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SOME ASPECTS OF OPERATIONS RESEARCH USING SOLVER

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ABSTRACT

Operational Research (OR) is the use of advanced analytical techniques to improve decision making, because it brings sense to make the best use of available resources. Hence every OR analyst must possess interpersonal skills and be able to work with management by providing *quick solutions* to the problems. Despite their theoretical knowledge in OR-techniques, familiarity in computer software is also highly desirable to meet the timely needs. This paper focuses on the simplest method of solving Linear Programming Problem (LPP) and Transportation Problem (TP) using *solver* tool available in MS-Excel, though several software available exclusively for OR solutions. But they need special attention and more time to understand and learn. This paper guides young researchers, students at postgraduate level, who feel difficulty in solving LPP and TP problems manually, and also managers of companies who don't have much mathematical background. Step-wise procedure explained in this paper takes care of persons who have only basic knowledge of computers.

Key words: LPP, TP, What-if-Analysis, MS-Excel and Solver

1. INTRODUCTION

Now days, most of the corporate companies appointing personnel at higher positions with versatile skills not only in technical aspects but also in managerial aspects. But the curriculum followed by higher educational institutions could not provide these multifaceted skills to the postgraduates. Hence practically, company managers are facing great difficulty in balancing technical and managerial aspects which involve decision making regarding production, supply, demand, hiring the services and cost on advertisements….etc subject to many constraints on resources. Hypothetically speaking, these problems come under Linear programming problem (LPP) and Transportation problems in Operations Research. But, solutions to these problems include many mathematical equations, tedious computations, iterations, etc. Due to this difficulty mangers can not apply their efforts to test various possibilities of resources in order to achieve the optimum solution from many solutions.

By keeping all the difficulties cited above, we made an attempt to provide a platform to achieve optimum solutions to Linear Programming Problems and Transportation

problem easily using freely available software Ms-Excel. Eventhough number of readymade software is available in the market to solve these problems which requires additional knowledge to use them.

With the help of the method presented in this paper, a Manager, who has minimum Mathematical background of Operations Research, can find the optimum solution subject to the constraints easily and quickly without depending on professionals.

2. Objectives

This paper aims at the following objectives

1. To elevate the features and advantages of *Solver* add-in tool available in MS-Excel
2. To provide working knowledge on *Solve*r to solve LPP and Transportation problems.
3. Working experience with Real time Problem using *Solver*.

3. Linear Programming Problem(LPP)

Linear programming is a mathematical programming technique to optimize performance (profit or cost) under a set of resource constraints (ex. machine hours, man-hours, money, materials, etc) as specified by an organization [1].

3.1 Concept of Linear Programming model

The model of any linear programming problem will contain Objective function, set of constraints and non-negativity restrictions. Each of the components may consist of one or more of the following:

- Decision variables
- Objective function coefficients
- Technological coefficients
- Availability of resources

3.2 Mathematical model of an LPP

The complete Linear Programming model is as shown below.

Maximize $Z= 250X_1+400 X_2$

Subject to $2X_1+5X_2 \leq 200$

$4X_1+2X_2 \leq 240$

$X_1, X_2 \geq 0$

4. Transportation Problem

The transportation problem is one of the sub-problems of LPP. Here the objective is to transport various quantities of a single homogeneous commodity that are initially stored or produced at various origins to different destinations in such a way that the transportation cost is Minimum [3]. To achieve this we must know the amount and location of available supplies and quantities demanded. In addition we must know the cost that result from transporting one unit from various origins to various destinations.

4.1 Applications

- To minimize the sum of shortage and shipping cost
- To minimize the purchase shipping cost
- To minimize the daily cost of processing checks.
- To maximize the revenue

