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Development of Optimal Route Method to Obtain the Optimal Solution of Transportation Problem

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Abstract | **Original Research Article**

The transportation problem is a special category of the linear programming problem and has many applications in the optimization theory to achieve the optimal cost. A given supply of the commodity is available at the different number of sources and there is a specified demand for the commodity at each of the various numbers of destinations and the unit transportation cost between each source-destination pair is known. The study focuses on development of Optimal Route Method to obtain the optimal solution in transportation problem. Algorithm was developed along with the existing method of transportation model. Data were collected from the website www.kaggle.com and was applied to all the methods. The modi u – v algorithm for Vogel was used to obtain the optimal solutions. The result of the analysis shows that the developed method performed better than the existing methods at initial basic feasible solution. At optimal solution, the developed method (Optimal Route) and modi u – v algorithm for Vogel compete favourably well among themselves and therefore the best method.

Keywords: Development, Optimal Route, Optimal Solution, Transportation Problem.

1. INTRODUCTION

We explore a special type of linear programming (LP) model. Its structure and model is called transportation model and it can be solved using more efficient computational procedure than the simplex method. The transportation problem is also called network flow problem. This model can be used for inventory control, employment scheduling, personnel and machine assignment, plant location, product mix problems, cash flow statements and many others so that the model is not really confined to transportation only. Transportation model plays a vital role to ensure the efficient movement and in time availability of raw materials and finished goods from sources to destinations.

A general transportation problem is represented by the network in figure 1.

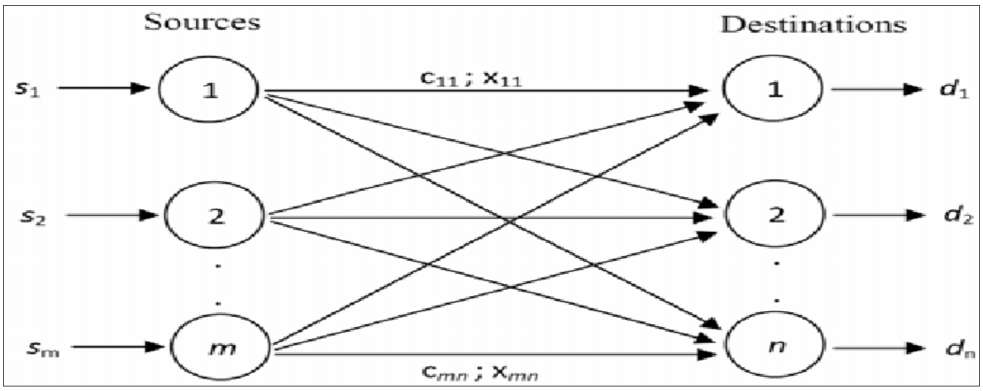

Figure 1

There are m sources and n destinations, each represented by a node. The arcs joining the source and a destination represent the route through which the commodity is transported.

Let S_i be the amount of supply at source *i* (*i = 1, 2 ,......,m*) and d_j be the amount of demand at destination *j* (*j = 1, 2 ,......,n*), C_{ij} be the unit transportation cost between source *i* and destination *j*, x_{ij} represents the amount transported from source *i* to destination *j*. Then the linear programming model representing the transportation problem is generally given below.

The transportation model will then be; minimizing the transportation cost

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

Subject to

$\sum_{j=1}^{n} x_{ij} = s_i$, $i = 1, 2, \ldots$ m (Supply constraints)

$\sum_{i=1}^{m} x_{ij} = d_j$, $j = 1, 2, \ldots$ n (Demand constraints)

$x_{ij} \geq 0$, for all *i* and *j* (quantities)

And obviously $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$ (Balanced condition)

$\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} b_j$ (Unbalanced condition)

This is a linear program with *m,n* decision variables, *m,n* functional constraints, and *m,n* nonnegative constraints.

m = Number of sources

n = Number of destinations

s_i= capacity of *i-th* source (in tons, pounds, litres, etc)

d_j= demand of *j-th* destination (in tons, pounds, litres, etc)

C_{ij}= cost coefficients of material shipping (unit shipping cost) between *i-th* source and *j-th* destination (in ₦, £ or as a distance in kilometers, miles, etc.)

