

The Traveling NET Trainer Problem

Methods for Optimizing New Equipment Training Travel Costs

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Thanks to
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Stephen Cox, UAH



Army LCCE Structure

The screenshot displays the ACE 7.0 software interface. The main window shows a table with columns for WBS/Item Number, WBS Indent, Approp, Expansion Available, Model, Service, Theater, MDEP, Key Unit Cost Category, PME Matrix, and nine Category columns (1-9). The table lists various WBS items, with item 17, 'NEW EQUIP TRAINING (NET)', highlighted in orange.

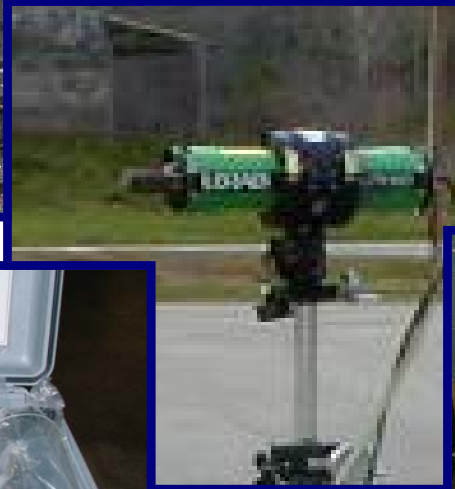
An inset window titled 'ACE 7.0 - [Session1 - WBS Definition (ID: PROCNET)]' is open over the table. It shows a rich text editor with the following text:

NEW EQUIPMENT TRAINING (NET)

This element includes the system-specific, procurement-funded costs of training services for new equipment training through which personnel will acquire sufficient concepts, skills, and aptitudes to operate and maintain the system with maximum efficiency. It includes the costs for TDY of Government personnel, of training initial-service test crews, maintenance personnel, instructors, initial crew, maintenance personnel and NET teams, as well as the one-time cost of establishing system-specific individual training programs, including all services and manuals. It excludes the costs of replacement training.

The inset window also shows a menu bar (File, Edit, View, Insert, Format, Tools, Window, Help), a toolbar with various icons, and a status bar at the bottom that reads 'Ready'.

Representative / Notional Systems



The Problem

- We need to send a team to a specified number of locations to perform New Equipment Training (NET)
- Locations are both in the Continental United States (CONUS) and Outside the Continental United States (OCONUS)
- How can the travel costs be optimized using common tools such as Microsoft Excel?
 - Travel costs include airfare, per diem, rental car and lodging

Original Estimating Method

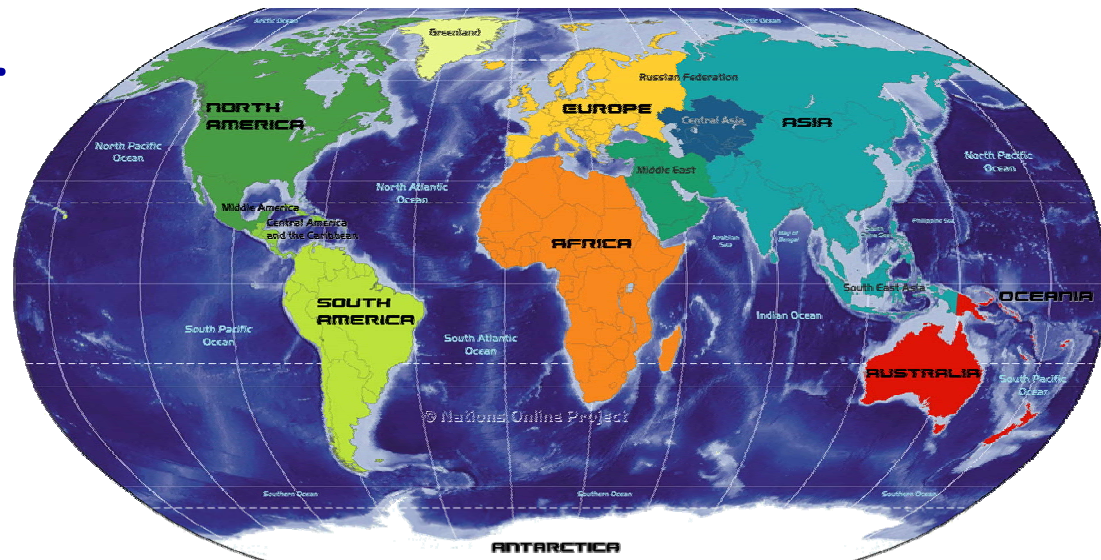
- Status Quo - Use the Mean
 - Estimate cost to travel from Huntsville, AL to each training location
 - NET training is one(1), two(2), or three(3) days
 - We assumed 2 person team, 2 travel days, 2 training days
 - If possible, travel only on week days
 - Always start travel from Huntsville, AL
 - Average CONUS travel cost
 - Average OCONUS travel cost