4.2 Mathematical Model of Transportation Problem as LPP

It is a special case of a linear programming problem. It helps us in minimizing cost associated with transporting a product from multiple origins to different destinations [2]. Let they are

m=origins

n=destinations

a_i =quantity of product available at origin i

b_j =quantity of product required at destination j

c_{ij} =cost of transporting one unit of product from origin i to destination j

X_{ij} =quantity of product transported from origin i to destination j

Z=total transportation cost

Objective Function

$$\text{Min } Z=\sum_{i=1}^{m}\sum_{j=1}^{n} cij\ xij$$

Constraints $\sum_{j=1}^{n} xij=a_i$

$\sum_{i=1}^{m} xij=b_j$

5. Solver tool in Ms-Excel and its Utilities

5.1 About *Solver*

Solver is a part of a suite of commands sometimes called **what-if analysis** (what-if analysis tools [5, 6]. With *Solver*, one can find an optimal value for a formula in one cell called the *target cell* on a worksheet. Solver works with a group of cells that are related,

either directly or indirectly, to the formula in the target cell. *Solver* adjusts the values in the *changing cells* specified, called the adjustable cells to produce the result specified from the target cell formula. One can apply constraints to restrict the values which *Solver* can use in the model, and the constraints can refer to other cells that affect the target cell formula. Use *Solver* to determine the *maximum or minimum* value of one cell by changing other cells, for example, one can change the amount of your projected advertising budget and see the effect on your projected profit amount.

5.2 Supporting Terminology

What –if –analysis tools: A process of changing the values in cells to see how those changes affect the outcome of formulas on the worksheet.

Formula: A sequence of values, cell references, names, functions, or operators in a cell that together produce a new value. A formula always begins with an equal sign (=)[5].

Constraints: The limitations placed on a Solver problem. One can apply constraints to adjustable cells, the target cell, or other cells that are directly or indirectly related to the target cell.

5.3 Solver Utilities:

With the help of *Solver* one can solve the problems like

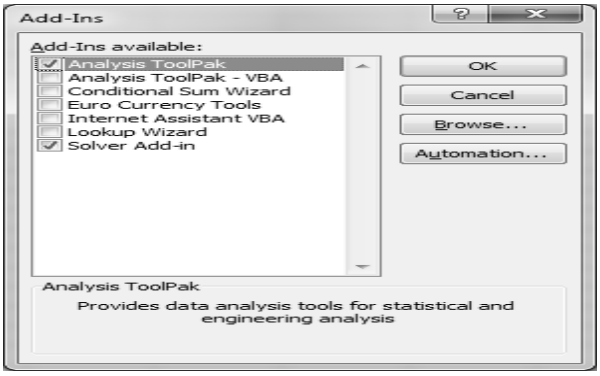
- Product Mix
- Shipping Routes
- Staff Scheduling
- Maximizing Income
- Portfolio of Securities
- and Engineering Design ..etc

5.4 How to install *Solver* in Excel

Excel has a built-in statistical package for carrying out LPP.This feature is usually hiden and can be brought out to the menu by clicking the button sequencing.

Office button → excel options → add- ins → analysis tool pack and solver add-in(as shown in MS-Excel Screen-1)→ OK[6].

MS-Excel Screen-1



Automatically solver can be included in the menu of data.

6. Step-wise procedure to solve Linear Programming Problem using *Solver*

Consider the example:[

Maximize $Z= 250X_1+400 X_2$

Subject to $2 X_1+5 X_2 \leq 200$

$4 X_1+2 X_2 \leq 240$

$X_1 , X_2 \geq 0$

Step-1: Enter descriptions of each variable, the objective function, and all the constraints (Under column A).

Step-2: Then enter the expressions in X_1 and X_2 from the objective function and all the constraints (under column B). Enter these as formulas: start with an equal sign, and finish by pressing ENTER (not a direction arrow).

Step-3: For example, the above problem could be typed in the way shown in Table-1 (the computer displays 0 for each cell in column B as soon as you press ENTER).

Table-1: Method of problem entry in Ms-Excel

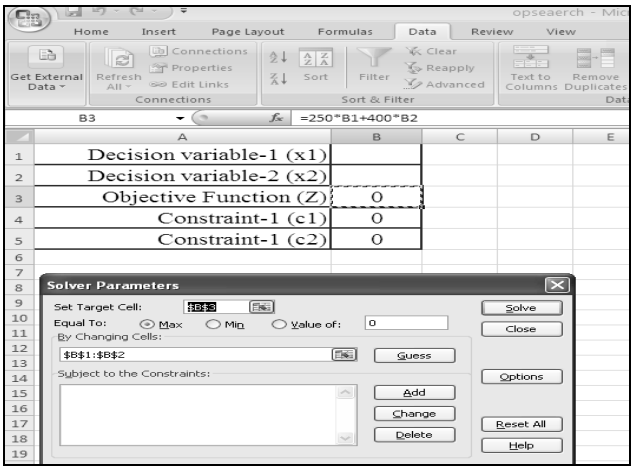
	A	B
1	Decision variable-1 (X_1)	
2	Decision variable-2 (X_2)	
3	Objective Function (Z)	=250*B1+400*B2
4	Constraint-1 (C_1)	=2*B1+5*B2
5	Constraint-1 (C_2)	=4*B1+2*B2

