Analysis of Schedule Rates for Bridge and Road Works in India using Solid Transportation Problem

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Abstract

In this paper we used solid transportation problem to analyze the cost of raw materials which are used for road and bridge works in PWD, West Bengal. We all are aware of the classical Transportation Problem Which involves only two components - supply and demand where a homogenous product is transported from various sources to different destinations in such a way that total transportation cost is minimum. But in real life situation mode of transportation plays an important role on transportation cost. From the practical point of view, an increase in transportation cost may also increase the selling price of commodity. So, keeping this in mind we can give our effort to slash down total transportation cost which in turn may reduce the selling price. That is why the mode of transportations is taken into the account in transportation problem and this causes the emergence of concept of solid transportation. Solid transportation problem (STP) involves three components – supply, demand and capacity of conveyance. Here the transportation cost is optimized by delivering a homogeneous commodity from various sources to different destinations in different conveyances. If there are m number of origins, n number of destinations and p number of conveyances, then for classical TP, no of feasible solutions is m+n-1, whereas for STP, number of feasible solutions is m+n+p-2. For making the problem generalized we have collected the data from PWD, Government of West Bengal. They published a Rate book which includes different types of rates for different material which are used for construction in West Bengal.Here we are taking data from the ‘SCHEDULE OF RATES’ for road and bridge works, published by The Superintending Engineer Building Planning Circle.

Keywords
Transportation Problem, Solid Transportation Problem, Feasible Solution

1. Introduction

The major components for classical TP are sources and destinations whereas those for STP are sources, destinations and conveyances which are defined as follows.

Source: The place or origin from where the commodities are transported is called the source for e.g. warehouse.

Destination: The place to which the commodities are to be transported is called destination.
Availability: The amount of goods available at a source that can be transported from the source is referred to as availability or resource.

Demand: The amount of goods that is required at some destination is referred to as the demand of that destination.

Transportation Cost: The cost of transporting one unit of product from a source to some destination is called unit transportation cost of the product for that source – destination route.

Constraint: The availability as well as the demands are always restricted to certain amounts. Limitations on resource availability at source and fulfillment of demand at each destination are known as constraints.

Conveyance: Modes of transportation (e.g., trucks, goods trains, cargo flights, ships, etc.) are called conveyances.

For classical Transportation Problem, let m be the number of sources (S₁, S₂, S₃, ..., Sₘ) and n be the number of destinations (D₁, D₂, D₃, ..., Dₙ). Let \( c_{ij} \) be the cost of shipping one unit of commodity from the source i to destination j. If \( x_{ij} \) be the units shipped from source i to destination j, then the general mathematical model of such transportation problem can be stated as follows:

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

subject to

\[ \sum_{j=1}^{n} x_{ij} = a_i , \quad i = 1, 2, 3, \ldots, m \]

\[ \sum_{i=1}^{m} x_{ij} = b_j , \quad j = 1, 2, 3, \ldots, n \]

\[ x_{ij} \geq 0, \quad \forall i, j \]

The transportation problem is called balanced TP if total availability = total demands, that is

\[ \sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \]

Where \( a_i \) the availability at the i-th source and \( b_j \) is the demand at j-th destination.

For the Solid Transportation Problem, let m be the number of sources (S₁, S₂, S₃, ..., Sₘ) n be the number of destinations (D₁, D₂, D₃, ..., Dₙ) and p be the number of conveyances (E₁, E₂, E₃, ..., Eₚ). Let \( c_{ijk} \) be per unit shipping cost of availability and \( x_{ijk} \) is the amount of goods to be transported from the source i to destination j through k-th conveyance where \( x_{ijk} \) is a decision variable. Then the general mathematical model of the STP can be stated as follows:
The above problem is a balanced one if total availability = total demand = total capacity of the conveyance i.e. otherwise the problem is unbalanced. Where be the availability at i-th origin and be the demand at j-th destination and is the capacity of k-th conveyance. In the STP if the value of p is 1, that is the number of conveyances is only one then the same model works for classical transportation problems. The condition for balanced problems is the necessary and sufficient condition for the feasible solution of the problem.

