SUPPLEMENT TO CHAPTER 9

A Case Study with Many Transportation Problems

Background

The Texago Corporation is a large, fully integrated petroleum company based in the United States. The company produces most of its oil in its own oil fields and then imports the rest of what it needs from the Middle East. An extensive distribution network is used to transport the oil to the company's refineries and then to transport the petroleum products from the refineries to Texago's distribution centers. The locations of these various facilities are given in Table 1.

Texago is continuing to increase market share for several of its major products. Therefore, management has made the decision to expand output by building an additional refinery and increasing imports of crude oil from the Middle East. The crucial remaining decision is where to locate the new refinery.

The addition of the new refinery will have a great impact on the operation of the entire distribution system, including decisions on how much crude oil to transport from each of its sources to each refinery (including the new one) and how much finished product to ship from each refinery to each distribution center. Therefore, the three key factors for management's decision on the location of the new refinery are

1. The cost of transporting the oil from its sources to all the refineries, including the new one.
2. The cost of transporting finished product from all the refineries, including the new one, to the distribution centers.
3. Operating costs for the new refinery, including labor costs, taxes, the cost of needed supplies (other than crude oil), energy costs, the cost of insurance, the effect of financial incentives provided by the state or city, and so forth. (Capitol costs are not a factor since they would be essentially the same at any of the potential sites.)

Management has set up a task force to study the issue of where to locate the new refinery. After considerable investigation, the task force has determined that there are three attractive potential sites. These sites and the main advantages of each are spelled out in Table 2. Other relevant factors, such as standard-of-living considerations for management and employees, are considered reasonably comparable at these sites.

Gathering the Necessary Data

The task force needs to gather a large amount of data, some of which requires considerable digging, in order to perform the analysis requested by management.

Management wants all the refineries, including the new one, to operate at full capacity. Therefore, the task force begins by determining how much crude oil each refinery would need to receive annually under these conditions. Using units of 1 million barrels, these needed amounts are shown on the left side of Table 3. The right side of the table shows the current annual output of crude oil from the various oil fields. These quantities are expected to remain stable for some years to come. Since the refineries need a total of 360 million barrels of crude oil, and the oil fields will produce a total of 240 million barrels, the difference of 120 million barrels will need to be imported from the Middle East.

TABLE 1 Location of Texago's current facilities

Type of Facility	Locations
Oil fields	1. Texas
	2. California
	3. Alaska
Refineries	1. Near New Orleans, Louisiana
	2. Near Charleston, South Carolina
	3. Near Seattle, Washington
Distribution centers	1. Pittsburgh, Pennsylvania
	2. Atlanta, Georgia
	3. Kansas City, Missouri
	4. San Francisco, California

TABLE 2 Potential sites for Texago's new refineries and their main advantages

Potential Site	Main Advantages
Near Los Angeles, California	1. Near California oil fields 2. Ready access from Alaska oil fields 3. Fairly near San Francisco distribution center
Near Galveston, Texas	1. Near Texas oil fields 2. Ready access from Middle East imports 3. Near corporate headquarters
Near St. Louis, Missouri	1. Low operating costs 2. Centrally located for distribution centers 3. Ready access to crude oil via Mississippi River

TABLE 3 Production data for Texago Corp.

Refinery	Crude Oil Needed Annually (Million Barrels)
New Orleans	100
Charleston	60
Seattle	80
New one	120
Total	360
Oil Fields	**Crude Oil Produced Annually (Million Barrels)**
Texas	80
California	60
Alaska	100
Total	240

Needed imports = 360 - 240 = 120

Since the amounts of crude oil produced or purchased will be the same regardless of which location is chosen for the new refinery, the task force concludes that the associated production or purchase costs (exclusive of shipping costs) are not relevant to the site selection decision. On the other hand, the costs for transporting the crude oil from its source to a refinery are very relevant. These costs are shown in Table 4 for both the three current refineries and the three potential sites for the new refinery.

Also very relevant are the costs of shipping the finished product from a refinery to a distribution center. Letting one unit of finished product correspond to the production of a refinery from 1 million barrels of crude oil, these costs are given in Table 5. The bottom row of the table shows the number of units of finished product needed by each distribution center. The final key body of data involves the *operating* costs for a refinery at each potential site. Estimating these costs requires site visits by several members of the task force to collect detailed information about local labor costs, taxes, and so forth. Comparisons then are made with the operating costs of the current refineries to help refine these data.

In addition, the task force gathers information on one-time site costs for land, construction, and so forth, and amortizes these costs on an equivalent uniform annual cost basis. This process leads to the estimates shown in Table 6.

