objective transportation model, the problem can also be represented as Table 1.

Table 1 Tabular representation of model (η)

Destination \rightarrow Source \downarrow	D_1	D_2	...	D_n	Supply (a_i)
S_1	c_{11}^1 ... c_{11}^l	c_{12}^1 ... c_{12}^l	...	c_{1n}^1 ... c_{1n}^l	a_1
S_2	c_{21}^1 ... c_{21}^l	c_{22}^1 ... c_{22}^l	...	c_{2n}^1 ... c_{2n}^l	a_2
\vdots	\vdots	\vdots	\vdots	\vdots	\vdots
S_m	c_{m1}^1 ... c_{m1}^l	c_{m2}^1 ... c_{m2}^l	...	c_{mn}^1 ... c_{mn}^l	a_m
Demand (b_j)	b_1	b_2	...	b_n	

3 Preliminaries

Some important basic definitions to proceed with proposed heuristic are given below:

Definition 1. Ringuest et al. (1987) An ideal solution to the multi-objective transportation problem would result in each objective simultaneously realizing its minimum. That is, if $z_r^* = \min \sum_{i=1}^m \sum_{j=1}^n c_{ij}^r x_{ij}$, then the vector $z^* = (z_1^*, \dots, z_l^*)$ is an ideal solution. When there is a feasible extreme point x^* such that $z_1^* = z_1(x^*), \dots, z_l^* = z_l(x^*)$.

Definition 2. The cells, in which allocations are made, called basic cells and rest are called non-basic cell.

Definition 3. Ringuest et al. (1987) A feasible vector $\bar{x} = \{\bar{x}_{ij}\}$ yields a non-dominated solution to the multi-objective transportation problem if, and only if, there is no other feasible vector $x = \{x_{ij}\}$ such that $\sum_{i=1}^m \sum_{j=1}^n c_{ij}^r x_{ij} \leq \sum_{i=1}^m \sum_{j=1}^n c_{ij}^r \bar{x}_{ij}, \forall r$ and $\sum_{i=1}^m \sum_{j=1}^n c_{ij}^r x_{ij} \neq \sum_{i=1}^m \sum_{j=1}^n c_{ij}^r \bar{x}_{ij}$, for some r . When this relationship holds \bar{x} is said to be efficient.

Definition 4. Closed loop is made by drawing only horizontal and vertical lines through basic cells on starting and ending with same non-basic cell.

Definition 5. For the non-basic cells, pointer cost ($\phi_{ij}^r, r = 1, 2, \dots, l$) is obtained by adding c_{ij}^r (for fixed r) of cells with plus sign and subtracting c_{ij}^r (for fixed r) of cells with negative sign for each closed loop.

Definition 6. The efficient solution which has minimum difference from ideal solution as compare to other efficient solutions is called most efficient solution.

4 Proposed Heuristic Algorithm

The following steps along with basic definitions given in Section 3 are considered to proceed with proposed heuristic:

- Step 1: Represent the given problem into the tabular form as Table 1 and make it balance if it is not balanced by adding (according to requirement) dummy row or column with transportation cost zero.
- Step 2: Consider any single objective from given problem and find its optimal solution by Modified Distribution Method Dantzig (1963) and put this solution in MOTP table.

- Step 3: Calculate the cost of each objective separately for current solution, which is an efficient solution for MOTP.
- Step 4: Make closed loop from each non-basic cell and assign alternatively plus (+) and minus (-) signs in the corner cell of each loop on starting with plus (+) sign from non-basic cell. Then calculate the pointer cost ϕ_{ij}^r . Calculate $\phi_{ij} = \sum_{r=1}^l \phi_{ij}^r$, for fixed i and j , if all $\phi_{ij} \geq 0$ then go to step 7 otherwise follow the step 5.
- Step 5: Select the non basic cell (c^*) having most negative ϕ_{ij} and make it basic cell by giving maximum possible allocation (x^*) and that x^* is the minimum allocation in cell with negative sign on the closed loop of c^* . Adjust the allocations of other cells by adding x^* to allocation of cell with plus sign and subtract from the allocation of cell with negative sign. Then go to step 3.
- Step 6: Repeat the processor from step 3 to step 5 until we get all $\phi_{ij} \geq 0$. Then follow the step 7.
- Step 7: Current solution is most efficient solution for MOTP.