Step-4: In terms of cell references, the goal will to maximize B3 by modifying the entries in B1 and B2. We can leave B1 and B2 blank, because they are unknown: the computer will supply their values.

Step-5: Next, click on cell B3 (the cell we want to maximize) and activate the *solver* with Tools...*Solver*.

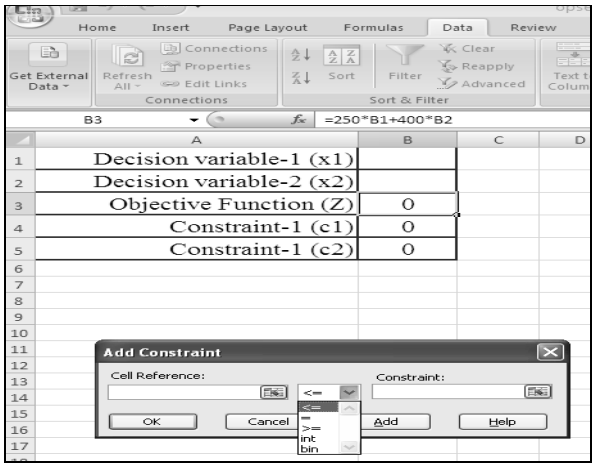
Step-6: Set the cell numbers for the target cell (B3, the cell we want to maximize) as well as the variables (B1:B2 Notice the use of the colon to denote the range of all cells from B1 to B2). Also click to find the Max (not Min) value as shown in MS-Excel Screen-2.

MS-Excel Screen-2



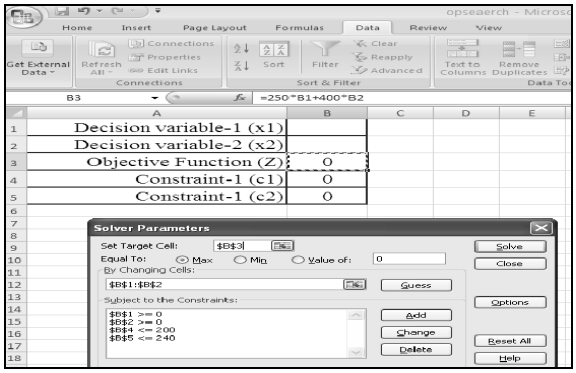
Step-7: Click on 'Add' to add each constraint. One will get a dialog box as shown in MS-Excel Screen-3, which will permit you to specify what cell contains the expression in X_1 and X_2, which inequality symbol to use, and the numerical constant.

MS-Excel Screen-3



Step-8: In addition to entering the constraints labeled here as C_1 and C_2, also add constraints to reflect that $X_1 \geq 0$ and $X_2 \geq 0$. When we click OK, the screen should look like the MS-Excel Screen-4.

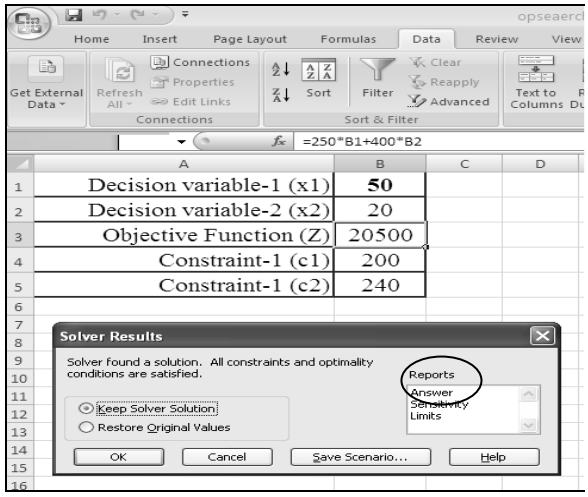
MS-Excel Screen-4



Step-9: When we select Solve, the computer will calculate the optimum solution, if possible, displaying the required values for X_1 and X_2 in cells B1 and B2, and showing the maximum value of Z in cell B3.

