Global Supply Chain Management At Printko Ink Company

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ABSTRACT

The Printko Ink Company case illustrates how network models can be used as an aid in spreadsheet model formulation. It also enriches students' knowledge how to use integer linear programming with binary (0-1) variables in dealing with fixed cost plant and warehouse location problems. Students completing the Printko Ink case will be able to develop a spreadsheet model that will solve for many logistic decision variables. It will help students decide where or whether to manufacture Printko Ink single product and how to get it to its customers around the world in the most economical manner.

Keywords: Linear programming, spreadsheet modeling, network models, logistics, and global supply chain

INTRODUCTION

Linear programming is a problem-solving approach developed to help managers make decisions. It is a powerful tool used by operations managers and other managers to obtain optimal solutions to problems that involve restrictions or limitations on their resources. These problems are referred to as constrained optimization problems. Numerous applications of linear programming can be found in today's competitive business environment. It is increasingly important to make sure that a company's limited resources are used in the most efficient way.

Linear programming is heavily used to minimize transportation and transshipment costs. Many transportation, transshipment and logistics problems fall into the category of problems known as minimum cost network flow model. All network flow problems can be represented by a collection of nodes and arcs. The nodes represent the suppliers, warehouses, or customers while the arcs represent suitable paths or routes between nodes. The transportation problem involves finding the lowest cost plan for distributing goods from multiple origins to multiple destinations that demand those goods. In the transshipment model, warehouses can be used as intermediaries to receive goods from suppliers and send them to customers.

In practice, opening a plant or a warehouse require fixed cost. Fixed cost is not a linear function; therefore, the use of binary variables (0, 1) will transform a non linear model into a linear one. This case study will help managers develop a spreadsheet model that will minimize total cost. Total cost involves production cost, shipping cost, and fixed cost. The model will also solve for which plant or warehouse to open in order to satisfy customer demand with the lowest cost possible.

Printko Ink Company: Considering Global Supply Chain Decisions Using Integer and Binary Variables in Linear Programming:

Overview:

Printko Ink, a manufacturer of printing inks, is located in Texas, USA. Roy Smith, the CEO of Printko Ink has received some information about a potential demand to his product worldwide. He called Nancy Rogers (the operation manager) and Mark Davidson (the marketing manager) to his office and requested both of them to do marketing research and collect more data regarding his interest of expanding his company globally.

After researching potential markets for Printko Ink product and studying several distributions locations, Nancy and Mark returned to Roy with some valuable information. They learned that their United States Plant Production capacity cannot meet the anticipated global demand. There is a potential market demand to their product in the United States, Canada, Brazil, Europe and Asia. Their suggested solution is to build one or more plant outside the United States. There are four potential locations in their research that deserve to be examined. Those locations are Germany, Japan, China, and Brazil. The fixed cost to operate these plants, the production capacity in tons per year, and the production cost per ton is listed in table 1.

Table 1: Plant Information

Country	Fixed cost /year	Production Capacity(tons/year)	Production cost/ton
United States	100,000 USD	350	11,000 USD
Germany	60,000 Euro	250	7500 Euro
Japan	2,000,000 Yen	500	267,000 Yen
China	45,000 RMB	600	6800 RMB
Brazil	50,000 Real	300	8000 Real

Nancy and Mark also included in their study that there are four locations that can be used as warehouses or distribution channels. They looked into the fixed cost to build and run those warehouses along with their storage capacity and listed their findings in table 2. The four potential warehouses locations are United States, Turkey, China, and India.

Table 2: Warehouse Information

Country	Fixed cost /year	Storage Capacity(tons/year)
United States	50,000 USD	400
Turkey	10,000 Lira	700
China	15,000 RMB	600
India	200,000 Rupees	500

Nancy and Mark reported the estimated yearly demand for their product and listed their findings in table 3.

Table 3: Customers Demand

Country	Yearly Demand (tons)
United States	300
Canada	250
Brazil	150
Europe	300
Asia	500

Nancy and Mark also estimated the transportation cost from each plant to each warehouse and from each warehouse to customers in U.S dollars. Their findings are listed in tables 4, 5 respectively.

Table 4: Transportation Costs in US Dollars per Ton from Plants to Warehouses

	United States	Turkey	China	India
Unites States	300	1300	1700	1500
Germany	1200	300	800	700
Japan	2000	700	500	600
China	1700	400	200	300
Brazil	700	1300	1500	1900

Table 5: Transportation Costs in US Dollars per Ton from Warehouses to Customers

	United States	Canada	Brazil	Europe	Asia
United States	200	400	600	1300	2000
Turkey	1300	1400	1500	400	500
China	1700	1800	1750	400	300
India	1500	1600	1650	500	400

Finally Nancy and Mark provided the anticipated exchange rate in 2009. The information is listed in table 6.