Travel Zone Method

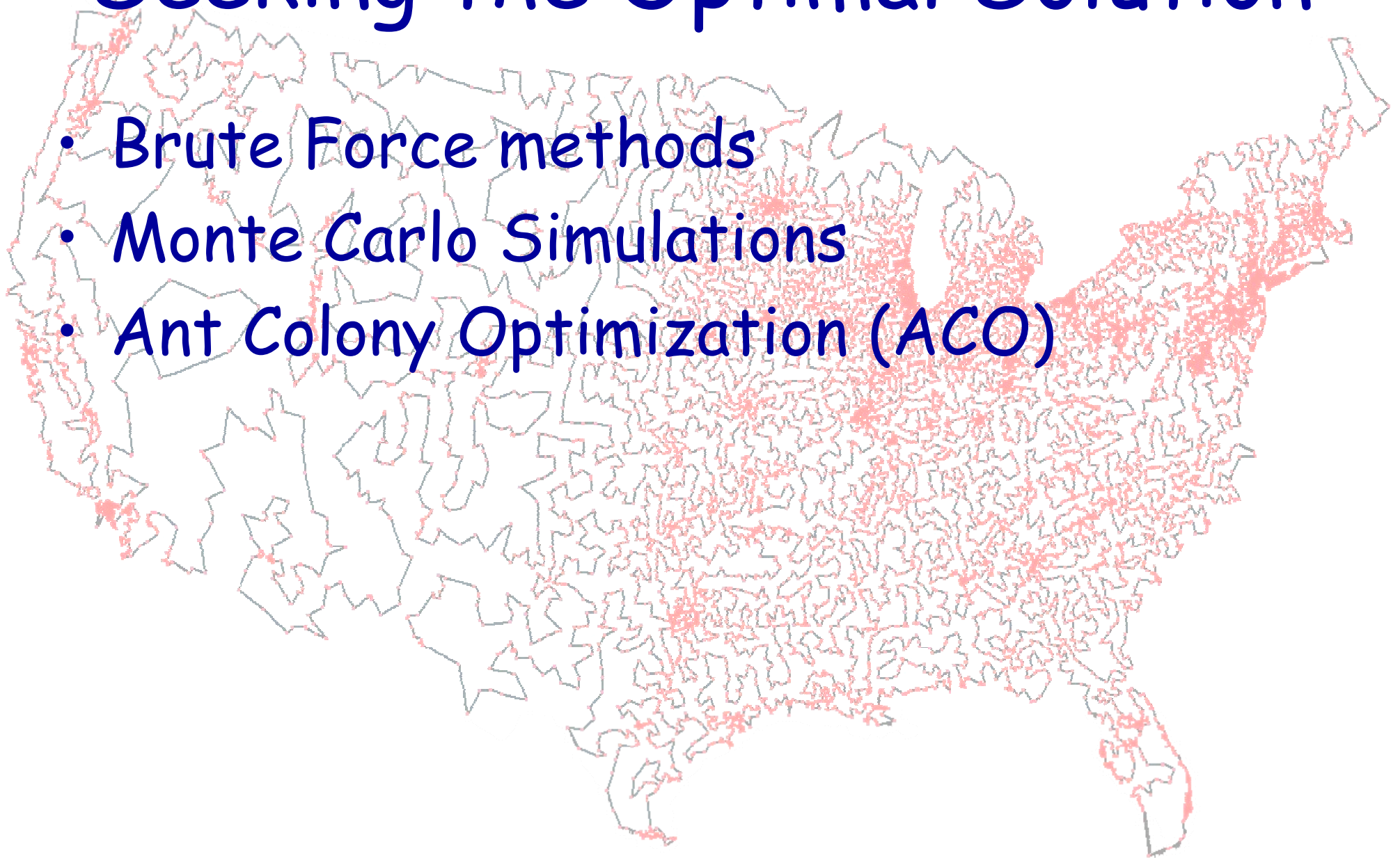
- Travel zones are based on neighboring training locations
- Travel to two(2) or three(3) locations in one trip, travel back to Huntsville, repeat until all locations have been visited

