

# A Reliable Solver of Euclidean Traveling Salesman Problems with Microsoft Excel Add-in Tools for Small-size Systems

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**Abstract**—The Traveling Salesman Problems (TSP) has been a very important topic of study for operations researchers and mathematicians for decades. Computer hardware and software advances in recent years have provided multiple alternative approaches to this classic combinatorial challenge. The objective of this paper is to present an approach to the Traveling Salesman Problems using Microsoft Excel Solver and Premium Solver Platform. The paper illustrates a solution approach which efficiently solves small-size Traveling Salesman Problems.

**Index Terms**—traveling salesman problems, linear programming, logistics education

## I. INTRODUCTION

Spreadsheet software, notably Microsoft Excel<sup>®</sup>, can be used very effectively for analyzing logistics and supply chain issues. Spreadsheet allow analysis from many different perspectives and can be modified and enhanced to reflect new situations and options. The methodology used for developing integrated spreadsheet models is similar to modeling with specialized software. The modeler develops a baseline model reflecting current operations, creates alternative scenarios and compares those scenarios to the baseline. Non-quantifiable factors and soft costs are also considered to develop a complete analysis. Using spreadsheet and its' add-in tools, the modeler can analyze the impact of business decisions on any number of variables such as logistics strategies, flow planning, inventory control, allocation and aggregate planning and network design and planning.

Our purpose in this article is to demonstrate the efficiency of a problemsolving algorithm that uses Microsoft Excel Solver and the readily available add-in tools Premium Solver Platform for Microsoft Excel<sup>®</sup>. We selected Microsoft Excel because it is well known and widely used. Premium Solver Platform may be purchased from Frontline Systems Inc. at a higher cost or can be downloaded from the website of <http://www.solver.com/> for a trial version (limited to 15 days), the latest Platform Solver Engines is version 8.2. This version includes an Evolutionary Solver, based on genetic or evolutionary algorithms, that finds “good” solutions to any Excel model, even those with functions such as IF(), CHOOSE(), and VLOOKUP(), which cause

difficulty for the standard Excel Solver (it comes from the standard Microsoft Excel package).

## II. TRAVELING SALESMAN PROBLEMS

The Traveling Salesman Problems (TSP) is stated as follows: *given a finite number of “cities” along with the cost or the distance of travel between each pair of them, find the cheapest or shortest way of visiting all the cities and returning to the starting point* [1]. The TSP is historically known and related mathematical problems were treated in the 1800s by the Irish mathematician Sir William Rowan Hamilton and by the British mathematician Thomas Penyngton Kirkman. There are applications of the TSP in many branches of science (genoma project, robotics, electronic circuits, logistics problems, etc), which constitutes an attractive area for a diversity of researchers. Since its formulation many studies and algorithms have been developed in order to solve the TSP. However, the TSP is classified as a NP-Complete problem (i.e., class of problems that unless P=NP, there is no polynomial time algorithm able to solve them), which requires great computational efforts to achieve a solution via an exact algorithm (specially when the number of “cities” grows). Thus, many heuristic methods have been developed in order to achieve a sub-optimal solution to the problem.

There are two forms of TSP, which are of interest: the Euclidean Traveling Salesman Problems (ETSP) and the Random Link Traveling Salesman Problems (RLTSP). In the ETSP, the  $n$  cities are distributed with uniform randomness in a  $d$ -dimensional hypercube and the distance is measured in the Euclidean metric (with  $\Delta l = \sqrt{\Delta x^2 + \Delta y^2}$ ), whereas in the random link TSP, the distances between the cities  $i$  and  $j$  are taken as independent random variables with a given distribution. It was noted that the random link TSP can be mapped onto the Euclidean model, provided the distribution is chosen appropriately and the correlations between three or more distances are neglected [2].

In the Euclidean TSP model, the question of which order to visit the cities can be resolved by consideration of a collection of yes-no decisions posed in the following form: Should city  $j$  (the coordinates is  $(x_j, y_j)$ ) be visited immediately after city  $i$  (the coordinates is  $(x_i, y_i)$ )? If the answer is yes, then city  $j$  will immediately follow city  $i$

in a tour and cost  $c_{ij}$  ( $c_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ ) will be incurred, If no, then city  $i$  should be immediately followed by some city other than  $j$ . Given  $n$  cities, there are  $n^2$  unique yes-no questions of this form. A feasible tour results from precisely  $n$  yes answers in such a way that each city is entered and exited once in a single continuous tour. In a single continuous tour, every city is visited immediately after another, that is to say, every city has only one city has been visited and one city to be visited. As the city  $i$ , if the arc of city has been visited to city  $i$  is Line-in, and The arc of city  $i$  to the city to be visited is Line-out, we find that every city has only one Line-in and Line-out (as shown in Fig. 1), this is very important in the algorithm of Excel Solver for the ETSP

