

Solving Transportation Problem Using Excel and C

K. Neelakanta¹, K. Harika² and Vidya²

¹*Dept of Mechanical Engineering, Srinivasa Ramanujan Institute of Technology, Ananthapur*

²*Department of MBA, Raghavendra Institute of Management Sciences, Ananthapur, A.P*

E-mail: k.meher.harika@gmail.com

Abstract—Transportation is one of the most vital services in modern society. One of the most important and successful applications of quantitative analysis to solving business problems has been in the physical distribution of products, commonly referred to as transportation problems. And it can be defined as to transport various amounts of a single homogeneous commodity that are initially stored at various origins, to different destinations in such a way that the total transportation cost is a minimum. In this article to obtain feasible solution we used NWCR, VAM, LCM in Excel and C-Programming.

Index Terms— Transportation, NWCR, LCM, VAM, Excel, C and cost minimization

I. INTRODUCTION

Transportation is a typical operation research technique intended to establish the 'least cost route' of transportation of goods from the company's plant to its warehouses located at different places. For example, the tyre manufacturing concern has m factories located in n different cities. The total supply potential of manufactured product is absorbed by n retail dealers in n different cities of the country. Then, transportation problem is to determine the transportation schedule that minimizes the total cost of transporting tyres from various factory locations to various retail dealers.

It is special type of linear programming problem (LPP) that involves transportation or physical distribution of goods and services from supply points (say factories) to demand points (ware houses). The problem involves determination of optimum routes to minimize shipping costs from supply source to destinations.

To illustrate the formulation of a transportation problem, let us assume that a manufacturing company has three plants P_1 , P_2 and P_3 producing the similar product and it has to distribute the product to four ware houses W_1 , W_2 , W_3 and W_4 . Each plant has limited capacity or supply (say S_1 , S_2 and S_3) and each ware house has specified demand (say D_1 , D_2 , D_3 and D_4). Product can be transported from each plant to each ware house as shown in the figure1, but the cost of transportation varies from different combinations. And our aim is to establish 'least cost route' of transportation.

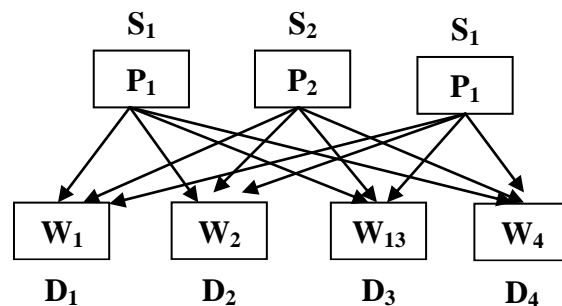


Fig. 1 Transportation Problem

1.1 MATHEMATICAL FORMULATION

Let there be m origin, i th origin possessing a_i units of a certain product, whereas there are n destinations (n may or may not be equal to m) with destination j requiring b_j units. Costs of shipping of an item from each m origins to each of the n destinations are known either directly or indirectly in terms of mileage, shipping hours, etc. Let C_{ij} be the cost of shipping one unit product from i th origin to j th destination. And ' x_{ij} ' be the amount to be shipped from i th origin to j th destination.

It is also assumed that total availabilities $\sum a_i$ satisfy the total requirements $\sum b_j$, i.e.,

$$\sum a_i = \sum b_j \quad (i = 1, 2, 3, \dots, m; j = 1, 2, 3, \dots, n) \quad (1)$$

(In case $\sum a_i \neq \sum b_j$ some manipulation is required to make $\sum a_i = \sum b_j$)

The problem now is to determine non-negative (≥ 0) values of ' x_{ij} ' satisfying both, the availability constraints:

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$$\sum_{j=1}^n x_{ij} = a_i \text{ For } i = 1, 2, 3, \dots, m. \text{---(2)}$$

As well as the requirement constraints:

$$\sum_{j=1}^m x_{ij} = b_j \text{ For } j = 1, 2, 3, \dots, n. \text{---(3)}$$

And minimizing the total cost of transportation (shipping)

$$Z = \sum_{j=1}^n \sum_{i=1}^m x_{ij} C_{ij} \text{ (objective function.---(4))}$$

It may be observed that the constraint equations (2), (3) and the objective function (4) are all linear in x_{ij} , so it may be looked like linear programming problem and this special type of LPP will be called a Transportation Problem (T.P).