Table 6: Anticipated Exchange Rate in 2009

	USA USD	Europe Euro	Japan Yen	China RMB	Brazil Real	Turkey Lira	India Rupee
USD	1.0	0.6727	88.98	6.8287	1.7315	1.4983	46.511

Printko Ink must decide which plants and warehouses to open, and which routes from plants to warehouses and from warehouses to customers to use. All customer demands must be met. A given customer's demand can be met from more than one warehouse. Roy Smith is asking for your input to help his team to come up with the best production plan that meets all his customers' demand.

Nancy and Mark are requesting your help to do the following:

1) Draw a network diagram for Printko Ink that will help Roy graphically visualize all his options.
2) If exchange rates are expected as in table 6, develop a spreadsheet model using mixed integer linear programming to determine the minimum-cost method for meeting customers' demand.
3) Which of the plants and which of the warehouses should they open?
4) Can adding 200 tons of production capacity to the plant in China reduce total cost? Explain your findings.
5) Refer to the original input, can adding 100 tons to China's warehouse storage capacity help reducing total cost? Explain your findings.
6) Given requirement 5 input, if China can produce all your demand (i.e.1500 tons), how does this change affect your decisions?

Teaching Notes (Solution to requirements):

Requirement 1: Draw a network diagram for Printko Ink that will help Roy graphically visualize all his options.

Requirement 1 solution: Figure 1 presents the network diagram for Printko Ink.

Requirement 2: If exchange rates are expected as in table 6, develop a spreadsheet model using mixed integer linear programming to determine the minimum-cost method for meeting customers' demand.

Requirement 2 solution: Figure 2 illustrates the spreadsheet model input for Printko Ink, figure 3 represents requirement 2 solution, and figure 4 depicts Excel Solver parameters.

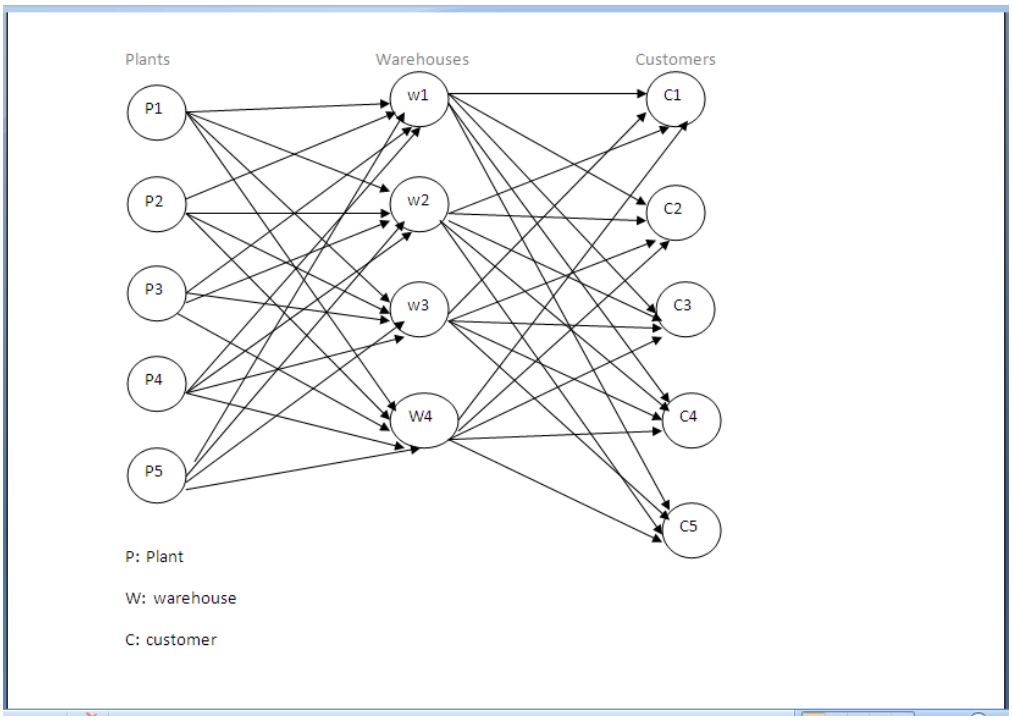


Figure1: Network diagram for Printko Ink.