A specially designed table is constructed and used in order to solve the transportation problems called the transportation table.

Table: 1 General Transportation Table

Origin (i)	Destination (j)				Supply (s_i)
	D_1	D_2	....	D_n	
s_1	c_{11} x_{11}	c_{12} x_{12}	....	c_{1n} x_{1n}	s_1
s_2	c_{21} x_{21}	c_{22} x_{22}	....	c_{2n} x_{2n}	s_2
......	.....	.....	....	.....	......
s_m	c_{m1} x_{m1}	c_{m2} x_{m2}	....	c_{mn}	s_m
Demand (d)	d_1	d_2	....	d_n	$\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j$

The above GTT consists of *m by n* rectangles in *m* rows and *n* columns, where *m* denotes the number of rows and n denotes the number of columns. Each rectangle is called a cell. The cell in *ith* row and *jth* column is termed as cell *(i,j)* each unit cost component c_{ij} is placed at the middle of the corresponding cell. A component of a feasible solution x_{ij}, *i* = 1,2, … m, *j* = 1,2, .. *n* if any, is to be placed at the left-top of c_{ij}. Supply capacities s_i of the different origins are shown on the rightmost column corresponding to each row of the table and the demands of different destinations d_j are listed on the lowermost row corresponding to each column.

The total number of variables is *m, n*

Total number of constraints is *m + n*

And the total number of allocation cells in a feasible solution is *m + n – 1*

Simplex algorithm is used to solve the Linear Programming Problem (LPP). But it is a laborious task. For this reason, researchers try to develop a way of avoiding the complexity of simplex algorithm. Resultant of one such effort is Transportation Model.

Vannan and Rekha [2013] have developed a new method for obtaining an optimal solution for transportation. Patel and Bhathawala [2010, 2014] have presented the new global approach to a transportation problem for finding an optimal solution for a wide range of transportation problems directly. Their method is based upon the total opportunity cost (TOC) and a maximum minimum penalty approach. But their method still has some limitations because it has not efficiently address the solution of transportation problem optimally.

Numerous approaches are available in the literature and also research works are ongoing to obtain more efficient algorithms to solve TP. Hence, the need for my research to propose a more better and efficient technique to obtain the optimal solution of transportation problem.

2. 1 Algorithm of Vogel's Approximation Method (VAM)

The Vogel approximation method is an iterative procedure for computing a basic feasible solution of the transportation problems. In VAM, the following steps are applied. Identify the boxes having minimum and next to minimum transportation cost in each row and write the difference (penalty) along the side of the table against the corresponding row. Identify the boxes having minimum and next to minimum transportation cost in each column and write the difference (penalty) against the corresponding column. Identify the maximum penalty. If it is along the side of the table, make maximum allotment to the box having minimum cost of transportation in that row. If it is below the table, make maximum allotment to the box having minimum cost of transportation in that column. If the penalties corresponding to two or more rows or columns are equal, select the top most row or the extreme left column.

2.2 Algorithm of the U - V Method

This method is based on the idea of computing the modifiers u_i and v_j for each row *i* and column *j*. The dual variable u_i represents the sum of row *i*, and v_j represents the sum of column *j* for the basic variables. Clearly, the value of u and v implicit the size of reduction for every cost. Meaning that the C_{ij} will be reduced twice by the u_i and v_j . Then it can be written as $c_{ij} - u_i - v_j$ which is the opportunity cost for all the non-basic variables. The interpretation of this procedure can be shown in the table below.