1.2 TABULAR REPRESENTATION

Suppose there are m origins and n destinations. The transportation problem is usually in a tabular form (Table 1). Calculations are made directly on the 'transportation arrays' which gives the current trial solution.

Warehouse Factory →	W ₁	W ₂	..	W _j	..	W _n	supply
F ₁	C ₁₁	C ₁₁	.	C _{1j}	.	C _{1n}	a ₁
F ₂	C ₂₁	C ₂₁	.	C _{2j}	.	C _{2n}	a ₂
.
.
.
F _i	C _{i1}	C _{i1}	.	C _{ij}	.	C _{in}	a _i
.
.
F _m	C _{m1}	C _{m1}	.	C _{mj}	.	C _{mn}	a _m
Demand	b ₁	b ₂	..	b _j	..	b _n	$\sum_{i=1}^m a_i = \sum_{j=1}^n b_j$

Table 1

Warehouse Factory →	W ₁	W ₂	..	W _j	..	W _n	supply
F ₁	C ₁₁	C ₁₁	.	C _{1j}	.	C _{1n}	a ₁
F ₂	C ₂₁	C ₂₁	.	C _{2j}	.	C _{2n}	a ₂
.
.
.
F _i	C _{i1}	C _{i1}	.	C _{ij}	.	C _{in}	a _i
.
.
F _m	C _{m1}	C _{m1}	.	C _{mj}	.	C _{mn}	a _m
Demand	b ₁	b ₂	..	b _j	..	b _n	$\sum_{i=1}^m a_i = \sum_{j=1}^n b_j$

Table 2

In general Tables 1 and 2 are combined by inserting each unit cost C_{ij} together with the corresponding amount X_{ij} into the cell (i, j) . The product $(X_{ij})(C_{ij})$ gives the net cost of shipping X_{ij} units from factory F_i to warehouse W_j . as shown in the below table 3.

Let

C_{ij} = Unit cost of transportation from i th plant to j th warehouse.

X_{ij} = Quantity of the product transported from i th plant to j th warehouse.

The above two tables can be tabulated as

P (i)	Warehouses(j)								Supply
	1		2		3		4		
1		C ₁₁		C ₁₂		C ₁₃		C ₁₄	S ₁
	X ₁₁		X ₁₂		X ₁₃		X ₁₄		
2		C ₂₁		C ₂₂		C ₂₃		C ₂₄	S ₂
	X ₂₁		X ₂₂		X ₂₃		X ₂₄		
3		C ₃₁		C ₃₂		C ₃₃		C ₃₄	S ₃
	X ₃₁		X ₃₂		X ₃₃		X ₃₄		
D	D ₁		D ₂		D ₃		D ₄		$\sum S = \sum D$

Table 3 Transportation Table

Therefore total cost of transportation

$$= C_{11}.X_{11} + C_{12}.X_{12} + C_{13}.X_{13} + C_{14}.X_{14} + C_{21}.X_{21} + C_{22}.X_{22} + C_{23}.X_{23} + C_{24}.X_{24} + C_{31}.X_{31} + C_{32}.X_{32} + C_{33}.X_{33} + C_{34}.X_{34}.$$

Since, the objective is to minimize the total cost of transportation, the LP objective function is:

$$\text{Minimize } Z = C_{11}.X_{11} + C_{12}.X_{12} + C_{13}.X_{13} + C_{14}.X_{14} + C_{21}.X_{21} + C_{22}.X_{22} + C_{23}.X_{23} + C_{24}.X_{24} + C_{31}.X_{31} + C_{32}.X_{32} + C_{33}.X_{33} + C_{34}.X_{34}.$$

Subjected to

(i) Supply Constraints

(ii) Demand Constraints

$$X_{11} + X_{12} + X_{13} + X_{14} = S_1$$

$$X_{11} + X_{21} + X_{31} = D_1$$

$$X_{21} + X_{22} + X_{23} + X_{24} = S_2$$

$$X_{12} + X_{22} + X_{32} = D_2$$

$$X_{31} + X_{32} + X_{33} + X_{34} = S_3$$

$$X_{13} + X_{23} + X_{33} = D_3$$

$$X_{14} + X_{24} + X_{34} = D_4$$

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2. ESTABLISH AN INITIAL SOLUTION

An initial solution must be feasible, i.e., it must satisfy all the supply and demand constraints. A solution is said to be feasible if $(m+n-1)$ cells of the transportation matrix are allocated some units/items. The cells having an allocation are known as 'Occupied Cells' while, other cells are termed as "Unoccupied Cells".