	A	B	C	D	E	F	G	H	I	J	K	L	M
2	Printko Ink	Transportation Model	(Spreadsheet model input))										
3				Warehouses				Production		Fixed cost		Production	
4		Plants	Jnited State	Turkey	China	India		cost/ton		per year		Capacity (tons)	
5		United Stat	300	1300	1700	1500		11,000 USD		100,000 USD		350	
6		Germany	1200	300	800	700		7500 Euro		60,000 Euro		250	
7		Japan	2000	700	500	600		267,000 Yen		2,000,000 Yen		500	
8		China	1700	400	200	300		6800 RMB		45,000 RMB		600	
9		Brazil	700	1300	1500	1900		8,000 Real		50,000 Real		300	
10													
11					Customers					Fixed		Storage	
12		Warehouse	Jnited State	Canada	Brazil	Europe	Asia			Cost/year		Capacity (tons)	
13		United Stat	200	400	600	1300	2000			50,000 USD		400	
14		Turkey	1300	1400	1500	400	500			10,000 Lira		700	
15		China	1700	1800	1750	400	300			15,000 RMB		600	
16		India	1500	1600	1650	500	400			200,000 Rupees		500	
17													
18													
19			United State	Canada	Brazil	Europe	Asia						
20		Demand	300	250	150	300	500						
21													
22	Anticipated	Exchange R	in 2009										
23		USA	Europe	Japan	China	Brazil	Turkey	India					
24		Dollar	Euro	Yen	RMB	Real	Lira	Rupee					
25	US Dollar	1	0.6727	88.98	6.8287	1.7315	1.4983	46.511					

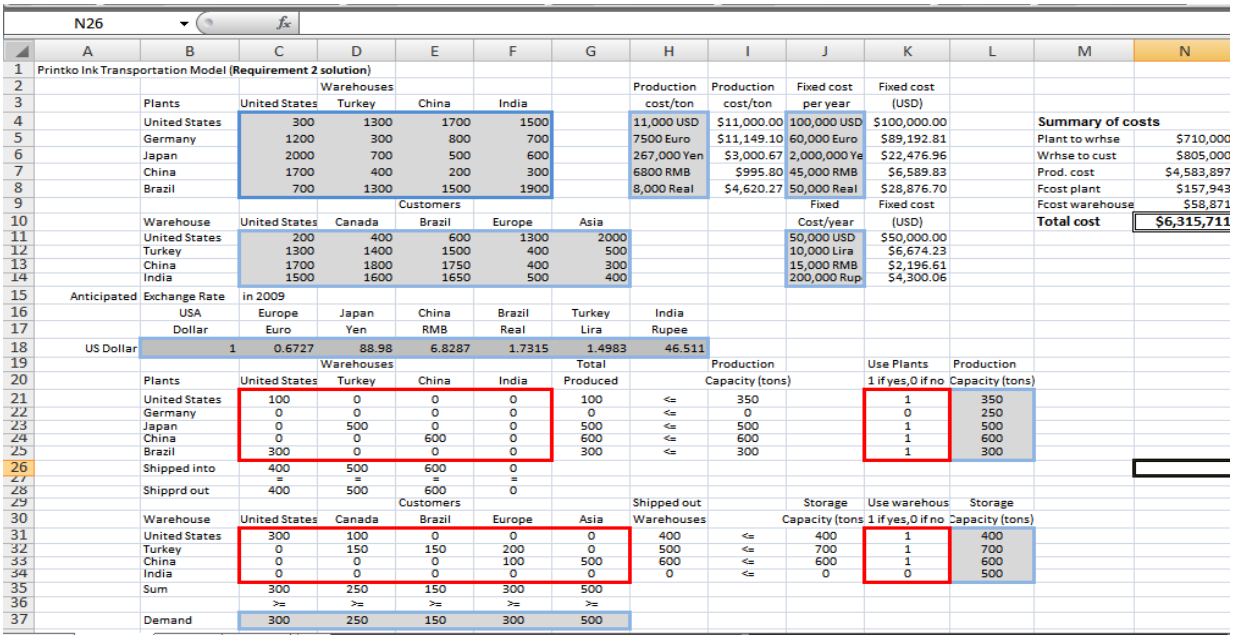
Figure 2: Spreadsheet Model Input

Spreadsheet model development:

The model should keep track of the following:

1. The quantity in tons that should be shipped from opened plants to opened warehouses.
2. The quantity in tons that should be shipped from opened warehouses to customers.
3. Fixed costs in US dollars of operating plants and warehouses if they kept open.
4. The production costs at the opened plants.