Step-10: Click on Answer in the Reports box, and then click OK to keep this solution as shown in MS-Excel Screen-5.

MS-Excel Screen-5



Optimum Solution:

The optimum solution obtained by the solver is $X_1 = 50$, $X_2 = 20$ and $Z = 20500$.

7. Step-wise procedure to solve

Transportation Problem using *Solver*

Consider the following transportation problem

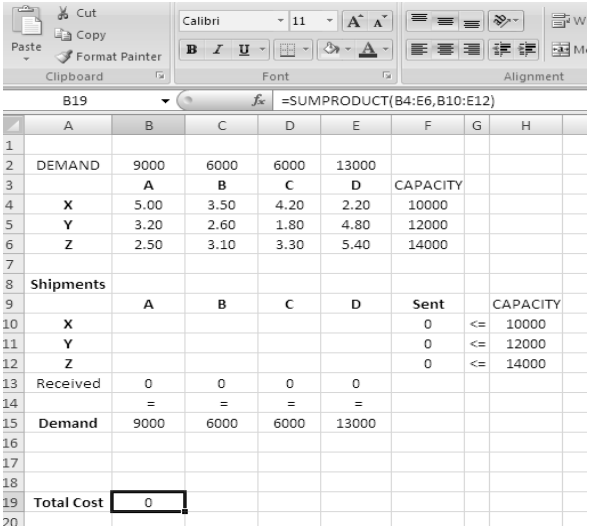
	A	B	C	D	CAPACITY
X	Rs.5.00	Rs.3.50	Rs.4.20	Rs.2.20	10000
Y	Rs.3.20	Rs.2.60	Rs.1.80	Rs.4.80	12000
Z	Rs.2.50	Rs.3.10	Rs.3.30	Rs.5.40	14000
DEMAND	9000	6000	6000	13000	

Step-1: Enter the problem as shown in Ms-Excel Screen-6 and to express our target cell B19, we need to find total shipping cost. After

leaving blanks in the cell range B10:E12 for our shipments from each supply point to each region, we can compute total shipping cost as below.

(Units sent from X to A) *(Sending cost/unit from X to A) +
(Units sent from X to B) *(Sending cost/unit from X to B) +
(Units sent from X to C) *(Sending cost/unit from X to C) +
(Units sent from X to D) *(Sending cost/unit from X to D) +
(Units sent from Y to A) *(Sending cost/unit from Y to A) +
(Units sent from Y to B) *(Sending cost/unit from Y to B) +
(Units sent from Y to C) *(Sending cost/unit from Y to C) +
(Units sent from Y to D) *(Sending cost/unit from Y to D) +
(Units sent from Z to A) * (Sending cost/unit from Z to A) +
(Units sent from Z to B) * (Sending cost/unit from Z to B) +
(Units sent from Z to C) * (Sending cost/unit from Z to C) +
(Units sent from Z to D) *(Sending cost/unit from Z to D)

MS-Excel Screen-6



	A	B	C	D	E	F	G	H
1								
2	DEMAND	9000	6000	6000	13000			
3		A	B	C	D	CAPACITY		
4	X	5.00	3.50	4.20	2.20	10000		
5	Y	3.20	2.60	1.80	4.80	12000		
6	Z	2.50	3.10	3.30	5.40	14000		
7								
8	Shipments							
9		A	B	C	D	Sent		CAPACITY
10	X					0	<=	10000
11	Y					0	<=	12000
12	Z					0	<=	14000
13	Received	0	0	0	0			
14		=	=	=	=			
15	Demand	9000	6000	6000	13000			
16								
17								
18								
19	Total Cost	0						
20								