u_1	$c_{11} - u_1 - v_1$	$c_{12} - u_1 - v_2$	….	$c_{1j} - u_1 - v_j$	…	$c_{1m} - u_1 - v_m$
u_2	$c_{21} - u_2 - v_1$	$c_{22} - u_2 - v_2$	….	$c_{2j} - u_2 - v_j$	…	$c_{2m} - u_2 - v_m$
:	:	:	:	:	:	:
u_n	$c_{n1} - u_n - v_1$	$c_{n2} - u_n - v_2$	…	$c_{nj} - u_n - v_j$	….	$c_{nm} - u_n - v_m$
	v_1	v_2	….	v_j		v_m

The steps for the U – V method can be illustrated below:

i. Determine the shadow costs u_i and v_j in the basic feasible solution for each allocations, where *i = 1,., n* and *j = 1,., m*. They can be obtained by using the formula $u_i + v_j = c_{ij}$ for the basic assignments. Notice that we will have m + n unknown variables and m + n-1 linear equations. Therefore, to solve the system we can assign an arbitrary value for any modifier in order to begin with the solution. Therefore, we can start with u_1 = 0, since we have one redundant constraint.

ii. Calculate the cost coefficient d_{ij} for the non-basic allocations by using the formula

$d_{ij} = c_{ij} - (u_i + v_j)$ Where these allocations equal to $(m \times n) - (m + n - 1)$.

Once all d_{ij} is calculated, we can determine if the solution is optimal or not based on the d_{ij} sign. Each d_{ij} represents the reduced cost that could be done on the current total cost if the non-basic variable at position *i, j* enters the basis.

A. If all d_{ij} > 0, then the optimality has been reached and the solution is unique.
B. If all d_{ij} > 0 and some d_{ij} = 0 (one at least), then the solution is optimal but not unique.
C. If at least one d_{ij} < 0, then the solution is not optimal and need to be improved. Go to II.

iii. Select the most negative value for d_{ij} if there is more than one. Then perform a closed cycle starting and ending at d_{ij} and go through any allocations in a clockwise direction. Adding and subtracting θ alternately from each corner in the cycle. The amount of θ can be determined as the lowest value among the values of allocation at the corner of the cycle.

iv. Now test the new solution for optimality by determining the new values for u_i , v_j and d_{ij}. Repeat the above steps if at least one of the new d_{ij} is negative.

By doing that we enter a new variable to the basis and remove the basic variable from the basis. That bring us to an important observation, the cost coefficient d_{ij} represents the opportunity to get a better solution for the Transportation model.

2.3 Algorithm for Proposed Method (Optimal Route) To Find Optimal Solution to Transportation Problem

Optimal Route is the most efficient and cost effective path for transporting goods and services to meet demand. The procedure includes;

Step 1: Set S_i : Supply amount of the i^{th} source;

Set D_j : Demand amount of the j^{th} destination;

Set C_{ij}:Unit transportation cost of i^{th}source to j^{th} destination;

Check: $if\, S_i < 0$ and $D_j < 0$, then stop

Step 2:

a. If $\sum_{i=1}^{m} S_i > \sum_{j=1}^{n} D_j$ or if $\sum_{i=1}^{m} S_i < \sum_{j=1}^{n} D_j$

Then balance the transportation problem adding dummy demand or dummy supply

b. Set: $C_{ij} = 0$ for all dummy rows or columns.

Step 3 Find the optimal route; this exist in the row or column with maximum C_{ij}

Step 4 Take the sum of all cost corresponding to the optimal route.

Step 5 Apply the principle of supply and demand (higher price lead to higher supply, lower price lead to lower

Supply and the higher the price the lower the level of demand). Allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. Then eliminate the entire row or column in which supply is exhausted or demand is satisfied.

Step 6 Repeat Step 3 to 5 until the entire available supply at various sources is exhausted and demand at various destinations is satisfied.

Finally calculate the total transportation cost. Minimize Z = $\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$

3. RESULTS AND DISCUSSION

3.1 Introduction

FMCG noodles Company ships noodles from six sites to four destinations. The supply (in truckloads) and the demand (also in truckloads) together with the unit transportation costs per truckload on the different routes are summarized in the transportation model in table 1.