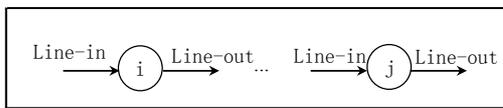


Figure 1. Line-in and Line-out of the city

A mathematical formulation of the problem makes this notion of a related collection of decisions precise. the TSP may be stated as an integer program of the following form [3]:

$$\min z = \sum_{i=1}^n \sum_{j=1}^n c_{ij} x_{ij} \quad (1)$$

$$s.t. \quad \sum_{i=1}^n x_{ij} = 1, \quad j = 1, 2, \dots, n \quad (2)$$

$$\sum_{j=1}^n x_{ij} = 1, \quad i = 1, 2, \dots, n \quad (3)$$

$$x_{ij} = 0, 1, \quad i, j = 1, 2, \dots, n \quad (4)$$

A feasible solution to Eqs. 1 to 4 consists of a single directed cycle that covers (visits) all the cities, that is, a Hamiltonian cycle. There are  $(n - 1)!$  feasible solutions. In a solution, travel occurs from city  $i$  to  $j$ ,  $x_{ij} = 1$ , and cost  $c_{ij}$  is incurred; otherwise  $x_{ij} = 0$ . An optimal solution is a minimum-distance Hamiltonian cycle[4,5].

Eqs. 1 to 4 are the classic Assignment Problem (AP) formulation for TSP. A solution to the AP may be interpreted as precisely  $n$  yes answers in such a way that every city is exited and entered exactly once, but it does not necessarily imply a single continuous tour [6]. An optimal assignment solution maybe have many subtours. Fig. 2 is an example cost matrix for optimal AP solution. An optimal assignment (distance=79) and optimal tour (distance=83) are shown in the boxes. From Fig. 2, we found three subtours in the optimal assignment solution.

Eqs. 1 to 4 are sufficient conditions not necessary conditions to the TSP. Xie and Xue added an additional constraints to avoid subtours as shown in Eqs. 5 [7].

$$u_i - u_j + nx_{ij} \leq n - 1, \quad 2 \leq i \neq j \leq n \quad (5)$$

$$u_i \geq 0, \quad i = 2, 3, \dots, n \quad (6)$$

$u_i$  is the tour sequence of city  $i$ , in Fig. 2, if we travel from City1, the tour sequence of City5 is 3 and City2 is 5.

Xie and Xue proved that any solution include subtours do not meet the constraints and a single continuous tour is bound to meet the constraints [7]. So the TSP problem converte to mixed integer linear programming problem:

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

$$s.t. \quad \sum_{i=1}^n x_{ij} = 1, \quad j = 1, 2, \dots, n$$

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

$$u_i - u_j + nx_{ij} \leq n - 1, \quad 2 \leq i \neq j \leq n$$

$$x_{ij} = 0, 1, \quad i, j = 1, 2, \dots, n$$

$$u_i \geq 0, \quad i = 2, 3, \dots, n$$

Incidentally, when the larger number of cities (more than 30), solving the mixed integer linear programming will have great difficulty. In the following sections, we will solve the small-size TSP problems based on this algorithm using Microsoft Excel add-in tools Solver and Premium Solver Platform.

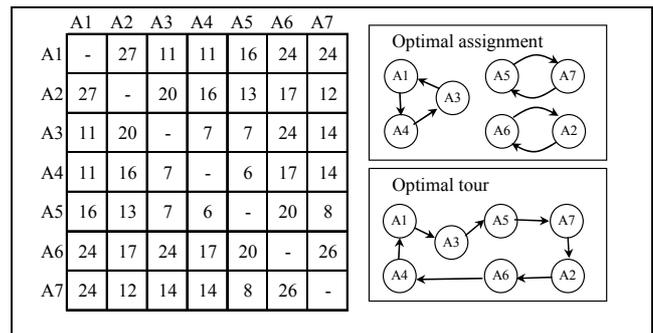


Figure 2. Optimal AP solution and TSP solution

### III. AN ALGORITHM FOR USING MICROSOFT EXCEL SOLVER FOR THE ETSP

Mike C. Patterson and Bob Harmel illustrated a solution approach which efficiently solved small TSP problems using Microsoft Excel Solver [8], two years later, they improved the approach and solved large scale TSP problems using Premium Solver Platform [9]. The objective of this paper is to present an alternative approach to solving bath small and large-scale Euclidean Traveling Salesman Problems using Microsoft Excel Solver and Premium Solver Platform, which is an optimization add-in tool for Microsoft Excel.

A small example problem of ETSP are shown in Tab. I. The X-coordinates and Y-coordinates which could be the longitude and latitude of the cities obtained form the GIS software like Mapinfo are randomly selected. This example will be solved by Microsoft Excel Solver or by Premium Solver Platform in the next two sections.

The Solver add-in tool is located under the Tools icon in Excel. If it is not available, it will need to be added from the custom install program for Excel. Solver was

developed for Microsoft by Frontline Systems Inc., which also developed similar add-ins for Lotus 123 and QuatroPro. The Web page maintained by Frontline (<http://www.solver.com/>) provides useful information regarding the use of optimization and the availability of more powerful versions of Solver.