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
		# Trainers	# Travel Days	# Training Days	Lodging	Full Per Diem	First & Last Day Per Diem	Air Fare to/from LOCATION X	Air fare between training	Airline Fees	Rental Car - 1 day	Rental Car - per week	Cost of Fuel	Total
1														
2	LOCATION A	2	2	2	\$107.00	\$54.00	\$40.50	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$144.00	\$1,164.00
3	LOCATION B	2	2	2	\$107.00	\$54.00	\$40.50	\$0.00	\$583.00	\$0.00	\$0.00	\$0.00	\$144.00	\$1,164.00
4	LOCATION C	2	2	2	\$97.00	\$44.00	\$33.00	\$448.00	\$0.00	\$0.00	\$63.49	\$174.49	\$48.00	\$2,983.96
5	LOCATION D	2	2	2	\$70.00	\$39.00	\$29.25	\$222.00	\$497.00	\$0.00	\$66.99	\$180.99	\$48.00	\$1,896.96
6	LOCATION E	2	2	2	\$70.00	\$39.00	\$29.25	\$429.60	\$0.00	\$0.00	\$44.49	\$159.49	\$48.00	\$2,637.86
7	LOCATION F	2	2	2	\$118.00	\$64.00	\$48.00	\$379.00	\$287.00	\$0.00	\$67.99	\$179.99	\$48.00	\$2,991.96
8	LOCATION G	2	2	2	\$177.00	\$112.00	\$84.00	\$1,138.00	\$350.00	\$0.00	\$61.49	\$245.49	\$48.00	\$6,691.96
9	LOCATION H	2	2	2	\$108.00	\$59.00	\$44.25	\$458.00	\$0.00	\$0.00	\$75.49	\$265.49	\$48.00	\$3,242.96
10	LOCATION J	2	2	2	\$149.00	\$64.00	\$48.00	\$276.00	\$440.00	\$0.00	\$70.49	\$318.49	\$48.00	\$2,775.96
11	LOCATION K	2	2	2	\$70.00	\$39.00	\$29.25	\$373.00	\$373.00	\$0.00	\$62.49	\$226.49	\$48.00	\$2,482.96
12	LOCATION L	2	2	2	\$159.00	\$84.00	\$48.00	\$385.00	\$385.00	\$0.00	\$66.49	\$259.49	\$48.00	\$3,255.96
13	LOCATION M	2	2	2	\$79.00	\$44.00	\$33.00	\$208.00	\$0.00	\$0.00	\$57.49	\$244.49	\$48.00	\$1,891.96
14	LOCATION N	2	2	2	\$121.00	\$64.00	\$48.00	\$413.00	\$391.00	\$0.00	\$73.49	\$250.99	\$48.00	\$3,167.96
15	LOCATION P	2	2	2	\$70.00	\$39.00	\$29.25	\$320.00	\$0.00	\$0.00	\$66.49	\$146.49	\$48.00	\$2,286.96
16	LOCATION Q	2	2	2	\$103.00	\$49.00	\$36.75	\$320.00	\$0.00	\$0.00	\$66.49	\$146.49	\$48.00	\$2,554.96
17	LOCATION R	2	2	2	\$97.00	\$54.00	\$40.50	\$171.00	\$0.00	\$0.00	\$72.49	\$174.49	\$48.00	\$1,981.96
18	LOCATION S	2	2	2	\$97.00	\$54.00	\$40.50	\$224.00	\$224.00	\$0.00	\$72.49	\$174.49	\$48.00	\$2,193.96
19	LOCATION T	2	2	2	\$87.00	\$44.00	\$33.00	\$558.00	\$0.00	\$0.00	\$62.49	\$197.49	\$48.00	\$3,359.96
20	LOCATION U	2	3	2	\$265.00	\$150.00	\$112.50	\$401.00	\$0.00	\$0.00	\$93.64	\$491.98	\$48.00	\$5,515.20
21	LOCATION W	2	3	2	\$230.00	\$120.00	\$90.00	\$739.00	\$0.00	\$0.00	\$66.09	\$366.14	\$48.00	\$6,194.45
22														
23	Region 1				\$ 5,786.88									
24	Region 2				\$ 3,676.34									
25	Region 3				\$ 7,679.76									
26	Region 4				\$ 8,109.32									
27	Region 5				\$ 5,629.34									
28	Region 6				\$ 5,313.92									
29	Region 7				\$ 8,088.32									
30	Region 8				\$ 5,524.40									
31														
32														
33	TOTAL				\$47,786.28									
34	MINIMUM COST Region				\$ 3,676.34									
35	MAXIMUM COST Region				\$ 8,109.32									
36	AVERAGE COST Region				\$ 5,973.29									