3.2 Numerical Examples with Illustration

Table 1.0: Problem table

	North	**South**	**East**	**West**	**supply**
Site A	3.67	3.7	9.2	4.09	460
Site B	5.22	9.82	5.64	5.49	535
Site C	7.88	3.61	3.47	3.31	511
Site D	5.44	3.55	3.7	5.19	483
Site E	4.82	4.8	4.7	9.45	505
Site F	5.39	5.43	5.69	5.45	411
Demand	777	812	550	612	

Total number of supply constraints: 6, Total number of demand constraints: 4

Here Total Demand = 2751 is less than Total Supply = 2905

This is an unbalanced transportation problem, so we add a dummy demand constraint with 0 unit cost and with allocation 154.

Table 1.1: New Problem Table

	North	South	East	West	Ddummy	Supply
Site A	3.67	3.7	9.2	4.09	0	460
Site B	5.22	9.82	5.64	5.49	0	535
Site C	7.88	3.61	3.47	3.31	0	511
Site D	5.44	3.55	3.7	5.19	0	483
Site E	4.82	4.8	4.7	9.45	0	505
Site F	5.39	5.43	5.69	5.45	0	411
Demand	777	812	550	612	154	

Optimal Route Solution Method to Problem Table 1.1

Table 1.2: Iteration1

	North	South	East	West	Ddummy	supply	
Site A	3.67	3.7	9.2	4.09	0	460	
Site B	5.22[535]	9.82	5.64	5.49	0	535 0	26.17 ⬅
Site C	7.88	3.61	3.47	3.31	0	511	
Site D	5.44	3.55	3.7	5.19	0	483	
Site E	4.82	4.8	4.7	9.45	0	505	
Site F	5.39	5.43	5.69	5.45	0	411	
Demand	~~777~~ 242	812	550	612	154		
		30.91 ⬆					

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. The optimal route. 26.17, occurs in row Site B, the minimum Cij in this row is C21=5.22, the maximum allocation in this cell is min (535,777) = 535. It satisfy supply of Site B and adjust the demand of North from 777 to 242 (777-535=242).

Table 1.3: Iteration 2

	North	South	East	West	Ddummy	Supply	
Site A	3.67	3.7	9.2	4.09	0	460	
Site C	7.88	3.61	3.47	3.31	0	511	
Site D	5.44	3.55	3.7	5.19	0	483	
Site E	4.82	4.8	4.7[505]	9.45	0	505	23.77
Site F	5.39	5.43	5.69	5.45	0	411	
Demand	242	812	~~550~~ 45	612	154		
				27.49			

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. The optimal route 23.77, occurs in Site E, the minimum Cij in this row is C53=4.7 The maximum allocation in this cell is min (505,550) = 505

It satisfy supply of Site E and adjust the demand of West from 550 to 45 (550- 505=45).

Table 1.4 Iteration 3

	North	South	East	West	Ddummy	Supply	
Site A	3.67	3.7	9.2	4.09	0	460	20.66
Site C	7.88	3.61	3.47	3.31	0	511	
Site D	5.44	3.55	3.7[45]	5.19	0	~~483~~ 438	
Site F	5.39	5.43	5.69	5.45	0	411	
Demand	242	812	~~45~~ 0	612	154		
			22.06				

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route, the optimal route 22.06, occurs in column east.

The minimum C_{ij} in this column is C43=3.7, according to the algorithm we allocate to the minimum cost that correspond to it, the maximum allocation in this cell is min (45,438) = 45

It satisfy the demand of East and adjust supply of Site D from 483 to 438 (483 – 45=438)

Table 1.5: Iteration 4

	North	South	West	Ddummy	supply	
Site A	3.67	3.7	4.09	0	460	
Site C	7.88	3.61	3.31[511]	0	~~511~~ 0	14.8
Site D	5.44	3.55	5.19	0	438	
Site F	5.39	5.43	5.45	0	411	
Demand	242	812	~~612~~ 101	154		
	22.38					