The following methods are commonly used to establish initial solution:

- i. North-West Corner Method (NWCM)
- ii. The Least Cost Method (LCM)
- iii. The VOGEL's Approximation Method (VAM).

2.1 NORTH-WEST CORNER METHOD

This is one of the earliest methods to find initial feasible solution. The steps for obtaining initial solution by this method are:

Step I:

The first assignment is made in the cell occupying the upper left-hand (north-west) corner of the transportation table. The maximum possible amount is allocated there. i.e., $x_{11} = \min(a_1, b_1)$. This value of x_{11} is then entered in the cell (1,1) of the transportation table.

Step II:

- (i) If $b_1 < a_1$, move vertically downwards to the second row and make the second allocation of amount $x_{21} = \min(a_2, b_1 - x_{11})$ in the cell (2, 1).
- (ii) If $b_1 < a_1$, move horizontally right-side to the second column and make the second allocation of amount $x_{12} = \min(a_1 - x_{11}, b_1)$ in the cell (1, 1).
- (iii) If $b_1 = a_1$, there is tie for the second allocation. One can make the second allocation of magnitude $x_{12} = \min(a_1 - a_1, b_2) = 0$ in the cell (1, 2) or $x_{21} = \min(a_2, b_1 - b_1) = 0$ in the cell (2, 1).

Step III:

Start from the new *north-west* corner of the transportation table and repeat the steps I and II until the requirements are satisfied.

An Illustrative example for NWCM

Find the initial BFS of the following T.P by NWCM.

	D ₁	D ₂	D ₃	Supply
S ₁	2	7	4	5
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7	9	18	34

Iteration 1

	D ₁	D ₂	D ₃	Supply
S ₁	2(5)	7	4	5
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7 2	9	18	

Iteration 2

	D ₁	D ₂	D ₃	Supply
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7 2	9	18	

Iteration 3

	D ₁	D ₂	D ₃	Supply
S ₂	3(2)	3	1	8 2
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	2	9	18	

Iteration 4

	D ₂	D ₃	Supply
S ₂	3	1	6
S ₃	4	7	7
S ₄	6	2	14
Demand	9	18	

Iteration 5

	D ₂	D ₃	Supply
S ₂	3(6)	1	6
S ₃	4	7	7
S ₄	6	2	14
Demand	9 3	18	

Iteration 6

	D ₂	D ₃	Supply
S ₃	4	7	7
S ₄	6	2	14
Demand	3	18	

Iteration 7

	D ₂	D ₃	Supply
S ₃	4(3)	7	7 4
S ₄	6	2	14
Demand	3	18	

Iteration 8

	D ₃	Supply
S ₃	7	4
S ₄	2	14
Demand	18	

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Iteration 9

	D ₁	Supply
S ₃	7(4)	4
S ₄	2(14)	14
Demand	18	

Iteration 10

	D ₁	D ₂	D ₃	Supply
S ₁	2(5)	7	4	5
S ₂	3(2)	3(6)	1	8
S ₃	5	4(3)	7(4)	7
S ₄	1	6	2(14)	14
Demand	7	9	18	34

The BFS is $X_{11} = 5$, $X_{21} = 2$, $X_{22} = 6$, $X_{32} = 3$, $X_{33} = 4$, $X_{43} = 14$.

The total cost of Transportation Cost = $5*2+2*3+3*6+4*3+7*4+2*14 = 102$

2.2 THE LEAST COST METHOD

In this method the cost is associated with each route i.e., cell is taken into consideration. The steps involved in LCM are

Step I:

Determine the smallest cost in the cost matrix of the transportation table. Let it be (C_{ij}) . Allocate $X_{ij} = \min(a_i, b_j)$ in the cell (i, j)

Step II:

- If $X_{ij} = a_i$, cross-out the i th row of the transportation table and decrease b_j by a_i . Go to step 3.
- If $X_{ij} = a_i$, cross-out the j th column of the transportation table and decrease a_i by b_j . Go to step 3.
- If $X_{ij} = a_i = b_j$, cross-out either the i th row or j th column of the transportation table and decrease a_i by b_j . Go to step 3.