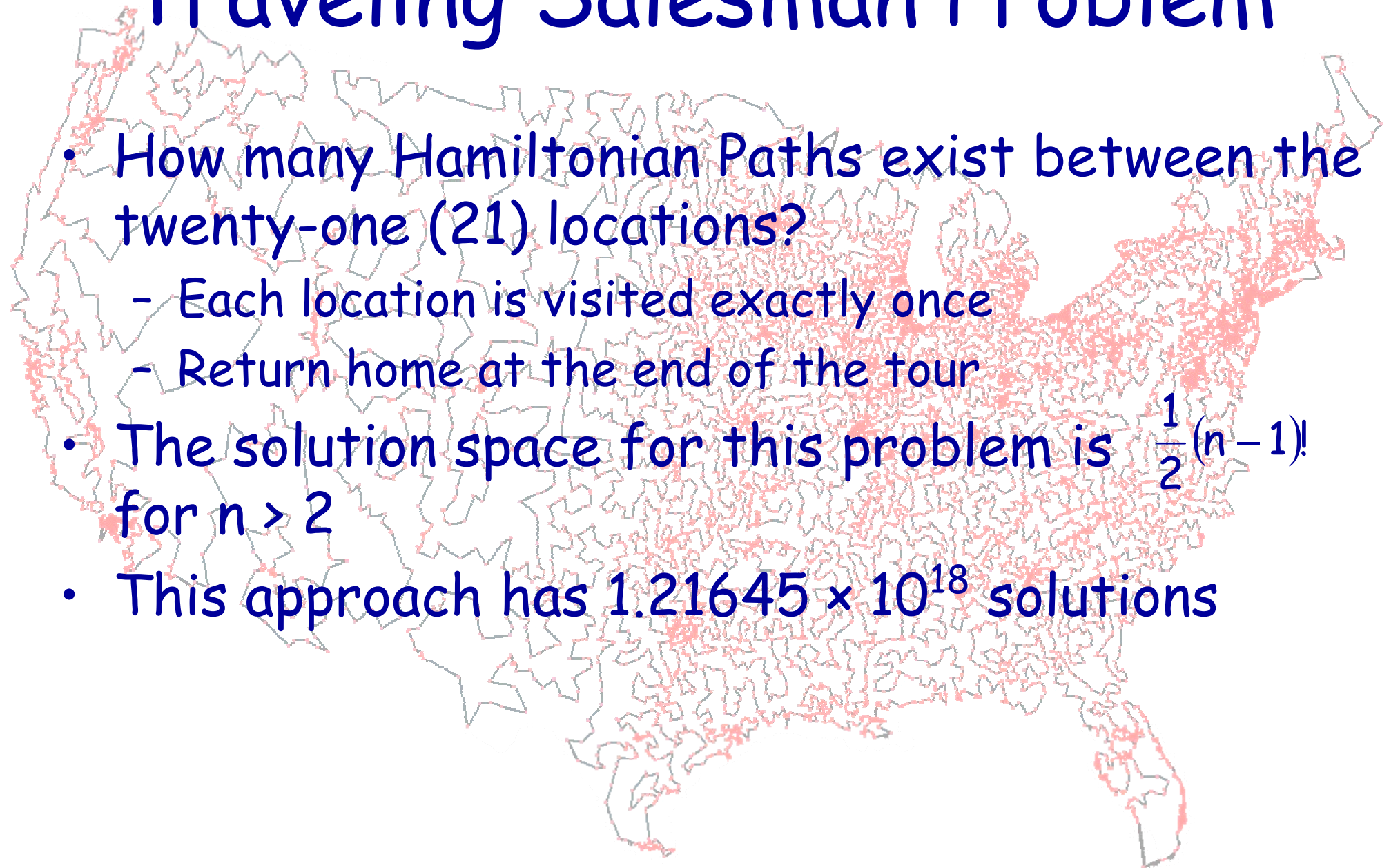
Seeking the Optimal Solution

- Brute Force methods
- Monte Carlo Simulations
- Ant Colony Optimization (ACO)



Traveling Salesman Problem

- How many Hamiltonian Paths exist between the twenty-one (21) locations?
 - Each location is visited exactly once
 - Return home at the end of the tour
- The solution space for this problem is $\frac{1}{2}(n-1)!$ for $n > 2$
- This approach has 1.21645×10^{18} solutions



TSP Background

- In 1962, Proctor and Gamble hosted a contest to solve the TSP for 33 cities
 - 54 \$1000 prizes
 - 1 \$10,000 prize
- The Traveling Salesman Problem website
 - <http://www.tsp.gatech.edu/>

HELP! WE'RE LOST!
HELP "CAR 54"... AND WIN CASH
54...\$1,000 PRIZES
ONE...\$10,000 GRAND PRIZE

Help Toody and Muldoon find the shortest round trip route to visit all 33 locations shown on the map. All you do is draw connecting straight lines from location to location to show the shortest round trip route.