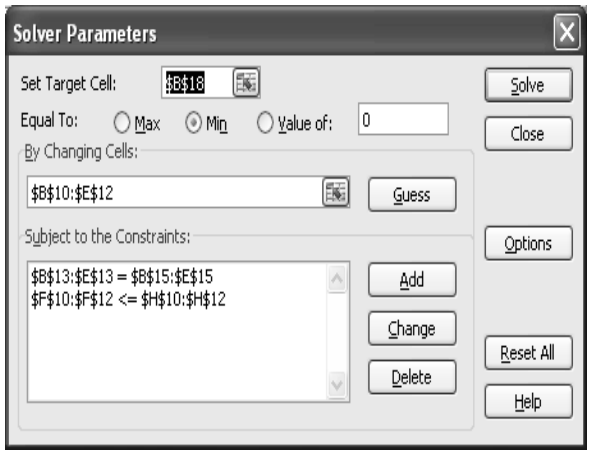
Step-2: The SUMPRODUCT function[5] can multiply corresponding elements in two separate rectangles (as long as the rectangles are the same size) and add together the products. If we name the cell range B4:E6 as *costs* and the changing-cells range (B10:E12) as *shipped*. Therefore, the total shipping cost is computed in cell B19 with the formula *SUMPRODUCT (costs, shipped)* i.e., *SUMPRODUCT (B4:E6, B10:E12) as shown in formula bar of* MS-Excel Screen-6.

Step-3: To express the constraints, first compute the total shipped from each supply point. By entering the formula *SUM (B10:E10)* in cell F10, we compute the total number of units shipped from X as *(X shipped to A) + (X shipped to B) + (X shipped to C) + (X shipped to D)*. Copying this formula to F11:F12 computes the total shipped from Y and Z production points. Later constraints (called *supply constraints*) that ensure the units shipped from each location do not exceed the plant's capacity can be added.

Step-4: Next compute the total received by each demand region by entering in cell B13 the formula *SUM (B10:B12)*. This formula computes the total number of units received by region-A as *(Units shipped from X to A) + (Units shipped from Y to A) + (Units shipped from Z to A)*. By copying this formula from C13:E13, we compute the total units received by the B, C, and D regions. Later, constraints (called *demand constraints*) are to be added which ensure that each region receives the units it requires.

Step-5: We now open the **Solver Parameters** dialog box (click **Solver** on the **Tools** menu), and then fill it in as shown in MS-Excel Screen-7.

MS-Excel Screen-7 (Solver)

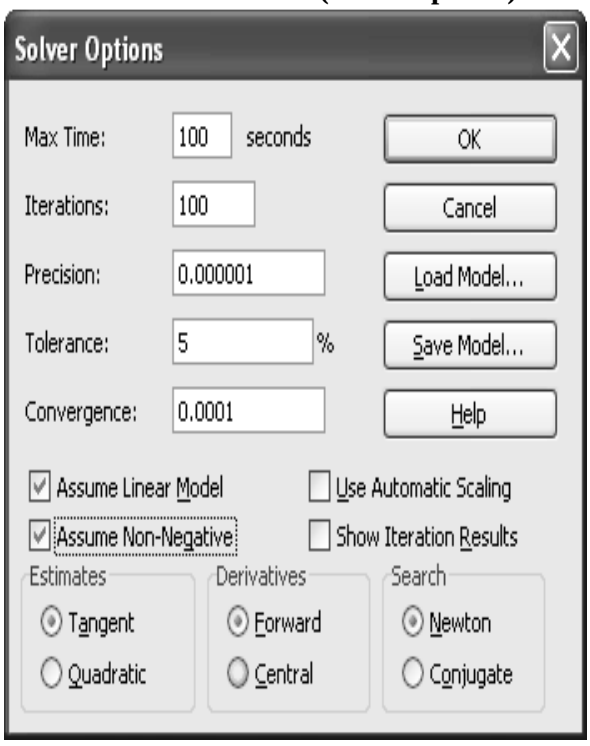


Step-6: We want to minimize total shipping cost (computed in cell B19). Our changing cells are the number of units shipped from each supply point to each demand region. (These units are listed in the range named *shipped*, consisting of cells B10:E12.) The constraint *F10:F12<=H10:H12* (the supply may be less than production/capacity) ensures that the units sent from each point does not exceed its capacity. The constraint *B13:E13 = B15:E15* (the demand constraint) ensures that each region receives exactly the number of units it needs.

Step-7: Since the model is a linear Solver model because our target cell is created by adding together terms of the form *(changing cell)*(constant)*, and both our supply and demand constraints are created by comparing the sum of changing cells to a constant.

Step-8: Now click **Options** in the ***Solver* Parameters** dialog box and select the **Assume Linear Model** and **Assume Non-Negative** options as shown in the MS-Excel Screen-8.