2. Literature Review

Schell (1955) proposed the concept of a solid transportation problem. K B Haley (1962) proposed a methodology which helped to find out the solutions for multi index transportation problems. For solid transportation problems with mixed constraints, Patel and Tripathy (1989) proposed some computational methods. Bit et al. (1993) presented a fuzzy programming approach to solve the multi objective solid transportation problem and it provided a better optimal solution. Basu et al. (1994) proposed an algorithm for finding optimum solution of fixed charge solid transportation problem. Gen et al. (1995) proposed a genetic algorithm for solving bicriteria solid transportation problems. Jimenez and Verdegay (1996) examined interval multi objective solid transportation problems and proposed a genetic algorithm based solution approach. Also in 1998 they described how uncertainty can be involved with transportation problems. They described Interval solid transportation problem and fuzzy solid transportation problem. Gao and Liu (2004) developed the two – phase fuzzy algorithms for multi - objective transportation problems. Yang and Liu (2007) presented an expected value model, chance-constrained programming model and dependent chance programming for fixed charge STP with unit transportation cost, supplies, demands and conveyance capacities as fuzzy variables. Liu and Lin (2007) solved a fuzzy fixed charge STP with chance constrained programming. Pandian and Natrajan (2010) introduced a method, named as zero - point method and used the method for solving Solid Transportation Problem. Researchers have done the sensitivity analysis over the solution of the solid transportation problem. Pandian and Kavitha (2012) proposed type II sensitivity analysis for solid transportation problems. Pramanik et al. (2014) developed bi fuzzy multi objective solid transportation problem and solved the problem using genetic algorithms. Das and Bera (2015) studied uncertain transportation problems and they successfully minimized uncertain time. Zhang et al. (2016) investigated fixed charge solid transportation problems for an uncertain environment. Haldar et al. (2017) considered some particular fixed charge multi item transportation problem where breakability was a constraint. They solved the problem in a crisp and fuzzy environment. Khalifa (2019) investigated a multi objective, multi product transportation problem using fuzzy programming approach. In our study, we consider the algorithm, which is proposed by Pandian and Anuradha (2010) with some modification. In that algorithm they used the concept of zero point method which helps us to find optimal solutions. We don’t use the MODI method because we don’t need to find an initial basic feasible solution. In this paper we used real life road and bridge construction data, which are collected from some rate book, issued by the state government.

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3. Methodology

Here is our algorithm which has fourteen basic steps. By which we obtain the optimal solution of the solid transportation problem.

Algorithm:

Step-1: First we have to check whether the problem is a balanced one or not for which the condition is,

\[
\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = \sum_{k=1}^{p} e_k ,
\]

if not then by adding a dummy source and/or destination and/or conveyance we have to convert it to a balanced problem.

Step-2: Initially we treat the problem as a two-dimensional problem with origin and destination and construct the O-D table, where rows represent origins and columns represent destinations.

Step-3: We choose the minimum element from each row, and subtract that element from the other elements of the corresponding row.

Step-4: In the reduced table, we select most minimum element of each destination and subtract that from corresponding elements of that destination.

Step-5: We then check, whether allocation of each supply is possible with the corresponding demand in the zero cost cell. If each row capacity is fully used over the corresponding column (which vertical plane is taken) using the cells having zero cost then,

   a) go to step-8
   b) Otherwise go to step-6

Step-6: Since transportation is not possible, we have to search for a new basic cell having zero cost for which we cover all the zero cost cells by drawing horizontal and vertical lines in the O-D plane.

Step-7: After covering all zeros, we choose the minimum of all uncovered elements and subtract that element from the remaining uncovered element in the table and add the same to all elements lying at the intersection of horizontal and vertical lines. Then go to step-5.

Step-8: Now we convert the table which is obtained from step-5 as D-E table, where rows are represented as demand (D) and columns are represented as conveyance (E) and then we follow a similar procedure as described in step-5 on this resulting table to make shipment.

Step-9: Again, the table obtained from step-8 is then converted to an E-O table, where rows are represented as conveyance (E) and columns are represented as origin (O) and then we again follow the procedure as described in step-5 on this resulting table to make shipment.

Step-10: If the shipment is possible in the last table then we construct the D-O/E-D/O-E table and check whether,

   i) Each demand can be assigned to the corresponding supplies using the cells having zero cost.
   ii) Each conveyance can be assigned to the corresponding demands using the cells having zero cost.
   iii) Each origin can be assigned to the corresponding conveyances having zero cost.

   a) If these allocations are not possible then go to step-6.
   b) If allocations are possible then go to the next stop.
Step-11: Let us identify the minimum no of zero cost cells along origin/demand/conveyance and we allocate maximum possible allocation in that zero cell. If more than one such cell exists, we select any one of them.