HERE'S THE CORRECT START...
Begin at Chicago, Illinois. From there, lines show correct route as far as Erie, Pennsylvania. Next, do you go to Carlisle, Pennsylvania or Wana, West Virginia? Check the easy instructions on back of this entry blank for details.

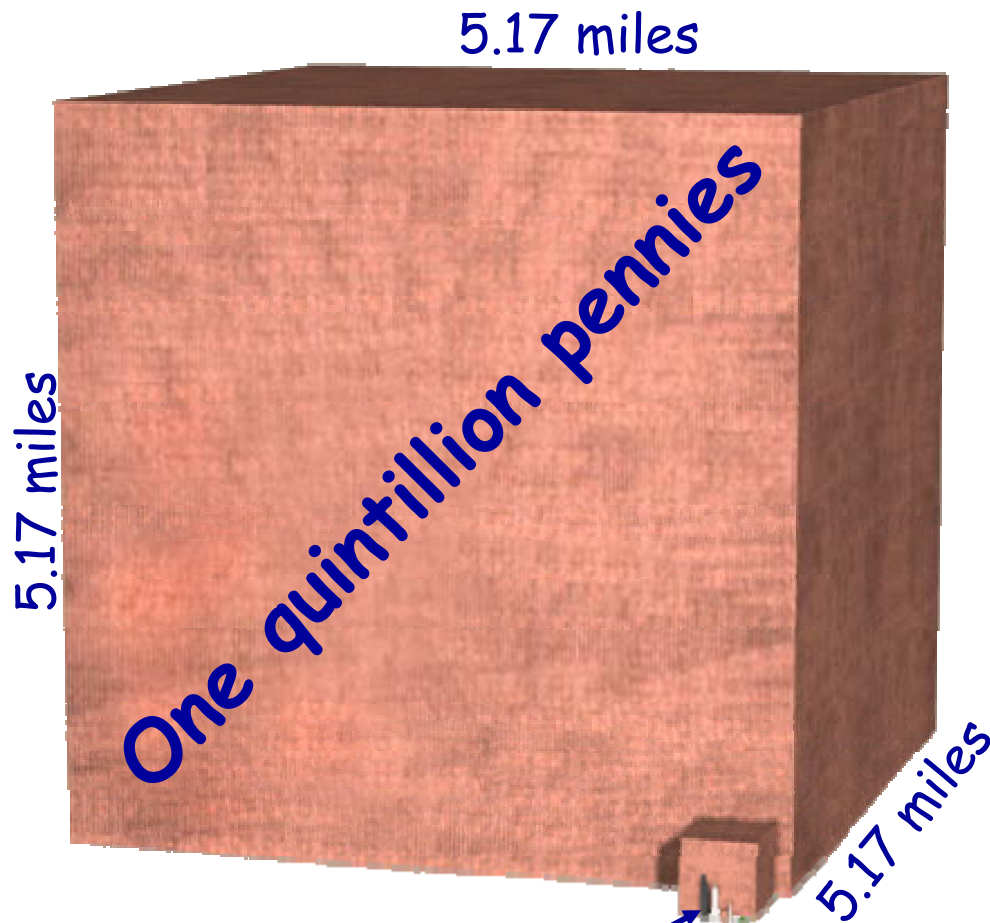
© PROCTOR & GAMBLE 1962

OFFICIAL RULES ON REVERSE SIDE

THE 8TH CIRCUIT AS TRAVELED BY MR. LINCOLN IN 1850

SCALE IN MILES

Solution Methods - Brute Force



The Sears Tower

- Brute Force Method

- Compute permutations throughout all twenty-one (21) locations

$$A \rightarrow B \rightarrow C \rightarrow D \neq D \rightarrow C \rightarrow B \rightarrow A$$

- Find the least of the solutions
- Solution set is $n!$
- In this method, the solution set would contain $21! = 51.0909422 \times 10^{18} = 51$ quintillion elements
- There are about 100 billion, or 10^{12} stars in the Milky Way Galaxy

Brute Force Solution

- An experienced programmer wrote a C program for this method
 - Spent 2 hours to understand problem and write code

Optimal Cost	Time to Optimal Cost	Total Time to Run*
\$43,755.88	1 hr 13 min 13 sec	2 days 20 hours (and counting)

Solution Methods - Monte Carlo Simulation

- ❖ There is no single Monte Carlo Method
 - ❖ Define data set
 - ❖ Perform repeated random sampling
 - ❖ Aggregate the results
- ❖ Monte Carlo Process for the Traveling Trainer
 - ❖ Collect cost data for traveling to all of the 21 locations
 - ❖ Carry out repeated random sampling on the data and calculate cost of each complete path
 - ❖ The algorithm runs for a specified number of iterations
 - ❖ Microsoft Excel and Visual Basic for Applications (VBA) were used to create this solution
 - ❖ Save the least cost and highest cost paths until a more optimal path is calculated