MS-Excel Screen-8 (Solver options)



Step-9: After clicking **Solve** in the ***Solver* Parameters** dialog box as shown in MS-Excel Screen-9, one can obtain the optimum solution.

MS-Excel Screen-9

Optimum solution to Transportation Problem using Solver

	A	B	C	D	CAPACITY
X	5.00	3.50	4.20	2.20	10000
Y	3.20	2.60	1.80	4.80	12000
Z	2.50	3.10	3.30	5.40	14000
DEMAND	9000	6000	6000	13000	

Shipments

	A	B	C	D	Sent		CAPACITY
X	0	0	0	10000	10000	<=	10000
Y	0	3000	6000	3000	12000	<=	12000
Z	9000	3000	0	0	12000	<=	14000
Received	9000	6000	6000	13000			
	=	=	=	=			
Demand	9000	6000	6000	13000			

Total Cost 86800

Optimum Solution:

The minimum cost of meeting customer demand is Rs. 86,800. This minimum cost can be achieved if the company uses the following shipping schedule:

1. Ship 10,000 units from production point X to the region D.
2. Ship 3,000 units from production point Y to the region B and from production point Y to the region D. Ship 6,000 units from production point Y to the region C.
3. Ship 9,000 units from production point Z to the region A and 3,000 units from Z to the region B.

8. Working Experience with Real Time Problem

In order to fulfill one of the important objectives of the study, one real-time problem is identified from NAVATA Transport Company and solved using *Solver* tool.

8.1 NAVATA Road Transport Company

NAVATA Company is one of the biggest transport companies with **710** branches, **404** vehicles, plying about **285** lakh Kms per year. During these thirty years of travel it is outstandingly & qualitatively servicing the customers due to commitment and the continuous support of sister concerns. The entire clearing operations are systematically

channeled into 47 routes covering all branches through its transshipment points.

8.2 A case study at NAVATA Transport Company

One day we visited a NAVATA branch in Tirupati and enquired about the functions of the company like number of routes, cost of the consignment, methods adopted …etc. After listening to them we came to know that there is lot of scope for the concepts of Operations Research viz, Transportation problem, assignment problem and Travelling salesman problems. Out of all routes at Andhra Pradesh we focused on the longest route i.e Tirupati to Srikakulam for our study. It covers 899 km and 11 main branches of this company viz Tirupati(TPT), Nellore(NLR), Kavali(KVL), Ongole(OGL), Chilakaluripeta(CHILK), Guntur(GNT), Vijayawada(VIZ), Eluru(ELR), Tadepalligudem(THAG), Rajahmandry(RAJM), Visakhaptnam(VISK), Vijayanagaram(VIZN) and Srikakulam(SKL). The minimum cost of carrying goods is Rs.48 up to 100 Kg of weight upto160 Km of distance, after that the cost changes based on the distance. The distance and their costs are given in Table-2.

Source: Chart from NAVATA Transport Company

We considered a case study of a Manger who visited NAVATA company and wish to transport machines to his branch offices located at different places with minimum cost of shipment. The clear description of the problem is as below.

8.3 Description of the Problem

A company manager wants to ship 900 machines to the branch offices located at Tirupati, Ongole, Visakhapatnam and Srikakulam about 150, 250, 300 and 200 machines respectively from the wholesale distributors located at Nellore, Guntur and Vijayawada by purchasing not more than 300 machines from each centre with minimum transportation cost. He wanted to know how many machines from which purchasing point to which branch office are to be transported according to their requirement. With the help of cost matrix the problem will become a transportation problem as shown in Table-3.

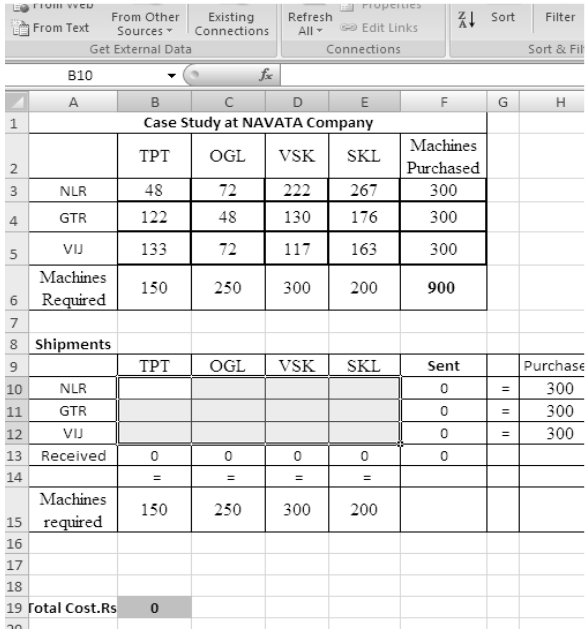
Table-3: Standard form of Transportation Problem