5. The shipping costs from opened plants to opened warehouses and from opened warehouses to customers.
6. Quantity in tons received by each opened warehouse should be equal to the quantity in tons shipped out of each opened warehouse. No storage should be kept at any warehouse.
7. Total amount shipped to final customers from opened warehouses should meet customer demands.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Printko Ink Transportation Model (**Requirement 2 solution**)													
2				Warehouses				Production	Production	Fixed cost	Fixed cost			
3		Plants	United States	Turkey	China	India		cost/ton	cost/ton	per year	(USD)			
4		United States	300	1300	1700	1500		11,000 USD	$11,000.00	100,000 USD	$100,000.00		**Summary of costs**	
5		Germany	1200	300	800	700		7500 Euro	$11,149.10	60,000 Euro	$89,192.81		Plant to wrhse	$710,000
6		Japan	2000	700	500	600		267,000 Yen	$3,000.67	2,000,000 Ye	$22,476.96		Wrhse to cust	$805,000
7		China	1700	400	200	300		6800 RMB	$995.80	45,000 RMB	$6,589.83		Prod. cost	$4,583,897
8		Brazil	700	1300	1500	1900		8,000 Real	$4,620.27	50,000 Real	$28,876.70		Fcost plant	$157,943
9					Customers					Fixed	Fixed cost		Fcost warehouse	$58,871
10		Warehouse	United States	Canada	Brazil	Europe	Asia			Cost/year	(USD)		**Total cost**	**$6,315,711**
11		United States	200	400	600	1300	2000			50,000 USD	$50,000.00			
12		Turkey	1300	1400	1500	400	500			10,000 Lira	$6,674.23			
13		China	1700	1800	1750	400	300			15,000 RMB	$2,196.61			
14		India	1500	1600	1650	500	400			200,000 Rup	$4,300.06			
15	Anticipated	Exchange Rate	in 2009											
16		USA	Europe	Japan	China	Brazil	Turkey	India						
17		Dollar	Euro	Yen	RMB	Real	Lira	Rupee						
18	US Dollar	1	0.6727	88.98	6.8287	1.7315	1.4983	46.511						
19				Warehouses			Total		Production		Use Plants	Production		
20		Plants	United States	Turkey	China	India	Produced		Capacity (tons)		1 if yes,0 if no	Capacity (tons)		
21		United States	100	0	0	0	100	<=	350		1	350		
22		Germany	0	0	0	0	0	<=	0		0	250		
23		Japan	0	500	0	0	500	<=	500		1	500		
24		China	0	0	600	0	600	<=	600		1	600		
25		Brazil	300	0	0	0	300	<=	300		1	300		
26		Shipped into	400	500	600	0								
27			=	=	=	=								
28		Shipprd out	400	500	600	0								
29					Customers			Shipped out		Storage	Use warehous	Storage		
30		Warehouse	United States	Canada	Brazil	Europe	Asia	Warehouses		Capacity (tons	1 if yes,0 if no	Capacity (tons)		
31		United States	300	100	0	0	0	400	<=	400	1	400		
32		Turkey	0	150	150	200	0	500	<=	700	1	700		
33		China	0	0	0	100	500	600	<=	600	1	600		
34		India	0	0	0	0	0	0	<=	0	0	500		
35		Sum	300	250	150	300	500							
36			>=	>=	>=	>=	>=							
37		Demand	300	250	150	300	500							