5 Numerical Example

To illustrate the proposed study, we consider the following examples of sugar transportation problem where supplies, and demands are considered. Suppose there are three sugar factories S_i from where the sugar is supplied to three cities D_j . Conveyances with three different capacities are available to be selected for transporting sugar, respectively. There are three examples are considered for the validity of previous defined technique.

5.1 Example 1

In this section, a numerical transportation is considered having three destination and three origins. Considered problem is solved using proposed algorithm for showing more effective application of developed algorithm. Input data of numerical example is shown in Table 2. The first entry of cell (i,j) represent quantity of fuel consumed during transportation of commodities from source i to destination j, second entry of cell (i,j) depict cost of road tax while transporting Goods and last entry of cell (i,j) denotes the transit time of transportation from source i to destination j. Last row and column denotes demand of goods at destination b_j and availability of goods at source a_i .

Table 2 Input data for Example 1

Destination → Source ↓	D_1	D_2	D_3	Supply (a_i)
S_1	3 2 7	1 4 7	-1 3 5	100
S_2	4 5 1	2 6 7	5 4 1	125
S_3	-1 3 5	6 -1 7	4 3 8	75
Demand (b_j)	60	80	160	

Table 3 Initial solution for Example 1

Destination → Source ↓	D_1	D_2	D_3	Supply (a_i)
S_1	3 2 7	1 4 7	100 -1 3 5	100
S_2	4 5 1	80 2 6 7	45 5 4 1	125
S_3	60 -1 3 5	6 -1 7	15 4 3 8	75
Demand (b_j)	60	80	160	

So step wise procedure for considered numerical problem according to the algorithm developed in previous section is given as follows:

- Step 1. Make the initial table for MOTP as shown in Table 2.
- Step 2. Find the optimal solution of problem by considering first objective on applying modified distribution method. Solution is shown in Table 3.
- Step 3. Efficient solution obtained from Table 3 for MOTP is (285, 1185, 1525).
- Step 4. Make the closed loop from each non-basic cells $c_{11}^r, c_{12}^r, c_{21}^r, c_{32}^r$ in Table 3 and pointer cost is:

$$\begin{aligned} \phi_{11}^1 &= c_{11}^1 - c_{13}^1 + c_{33}^1 - c_{31}^1 = 3 + 1 + 4 + 1 = 9, \\ \phi_{11}^2 &= c_{11}^2 - c_{13}^2 + c_{33}^2 - c_{31}^2 = 2 - 3 + 3 - 3 = -1, \\ \phi_{11}^3 &= c_{11}^3 - c_{13}^3 + c_{33}^3 - c_{31}^3 = 7 - 5 + 3 - 5 = 0 \\ \phi_{12}^1 &= c_{12}^1 - c_{13}^1 + c_{23}^1 - c_{22}^1 = 1 + 1 + 5 - 2 = 5, \\ \phi_{12}^2 &= c_{12}^2 - c_{13}^2 + c_{23}^2 - c_{22}^2 = 4 - 3 + 4 - 6 = -1, \\ \phi_{12}^3 &= c_{12}^3 - c_{13}^3 + c_{23}^3 - c_{22}^3 = 7 - 5 + 1 - 7 = -4 \end{aligned}$$

$$\begin{aligned} \phi_{21}^1 &= c_{21}^1 - c_{23}^1 + c_{33}^1 - c_{31}^1 = 4 - 5 + 4 + 1 = 4, \\ \phi_{21}^2 &= c_{21}^2 - c_{23}^2 + c_{33}^2 - c_{31}^2 = 5 - 4 + 3 - 3 = 1, \\ \phi_{21}^3 &= c_{21}^3 - c_{23}^3 + c_{33}^3 - c_{31}^3 = 1 - 1 + 3 - 5 = -2 \\ \phi_{32}^1 &= c_{32}^1 - c_{22}^1 + c_{23}^1 - c_{33}^1 = 6 - 4 + 5 - 2 = 5, \\ \phi_{32}^2 &= c_{32}^2 - c_{22}^2 + c_{23}^2 - c_{33}^2 = -1 - 3 + 7 - 6 = -3, \\ \phi_{32}^3 &= c_{32}^3 - c_{22}^3 + c_{23}^3 - c_{33}^3 = 7 - 8 + 1 - 7 = -7 \end{aligned}$$