Monte Carlo Solution

	H	I	J	K	L	M	N
						LOCATION A	LOCATION B
			%	Y		1	2
	0.6047	LOCATION A	53.548	71.149		\$ -	\$ 2,991.96
	0.3845	LOCATION B	50.588	39.406		\$ 2,991.96	\$ -
	0.1164	LOCATION C	42.144	76.2		\$ 2,637.36	\$ 1,722.96
	0.0829	LOCATION D	112	168.379		\$ 5,515.20	\$ 5,358.56
	0.5132	LOCATION E	0	0		\$ 6,691.96	\$ 2,287.96
	0.6768	LOCATION F	74	71.65			
	0.6252	LOCATION G	71.24	63.188			
	0.4846	LOCATION H	61.456	70.35			
	0.2292	LOCATION J	65.08	284.703			
	0.2150	LOCATION K	72.008	81.192			
	0.4250	LOCATION L	94.76				
	0.4855	LOCATION M	69.884				
	0.1189	LOCATION N	77.256				
	0.0083	LOCATION P	91.212				
	0.0484	LOCATION Q	55.452				
	0.3972	LOCATION R	74.8036				
	0.9749	LOCATION S	58.8	11.281			
	0.7433	LOCATION T	35.928	60.058			

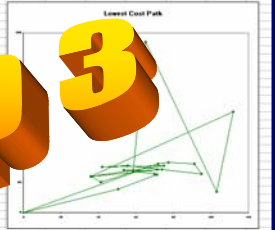
COST	
=VLOOKUP(B4,table_location_cost,HLOOKUP(B3,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B5,table_location_cost,HLOOKUP(B4,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B6,table_location_cost,HLOOKUP(B5,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B7,table_location_cost,HLOOKUP(B6,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B8,table_location_cost,HLOOKUP(B7,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B9,table_location_cost,HLOOKUP(B8,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B10,table_location_cost,HLOOKUP(B9,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B11,table_location_cost,HLOOKUP(B10,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B12,table_location_cost,HLOOKUP(B11,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B13,table_location_cost,HLOOKUP(B12,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B14,table_location_cost,HLOOKUP(B13,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B15,table_location_cost,HLOOKUP(B14,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B16,table_location_cost,HLOOKUP(B15,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B17,table_location_cost,HLOOKUP(B16,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B18,table_location_cost,HLOOKUP(B17,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B19,table_location_cost,HLOOKUP(B18,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B20,table_location_cost,HLOOKUP(B19,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B21,table_location_cost,HLOOKUP(B20,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B22,table_location_cost,HLOOKUP(B21,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B23,table_location_cost,HLOOKUP(B22,table_location_cost,2,FALSE)+4,FALSE)	
=VLOOKUP(B24,table_location_cost,HLOOKUP(B23,table_location_cost,2,FALSE)+4,FALSE)	

\$ -	\$ 2,991.96	\$ 2,637.36	\$ 5,515.20	\$ 6,691.96	\$ 2,287.96
\$ 2,991.96	\$ -	\$ 1,722.96	\$ 5,358.56	\$ 3,287.96	\$ 2,287.96
\$ 2,637.36	\$ 1,722.96	\$ -	\$ 4,618.56	\$ 6,579.96	\$ 2,287.96
\$ 5,515.20	\$ 5,358.56	\$ 4,618.56	\$ -	\$ 6,954.63	\$ 2,287.96
\$ 6,691.96	\$ 3,287.96	\$ 6,579.96	\$ 6,954.63	\$ -	\$ 2,287.96
\$ 2,983.96	\$ 2,191.96	\$ 2,771.96	\$ 2,631.96	\$ 2,615.63	\$ -
\$ 2,286.96	\$ 1,666.96	\$ 1,518.96	\$ 2,496.96	\$ 3,638.96	\$ 1,666.96
\$ 1,436.83	\$ 2,384.83	\$ 2,392.83	\$ 3,112.83	\$ 2,925.83	\$ 1,436.83
\$ 6,194.45	\$ 2,409.96	\$ 3,293.96	\$ 2,593.96	\$ 5,323.96	\$ 7,881.96
\$ 1,891.96	\$ 2,189.96	\$ 3,263.96	\$ 3,027.96	\$ 3,027.96	\$ 1,891.96
\$ 3,167.96	\$ 2,193.96	\$ 3,293.96	\$ 2,593.96	\$ 3,027.96	\$ 3,167.96
\$ 2,554.96	\$ 2,409.96	\$ 3,293.96	\$ 2,593.96	\$ 3,027.96	\$ 2,554.96
\$ 3,255.96	\$ 2,395.96	\$ 2,731.96	\$ 2,731.96	\$ 2,731.96	\$ 3,255.96
\$ 2,482.96	\$ 1,826.96	\$ 1,826.96	\$ 2,642.96	\$ 2,642.96	\$ 2,482.96
\$ 1,896.96	\$ 2,012.96	\$ 1,104.96	\$ 2,252.96	\$ 2,252.96	\$ 1,896.96
\$ 2,775.96	\$ 2,359.96	\$ 2,467.96	\$ 3,843.96	\$ 3,843.96	\$ 2,775.96
\$ 1,436.83	\$ 2,384.83	\$ 2,392.83	\$ 3,112.83	\$ 3,112.83	\$ 1,436.83
\$ 1,981.96	\$ 2,409.96	\$ 3,293.96	\$ 2,593.96	\$ 2,593.96	\$ 1,981.96
\$ 3,359.96	\$ 2,189.96	\$ 3,263.96	\$ 3,027.96	\$ 3,027.96	\$ 3,359.96
\$ 2,193.96	\$ 2,409.96	\$ 3,293.96	\$ 2,593.96	\$ 2,593.96	\$ 2,193.96
\$ 3,242.96	\$ 1,810.96	\$ 2,654.96	\$ 3,082.96	\$ 3,082.96	\$ 3,242.96