Analysis (Six Applications of a Transportation Problem)

Armed with these data, the task force now needs to develop the following key financial information for management:

1. Total shipping cost for crude oil with each potential choice of a site for the new refinery.
2. Total shipping cost for finished product with each potential choice of a site for the new refinery.

TABLE 4 Cost data for shipping crude oil to a Texago refinery

		Cost per Unit Shipped (Millions of Dollars per Million Barrels) Refinery or Potential Refinery					
		New Orleans	Charleston	Seattle	Los Angeles	Galveston	St. Louis
Source	Texas	2	4	5	3	1	1
	California	5	5	3	1	3	4
	Alaska	5	7	3	4	5	7
	Middle East	2	3	5	4	3	4

TABLE 5 Cost data for shipping finished product to a distribution center

		Cost per Unit Shipped (Millions of Dollars) Distribution Center			
		Pittsburgh	Atlanta	Kansas City	San Francisco
Refinery	New Orleans	6.5	5.5	6	8
	Charleston	7	5	4	7
	Seattle	7	8	4	3
Potential Refinery	Los Angeles	8	6	3	2
	Galveston	5	4	3	6
	St. Louis	4	3	1	5
Number of units needed		100	80	80	100

TABLE 6 Estimated operating costs for a Texago refinery at each potential site

Site	Annual Operating Cost (Millions of Dollars)
Los Angeles	620
Galveston	570
St. Louis	530

For both types of costs, once a site is selected, an optimal shipping plan will be determined and then followed. Therefore, to find either type of cost with a *potential* choice of a site, it is necessary to solve for the optimal shipping plan given that choice and then calculate the corresponding cost.

The task force recognizes that the problem of finding an optimal shipping plan for a given choice of a site is just a transportation problem. In particular, for shipping crude oil, Fig. 1 shows the spreadsheet model for this transportation problem, where the entries in the data cells come directly from Tables 3 and 4. The entries for the *New Site* column (cells G5 : G8) will come from one of the last three columns of Table 4, depending on which potential site currently is being evaluated. At this point, before entering this column and clicking on the Solve button, a trial solution of 0 for each of the shipment quantities has been entered into the changing cells ShipmentQuantity (D13 : G16).

These same changing cells in Figs. 2, 3, and 4 show the optimal shipping plan for each of the three possible choices of a site. The objective cell TotalCost (J20) gives the resulting total annual shipping cost in millions of dollars. In particular, if Los Angeles were to be chosen as the site for the new refinery (Fig. 2), the total annual cost of shipping crude oil in the optimal manner would be $880 million. If Galveston were chosen instead (Fig. 3), this cost would be $920 million, whereas it would be $960 million if St. Louis were chosen (Fig. 4).

	A	B	C	D	E	F	G	H	I	J
1	**Texago Corp. Site-Selection Problem (Shipping to Refineries)**									
2										
3					Refineries					
4		**Unit Cost ($millions)**		New Orleans	Charleston	Seattle	New Site			
5			Texas	2	4	5				
6		Oil	California	5	5	3				
7		Fields	Alaska	5	7	3				
8			Middle East	2	3	5				
9										
10										
11		**Shipment Quantity**			Refineries					
12		**(millions of barrels)**		New Orleans	Charleston	Seattle	New Site	Total Shipped		Supply
13			Texas	0	0	0	0	0	=	80
14		Oil	California	0	0	0	0	0	=	60
15		Fields	Alaska	0	0	0	0	0	=	100
16			Middle East	0	0	0	0	0	=	120
17			Total Received	0	0	0	0			
18				=	=	=	=			Total Cost
19			Demand	100	60	80	120			($millions)
20										0

Solver Parameters

Set Objective Cell : TotalCost
To: Min
By Changing Variable Cells:
ShipmentQuantity
Subject to the Constraints:
TotalReceived = Demand
TotalShipped = Supply
Solver Options:
Make Variables Nonnegative
Solving Method: Simplex LP

Range Name	Cells
Demand	D19:G19
ShipmentQuantity	D13:G16
Supply	J13:J16
TotalCost	J20
TotalReceived	D17:G17
TotalShipped	H13:H16
UnitCost	D5:G8

	H
12	Total Shipped
13	=SUM(D13:G13)
14	=SUM(D14:G14)
15	=SUM(D15:G15)
16	=SUM(D16:G16)

	C	D	E	F	G
17	Total Received	=SUM(D13:D16)	=SUM(E13:E16)	=SUM(F13:F16)	=SUM(G13:G16)

	J
18	Total Cost
19	($millions)
20	=SUMPRODUCT(UnitCost,ShipmentQuantity)

FIGURE 1
The basic spreadsheet formulation for the Texago transportation problem for shipping crude oil from the oil fields to the refineries, including the new refinery at a site still to be selected. The objective cell is TotalCost (J20), and the other output cells are TotalShipped (H13:H16) and TotalReceived (D17:G17). Before entering the data for a new site and then clicking on the Solve button, a trial solution of 0 has been entered into each of the changing cells ShipmentQuantity (D13:G16).