TABLE I.  
THE COORDINATES OF THE CITIES

City	X-coordinates	Y-coordinates
City1	25.47	4.67
City2	5.55	22.47
City3	14.95	4.71
City4	16.62	11.57
City5	10.49	10.71
City6	21.34	27.95
City7	2.58	10.65

To define an optimization model in Excel Solver for the ETSP, one can follow these essential steps, The definitions and descriptions or the formulas in Excel mentioned in step 1 are shown in Fig. 3 and Tab. II.

A. Step 1: Creating an Excel Worksheet

(1) Create an Euclidean mileage spreadsheets. These spreadsheets should be based on the typical ETSP as defined in Tab. I and contain the mileage matrix of each cities in the problem. In Fig. 3, Cell Q2 is an array

formula, the Excel formula of Q2 is: =TRANSPOSE(N6:P13), we can select the cells Q2:X4 and press Ctrl + Shift + Enter to enter the array formula. Cell R7 is the Euclidean distance of City1 to City1, the Excel formula of R7 is: =SQRT((S07-R\$3)^2+(S\$7-R\$4)^2), we can fill series from cell R7 to cell X13, R7:X13 is the Euclidean mileage matrix of city *i* to city *j*.

(2) Create a From/To table. According to the mileage matrix R7:X13, we create From/To table as shown in cells B6:D48.

(3) Calculate the Line-in and Line-out of each city. Cell J7 is the Line-in of the City1, the Excel formula of J7 is: =SUMIF(\$B\$7:\$B\$48,G7,\$E\$7:\$E\$48), Cell K7 is the Line-out of the City1, the Excel formula of K7 is: =SUMIF(\$C\$7:\$C\$48,G7,\$E\$7:\$E\$48), both cell J7 and K7 should be filled series to cell J13 and K13.

(4) Create the subtour constraints. Cell L13 is the subtour constraints, the Excel formula of L13 is: =VLOOKUP(B14,\$G\$7:\$H\$13,2,FALSE) - VLOOKUP(C14,\$G\$7:\$H\$13, 2, FALSE) + 7\*E14, cell L13 should be filled series to cell L48.

(5) Define the distance of the tour. In this example, the distance of the tour is defined in cell J16. Cell J16 is the sum of the product of D7:D48 (matrix) times E7:E48, the Excel formula of J16 is: =SUMPRODUCT(D7:D48, E7:E48).

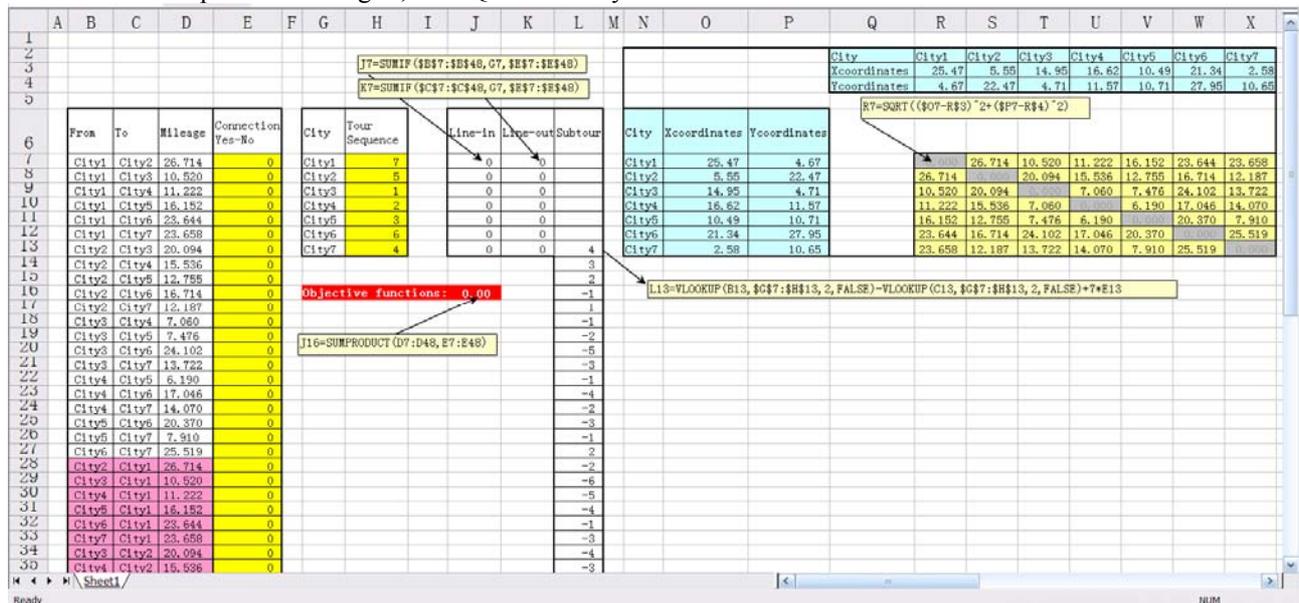


Figure 3. The simulator dashboard for Excel Solver to ETSP

B. Step 2: Using the Solver Dialogs

(1) Running the Macro Solver Add-in tool. If the Macro Solver Add-in tool is not running, we can execute the Macro by choosing “tool/Add-Ins”, and select the “Solver Add-in” to run Macro Solver.

