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 distribution 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

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

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Fixed cost /year</th>
<th>Storage Capacity (tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>50,000 USD</td>
<td>400</td>
</tr>
<tr>
<td>Turkey</td>
<td>10,000 Lira</td>
<td>700</td>
</tr>
<tr>
<td>China</td>
<td>15,000 RMB</td>
<td>600</td>
</tr>
<tr>
<td>India</td>
<td>200,000 Rupees</td>
<td>500</td>
</tr>
</tbody>
</table>

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

### Table 3: Customers Demand

<table>
<thead>
<tr>
<th>Country</th>
<th>Yearly Demand (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>300</td>
</tr>
<tr>
<td>Canada</td>
<td>250</td>
</tr>
<tr>
<td>Brazil</td>
<td>150</td>
</tr>
<tr>
<td>Europe</td>
<td>300</td>
</tr>
<tr>
<td>Asia</td>
<td>500</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Country</th>
<th>United States</th>
<th>Turkey</th>
<th>China</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>300</td>
<td>1300</td>
<td>1700</td>
<td>1500</td>
</tr>
<tr>
<td>Germany</td>
<td>1200</td>
<td>300</td>
<td>800</td>
<td>700</td>
</tr>
<tr>
<td>Japan</td>
<td>2000</td>
<td>700</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>China</td>
<td>1700</td>
<td>400</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Brazil</td>
<td>700</td>
<td>1300</td>
<td>1500</td>
<td>1900</td>
</tr>
</tbody>
</table>
Table 5: Transportation Costs in US Dollars per Ton from Warehouses to Customers

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Canada</th>
<th>Brazil</th>
<th>Europe</th>
<th>Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>200</td>
<td>400</td>
<td>600</td>
<td>1300</td>
<td>2000</td>
</tr>
<tr>
<td>Turkey</td>
<td>1300</td>
<td>1400</td>
<td>1500</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>China</td>
<td>1700</td>
<td>1800</td>
<td>1750</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>India</td>
<td>1500</td>
<td>1600</td>
<td>1650</td>
<td>500</td>
<td>400</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>USA USD</th>
<th>Europe Euro</th>
<th>Japan Yen</th>
<th>China RMB</th>
<th>Brazil Real</th>
<th>Turkey Lira</th>
<th>India Rupee</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD</td>
<td>1.0</td>
<td>0.6727</td>
<td>88.98</td>
<td>6.8287</td>
<td>1.7315</td>
<td>1.4983</td>
<td>46.511</td>
</tr>
</tbody>
</table>

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.
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.

Figure 3: Requirement 2 Solution

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 requirement 2, the plant in Germany and the warehouse in India should not be open.

Requirement 4: 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.

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.

![Figure 6: Requirement 5 Solution](image)

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 United 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](image)

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 United 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.

AUTHOR INFORMATION

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REFERENCES