Step III:

Repeat steps I and II for the resulting reduced transportation table until all the requirements are satisfied. Whenever the minimum cost is not unique, make an arbitrary choice among the minima.

An Illustrative example for LCM

	D ₁	D ₂	D ₃	Supply
S ₁	2	7	4	5
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7	9	18	34

Iteration 1

	D ₁	D ₂	D ₃	Supply
S ₁	2	7	4	5
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7	9	10	

Iteration 2

	D ₂	D ₃	Supply
S ₁	7	4	5
S ₃	4	7	7
S ₄	6	2	7
Demand	9	10	

Iteration 3

	D ₂	D ₃	Supply
S ₁	7	4	5
S ₃	4	7	7
Demand	9	3	

Iteration 4

	D ₂	D ₃	Supply
S ₁	7	4	5
Demand	2	3	

Iteration 5

	D ₁	D ₂	D ₃	Supply
S ₁	2	7(2)	4(3)	5
S ₂	3	3	1(8)	8
S ₃	5	4(7)	7	7
S ₄	1(7)	6	2(7)	14
Demand	7	9	18	34

The BFS is $X_{12} = 2$, $X_{13} = 3$, $X_{23} = 8$, $X_{32} = 7$, $X_{41} = 7$, $X_{43} = 7$.

The total cost of Transportation Cost = $7*2+4*3+1*8+4*7+7*1+2*7 = 83$

2.3 THE VOGEL'S APPROXIMATION METHOD

Step I:

For each row of the transportation table identify the *smallest* and *next-smallest* cost. Determine the difference between them for each row. This is called '*Penalties*'. Put them along the side the transportation table by enclosing them in the *parentheses* against the respective rows. Similarly compute these penalties for each column.

Step II:

Identify the row or column with the largest penalty among all the rows and columns. If a tie occurs, use any arbitrary

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tie breaking choice. Let the largest penalty correspond to i th row and let C_{ij} be the smallest cost in the i th row. Allocate the largest possible amount $X_{ij} = \min(a_i, b_j)$ in the cell (i, j) and cross-out the i th row or j th column in the usual manner

Step III:

Again compute the column and row penalties for the reduced transportation table and then go to step 2. Repeat the procedure until all the requirements are satisfied.

An Illustrative example for VAM

	D ₁	D ₂	D ₃	Supply
S ₁	2	7	4	5
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7	9	18	34

	D ₁	D ₂	D ₃	Sy	R P
S ₁	2	7	4	5	(2) (2) (5) (5)
S ₂	3	3	1	8	(2) - - -
S ₃	5	4	7	7	(1) (1) (1) (1)
S ₄	1	6	2	14/4/0	(1) (1) (5) -
Dd	7/0	9-7/2/0	18-10/0	34	
CP	(1)	(1)	(1)		
	(1)	(1)	(1)		
	(1)	(1)	-		
	(3)	(3)	-		

SOLUTION BY VAM

	D ₁	D ₂	D ₃	Supply
S ₁	2(3)	7(2)	4	5
S ₂	3	3	1(8)	8
S ₃	5	4(7)	7	7
S ₄	1(4)	6	2(10)	14
Demand	7	9	18	34

The BFS is $X_{11} = 3, X_{12} = 2, X_{23} = 8, X_{32} = 7, X_{41} = 4, X_{43} = 10$.

The total cost of Transportation Cost = $2*3+7*2+1*8+4*7+1*4+2*10 = 80$

2.4 TESTING THE INITIAL SOLUTION FOR ACCEPTABILITY

For acceptability the initial solution must satisfy the following two conditions.

- The number of allocations in the initial solutions must be equal to $(m+n-1)$ where m = number of rows and n = number of columns in the transportation matrix.
- The allocations are in the independent positions

The squares having, allocations (occupied cells) are scaled 'stone squares' and the other (unoccupied cell) are called 'water squares'. And each allocation is called "stone".

If in the initial solution, the above condition is not satisfied, it is called 'degeneracy'.

3. ESTABLISH AN INITIAL SOLUTION BY EXCEL & C.

An initial solution can be found by using excel solver and C-Programming.