(2) Define the objective. This is executed by choosing “Tools/Solver”, “Set Target Cell.” The cell in this example is J16.

(3) Define the cells to change. This is done by identifying the cells in “By Changing Cells.” The cells in

this example are the tour connection (cells \$E\$7:\$E\$48) and tour sequence (cells \$H\$7:\$H\$13).

(4) Define the constraints. This is done in the Solver section “Subject to Constraints.” When defining the constraints, one should refer to the linear programming section.

(5) Format the cells. Format the cells E7:E48 and H7:H13 to be numbers with 0 decimal points. Extensive testing with Solver indicates that even if the values are defined as integers, Solver will frequently provide very small non-integer values such as 2.34444E-14. To force

the spreadsheet to provide only 0 or 1 or integer, format these cells as numbers with no decimals.

(6) *Select the appropriate options for Solver.* Select “Assume Linear Model.”

Fig. 4 shows the objective and constraint definition to the ETSP problem in the Excel Solver.

TABLE II.  
EXCEL SOLVER FORMULATION OF ETSP

Definitions	Cell(s)	Descriptions or Formulas in Excel	Remarks
Variables	E7:E48	One indicate connect and Zero indicate not connect	Tour connection
	H7:H13	Tour sequence	Integer
Constraints	E7:E48	Zero-one	One indicate connect and Zero indicate not connect
	H7:H13	Integer	Tour sequence
	J7	=SUMIF(\$B\$7:\$B\$48,G7,\$E\$7:\$E\$48)	Line-in: fill series to cell J13
	K7	=SUMIF(\$C\$7:\$C\$48,G7,\$E\$7:\$E\$48)	Line-out: fill series to cell K13
	L13	=VLOOKUP(B13,\$G\$7:\$H\$13,2,FALSE)-VLOOKUP(C13,\$G\$7:\$H\$13,2,FALSE)+7*E13	Subtour constraints: fill series to cell L48
Coordinates transpose	Q2	{=TRANSPOSE(N6:P13)}	Array formula: select the cells Q2:X4 and press Ctrl + Shift + Enter
Mileage matrix	R7	=SQRT((S07-R\$3)^2+(SP7-R\$4)^2)	Fill series to cell X13
Objective functions	J16	=SUMPRODUCT(D7:D48,E7:E48)	The distance of the tour

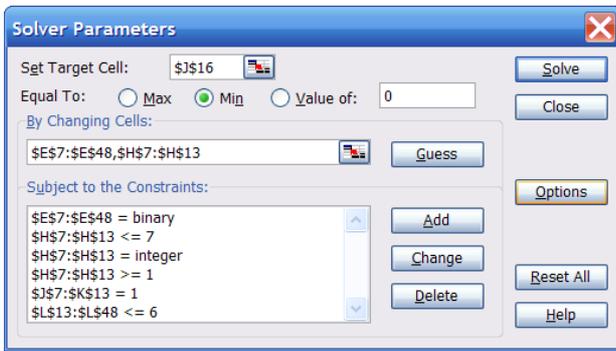


Figure 4. Excel Solver Parameters

TABLE III.  
THE SOLUTION TO ETSP IN EXCEL SOLVER

From	To	Distance	Connection(Yes-No)
City1	City4	11.22197	1
City2	City7	12.18742	1
City4	City6	17.04649	1
City3	City1	10.52008	1
City6	City2	16.7139	1
City5	City3	7.476068	1
City7	City5	7.910228	1

TABLE IV.  
THE TOUR SEQUENCE TO ETSP IN EXCEL SOLVER

City	Sequence
City1	7
City2	3
City3	6
City4	1
City5	5
City6	2
City7	4

C. Step 3: Finding and Using the Solution

Select “Solve.” When the solution is found, the following option is shown: “Keep Solver Solution,” which saves the final solution; “Return Original Values,” which restores the original values to spreadsheet. The solution is shown in Tab. III and IV, the tour sequence is City4→ City6→ City2→ City7→ City5→ City3→ City1→ City4 (as shown in Fig. 5), the distance of the tour is 83.08.

IV. AN ALGORITHM FOR USING PREMIUM SOLVER PLATFORM FOR THE ETSP

The standard Solver add-in is limited in the size of model that it can solve. When we attempted to use this algorithm for problems involving more than 13 cities, we observed an error message, indicating that the problem was too large for Solver. Frontline Systems Inc. offers commercial versions of the software Premium Solver Platform that are capable of solving larger problems.