Figure 3: Requirement 2 Solution

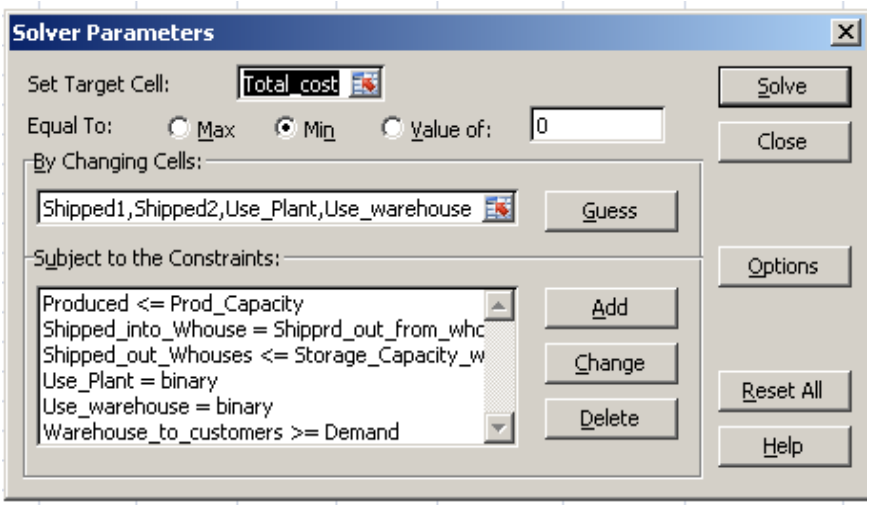


Figure 4: Excel Solver Parameters

According to figure 3 solution, the minimum cost for this plan is $6,315,711. Figure 4 illustrates solver input for the spreadsheet model. The minimum cost plan suggested the following:

- United States plants should produce 100 tons of ink and ship it to United States warehouse.
- Japan plant should produce 500 tons and ship it to Turkey warehouse.
- China plant should produce 600 tons and ship it to China warehouse.

- Brazil Plant should produce 300 tons and ship it to United States warehouse.
- Out of the 400 tons received at the United States warehouse, 300 tons should be shipped to United States customers and 100 tons to Canada customers.
- Out of the 500 tons received at Turkey warehouse, 150 tons should be shipped to Canada customers, 150 tons to Brazil customers, and 200 tons to Europe customers.
- Out of the 600 tons received at China warehouse, 100 tons should be shipped to Europe customers and 500 tons to Asia customers.

Requirement 3: Which of the plants and which of the warehouses should they open?

Requirement 3 solution:

According to the spreadsheet solution for requrement 2, the plant in Germany and the warehouse in India *should not* be open.

Requirement4: Can adding 200 tons of production capacity to the plant in China reduce the total cost? Explain your findings.

Requirement 4 solution:

Figure 5 represents the spreadsheet solution for requirement 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	Printko Ink Transportation Model (**Requirment 4 Solution**)													
3				Warehouses				Production	Production	Fixed cost	Fixed cost		**Summary of costs**	
4		Plants	United States	Turkey	China	India		cost/ton	cost/ton	per year	(USD)		Plant to whse	$690,000
5		United States	300	1300	1700	1500		11,000 USD	$11,000.00	100,000 USD	$100,000.00		Whse to cust	$1,015,000
6		Germany	1200	300	800	700		7500 Euro	$11,149.10	60,000 Euro	$89,192.81		Prod. cost	$3,221,029
7		Japan	2000	700	500	600		267,000 Yen	$3,000.67	2,000,000 Yen	$22,476.96		Foost plant	$57,943
8		China	1700	400	200	300		6800 RMB	$995.80	45,000 RMB	$6,589.83		Foost warehouse	$58,871
9		Brazil	700	1300	1500	1900		8,000 Real	$4,620.27	50,000 Real	$28,876.70		**Total cost**	**$5,042,843**
10					Customers									
11		Warehouse	United States	Canada	Brazil	Europe	Asia			Fixed Cost/year	Fixed cost (USD)			
12		United States	200	400	600	1300	2000			50,000 USD	$50,000.00			
13		Turkey	1300	1400	1500	400	500			10,000 Lira	$6,674.23			
14		China	1700	1800	1750	400	300			15,000 RMB	$2,196.61			
15		India	1500	1600	1650	500	400			200,000 Rupees	$4,300.06			
16			United States	Canada	Brazil	Europe	Asia							
17		Demand	300	250	150	300	500							
18	Anticipated	Exchange Rate	in 2009											
19		USA	Europe	Japan	China	Brazil	Turkey	India						
20		Dollar	Euro	Yen	RMB	Real	Lira	Rupee						
21	US Dollar	1	0.6727	88.98	6.8287	1.7315	1.4983	46.511						
22				Warehouses			Total		Production		Use Plants	Production		
23		Plants	United States	Turkey	China	India	Produced		Capacity (tons)		1 if yes,0 if no	Capacity (tons)		
24		United States	0	0	0	0	0	<=	0		0	350		
25		Germany	0	0	0	0	0	<=	0		0	250		
26		Japan	0	500	0	0	500	<=	500		1	500		
27		China	0	200	600	0	800	<=	800		1	800		
28		Brazil	200	0	0	0	200	<=	300		1	300		
29		Shipped into	200	700	600	0								
30			=	=	=	=								
31		Shipprd out	200	700	600	0								
32					Customers			Shipped out		Storage	Use warehouse	Storage		
33		Warehouse	United States	Canada	Brazil	Europe	Asia	Warehouses		Capacity (tons)	1 if yes,0 if no	Capacity (tons)		
34		United States	200	0	0	0	0	200	<=	400	1	400		
35		Turkey	100	250	150	200	0	700	<=	700	1	700		
36		China	0	0	0	100	500	600	<=	600	1	600		
37		India	0	0	0	0	0	0	<=	0	0	500		
38		Sum	300	250	150	300	500							
39			>=	>=	>=	>=	>=							
40		Demand	300	250	150	300	500							
41														