3.1 Introduction to EXCEL

Excel is a powerful tool that uses the data presented in rows and columns to perform a very effective data analysis and produce visually appealing graphical or tabular reports. We can as well program it to perform much deeper and effective analysis on data and even provide ability to intelligently work with non technical users.

3.2 Proposed Method (EXCEL)

Step by step procedure to solve T.P. using EXCEL Solver.

Consider the above problem.

	D ₁	D ₂	D ₃	Supply
S ₁	2	7	4	5
S ₂	3	3	1	8
S ₃	5	4	7	7
S ₄	1	6	2	14
Demand	7	9	18	34

STEP I

Enter the problem as shown in the EXCEL SCREEN SHOT-I and to express target cell D10, we need to find the total shipping cost.

EXCEL SCREEN SHOT-I

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The shipments from each supply point to demand point, we can compute the total cost as follows.

(Units allocated from S_1 to D_1)(Cost of transportation /Units transported from S_1 to D_1) + (Units allocated from S_1 to D_2)(Cost of transportation /Units transported from S_1 to D_2) + (Units allocated from S_1 to D_3)(Cost of transportation /Units transported from S_1 to D_3) + (Units allocated from S_2 to D_1)(Cost of transportation /Units transported from S_2 to D_1) + (Units allocated from S_2 to D_2)(Cost of transportation /Units transported from S_2 to D_2) + (Units allocated from S_2 to D_3)(Cost of transportation /Units transported from S_2 to D_3) + (Units allocated from S_3 to D_1)(Cost of transportation /Units transported from S_3 to D_1) + (Units allocated from S_3 to D_2)(Cost of transportation /Units transported from S_3 to D_2) + (Units allocated from S_3 to D_3)(Cost of transportation /Units transported from S_3 to D_3) + (Units allocated from S_4 to D_1)(Cost of transportation /Units transported from S_4 to D_1) + (Units allocated from S_4 to D_2)(Cost of transportation /Units transported from S_4 to D_2) + (Units allocated from S_4 to D_3)(Cost of transportation /Units transported from S_4 to D_3).

STEP II

The SUMPRODUCT function is used to multiply the elements in two rectangles and add together the products. The cell range $B13:E15$ as cost and the changing cell range $B3:E5$ as shipped. And the total shipping cost is calculated in the target cell $D9$, by SUMPRODUCT function. i.e., SUMPRODUCT (B3:E5, B13:E15) as shown in *EXCEL SCREEN SHOT-II*.

The screenshot shows an Excel spreadsheet with a table of data. In cell D9, the formula `=SUMPRODUCT(B3:E5,B13:E15)` is entered. The table data is as follows:

	PLANT	1	2	3	SUPPLY	TOTAL
1	1	2	7	4	5	13
2	2	3	3	1	8	7
3	3	5	4	7	16	18
4	4	1	6	2	14	9
5	TOTAL	11	20	14		

EXCEL SCREEN SHOT-II

STEP III

Now we need to express the both supply and demand constraints by using the SUM formulae for each supply and demand point as shown in the *EXCEL SCREEN SHOT-III & EXCEL SCREEN SHOT-IV*

The screenshot shows the initial data table in Excel. The table data is as follows:

	PLANT	1	2	3	SUPPLY	TOTAL
1	1	2	7	4	5	13
2	2	3	3	1	8	7
3	3	5	4	7	16	18
4	4	1	6	2	14	9
5	TOTAL	11	20	14		

EXCEL SCREEN SHOT-III

The screenshot shows the data table with cell D9 highlighted. The table data is as follows:

	PLANT	1	2	3	SUPPLY	TOTAL
1	1	2	7	4	5	13
2	2	3	3	1	8	7
3	3	5	4	7	16	18
4	4	1	6	2	14	9
5	TOTAL	11	20	14		

EXCEL SCREEN SHOT-IV

STEP V

Now open the solver from DATA tab and set the target cell range $D9$ as shown in the *EXCEL SCREEN SHOT-V*

The screenshot shows the Solver dialog box open. The 'Set Target Cell' is $D9$. The 'To: Value of' is 0. The 'By Changing Variable Cells' is $B3:E5$. The 'Subject to the Constraints' section is empty. The 'Solving Method' is 'GRG Nonlinear Engine'. The 'Load/Save' button is visible.