To define an optimization model in Premium Solver Platform for the ETSP, one can follow these essential steps:

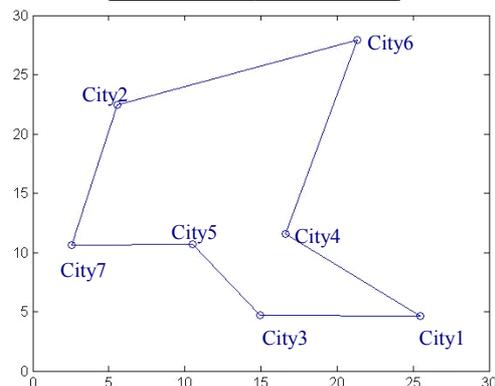


Figure 5. Optimal solution to ETSP in Excel Solver

**A. Step 1: Creating an Excel Worksheet**

**(1) Create an Euclidean mileage matrix spreadsheets.**

The first step in formulating the TSP problem using Premium Solver Platform is to develop the direct mileage matrix. Using the X-coordinates and Y-coordinates of the cities from Tab. I. Cell I2 is an array formula, the Excel formula of I2 is: =TRANSPOSE(F6:H13), we can select the cells I2:P4 and press Ctrl + Shift + Enter to enter the array formula. Cell J7 is the Euclidean distance of City1 to City1, the Excel formula of J7 is: =SQRT((\$G7-J\$3)^2+(H7-J\$4)^2), we can fill series cell J7 to cell P13, J7:P13 is the Euclidean mileage matrix of city *i* to city *j*.

**(2) Define the tour Sequence.** Cells B7:B13 initially contain integer values 1 to 7. Upon completion of the final solution, these cells will contain the integer values associated with cities and will define the final sequence for the tour. Cell B14 assures that the final solution tour returns to the city where the tour began, the Excel formula of B14 is: =B7.

**(3) Find the tour city.** Cells C7 use the Excel function VLOOKUP() to find the name of the city associated with the integer values (1-7), the Excel formula of C7 is: =VLOOKUP(B7,\$E\$7:\$F\$13,2), we can fill series cell from C7 to cell C14.

**(4) Find the mileage of each step of the tour.** Cells D8 use the Excel function INDEX() to find the mileage from one city to the next. This instruction finds the associated mileage from the mileage matrix from the city associated with the integer value in cell B(N) to the next city B(N+1). For example, initially cell D8 will hold the distance (26.714) from the city associated with integer 1 (City1) to the city associated with integer 2 (City2).

**(5) Define the distance of the tour.** In this example, the distance of the tour is defined in cell D15. Cell D15 is the sum of the cells D8:D14, the Excel formula of D15 is: =SUM(D8:D14).

The definitions and descriptions or the formulas in Excel mentioned above are shown in Fig. 6 and Tab. V.