Also,

$$\phi_{11} = \sum_{r=1}^3 \phi_{11}^r = 9 - 1 + 0 = 8,$$

$$\phi_{12} = \sum_{r=1}^3 \phi_{12}^r = 5 - 1 - 4 = 0,$$

$$\phi_{21} = \sum_{r=1}^3 \phi_{21}^r = 2 + 1 - 2 = 1,$$

$$\phi_{32} = \sum_{r=1}^3 \phi_{32}^r = 5 - 3 - 7 = -5.$$

As $\phi_{32} = -5 < 0$, therefore go to step 5.

Step 5. Make c_{32}^r as basic cell by giving maximum possible allocation i.e. 15 and adjust allocations of cells c_{22}^r, c_{23}^r and c_{33}^r as 65, 60 and 0 respectively as shown in Table 4 and efficient solution obtained from Table 4 is (360, 1095, 1420).

Table 4 Solution obtained after making c_{32}^r as basic cell.

Destination → Source ↓	D_1	D_2	D_3	Supply (a_i)
S_1	3 2 7	1 4 7	100 -1 3 5	100
S_2	4 5 1	65 2 6 7	60 5 4 1	125
S_3	60 -1 3 5	15 6 -1 7	4 3 8	75
Demand (b_j)	60	80	160	

Step 6. Now again make closed loop from non-basic cells $c_{11}^r, c_{12}^r, c_{21}^r$ and c_{33}^r in Table 4 and pointer cost is:

$$\begin{aligned}\phi_{11}^1 &= c_{11}^1 - c_{13}^1 + c_{23}^1 - c_{22}^1 + c_{32}^1 - c_{31}^1 \\ &= 3 + 1 + 5 - 2 + 6 + 1 = 14, \\ \phi_{11}^2 &= c_{11}^2 - c_{13}^2 + c_{23}^2 - c_{22}^2 + c_{32}^2 - c_{31}^2 \\ &= 2 - 3 + 4 - 6 - 1 - 3 = -7, \\ \phi_{11}^3 &= c_{11}^3 - c_{13}^3 + c_{23}^3 - c_{22}^3 + c_{32}^3 - c_{31}^3 \\ &= 7 - 5 + 1 - 7 + 7 - 5 = -2 \\ \phi_{12}^1 &= c_{12}^1 - c_{13}^1 + c_{23}^1 - c_{22}^1 = 1 + 1 + 5 - 2 = 5, \\ \phi_{12}^2 &= c_{12}^2 - c_{13}^2 + c_{23}^2 - c_{22}^2 = 4 - 3 + 4 - 6 = -1, \\ \phi_{11}^3 &= c_{11}^3 - c_{13}^3 + c_{33}^3 - c_{31}^3 = 7 - 5 + 1 - 7 = -4 \\ \phi_{21}^1 &= c_{21}^1 - c_{22}^1 + c_{32}^1 - c_{31}^1 = 4 - 2 + 6 + 1 = 9, \\ \phi_{21}^2 &= c_{21}^2 - c_{22}^2 + c_{32}^2 - c_{31}^2 = 5 - 6 - 1 + 3 = 1, \\ \phi_{21}^3 &= c_{21}^3 - c_{22}^3 + c_{32}^3 - c_{31}^3 = 1 - 7 + 7 - 5 = -4, \\ \phi_{33}^1 &= c_{33}^1 - c_{23}^1 + c_{22}^1 - c_{32}^1 = 4 - 5 + 2 - 6 = -3, \\ \phi_{33}^2 &= c_{33}^2 - c_{23}^2 + c_{22}^2 - c_{32}^2 = 3 - 4 + 6 + 1 = 6, \\ \phi_{33}^3 &= c_{33}^3 - c_{23}^3 + c_{22}^3 - c_{32}^3 = 8 - 1 + 7 - 7 = 7\end{aligned}$$

Also,

$$\begin{aligned}\phi_{11} &= \sum_{r=1}^3 \phi_{11}^r = 14 - 7 - 2 = 5, \\ \phi_{12} &= \sum_{r=1}^3 \phi_{12}^r = 5 - 1 - 4 = 0, \\ \phi_{21} &= \sum_{r=1}^3 \phi_{21}^r = 9 + 1 - 4 = 6, \\ \phi_{32} &= \sum_{r=1}^3 \phi_{33}^r = -3 + 6 + 7 = 10\end{aligned}$$

As all $\phi_{ij} > 0$, therefore current solution is most efficient solution.