Sheet1 Sheet2 Sheet3

Figure 5: Requirement 4 Solution

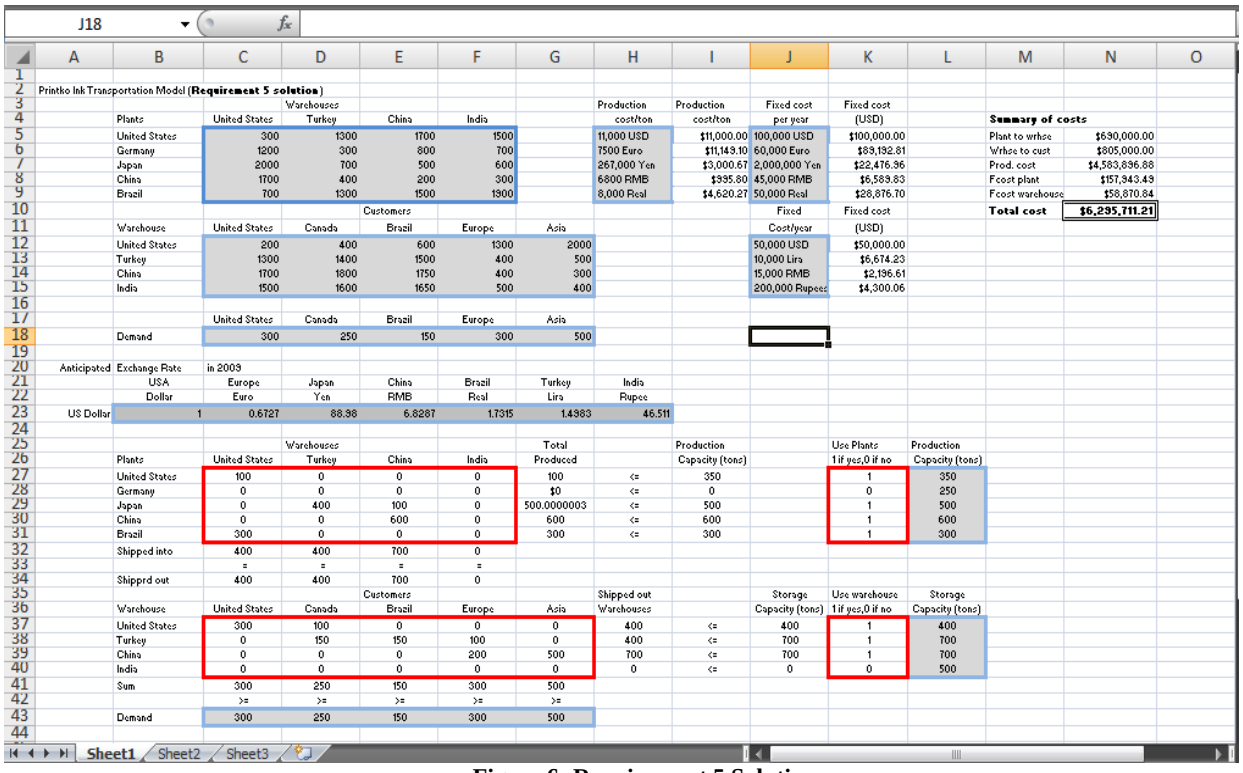
According to the spreadsheet solution, the minimum cost plan is $5,042,843. Therefore, adding 200 tons to production capacity to the plant in china will reduce the cost by $1,272,868. The solution suggested closing the plant in United States and the plant in Germany along with closing the warehouse in India. The minimum cost plan for requirement 4 suggested the following:

- Japan plant should produce 500 tons and ship it to Turkey warehouse.
- Out of the 800 tons produced in China's plant, 200 tons should be shipped to Turkey warehouse and 600 tons to China warehouse.
- Brazil Plant should produce 200 tons and ship it to United States warehouse.
- United States warehouse should ship 200 tons to United States customers.
- Out of the 700 tons received by Turkey warehouse, 100 tons should be shipped to United States customers, 250 tons to Canada customers, 150 tons to Brazil customers, and 200 tons to Europe customer.
- Out of the 600 tons received by China warehouse, 100 tons should be shipped to Europe customers and 500 tons to Asia customers.

