

*CASE STUDY*

*eleven*  
**Supply Chain  
Management**

*case study*  
**OVERVIEW**

CS11.1	Application Overview and Model Development
CS11.2	Worksheets
CS11.3	User Interface
CS11.4	Procedures
CS11.5	Re-solve Options
CS11.6	Summary
CS11.7	Extensions

## CS11.1 *Application Overview and Model Development*

In this application, we seek the best production and shipping schedule that minimizes the supply chain's costs. These costs include production costs, holding costs, and shipping costs. For a given number of factories, products, customers, resources, and periods, we determine the number of products produced and shipped to each customer in order to minimize the total supply chain cost.

### CS11.1.1 **Model Definition and Assumptions**

The supply chain management model is a linear programming model in which we are trying to ascertain the number of products to produce and ship in order to minimize total costs of the supply chain. We define the parts of the model below. Keep in mind that the data given is multi-dimensional; in other words, some decisions are made per product  $i$ , per factory  $j$ , per customer  $k$ , per period  $t$ , and per resource  $r$ .

#### **Decision variables:**

- The number of each product to produce (in each factory for each period) =  $x_{ijt}$
- The number of each product to ship (from each factory to each customer for each period) =  $y_{jkt}$

#### **Constraints:**

- The amount shipped of each product (per factory in each period) must be less than or equal to the amount produced of each product (at each factory in each period). Remember that the amount shipped is also per customer; therefore we must sum these values over all customers for each product, factory, and period to compare it to the production amount.

$$\sum_k y_{jkt} \leq x_{ijt} \quad \text{for all } i, j, t$$

- The resources used (per factory per period) must be less than or equal to the available resources (per factory per period). Here, resources used are equal to the resources needed per product (given,  $N_{ri}$ ) times the amount produced of each product, and the available resources are given (per factory per period,  $A_{rjt}$ ).

$$\sum_i N_{ri} * x_{ijt} \leq A_{rjt} \quad \text{for all } r, j, t$$

- The ending inventory (per product per factory per period,  $V_{ijt}$ ) must be greater than 0 for each period. Here, we define the ending inventory of period  $t+1$  as equal to the ending inventory in period  $t$  plus the amount produced in period  $t+1$  minus the amount shipped in period  $t+1$ .

$$V_{ij(t+1)} = V_{ijt} + x_{ij(t+1)} - y_{ij(t+1)}$$

$$V_{ijt} \geq 0 \quad \text{for all } i, j, t$$

- The amount shipped (of each product from each factory to each customer) must meet the demand per customer. Here, the demand has been given per product per customer per period,  $D_{jkt}$ . Remember that the amount shipped is also per

factory; therefore we must sum these values over all factories for each product, customer, and period to compare it to the demand values.

$$\sum_j y_{ijkt} \geq D_{ikt}$$

- All decision variables should be greater than or equal to 0.

$$y_{ijkt} \geq 0, x_{ijt} \geq 0$$

**Objective function:**

Minimize total costs = total shipping costs + total holding costs + total production costs.

- Total shipping costs = amount shipped \* shipping costs per product from each factory to each customer. Here, shipping costs have been given per product per factory per customer,  $s_{ijk}$ . Remember that the amount shipped is also per period; therefore we must sum these values over all periods for each product, customer, and factory to multiply with the shipping costs.

$$\sum_t y_{ijkt} * s_{ijk}$$

- Total holding costs = ending inventory \* holding cost per product per factory per period. Here, holding costs have been given per product per period,  $h_{it}$ . Remember that the ending inventory is also in terms of factories; therefore we must sum these values over all factories to multiply with the holding costs.

$$\sum_j V_{ijt} * h_{it}$$

- Total production costs = amount produced \* production cost per product per factory per period. Here, production costs are given per product per factory per period,  $p_{ijt}$ .

$$x_{ijt} * p_{ijt}$$

- Total costs:

$$z = \sum_i \sum_j \sum_k (\sum_t y_{ijkt} * s_{ijk}) + \sum_i \sum_t (\sum_j V_{ijt} * h_{it}) + \sum_i \sum_j \sum_t (x_{ijt} * p_{ijt})$$

To prepare this model, we use a worksheet that includes the Solver, which finds the solution. We place empty cells for each decision variable and use these cells as well as some input cells to create the formulas for the constraints and the objective function.