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route, the optimal route. 14.8, occurs in row Site C, The minimum Cij in this row is C34=3.31, the maximum allocation in this cell is min (612,511) = 511. It satisfy the Supply of Site C and adjust demand of West from 612 to 101 (612 - 511=101)

Table 1.6 Iteration 5

	North	South	West	Ddummy	Supply	
Site A	3.67	3.7	4.09	0	460	
Site D	5.44	3.55	5.19	0	438	
Site F	5.39	5.43	5.45	0[154]	~~411~~ 257	16.27
Demand	242	812	101	~~154~~ 0		
			14.73			

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route, the optimal route. 16.27, occurs in row Site F. The minimum Cij in this row is C65=0, the maximum allocation in this cell is min (411,154) = 154, It satisfy the demand of Ddummy and adjust Supply of Site F from 411 to 257(411-154=257)

Table 1.7: Iteration 6

	North	South	West	supply	
Site A	3.67	3.7	4.09	460	
Site D	5.44	3.55	5.19	438	
Site F	5.39	5.43	5.45[101]	~~257~~156	16.27
Demand	242	812	~~101~~ 0		
			14.73		

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. The optimal route. 16.27, occurs in row Site F.

The minimum Cij in this row is C61=5.39, but we take C64 = 5.45. The maximum allocation in this cell is min (257,101) = 101, It satisfy the demand of West and adjust Supply of Site F from 257 to 156 (257-101 =156)

Table 1.8: Iteration 7

	North	South	Supply	
Site A	3.67	3.7	460	
Site D	5.44	3.55[438]	~~438~~ 0	8.99
Site F	5.39	5.43	156	
Demand	242	~~812~~ 374		
	14.5			

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. The optimal route. 8.99, occurs in row Site D.

The minimum Cij in this row is C42=3.55. The maximum allocation in this cell is min (812,438) = 438, It satisfy the Supply of Site D and adjust demand of south from 812 to 374 (812-438 =374)

Table 1.9: Iteration 8

	North	South	Supply	
Site A	3.67	3.7[374]	~~460~~ 86	
Site F	5.39	5.43	156	10.82
Demand	242	~~374~~ 0		
		9.13		

According to the algorithm we allocate to the minimum cost that satisfies the law of supply and demand that correspond to the optimal route. The optimal route 9.13, occurs in column south. The minimum Cij in this row is C12=3.7. The maximum allocation in this cell is min (460,374) = 374 It satisfy the demand of south and adjust Supply of Site A from 460 to 86 (460-374=86)

Table 1.10: Iteration 9

	North	Supply
Site A	$3.67^{[86]}$	~~86~~ 0
Site F	$5.39^{[156]}$	~~156~~ 0
Demand	~~242~~ ~~156~~ 0	

Entire available supply at various sources is exhausted and demand at various destinations is satisfied.
The allocated table becomes

Table 1.11

	D1	D2	D3	D4	Ddummy		Supply
S1	3.67 (86)	3.7 (374)	9.2	4.09	0		0
S2	5.22 (535)	9.82	5.64	5.49	0		0
S3	7.88	3.61	3.47	3.31 (511)	0		0
S4	5.44	3.55 (438)	3.7 (45)	5.19	0		0
S5	4.82	4.8	4.7 (505)	9.45	0		0
S6	5.39 (156)	5.43	5.69	5.45 (101)	0 (154)		0
Demand	0	0	0	0	0		

Finally calculate the total transportation cost.
The minimum total transportation cost
=3.67×86+3.7×374+5.22×535+3.31×511+3.55×438+3.7×45+4.7×505+5.39×156+5.45×101+0×154
=11669.72
This is the optimal solution as compared with Modi u- v Method for Vogel