Requirement 5: Refer to the original input; can an increase of 100 tons to China's warehouse storage capacity help reducing total cost? Explain your findings.

Requirement 5 solution:

Figure 6 represents the solution to requirement 5.



Printko Ink Transportation Model (**Requirement 5 solution**)

Plants	United States	Turkey	China	India	Production cost/ton	Production cost/ton	Fixed cost per year	Fixed cost (USD)
United States	300	1300	1700	1500	11,000 USD	$11,000.00	100,000 USD	$100,000.00
Germany	1200	300	800	700	7500 Euro	$11,143.10	60,000 Euro	$89,132.81
Japan	2000	700	500	600	267,000 Yen	$3,000.67	2,000,000 Yen	$22,476.36
China	1700	400	200	300	6800 RMB	$395.80	45,000 RMB	$6,583.83
Brazil	700	1300	1500	1900	8,000 Real	$4,620.27	50,000 Real	$28,876.70

Summary of costs	
Plant to whse	$690,000.00
Whse to cust	$805,000.00
Prod. cost	$4,583,896.88
Fcost plant	$157,943.43
Fcost warehouse	$58,870.84
Total cost	**$6,295,711.21**

Warehouse	United States	Canada	Brazil	Europe	Asia	Fixed Cost/year	Fixed cost (USD)
United States	200	400	600	1300	2000	50,000 USD	$50,000.00
Turkey	1300	1400	1500	400	500	10,000 Lira	$6,674.23
China	1700	1800	1750	400	300	15,000 RMB	$2,196.61
India	1500	1600	1650	500	400	200,000 Rupees	$4,300.06

	United States	Canada	Brazil	Europe	Asia
Demand	300	250	150	300	500

Anticipated Exchange Rate in 2009

	USA Dollar	Europe Euro	Japan Yen	China RMB	Brazil Real	Turkey Lira	India Rupee
US Dollar	1	0.6727	88.38	6.8287	1.7315	1.4383	46.511

Plants	United States	Turkey	China	India	Total Produced		Production Capacity (tons)	Use Plants 1 if yes,0 if no	Production Capacity (tons)
United States	100	0	0	0	100	<=	350	1	350
Germany	0	0	0	0	$0	<=	0	0	250
Japan	0	400	100	0	500.0000003	<=	500	1	500
China	0	0	600	0	600	<=	600	1	600
Brazil	300	0	0	0	300	<=	300	1	300
Shipped into	400	400	700	0					
	=	=	=	=					
Shipprd out	400	400	700	0					

Warehouse	United States	Canada	Brazil	Europe	Asia	Shipped out Warehouses		Storage Capacity (tons)	Use warehouse 1 if yes,0 if no	Storage Capacity (tons)
United States	300	100	0	0	0	400	<=	400	1	400
Turkey	0	150	150	100	0	400	<=	700	1	700
China	0	0	0	200	500	700	<=	700	1	700
India	0	0	0	0	0	0	<=	0	0	500
Sum	300	250	150	300	500					
	>=	>=	>=	>=	>=					
Demand	300	250	150	300	500					

Figure 6: Requirement 5 Solution

According to the spreadsheet solution to requirement 5, the minimum cost plan is $6,295,711. Therefore, increasing China's warehouse storage capacity by 100 tons will reduce the cost by $20,000. The solution suggested closing the plant in Germany along with closing the warehouse in India. The minimum cost plan for requirement 5 suggested the following:

- United States plants should produce 100 tons of ink and ship it to United States warehouse.
- Out of the 500 tons produced at Japan's plant, 400 tons should be shipped to Turkey warehouse and 100 tons to China warehouse.

- China plant should produce 600 tons and ship it to China warehouse.
- Brazil Plant should produce 300 tons and ship it to United States warehouse.
- Out of the 400 tons received at the United States warehouse, 300 tons should be shipped to Unites States customers and 100 tons to Canada customers.
- Out of the 400 tons received at Turkey warehouse, 150 tons should be shipped to Canada customers, 150 tons to Brazil customers, and 100 tons to Europe customers.
- Out of the 700 tons received at China warehouse, 200 tons should be shipped to Europe customers and 500 tons to Asia customers.