	Tirupati	Ongole	Visakhapatnam	Srikakulam	Machines Purchased
Nellore	Rs .48	Rs.72	Rs.222	Rs.267	300
Guntur	Rs.122	Rs.48	Rs.130	Rs.176	300
Vijayawada	Rs.133	Rs.72	Rs.117	Rs.163	300
Machines required	150	250	300	200	**900**

8.4 Optimum Solution using *Solver* tool

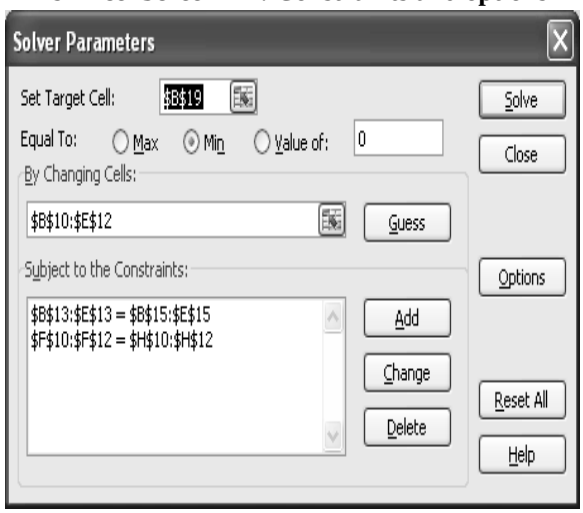
The following sequence of screens provide optimum solution to the problem given in the Section 8.3 with the help of *solver*

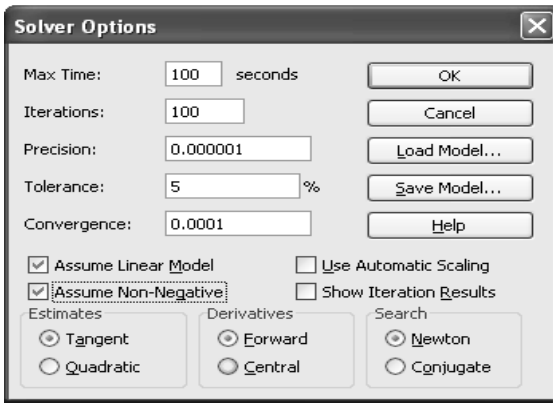
MS-Excel Screen-10: Method of problem entry in Excel sheet



	A	B	C	D	E	F	G	H
1	Case Study at NAVATA Company							
2		TPT	OGL	VSK	SKL	Machines Purchased		
3	NLR	48	72	222	267	300		
4	GTR	122	48	130	176	300		
5	VIJ	133	72	117	163	300		
6	Machines Required	150	250	300	200	**900**		
7								
8	**Shipments**							
9		TPT	OGL	VSK	SKL	Sent		Purchase
10	NLR					0	=	300
11	GTR					0	=	300
12	VIJ					0	=	300
13	Received	0	0	0	0	0		
14		=	=	=	=			
15	Machines required	150	250	300	200			
16								
17								
18								
19	Total Cost.Rs	0						

Ms-Excel Screen -11: Constraints and options





Ms-Excel Screen -12: Optimum Solution

K4

	A	B	C	D	E	F	G	H
1	Case Study at NAVATA Company							
2		TPT	OGL	VSK	SKL	Machines Purchased		
3	NLR	48	72	222	267	300		
4	GTR	122	48	130	176	300		
5	VIJ	133	72	117	163	300		
6	Machines Required	150	250	300	200	900		
7								
8	Shipments							
9		TPT	OGL	VSK	SKL	Sent		Purchased
10	NLR	150	150	0	0	300	=	300
11	GTR	0	100	0	200	300	=	300
12	VIJ	0	0	300	0	300	=	300
13	Received	150	250	300	200	900		
14		=	=	=	=			
15	Machines required	150	250	300	200			
16								
17								
18								
19	Total Cost.Rs	93100						