	A	B	C	D	E	F	G	H	I	J
1	**Texago Corp. Site-Selection Problem (Shipping to Refineries, Including Los Angeles)**									
2										
3					Refineries					
4		**Unit Cost ($millions)**		New Orleans	Charleston	Seattle	Los Angeles			
5			Texas	2	4	5	3			
6		Oil	California	5	5	3	1			
7		Fields	Alaska	5	7	3	4			
8			Middle East	2	3	5	4			
9										
10										
11		**Shipment Quantity**			Refineries					
12		**(millions of barrels)**		New Orleans	Charleston	Seattle	Los Angeles	Total Shipped		Supply
13			Texas	40	0	0	40	80	=	80
14		Oil	California	0	0	0	60	60	=	60
15		Fields	Alaska	0	0	80	20	100	=	100
16			Middle East	60	60	0	0	120	=	120
17			Total Received	100	60	80	120			
18				=	=	=	=			Total Cost
19			Demand	100	60	80	120			($millions)
20										880

FIGURE 2
The changing cells ShipmentQuantity (D13 : G16) give Texago management an optimal plan or shipping crude oil if Los Angeles is selected as the new site for the refinery in column G of Fig. 1.

	A	B	C	D	E	F	G	H	I	J
1	Texago Corp. Site-Selection Problem (Shipping to Refineries, Including Galveston)									
2										
3				Refineries						
4		**Unit Cost ($millions)**		New Orleans	Charleston	Seattle	Galveston			
5			Texas	2	4	5	1			
6		Oil	California	5	5	3	3			
7		Fields	Alaska	5	7	3	5			
8			Middle East	2	3	5	3			
9										
10										
11		**Shipment Quantity**		Refineries						
12		**(millions of barrels)**		New Orleans	Charleston	Seattle	Galveston	Total Shipped		Supply
13			Texas	20	0	0	60	80	=	80
14		Oil	California	0	0	0	60	60	=	60
15		Fields	Alaska	20	0	80	0	100	=	100
16			Middle East	60	60	0	0	120	=	120
17			Total Received	100	60	80	120			
18				=	=	=	=			Total Cost
19			Demand	100	60	80	120			($millions)
20										920

FIGURE 3
The changing cells ShipmentQuantity (D13 : G16) give Texago management an optimal plan for shipping crude oil if Galveston is selected as the new site for a refinery in column G of Fig. 1.

	A	B	C	D	E	F	G	H	I	J
1	Texago Corp. Site-Selection Problem (Shipping to Refineries, Including St. Louis)									
2										
3				Refineries						
4		**Unit Cost ($millions)**		New Orleans	Charleston	Seattle	St. Louis			
5			Texas	2	4	5	1			
6		Oil	California	5	5	3	4			
7		Fields	Alaska	5	7	3	7			
8			Middle East	2	3	5	4			
9										
10										
11		**Shipment Quantity**		Refineries						
12		**(millions of barrels)**		New Orleans	Charleston	Seattle	St. Louis	Total Shipped		Supply
13			Texas	0	0	0	80	80	=	80
14		Oil	California	0	20	0	40	60	=	60
15		Fields	Alaska	20	0	80	0	100	=	100
16			Middle East	80	40	0	0	120	=	120
17			Total Received	100	60	80	120			
18				=	=	=	=			Total Cost
19			Demand	100	60	80	120			($millions)
20										960

FIGURE 4
The changing cells ShipmentQuantity (D13 : G16) give Texago management an optimal plan for shipping crude oil if St. Louis is selected as the new site for a refinery in column G of Fig. 1.

The analysis of the cost of shipping finished product is similar. Figure 5 shows the spreadsheet model for this transportation problem, where rows 5–7 come directly from the first three rows of Table 5. The *New Site* row would be filled in from one of the next three rows of Table 5, depending on which potential site for the new refinery is currently under evaluation. Since the units for finished product leaving a refinery are equivalent to the units for crude oil coming in, the data in Supply (J13 : J16) come from the left side of Table 3.