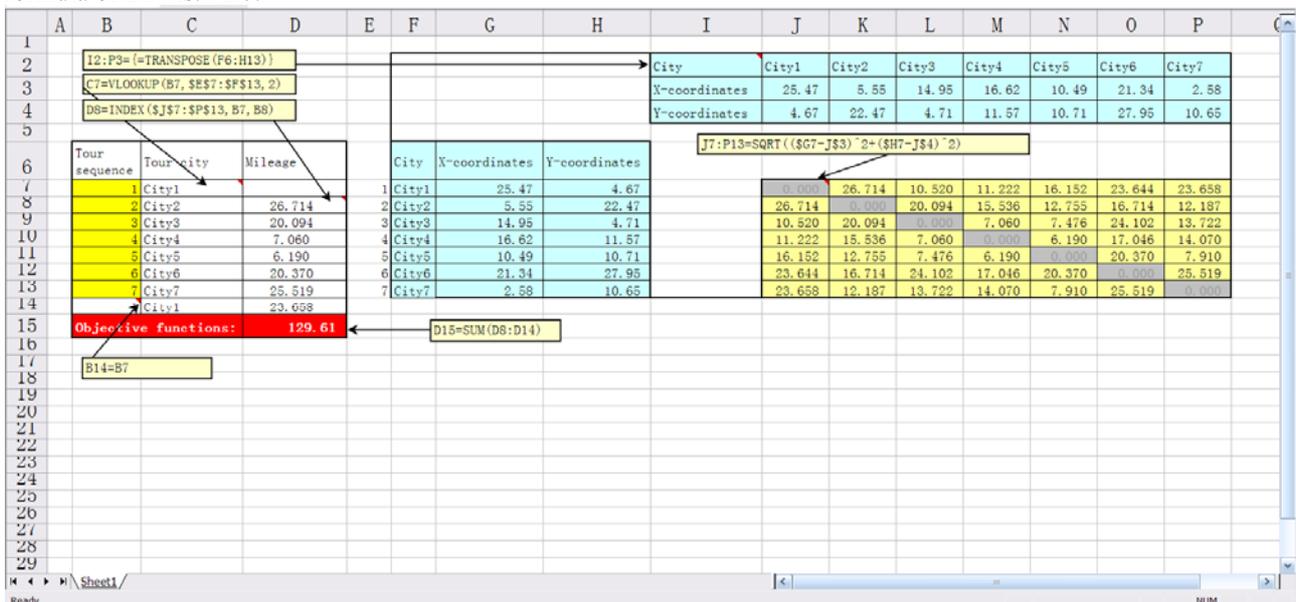


Figure 6. The simulator dashboard for Premium Solver Platform to ETSP

TABLE V.  
PREMIUM SOLVER PLATFORM FORMULATION TO ETSP

Definitions	Cell(s)	Descriptions or Formulas in Excel	Remarks
Variables	B7:B13	Tour sequence	Integer all different
Coordinates transpose	I2	{=TRANSPOSE(F6:H13)}	Array formula: select the cells I2:P3 and press Ctrl + Shift + Enter
Mileage matrix	J7	=SQRT((\$G7-J\$3)^2+(H7-J\$4)^2)	Fill series to cell P13
Tour city	C7	=VLOOKUP(B7,\$E\$7:\$F\$13,2)	Fill series to cell C14
Distance	D8	=INDEX(\$J\$7:\$P\$13,B7,B8)	Fill series to cell D14
Objective functions	D15	=SUM(D8:D14)	The distance of the tour

**B. Step 2: Using the Solver Dialogs**

**(1) Define the objective.** This is executed by choosing “Tools/Solver”, the “Set Cell” parameter defines the spreadsheet cell which we wish to optimize. In this example we wish to minimize Cell D15, which holds the total distance of the tour.

**(2) Define the cells to change.** This is done by identifying the cells in “By Changing Variable Cells.” The “By Changing Variable Cells” parameter defines the cells which we wish to change, in order to minimize the total distance. In this example, these are cells B7:B13, which hold the integer values assigned to the seven cities.

(3) *Define the constraints.* The “Subject to the Constraints” declares that the values in cells B7:B13 will be “all different”, this option which is currently only available with Premium Solver Platform, defines that the integer values will all be different. Thus, there will be only one entry and one exit to each city, and the tour will conclude where it began.

(4) *Select the model.* Select the appropriate options for Solver. We select “Standard Evolutionary” model.

Fig. 7 shows the objective and constraint definition to the ETSP problem in the Premium Solver Platform.

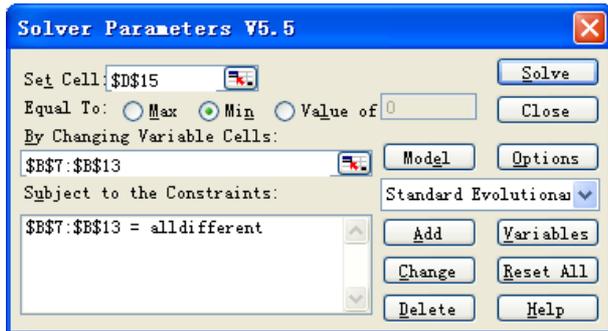


Figure 7. Premium Solver Platform Parameters

C. Step 3: Finding and Using the Solution

(1) *Modify the Solver parameters.* In order to test the model development approach outlined in this paper, other problems were formulated and solved. In all cases, even those that were relatively large, model development time was minimal. For large problems, some Solver parameters need to be modified. Suggested modifications, which are made by selecting Options and Limit Options, are intended to prevent the calculations from ending prematurely. A summary of the modifications is shown in Tab. VI.

TABLE VI. A SUMMARY OF THE MODIFICATIONS IN PREMIUM SOLVER PLATFORM

Solver Parameters		Suggested modifications
General	Max Time	1,000,000
	Iterations	1,000,000
	Precision	0.00000001
	Convergence	0.00000001
	Population Size	100
	Mutation Rate	0.075
Integer	Max Subproblems	1,000,000,000
	Max Feasible Solutions	1,000,000,000
	Tolerance	0
	Max Time w/o Improvement	10,000

(2) *Solve the ETSP.* The Standard Evolutionary option is appropriate for a ETSP problem. Once the model is defined, one should select Solve. The complete solution spreadsheet is shown in Tab. VII, the tour sequence is City1→ City3→ City5→ City7→ City2→ City6→ City4→ City1, the distance of the tour is as same as the distance found in Excel Solver (83.08).

TABLE VII. THE TOUR SEQUENCE TO ETSP IN PREMIUM SOLVER PLATFORM

Tour sequence	Tour city
1	City1
3	City3
5	City5
7	City7
2	City2
6	City6
4	City4
1	City1

In addition to the above changes, one will need to execute multiple runs of the same problem to increase the probability of finding the optimal solution. The evolutionary solver is designed to find feasible, good and optimal solutions. While the evolutionary solver, which is based on genetic algorithms, is designed to find optimal solutions-ideally the global optimal, this is not always possible. Multiple runs for large problems, with the parameter changes discussed above, will likely yield the optimal solution.