Step-12: Remove the supply/demand/conveyance which is fully used. If the supply/demand/conveyance are partially used, then make a new table which must have the reduced supply/demand/conveyance as applicable.

Step-13: Repeat step-11 and 12 until all supplies, demands and conveyances are fully used.

Step-14: Now we calculate the total cost, by using the formula,

\[ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} C_{ijk} X_{ijk} \]

This \( Z \) is the optimal cost and we can write the optimal transportation schedules for the Solid Transportation Problem.

4. Problem Formulation

We have collected the data from the PWD, Government of West Bengal. They published a Rate book which includes different types of rates for different material which are used for construction in West Bengal. Here we are taking data from the ‘SCHEDULE OF RATES’ for road and bridge works, published by “The Superintending Engineer Building Planning Circle.” The rates mentioned here were effective till November 2015. We have taken Bitumen (packed) one of the components required for construction of roads. It is transported from various sources to different destinations using several modes of conveyances. The two major sources of Bitumen are Haldia and Uluberia. For construction of road the product is required in different departmental divisions like Diamond Harbour Highway division, 24 Parganas Highway division and Tamluk Highway division where each division has more than one departmental stack yards. So, firstly we are finding transportation costs for transporting 1MT Bitumen (packed) from each source to each departmental stack yard using different types of vehicles. After that we have found the average of that cost for each Highway division. In our problem we have taken Haldia and Uluberia as two sources and Diamond Harbour, 24 Parganas, Tamluk divisions as three destinations. Here Bitumen is transported only by road through trucks. There are two types of trucks, one with the capacity of 10 MT and the other one with the capacity of 15MT. Five trucks are available for transportation of Bitumen from the above two sources to three destinations among which three of them are of capacity 15MT and two of them are of capacity 10MT. Using these two sources, three destinations and five conveyances we have developed our transportation model to calculate minimum cost of transportation using the stated algorithm.

4.a. Transportation cost of Bitumen (source to destination/departmental stack yards)

The method for finding the price of Bitumen at source point as well as at the departmental stores / stack yards, followed by P.W.D., is given below:

\[
\text{Cost at destination/Departmental issue rate} = \text{Cost of the materials including all taxes at the nearest source of the manufacturer} + \text{Cost for loading, unloading, stacking} + \text{Carriage cost from source to departmental godowns} + \text{Storage cost(i)Transportation cost} = \text{Departmental issue rate} - \text{Cost of the material at the source(ii)}
\]

Thus, transportation cost includes all taxes, loading, unloading, stacking and storage cost. According to data available from P.W.D. Bitumen (packed) price at the different sources include the container (drums) price where container price is Rs. 1000/- per MT.

After calculating all transportation costs for transporting 1MT Bitumen (packed) from two different sources (Haldia and Uluberia) to three different destinations (24 Parganas highway division, Tamluk highway division and Diamond Harbour highway division) using five conveyances. There are two types of conveyances (trucks) which we already know. Type 1 trucks have the capacity of 10MT and type 2 trucks have the capacity of 15MT. We are using
three 15MT capacity trucks and two 10MT capacity trucks. We are representing sources (Uluberia and Haldia) as O1 and O2, destinations (24 Parganas highway division, Tamluk highway division, Diamond Harbour highway division) as D1, D2 and D3, and conveyances (two trucks having capacity 10MT each and three trucks having capacity 15MT each) as E1, E2, E’1, E’2 and E’3.

Mathematical Model: For this problem, we are considering a mathematical model which is given below,

\[
\text{Minimize } z = \sum_{i=1}^{3} \sum_{j=1}^{3} \sum_{k=1}^{5} c_{ijk} x_{ijk}
\]

subject to

\[
\sum_{j=1}^{3} \sum_{k=1}^{5} x_{ijk} = a_i
\]

\[
\sum_{i=1}^{3} \sum_{k=1}^{5} x_{ijk} = b_j
\]

\[
\sum_{i=1}^{3} \sum_{j=1}^{3} x_{ijk} = c_k
\]

\[
x_{ijk} \geq 0, \forall i, j, k
\]

where total availability - total demand = total capacity i.e. \(\sum_{i=1}^{3} a_i - \sum_{j=1}^{3} b_j - \sum_{k=1}^{5} c_k\)

Now we are applying our algorithm over the following example,

Table1:

<table>
<thead>
<tr>
<th>CONVEYANCE</th>
<th>E1</th>
<th>E2</th>
<th>E1</th>
<th>E2</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>E’1</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>E’2</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>E’3</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>868.43</td>
<td>868.43</td>
<td>868.43</td>
<td>868.43</td>
</tr>
<tr>
<td>D2</td>
<td>1207.7</td>
<td>1207.7</td>
<td>1207.7</td>
<td>1207.7</td>
</tr>
<tr>
<td>D3</td>
<td>25</td>
<td>40</td>
<td>65</td>
<td>65</td>
</tr>
</tbody>
</table>

We have to determine the optimal transportation schedule with minimum transportation cost. Here, the total supply, total demand and the total capacity of the conveyance are equal i.e. \(\sum_{i=1}^{3} a_i = \sum_{j=1}^{3} b_j = \sum_{k=1}^{5} c_k = 65\) So we can say that the problem is a balanced solid transportation problem. Now we can apply our algorithm over this problem. We are considering the last table as Table1. Now subtracting the minimum of each row from the corresponding elements of that row, we obtain the following reduced O-D table.

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Now subtracting the minimum of each destination from the elements of the corresponding destination, we obtain the Table3.

We are applying step-5 and we have seen that the shipment is not possible. Supply is not fulfilled over the demand. So we have to find the new combination of the basic cells applying step-6 of our algorithm.

The minimum most uncovered element is 222.90. By adding this one at each intersection points and subtracting it from each uncovered element table looks like,
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Table 5:

<table>
<thead>
<tr>
<th>CONVEYANCE</th>
<th>E1</th>
<th>E1</th>
<th>E1</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2</td>
<td>E2</td>
<td>E2</td>
<td>E2</td>
</tr>
<tr>
<td>E'1</td>
<td>E'1</td>
<td>E'1</td>
<td>E'1</td>
</tr>
<tr>
<td>E'2</td>
<td>E'2</td>
<td>E'2</td>
<td>E'2</td>
</tr>
<tr>
<td>E'3</td>
<td>E'3</td>
<td>E'3</td>
<td>E'3</td>
</tr>
<tr>
<td>D1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

CAPACITY

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E1</td>
<td>E2</td>
<td>E'1</td>
</tr>
<tr>
<td></td>
<td>E2</td>
<td>E'1</td>
<td>E'2</td>
</tr>
<tr>
<td></td>
<td>E'2</td>
<td>E'3</td>
<td>E'3</td>
</tr>
</tbody>
</table>

This shipment is possible. Supply is fulfilled over the demand. So we can move to the DE table.

Table 6:

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>O1</th>
<th>O1</th>
<th>O1</th>
<th>O1</th>
<th>O1</th>
<th>O1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O2</td>
<td>O2</td>
<td>O2</td>
<td>O2</td>
<td>O2</td>
<td>O2</td>
</tr>
<tr>
<td></td>
<td>E1</td>
<td>E2</td>
<td>E1</td>
<td>E2</td>
<td>E1</td>
<td>E2</td>
</tr>
<tr>
<td></td>
<td>O2</td>
<td>222.90</td>
<td>0</td>
<td>222.90</td>
<td>0</td>
<td>222.90</td>
</tr>
<tr>
<td></td>
<td>O3</td>
<td>0</td>
<td>70.57</td>
<td>0</td>
<td>70.57</td>
<td>0</td>
</tr>
</tbody>
</table>

SUPPLY

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

In this shipment is possible because all the demands are fulfilled over the capacity of the conveyances. So we can move to the EO table.

Table 7:

<table>
<thead>
<tr>
<th>DESTINATION</th>
<th>D1</th>
<th>D1</th>
<th>D2</th>
<th>D2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D3</td>
<td>D3</td>
<td>D3</td>
<td>D3</td>
</tr>
<tr>
<td></td>
<td>O1</td>
<td>O2</td>
<td>O1</td>
<td>O2</td>
</tr>
<tr>
<td></td>
<td>E1</td>
<td>E2</td>
<td>E1</td>
<td>E2</td>
</tr>
<tr>
<td></td>
<td>E'1</td>
<td>E'2</td>
<td>E'1</td>
<td>E'2</td>
</tr>
<tr>
<td></td>
<td>E'2</td>
<td>E'3</td>
<td>E'2</td>
<td>E'3</td>
</tr>
<tr>
<td></td>
<td>SUPPLY</td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

DEMAND

Here also shipment is possible over the capacity of the conveyances or we can say that all the capacity of the conveyances are fulfilled over the supply of the origins.