Optimum Solution:

Manager can complete shipment with minimum cost of **Rs. 93,100** only when his Shipment schedule is as below

1. Ship 150 machines from Nellore to Tirupati branch office.
2. Ship 150 machines from Nellore to Ongole branch office.
3. Ship 100 machines from Guntur to Ongole branch office.
4. Ship 200 machines from Guntur to Srikakulam branch office.
5. Ship 300 machines from Vijayawada to Visakhapatnam branch office.

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CONCLUSION

The advantage of *Solver* tool of what-if analysis family in MS-Excel is highlighted along with its utilities especially in Operations Research. Step-wise procedure explained using *Solver* tool with numerical examples make the solutions of Linear Programming and Transportation Problems much easier to a person who does not have very good Mathematical and Computer knowledge. Several possibilities of resources based on their expected availability can be verified using *Solver* tool easily. A practical experience with a real time problem considered at NAVATA Transport Company guides young researchers to have clear cut idea not only in framing mathematical model of Transportation problem but also in solving it quickly.

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Table-2: Distance and shipping Cost matrix of the route 'Tirupati to Srikakulam

	TPT	NLR	KVL	OGL	CHILK	GNT	VIZ	ELR	THAG	RAJM	VISK	VIZN	SKL
TPT	1(48)	135 (48)	190 (72)	299 (85)	368 (101)	407 (122)	445 (133)	503 (150)	556 (162)	604 (192)	797 (258)	845 (277)	899 (294)
NLR	135 (48)	1(48)	55 (48)	162 (72)	234 (80)	276 (92)	314 (104)	372 (124)	425 (142)	472 (157)	665 (222)	735 (245)	802 (267)
KVL	190 (72)	55 (48)	1(48)	107 (48)	179 (72)	221 (74)	259 (83)	318 (106)	371 124)	418 (139)	611 (204)	681 (229)	748 (249)
OGL	299 (85)	162 (72)	107 (48)	1(48)	72 (48)	114 (48)	152 (72)	211 (72)	264 (88)	311 (104)	504 (168)	574 (191)	641 (214)
CHILK	368 (101)	234 (80)	179 (72)	72 (48)	1(48)	42 (48)	80 (48)	139 (48)	192 (72)	239 (80)	432 (144)	502 (167)	569 (190)
GNT	407 (122)	27 6(92)	221 (74)	114 (48)	42 (48)	1(48)	38 (48)	97 (48)	150 (48)	197 (72)	390 (130)	460 (153)	527 (176)
VIZ	445 (133)	314 (104)	259 (83)	152 (72)	80 (48)	38 (48)	1(48)	59 (48)	112 (48)	159 (72)	352 (117)	422 (141)	489 (163)
ELR	503 (150)	372 (124)	318 (106)	211 (72)	139 (48)	97 (48)	59 (48)	1(48)	53 (48)	100 (48)	293 (98)	363 (121)	430 (143)
THAG	556 (162)	425 (142)	371 (124)	264 (88)	192 (72)	150 (48)	112 (48)	53 (48)	1(48)	47 (48)	240 (80)	310 (103)	377 (126)
RAJM	604 (192)	472 (157)	418 (139)	311 (104)	239 (80)	197 (72)	159 (72)	100 (48)	47 (48)	1(48)	193 (72)	263 (88)	330 (110)
VISK	797 (258)	665 (222)	611 (204)	504 (168)	432 (144)	390 (130)	352 (117)	293 (98)	240 (80)	193 (72)	1(48)	70 (48)	137 (48)
VIZN	845 (277)	735 (245)	681 (229)	574 (191)	502 (167)	460 (153)	422 (141)	363 (121)	310 (103)	263 (88)	70 (48)	1(48)	67 (48)
SKL	899 (294)	802 (267)	748 (249)	641 (214)	569 (190)	527 (176)	489 (163)	430 (143)	377 (126)	330(11 0)	137 (48)	67 (48)	1(48)

Source: Chart from NAVATA Transport

(Figures in bracket indicate cost in rupees)