The changing cells ShipmentQuantity (D13 : G16) in Figs. 6, 7, and 8 show the optimal plan for shipping finished product for each of the sites being considered for the new refinery. The objective cell TotalCost (J20) in Fig. 6 indicates that the resulting total annual cost for shipping finished product if the new refinery were in Los Angeles is $1.57 billion. Similarly, this total cost would be $1.63 billion if Galveston were the chosen site (Fig. 7) and $1.43 billion if St. Louis were chosen (Fig. 8).

For each of the three alternative sites, two separate spreadsheet models have been used for planning the shipping of crude oil and the shipping of finished product. However, another option would have been to combine all this planning into a single spreadsheet model for each site and then to simultaneously optimize the plans for the two types of shipments.This would essentially involve combining Fig. 2 with Fig. 6, Fig. 3 with Fig. 7, and Fig. 4 with Fig. 8, and then using the sum of the shipping costs for the pair of transportation problems as the objective cell to be minimized. This would have the advantage of showing all the shipment planning for a given site on a single spreadsheet. Case 9.2 will continue this Texago case study by considering a situation where this kind of combined spreadsheet model is needed to find the best overall shipping plan for each possible choice of a site.

	A	B	C	D	E	F	G	H	I	J
1	Texago Corp. Site-Selection Problem (Shipping to D.C.'s)									
2										
3				Distribution Center						
4		Unit Cost ($millions)		Pittsburgh	Atlanta	Kansas City	San Francisco			
5			New Orleans	6.5	5.5	6	8			
6		Refineries	Charleston	7	5	4	7			
7			Seattle	7	8	4	3			
8			New Site							
9										
10										
11		Shipment Quantity		Distribution Center						
12		(millions of barrels)		Pittsburgh	Atlanta	Kansas City	San Francisco	Total Shipped		Supply
13			New Orleans	0	0	0	0	0	=	100
14		Refineries	Charleston	0	0	0	0	0	=	60
15			Seattle	0	0	0	0	0	=	80
16			New Site	0	0	0	0	0	=	120
17			Total Received	0	0	0	0			
18				=	=	=	=			Total Cost
19			Demand	100	80	80	100			($millions)
20										0

Range Name	Cells
Demand	D19:G19
ShipmentQuantity	D13:G16
Supply	J13:J16
TotalCost	J20
TotalReceived	D17:G17
TotalShipped	H13:H16
UnitCost	D5:G8

Solver Parameters

Set Objective Cell : TotalCost
To: Min
By Changing Variable Cells:
ShipmentQuantity
Subject to the Constraints:
TotalReceived = Demand
TotalShipped = Supply
Solver Options:
Make Variables Nonnegative
Solving Method: Simplex LP

	H
12	Total Shipped
13	=SUM(D13:G13)
14	=SUM(D14:G14)
15	=SUM(D15:G15)
16	=SUM(D16:G16)

	C	D	E	F	G
17	Total Received	=SUM(D13:D16)	=SUM(E13:E16)	=SUM(F13:F16)	=SUM(G13:G16)

	J
18	Total Cost
19	($millions)
20	=SUMPRODUCT(UnitCost,ShipmentQuantity)

FIGURE 5
The basic spreadsheet formulation for the Texago transportation problem for shipping finished product from the refineries (including the new one at a site still to be selected) to the distribution centers. The objective cell is TotalCost (J20), and the other output cells are TotalShipped (H13:H16) and TotalReceived (D17:G17). Before entering the data for a new site and then clicking on the Solve button, a trial solution of 0 has been entered into each of the changing cells ShipmentQuantity (D13:G16).

	A	B	C	D	E	F	G	H	I	J
1	**Texago Corp. Site-Selection Problem (Shipping to D.C.'s When Choose Los Angeles)**									
2										
3				Distribution Center						
4		**Unit Cost ($millions)**		Pittsburgh	Atlanta	Kansas City	San Francisco			
5			New Orleans	6.5	5.5	6	8			
6		Refineries	Charleston	7	5	4	7			
7			Seattle	7	8	4	3			
8			Los Angeles	8	6	3	2			
9										
10										
11		**Shipment Quantity**		Distribution Center						
12		**(millions of barrels)**		Pittsburgh	Atlanta	Kansas City	San Francisco	Total Shipped		Supply
13			New Orleans	80	20	0	0	100	=	100
14		Refineries	Charleston	0	60	0	0	60	=	60
15			Seattle	20	0	0	60	80	=	80
16			Los Angeles	0	0	80	40	120	=	120
17			Total Received	100	80	80	100			
18				=	=	=	=			Total Cost
19			Demand	100	80	80	100			($millions)
20										1,570

FIGURE 6
The changing cells ShipmentQuantity (D13 : G16) give Texago management an optimal plan for shipping finished product if Los Angeles is selected as the new site for a refinery in rows 8 and 16 of Fig. 5.