V. ILLUSTRATIVE EXAMPLES OF USING PREMIUM SOLVER PLATFORM FOR SMALL-SIZE ETSP

The Premium Solver Platform handles linear programming, integer programming, and quadratic programming (for investment portfolio optimization) problems up to 2,000 variables (standard Solver up to 200 variables); nonlinear and global optimization problems with improved GRG, multistart, and new Interval Global Solvers; and arbitrary Excel models with an Evolutionary Solver based on genetic algorithms [10]. This powerful feature has dramatically simplified the formulation of the Traveling Salesman Problems.

A typical optimal tour is shown for 50 and 100 “cities” for 2 dimensions (as shown in Fig. 8 (a) and (b)). The cities are represented by the dots and the optimal tour is indicated using a solid line, similarly, a typical optimal tour is shown for 50 and 100 “cities” for 3 dimensions (as shown in Fig. 9 (a) and (b)). The cities are represented by the dots and the optimal tour is indicated using a solid line.

Another example is used in logistics coporation. Some logistics managers in the corporations like Hangzhou Tobacco, ANNTO, TRANSFOR and BADA in Zhejiang province of P.R. China. use this algorithm to help them to make decisions. If we have the longitude and latitude of the cities obtained form the GIS software like Mapinfo, we can easily use the algorithm to calculate the shortest tour for the vehicle.

In ANNTO logistics corporation, logistics managers established an original solution of 140 cities TSP by experience (see Fig. 10), the total distance of the tour is 21,014 Kms. After they use this algorithms mentioned in this paper, they found a better solution (see Fig. 11). In this solution, the total distance of the tour is 20,055 Kms, ANNTO uses 10 vehicles in this Milk-Run and save more than 5% cost to its primal solution.