Requirement 6: Given requirement 5 input, if China can produce all your demand (i.e.1500 tons), how does this change affect your decisions?

Requirement 6 solution:

Figure 7 represents the solution to requirement 6.

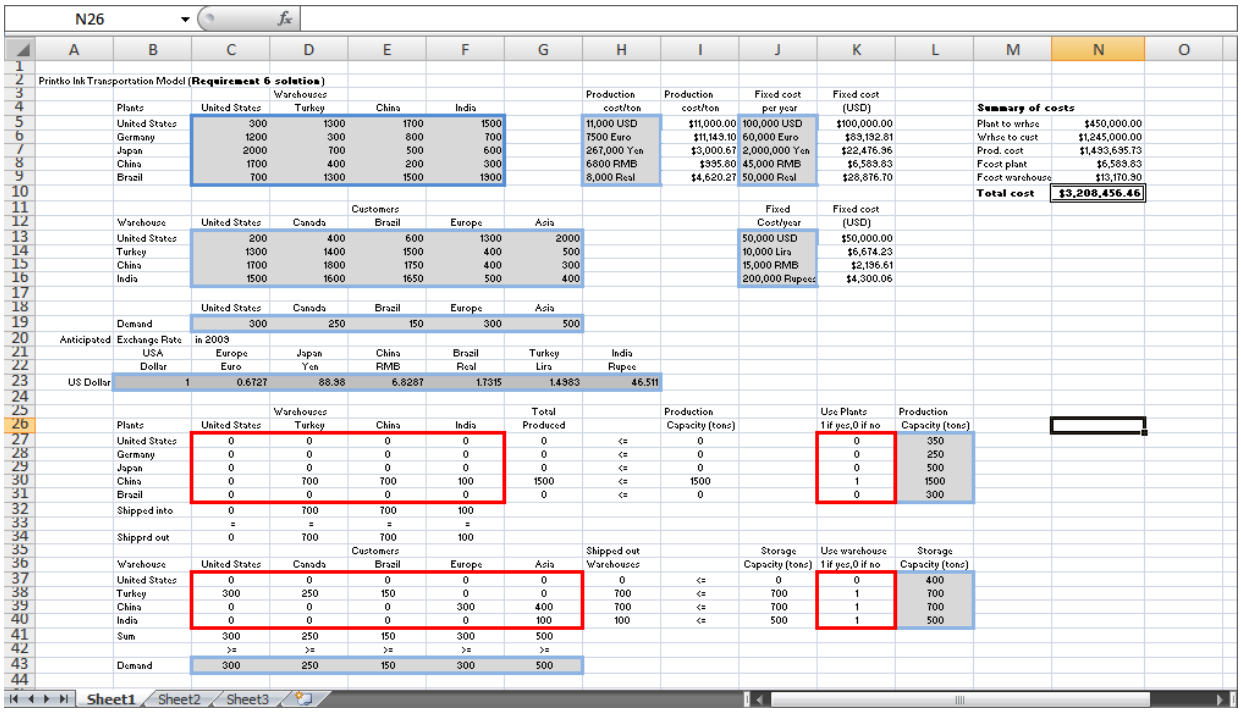


Figure 7: Requirement 6 Solution

According to the spreadsheet solution to requirement 6, the minimum cost plan is $3,208,456. If China can produce all the required demand, there is a reduction in the total cost by $3,107,255. The solution suggested closing all the plants except the plant in China along with closing the warehouse in Unites States. The minimum cost plan for requirement 6 suggested the following:

- Out of the 1500 tons produced in China's plant, 700 tons should be shipped to Turkey warehouse, 700 tons to China warehouse, and 100 tons to India warehouse.
- Out of the 700 tons received by Turkey warehouse, 300 tons should be shipped to the United States customers, 250 tons to Canada customers, and 150 tons to Brazil customers.
- Out of the 700 tons received by China warehouse, 300 tons should be shipped to Europe customers and 400 tons to Asia customers.
- India warehouse should ship 100 tons to Asia customers.

Learning Objectives:

1. To use network diagrams to represent the problem graphically. This graphic presentation will be used to develop the spreadsheet model.
2. To use binary variable (0&1) in order to take care of fixed costs. Fixed cost is not a linear function; therefore the use of binary variables will transform a non linear model into a linear one.
3. To develop a spreadsheet model to minimize total cost without the need to formulate the problem algebraically.
4. To be able to transfer all the cost into U.S dollars using the exchange rates.

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