	A	B	C	D	E	F	G	H	I	J
1	**Texago Corp. Site-Selection Problem (Shipping to D.C.'s When Choose Galveston)**									
2										
3				Distribution Center						
4		**Unit Cost ($millions)**		Pittsburgh	Atlanta	Kansas City	San Francisco			
5			New Orleans	6.5	5.5	6	8			
6		Refineries	Charleston	7	5	4	7			
7			Seattle	7	8	4	3			
8			Galveston	5	4	3	6			
9										
10										
11		**Shipment Quantity**		Distribution Center						
12		**(millions of barrels)**		Pittsburgh	Atlanta	Kansas City	San Francisco	Total Shipped		Supply
13			New Orleans	100	0	0	0	100	=	100
14		Refineries	Charleston	0	60	0	0	60	=	60
15			Seattle	0	0	0	80	80	=	80
16			Galveston	0	20	80	20	120	=	120
17			Total Received	100	80	80	100			
18				=	=	=	=			Total Cost
19			Demand	100	80	80	100			($millions)
20										1,630

FIGURE 7
The changing cells ShipmentQuantity (D13 : G16) give Texago management an optimal plan for shipping finished product if Galveston is selected as the new site for a refinery in rows 8 and 16 of Fig. 5.

	A	B	C	D	E	F	G	H	I	J
1	**Texago Corp. Site-Selection Problem (Shipping to D.C.'s When Choose St. Louis)**									
2										
3				Distribution Center						
4		**Unit Cost ($millions)**		Pittsburgh	Atlanta	Kansas City	San Francisco			
5			New Orleans	6.5	5.5	6	8			
6		Refineries	Charleston	7	5	4	7			
7			Seattle	7	8	4	3			
8			St. Louis	4	3	1	5			
9										
10										
11		**Shipment Quantity**		Distribution Center						
12		**(millions of barrels)**		Pittsburgh	Atlanta	Kansas City	San Francisco	Total Shipped		Supply
13			New Orleans	100	0	0	0	100	=	100
14		Refineries	Charleston	0	60	0	0	60	=	60
15			Seattle	0	0	0	80	80	=	80
16			St. Louis	0	20	80	20	120	=	120
17			Total Received	100	80	80	100			
18				=	=	=	=			Total Cost
19			Demand	100	80	80	100			($millions)
20										1,430

FIGURE 8
The changing cells ShipmentQuantity (D13:G16) give Texago management an optimal plan for shipping finished product if St. Louis is selected as the new site for a refinery in rows 8 and 16 of Fig. 5.

The Message to Management

The task force now has completed its financial analysis of the three alternative sites for the new refinery. Table 7 shows all the major *variable* costs (costs that vary with the decision) on an annual basis that would result from each of the three possible choices of the site. The second column summarizes what the total annual cost of shipping crude oil to all refineries (including the new one) would be for each alternative (as already given in Figs. 2, 3, and 4). The third column repeats the data in Figs. 6, 7, and 8 on the total annual cost of shipping finished product from the refineries to the distribution centers. The fourth column shows the estimated operating costs for a refinery at each potential site, as first given in Table 6.

TABLE 7 Annual variable costs resulting from the choice of each site for the new Texago refinery

Site	Total Cost of Shipping Crude Oil	Total Cost of Shipping Finished Product	Operating Cost for New Refinery	Total Variable Cost
Los Angeles	$880 million	$1.57 billion	$620 million	$3.07 billion
Galveston	920 million	1.63 billion	570 million	3.12 billion
St. Louis	960 million	1.43 billion	530 million	2.92 billion

Adding across these three columns gives the total variable cost for each alternative. *Conclusion:* From a purely financial viewpoint, St. Louis is the best site for the new refinery. This site would save the company about $200 million annually as compared to the Galveston alternative and about $150 million as compared to the Los Angeles alternative.

However, as with any site selection decision, management must consider a wide variety of factors, including some nonfinancial ones. (For example, remember that one important advantage of the Galveston site is that it is close to corporate headquarters.)

Furthermore, if ways can be found to reduce some of the costs in Table 7 for either the Los Angeles or Galveston sites, this might change the financial evaluation substantially. Management also must consider whether there are any cost trends or trends in the marketplace that might alter the picture in the future.

After careful consideration, Texago management chooses the St. Louis site. (This story continues in Case 9.2, where the task force is asked to analyze the option of enlarging the capacity of the new refinery before the final decision is made on its site.)