EXCEL SCREEN SHOT-V

Our changing cells are the number of units shipped from each supply point to demand region as shown in the *EXCEL SCREEN SHOT-VI*

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Excel Screen Shot-VI shows the Solver dialog box with the following settings:

- Set Objective: \$B\$10
- To: Of Max Value Of
- By Changing Variable Cells: \$B\$3:\$D\$3
- Subject to the Constraints: (empty)
- Options: (empty)
- Help: (empty)
- Buttons: OK, Cancel, Add, Load/Save, Options, Help

EXCEL SCREEN SHOT-VI

STEPVI

Now we need to add the Supply and Demand constraints as shown in the EXCEL SCREEN SHOT-VII & EXCEL SCREEN SHOT-VIII

Excel Screen Shot-VII shows the Solver dialog box with the following constraints added:

- \$B\$3:\$D\$3 <= \$E\$3:\$E\$5
- \$B\$6:\$D\$6 <= \$F\$6:\$F\$8

EXCEL SCREEN SHOT-VII

Excel Screen Shot-VIII shows the Solver dialog box with the following constraints added:

- \$B\$3:\$D\$3 <= \$E\$3:\$E\$5
- \$B\$6:\$D\$6 <= \$F\$6:\$F\$8

EXCEL SCREEN SHOT-VIII

Initial Basic Feasible SOLUTION

The minimum cost of shipping is Rs 76. And this can be achieved by following schedule.

1. Shipping 5 units from S_1 to D_1
2. Shipping 2 units from S_2 to D_2 and Shipping 6 units from S_2 to D_3 .
3. Shipping 7 units from S_3 to D_2
4. Shipping 2 units from S_4 to D_1 and

Shipping 12 units from S_4 to D_3 .

STEP VII

Now select the options in SLOVER dialog box and select the **Assume Linear Model** and **Assume Non-Negative** options as shown in the EXCEL SCREEN SHOT-IX.

Excel Screen Shot-IX shows the Solver Options dialog box with the following options checked:

- Assume Linear Model
- Assume Non-Negative

EXCEL SCREEN SHOT-IX

STEP X

Now click on the **Solve** button from Solver dialog box as shown in EXCEL SCREEN SHOT-X, and one can obtain the optimum solution.

Excel Screen Shot-X shows the Solver dialog box with the 'Solve' button highlighted.

EXCEL SCREEN SHOT-X

3.3 Introduction to C

One of the widely used, platforms independent structured programming language and is highly efficient. Even after 40 years of invention, it is still popular and used in a range of software including operating system algorithm designs.

3.4 Proposed Method with C

In the above example cited we use c-language to minimize the total cost of T.P and determine the number of units transported from origin i to destination j .

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The results are discussed below.

The result of **North-West Corner Method** by using C, the total transportation cost = 102

The number of units transported from source i to destination j .

Supply [1] to demand [1] = 5

Supply [2] to demand [1] = 2

Supply [2] to demand [2] = 6

Supply [3] to demand [2] = 3

Supply [3] to demand [3] = 4

Supply [4] to demand [3] = 14

The result of **The Least Cost Method** (LCM) by using C, the total transportation cost = 83

The number of units transported from source i to destination j .

Supply [1] to demand [2] = 2

Supply [1] to demand [3] = 3

Supply [2] to demand [3] = 8

Supply [3] to demand [2] = 7

Supply [4] to demand [1] = 7

Supply [4] to demand [3] = 7

The result of **VOGEL's Approximation Method** by using C, the total transportation cost = 80

The number of units transported from source i to destination j .

Supply [1] to demand [1] = 3

Supply [1] to demand [2] = 2

Supply [2] to demand [3] = 8

Supply [3] to demand [2] = 7

Supply [4] to demand [1] = 4

Supply [4] to demand [3] = 10

4 CONCLUSION

The advantage of **Solver Tool** in excel is colored along with its utilities for **Operation Research**. The step wise procedure is explained using **Solver** tool with screen shots, taking numerical example of an **XYZ Company** of Transportation Problem to make better understand and to take better decision. Along with this it is much easier to understand by a common man who does not processes computer knowledge.

Running all the three C programs for solving transportation problem show that the results of the three C programming's all are equal to the result of the LP solution. But the results of three programs are different. The decision maker may choose the optimal result of the running of the three programs (minimum) and determined the number of units transported from source i to destination j .

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