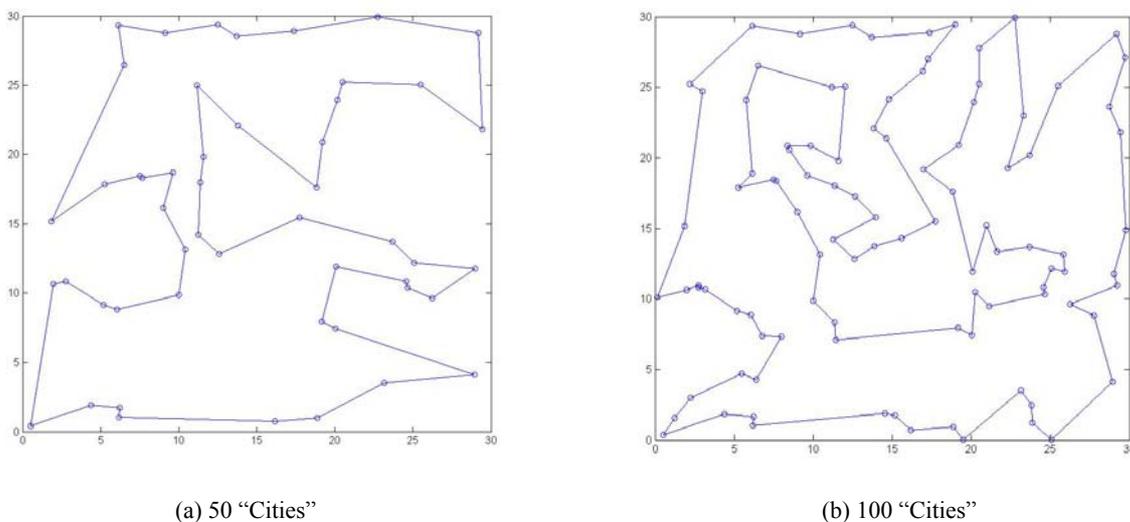


Figure 8. A typical optimal tour for 2 dimensions

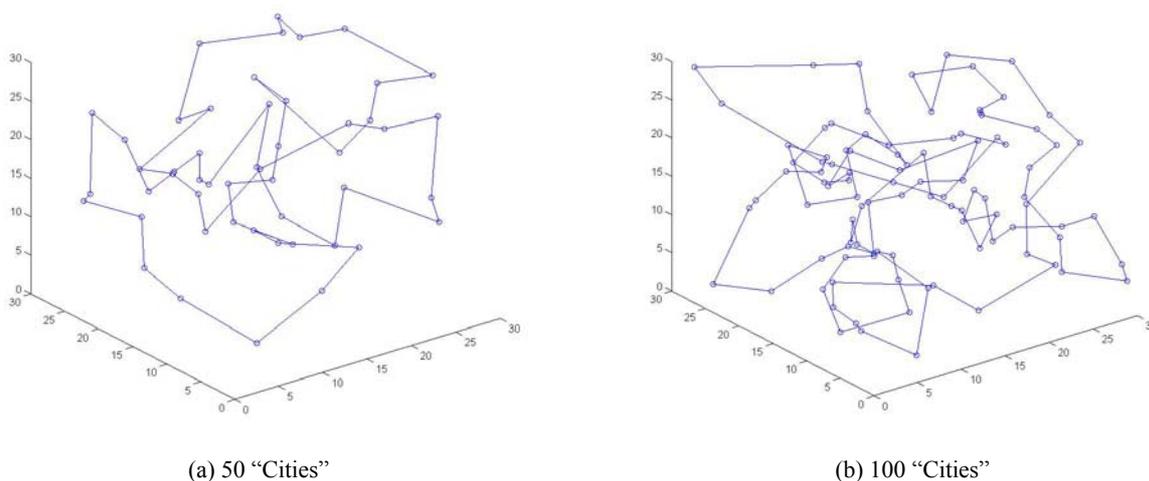


Figure 9. A typical optimal tour for 3 dimensions

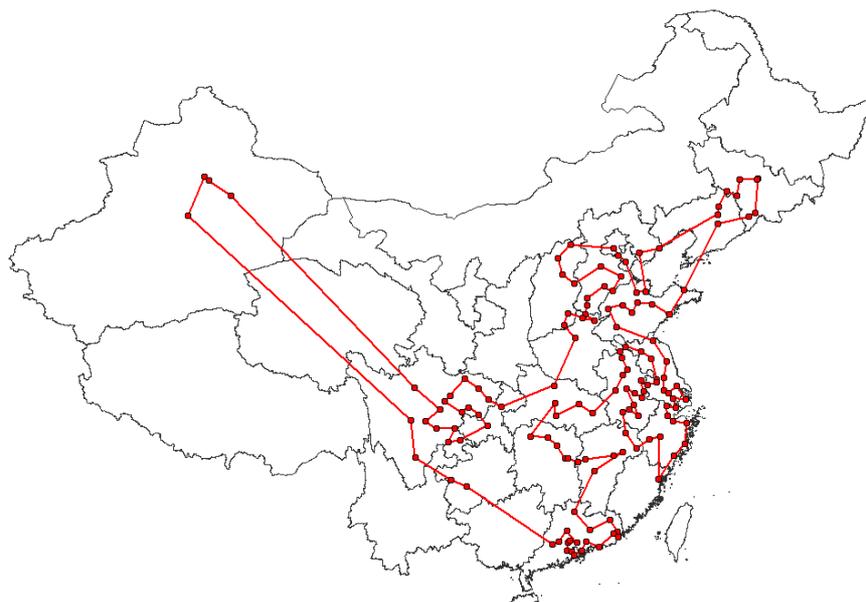


Figure 10. The original solution of 140 cities TSP by experience in ANNTTO corporation

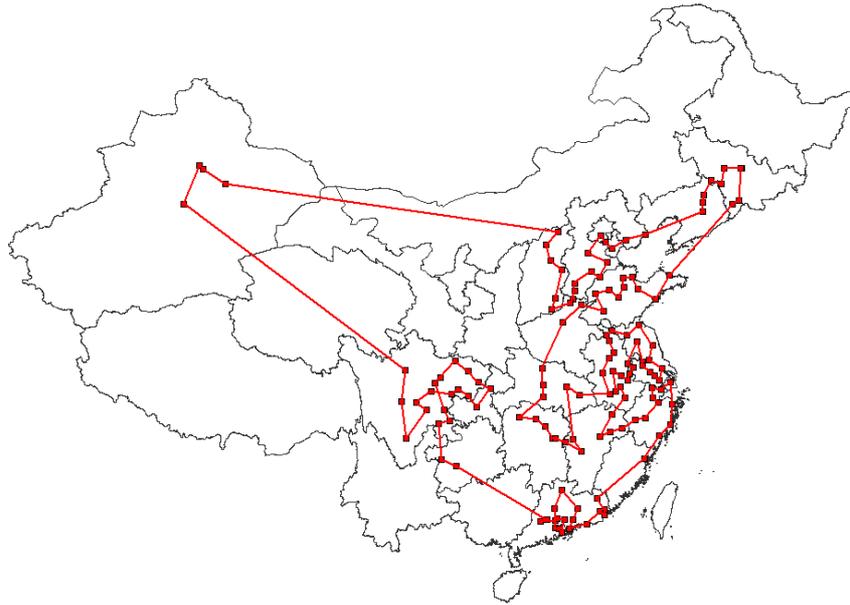


Figure 11. The optimal solution of 140 cities TSP Milk-Run solution for ANNTO corporation

## VI CONCLUSION

The Traveling Salesman Problem has been an important and popular operations research topic for decades. Numerous algorithms and computer programs have been developed by researchers attempting to more efficiently solve the problems. Significant advances have been made possible with the release of Premium Solver Platform, which includes the “alldifferent” constraint. This paper illustrates an efficient solution approach for the successful application of this powerful new software tool as this paper illustrates, the approach efficiently solves both small and large scale Traveling Salesman Problems. Premium Solver Platform should increase the accessibility of Traveling Salesman applications and further advance the development of real world models.

## ACKNOWLEDGMENT

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