	H	I	J	K	L	M	N
LOCATION A	53.548	71.149	69.884	77.256	91.212	55.452	74.8036
LOCATION B	50.588	39.406	69.884	77.256	91.212	55.452	74.8036
LOCATION C	42.144	76.2	69.884	77.256	91.212	55.452	74.8036
LOCATION D	112	168.379	69.884	77.256	91.212	55.452	74.8036
LOCATION E	0	0	69.884	77.256	91.212	55.452	74.8036
LOCATION F	74	71.65	69.884	77.256	91.212	55.452	74.8036
LOCATION G	71.24	63.188	69.884	77.256	91.212	55.452	74.8036
LOCATION H	61.456	70.35	69.884	77.256	91.212	55.452	74.8036
LOCATION J	65.08	284.703	69.884	77.256	91.212	55.452	74.8036
LOCATION K	72.008	81.192	69.884	77.256	91.212	55.452	74.8036
LOCATION L	94.76		69.884	77.256	91.212	55.452	74.8036
LOCATION M	69.884		69.884	77.256	91.212	55.452	74.8036
LOCATION N	77.256		69.884	77.256	91.212	55.452	74.8036
LOCATION P	91.212		69.884	77.256	91.212	55.452	74.8036
LOCATION Q	55.452		69.884	77.256	91.212	55.452	74.8036
LOCATION R	74.8036		69.884	77.256	91.212	55.452	74.8036
LOCATION S	58.8	11.281	69.884	77.256	91.212	55.452	74.8036
LOCATION T	35.928	60.058	69.884	77.256	91.212	55.452	74.8036