Input data for three more examples is given in Tables 5 to 7. These examples are solved using proposed method and existing algorithm and data for obtained results is given in Table 8.

Table 5 Input data for Example 2

Destination → Source ↓	D_1	D_2	D_3	Supply (a_i)
S_1	6 3	5 5	4 2	7
S_2	10 8	8 4	12 6	5
S_3	10 9	11 10	8 7	8
Demand (b_j)	8	10	2	

Table 6 Input data for Example 3

Destination → Source ↓	D_1	D_2	D_3	D_4	Supply (a_i)
S_1	1 4	2 7	7 3	7 4	8
S_2	1 5	9 8	3 9	4 10	19
S_3	8 6	9 2	4 5	6 1	17
Demand (b_j)	11	3	14	16	

Table 7 Input data for Example 4

Destination → Source ↓	D_1	D_2	D_3	D_4	D_5	Supply (a_i)
S_1	9 2 2	12 9 4	9 8 6	6 1 3	9 4 6	5
S_2	7 1 4	3 9 8	7 9 4	7 5 9	5 2 2	4
S_3	6 8 5	5 1 3	9 8 5	1 4 3	3 5 6	2
S_4	6 2 6	8 8 9	11 6 6	2 9 3	2 8 1	9
Demand (b_j)	4	4	6	2	4	

5.2 Example 2

In this section, a numerical transportation is considered having three destination and three sources. Considered problem is solved using proposed algorithm for showing more effective application of developed algorithm. Input data of numerical example is shown in Table 5.

5.3 Example 3

In this section, a numerical transportation is considered having four destination and Three sources. Considered problem is solved using proposed algorithm for showing more effective application of developed algorithm. Input data of numerical example is shown in Table 6.

Table 8 Comparative analysis of solution obtained by proposed heuristic of considered examples

Sr. No.	Source	Efficient Solution	Most Efficient Solution	Ideal Solution
Ex.1	Gupta et al. (1983)	(285, 1185, 1525) (360, 1095, 1420)	(360, 1095, 1420)	(285, 670, 1160)
Ex.2	Bai et al. (2011)	(153, 121) (153, 119)	(153, 119)	(153, 114)
Ex.3	Aneja et al. (1979)	(143, 265) (168, 215) (176, 175)	(176, 175)	(143, 167)
Ex.4	Isermann (1979)	(101, 137, 101) (101, 130, 195) (106, 120, 88) (112, 112, 88) (127, 104, 76)	(127, 104, 76)	(101, 72, 64)

5.4 Example 4

In this section, a numerical transportation is considered having five destination and four origins. Considered problem is solved using proposed algorithm for showing more effective application of developed algorithm. Input data of numerical example is shown in Table 7.

6 Comparative Study

In the previous subsection, the mathematical model of the example for different cases is formulated and our methodology to establish the deterministic model for each case is used. The equivalent deterministic forms of the chance constraints. Hence, the deterministic form of the multi-objective transportation problems. The approach is used to tackle the multiple conflicting objectives. The comparison can be show in table and results of previous problems with another existing methods effectively in Table 8.

7 Conclusions

In this research, a transportation problem has been formulated in multi-objective environment and an novel algorithm is proposed to find efficient solutions with ideal one's. The values obtained by the proposed algorithm shows that the decision maker has the more flexibility. The proposed

algorithm avoids the degeneracy and gives the efficient solution faster than others existing algorithms for the given in the field of transportation problems. It also reduces the computational work. From the comparative study, it has been concluded that the proposed approach is more suitable and practicable, and provide a better way to solve the transportation problems where the existing are unable to find the results. In future, we extend this approach to the other domain. In future, the method can be modified to solve the type of multi objective transportation problems with all the parameters, i.e., availability, demand and unit transportation cost, uncertain.

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