### CS11.1.2 **Input**

The input for this application is the following:

- The number of factories
- The number of products
- The number of customers
- The number of resources
- The number of periods
- The demand per product per customer per period
- The availability per resource per factory per period

- The need per resource per product
- The holding costs per product per period
- The production costs per product per factory per period
- The shipping costs per product per factory per customer
- The initial inventory per product per factory

### CS11.1.3 Output

The output for this application is the following:

- The total supply chain costs
- The production plan per product per factory per period
- The shipping plan per product per factory per customer per period
- The total shipping costs per product per factory per customer
- The total holding costs per product per factory per period
- The total production costs per product per factory per period

## CS11.2 Worksheets

This application requires over twenty worksheets: the welcome sheet, a model description sheet, seven input sheets, the model calculations sheet, a report sheet, a detailed output sheet, and ten output sheets that include pivot tables and pivot charts. The welcome sheet contains the title, the description of the application, and the “Start” button. (See Figure CS11.1.) There is also a “Model Description” button in the application description that takes the user to the model description sheet. (See Figure CS11.2.) The model description sheet explains the supply chain management model in detail.



Figure CS11.1 The welcome sheet.

### Supply Chain Management Model Description

For a given number of factories, products, customers, resources, and periods, the number of products produced and shipped to each customer is determined to minimize the total supply chain cost.

Decisions are made per product  $i$ , per factory  $j$ , per customer  $k$ , per period  $t$ , and per resource  $r$ .



**Decision variables:**

- 1 Number to produce of each product (in each factory for each period) =  $x(ijt)$
- 2 Number to ship of each product (from each factory to each customer for each period) =  $y(ijkt)$

**Constraints:**

- 1 Amount shipped of each product (per factory in each period) must be less than or equal to the amount produced of each product (at each factory in each period). Remember that the amount shipped is also per customer, therefore we must sum these values over all customers for each product, factory, and period to compare it to the production amount.
 
$$\sum(k) y(ijkt) \leq x(ijt) \quad \text{for all } i, j, t$$
- 2 Resources used (per factory per period) must be less than or equal to available resources (per factory per period). Here, resources used are equal to the resources needed per product (given,  $N(rj)$ ) times the amount produced of each product, and the available resources are given (per factory per period,  $A(rjt)$ ).
 
$$\sum(i) N(rj) * x(ijt) \leq A(rjt) \quad \text{for all } r, j, t$$
- 3 Ending inventory (per product per factory per period,  $V(ijt)$ ) must be greater than 0 for each period. Here, we define the ending inventory of period  $t+1$  to be equal to the ending inventory in period  $t$  plus the amount produced in period  $t+1$  minus the amount shipped in period  $t+1$ .

Figure CS11.2 The model description sheet.

The seven input sheets are organized to receive the multi-dimensional input in tables corresponding to the problem size. The first of these is the demand sheet, which receives input on the demand per product per customer per period. (See Figure CS11.3.)

### Demand



Product	Customer	Period	Demand
1	1	1	1333
		2	2000
	2	1	1333
		2	2000
	3	1	1333
		2	2000
2	1	1	1333
		2	2000
	2	1	1333
		2	2000
	3	1	2000
		2	2133
3	1	1	2266
		2	2400
	2	1	2533
		2	2666
	3	1	2800
		2	2933

Figure CS11.3 The demand input sheet.

The available resources input sheet receives input on the amount of each resource available for each factory in each period. (See Figure CS11.4.)

Available Resources			
Resource	Factory	Period	Amount Available
1	1	1	100000
		2	100000
	2	1	100000
		2	100000
	3	1	100000
		2	100000
2	1	1	100000
		2	100000
	2	1	100000
		2	100000
	3	1	100000
		2	100000
3	1	1	100000
		2	100000
	2	1	100000
		2	100000
	3	1	100000
		2	100000

Figure CS11.4 The available resources input sheet.

The resources needed input sheet receives input about the amount needed of each resource for each product. (See Figure CS11.5.)

Resources Needed		
Resource	Product	Amount Needed
1	1	10
	2	10
	3	10
2	1	10
	2	10
	3	10
3	1	10
	2	10
	3	10

Figure CS11.5 The resources needed input sheet.