Step 2

Step 3



```

To Range("integer_number_iterations"
tion") = integer_Monte_Carlo_loop
y_paste_sort")
nce") Then
copy_current_path")
stance") Then
macro_copy_current_path_max")
    
```

```

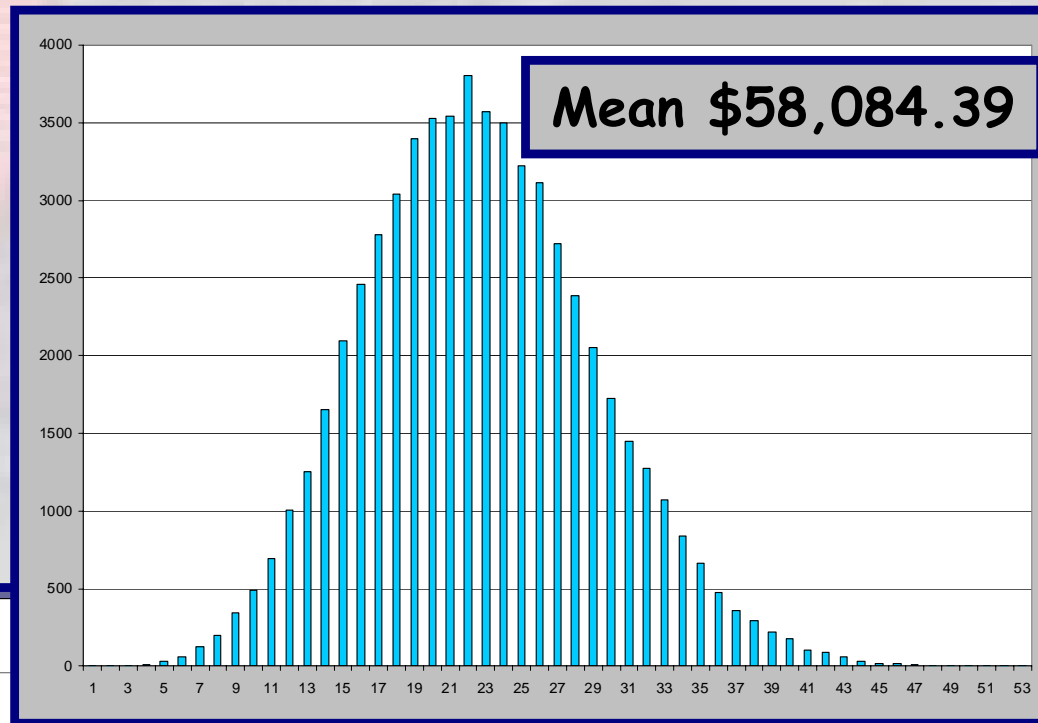
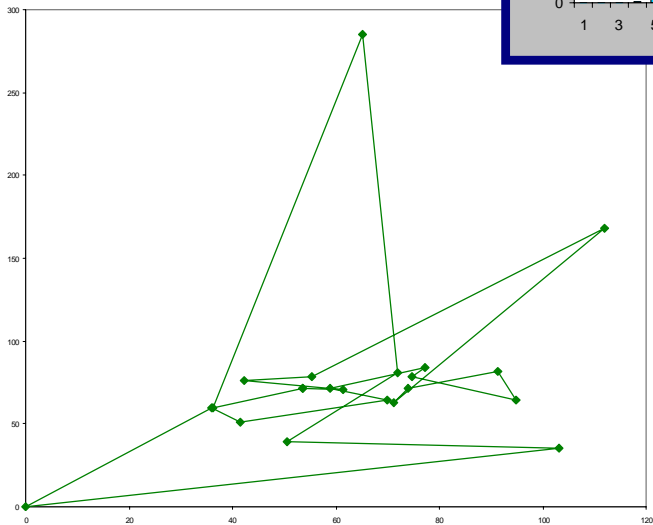
End If
End If
Next integer_Monte_Carlo_loop
    
```

Monte Carlo Results - 60K Iterations

**Optimal Cost
\$47,058.64**



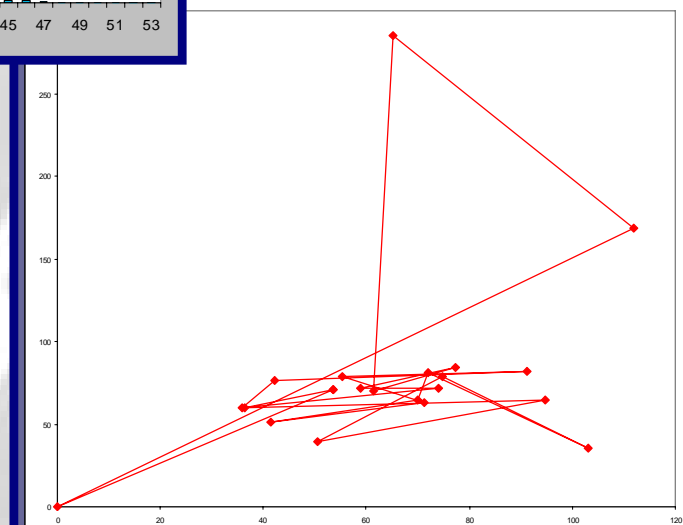
Lowest Cost Path



**Maximum Cost
\$73,293.87**



Highest Cost Path



⚙️ Path is (X, Y) coordinates to show distance
⚙️ Distance is not indicative of cost

Monte Carlo Results

	Least	Highest	Time
1 K	\$48,678.17- \$48,809.43	\$67,617.20- \$71,371.07	19 sec 7 sec
10 K	\$47,672.77- -\$48,325.17	\$70,886.80- \$71,249.53	1 min 7 sec 2 min 33 sec
30 K	\$47,217.44- \$47,318.30	\$70,560.74- \$71,837.03	3 min 2 sec 3 min 22 sec
1,000 K	\$45,576.64	\$74,213.40	90 min 34 sec
5,630 K	\$44,740.17	\$76,209.80	~ 23 hrs



Photo: Wild, Alex. <http://www.dphotojournal.com/daily-inspiration-macro-photography/> April 12, 2008.