We have already checked the three combinations of O-D-E. Now we have to check the alternatives also. Let us consider the O-E-D table. Where origins are the rows, conveyances are the columns over the demand constraints.
Here each supply is fulfilled over the capacity of the conveyances. Similarly each capacity is fulfilled over the demands and also each demand is fulfilled over the supply of the origins. Thus, the current reduced solid transportation table is the final shipment table. Let’s check out all the allocations. So the table looks like,

Table9:

<table>
<thead>
<tr>
<th>CONVEYANCE</th>
<th>E1</th>
<th>E2</th>
<th>E'1</th>
<th>E'2</th>
<th>E'3</th>
<th>CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>E2</td>
<td>222.90</td>
<td>222.90</td>
<td>222.90</td>
<td>222.90</td>
<td>222.90</td>
<td>222.90</td>
</tr>
<tr>
<td>E'1</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
</tr>
<tr>
<td>E'2</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
</tr>
<tr>
<td>E'3</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
<td>70.57</td>
</tr>
</tbody>
</table>

Now we identify the minimum number of zero cost cells in origins/demands/conveyances and we assign the maximum possible allocation on that cell. We will apply step-11 to step-14 until all the shipment is done. Optimal shipment table is found as follows,

Table10:

<table>
<thead>
<tr>
<th>CONVEYANCE</th>
<th>E1</th>
<th>E2</th>
<th>E'1</th>
<th>E'2</th>
<th>E'3</th>
<th>CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>864.48</td>
<td>864.48</td>
<td>864.48</td>
<td>1092.76</td>
<td>864.48</td>
<td>10</td>
</tr>
<tr>
<td>E2</td>
<td>864.48</td>
<td>864.48</td>
<td>864.48</td>
<td>1092.76</td>
<td>864.48</td>
<td>10</td>
</tr>
<tr>
<td>E'1</td>
<td>864.48</td>
<td>864.48</td>
<td>864.48</td>
<td>1092.76</td>
<td>864.48</td>
<td>10</td>
</tr>
<tr>
<td>E'2</td>
<td>864.48</td>
<td>864.48</td>
<td>864.48</td>
<td>1092.76</td>
<td>864.48</td>
<td>10</td>
</tr>
<tr>
<td>E'3</td>
<td>864.48</td>
<td>864.48</td>
<td>864.48</td>
<td>1092.76</td>
<td>864.48</td>
<td>10</td>
</tr>
</tbody>
</table>

Therefore, the optimal solution to the given solid transportation problem is

\[ x_{11} = 4, \; x_{12} = 5, \; x_{13} = 5, \; x_{14} = 11, \; x_{21} = 10, \; x_{22} = 10, \; x_{23} = 10, \; x_{24} = 10 \]

and the total minimum transportation cost is Rs. 64075.18/-.
5. Discussion of the result and conclusion

We have obtained an optimal transportation schedule and the corresponding minimum transportation cost. The transportation schedules indicate that

- 4 MT of Bitumen will be transported from Uluberia to 24 Parganas highway division through 5th mode of conveyance. Represented by $x_{115} = 4$
- 5 MT of Bitumen will be transported from Uluberia to Diamond Harbour highway division through 3rd mode of conveyance. Represented by $x_{133} = 5$
- 5 MT of Bitumen will be transported from Uluberia to Diamond Harbour highway division through 4th mode of conveyance. Represented by $x_{134} = 5$
- 11 MT of Bitumen will be transported from Uluberia to Diamond Harbour highway division through 5th mode of conveyance. Represented by $x_{135} = 11$
- 10 MT of Bitumen will be transported from Haldia to 24 Parganas highway division through 1st mode of conveyance. Represented by $x_{211} = 10$
- 10 MT of Bitumen will be transported from Haldia to 24 Parganas highway division through 2nd mode of conveyance. Represented by $x_{212} = 10$
- 10 MT of Bitumen will be transported from Haldia to 24 Parganas highway division through 3rd mode of conveyance. Represented by $x_{213} = 10$
- 10 MT of Bitumen will be transported from Haldia to Tamluk highway division through 4th mode of conveyance. Represented by $x_{224} = 10$.

The minimum transportation cost is Rs.64075.18/-. 

In our project of STP, we have considered three constraints namely availability, demand and capacity (of conveyances) restriction with an objective of minimizing the total transportation cost. The algorithm in general can be applied on any balanced STP with a finite number of sources, destinations and conveyances to determine minimum transportation cost while transporting a homogeneous commodity from various sources to different destinations through different modes of conveyances.

6. References


Biographies

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