Table 2.0: Problem

	North	**South**	**East**	**West**	**Supply**
Site A	4.56	2.6	6.7	5.02	744
Site B	7.66	8.62	2.96	6.69	199
Site C	3.78	5.77	4.62	8.22	304
Site D	6.22	6.72	2.5	6.21	460
Site E	5.2	9.2	8.63	4.24	252
Site F	8.52	4.92	3.55	6.23	507
Demand	725	660	373	708	

Table 3.0: Problem

	***D*1**	***D*2**	***D*3**	***D*4**	**Supply**
*S*1	2.56	2.9	8.62	3.22	800
*S*2	1	2.82	3	4.55	728
*S*3	5.22	3.72	7.82	2.88	156
*S*4	3.11	4	2.18	6.99	219
*S*5	1.91	5.22	2.8	8.32	354
*S*6	4.65	8.5	6.76	7.22	80
Demand	605	599	210	823	

Table 4.0 problem table

	North	**South**	**East**	**West**	**supply**
*S*ite A	8.01	3.55	5.54	12.69	418
Site B	8.55	8.18	3.06	8.11	632
*S*ite C	2.27	8.45	7.97	11.58	506
*S*ite D	7.88	3.61	8.38	9.13	804
*S*ite E	5.62	8.9	3.71	5.2	120
*S*ite F	6.9	7.8	9.9	4.52	316

Demand	656	856	542	742	

3.4 DISCUSSION OF RESULT

Table 3.0: Comparison of the Result obtained by various methods

Methods / Examples	Least cost method	North west corner method	Vogel approximation Method	Modi optimality method	Proposed Method (Optimal Route method)	Optimal solution
Example 1	11713.98	14563.46	12033.34	11669.72	11669.72	11669.72
Example 2	10788.38	13008.2	10327.17	10311.36	10311.36	10311.36
Example 3	7036.41	9161.25	6099.06	5671.77	5671.77	5671.77
Example 4	11808.52	21879.92	11808.52	11808.52	11808.52	11808.52

By observing the numerical results (see Table 3.0) closely, it is discoverable that the calculated total transportation cost of proposed method (Optimal Route method) is as same as the modi method for vogel yielding optimal solution

From Example 1:

The total cost obtained using the NWCM is 14563.46, LCM is 11713.98, VAM is 12033.34, modi method for vogel is same as the proposed (Optimal Route method) = 11669.72, which yields the optimal solution.

From Example 2:

The total cost obtained using the NWCM is 13008.2, LCM is 10788.38, VAM is 10327.17, modi method for vogel is same as the proposed (Optimal Route method) = 5671.77, which yields the optimal solution

From Example 3:

The total cost obtained using the NWCM is 9161.25, LCM is 7036.41, VAM is 6099.06, modi method for vogel is same as the proposed (Optimal Route method) = 5671.77, which yields the optimal solution

From Example 4:

The total cost obtained using the NWCM is 21879.92, LCM is 11808.52, VAM and modi method for vogel is same as the proposed (Optimal Route method) = 11808.52, which yields the optimal solution.

A comparison for proposed algorithm is made with Least Cost Method, North West Corner Method, vogel approximation method, and modi optimality test method by considering 4 numerical examples. It is observed that the proposed algorithm yields more reliable results in contrast to the modi method. The proposed algorithm is tested for optimality.

4. CONLUSION

In today's highly competitive market, various organizations want to deliver products to the customers in a cost effective way, so that the market becomes competitive. To meet this challenge, transportation model provides a powerful framework to determine the best ways to deliver goods to the customer.

In this research, a new approach titled "Optimal Route" for finding an optimal solution of transportation problems is proposed. Its efficiency has also been tested by solving several number of cost minimizing transportation problems.

The proposed method is simple, easy to understand and well organized. As observed from Table 3.0, the proposed Optimal Route method provides comparatively a better initial basic feasible solution and an optimal solution as the results obtained by the modi method for Vogel which is optimal.

Our main contribution to this research is that we have incorporated a new and unique idea i.e. Optimal Route which will play a significant role in modeling TP. As it is a new way to think about solving TP, we hope by performing further intensive research works, some excellent and fruitful outputs might come out.

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