The holding costs input sheet receives the holding costs per product in each period. (See Figure CS11.6.)

Holding Costs		
Product	Period	Holding Cost
1	1	0.5
	2	0.5
2	1	0.5
	2	0.5
3	1	0.5
	2	0.5

Figure CS11.6 The holding costs input sheet.

The production costs input sheet receives input on the production cost per product for each factory in each period. (See Figure CS11.7.)

Production Costs

Return to Form

Product 1	Factory	Period	Production Cost
1	1	1	0.25
		2	0.25
	2	1	0.25
		2	0.25
	3	1	0.25
		2	0.25
2	1	1	0.25
		2	0.25
	2	1	0.25
		2	0.25
	3	1	0.25
		2	0.25
3	1	1	0.25
		2	0.25
	2	1	0.25
		2	0.25
	3	1	0.25
		2	0.25

Figure CS11.7 The production costs input sheet.

The shipping costs input sheet receives input for the shipping costs per product from each factory to each customer. (See Figure CS11.8.)

Shipping Costs

Return to Form

Product	Factory	Customer	Shipping Cost
1	1	1	0.15
		2	0.15
		3	0.15
	2	1	0.15
		2	0.15
		3	0.15
	3	1	0.15
		2	0.15
		3	0.15
2	1	1	0.15
		2	0.15
		3	0.15
	2	1	0.15
		2	0.15
		3	0.15
	3	1	0.15
		2	0.15
		3	0.15
3	1	1	0.15
		2	0.15
		3	0.15
	2	1	0.15
		2	0.15
		3	0.15
	3	1	0.15
		2	0.15
		3	0.15

Figure CS11.8 The shipping costs input sheet.

The initial inventory input sheet receives input on the initial inventory of each product at each factory. (See Figure CS11.9.)

Product	Factory	Initial Inventory
1	1	1000
	2	1000
	3	1000
2	1	1000
	2	1000
	3	1000
3	1	1000
	2	1000
	3	1000

Figure CS11.9 The initial inventory input sheet.

The model calculations sheet references all of the input on these input sheets to set up the constraints and the objective function for the model. (See Figure CS11.10.) This sheet prepares the decision variable cells, the constraint formulas, the constraint right-hand side values, and the objective function formulas so the Solver can optimize the supply chain management problem.

**Decision Variables**  
Number of products to produce at each factory per period

Product	Factory	Period	Number to Produce
1	1	1	0
	2	1	0
	3	1	0
2	1	1	3999
	2	1	5868
	3	1	0
	2	2	132
2	1	1	2401
	2	2	2001
2	2	1	2265
	2	2	4132
3	1	1	0
	2	2	0
3	1	1	7599
	2	2	7999
2	1	1	0
	2	2	0
3	1	1	0
	2	2	0

Number of products to ship to each customer

Product	Factory	Customer	Period	Number to Ship
1	1	1	1	0
		2	1	0
		3	1	0
	2	1	1	1333
		2	2	1868
	2	1	1	1333
		2	2	2000
	3	1	1	1333
		2	2	2000
	3	1	1	0
		2	2	132
2	1	1	1	0
		2	1	401
		3	1	2000
		2	2	2001

**Constraints**  
Amount shipped per factory must be less than or equal to amount available

Product	Factory	Period	Number Shipped	Constraint
1	1	1	0	<=
	2	1	0	<=
	3	1	0	<=
2	1	1	3999	<=
	2	1	5868	<=
	3	1	0	<=
	2	2	132	<=
2	1	1	2401	<=
	2	2	2001	<=
2	2	1	2265	<=
	2	2	4132	<=
3	1	1	0	<=
	2	2	0	<=
3	1	1	7599	<=
	2	2	7999	<=
2	1	1	0	<=
	2	2	0	<=
3	1	1	0	<=
	2	2	0	<=

Figure CS11.10 The model sheet.

Once the problem has been solved, the user is taken to the report sheet. (See Figure CS11.11.) This sheet is used as a navigational interface for all of the output sheets. The user can also view the model calculations sheet or a detailed output sheet. The detailed output sheet stores the resulting decision variable and the cost values found by the Solver. (See Figure CS11.12.)

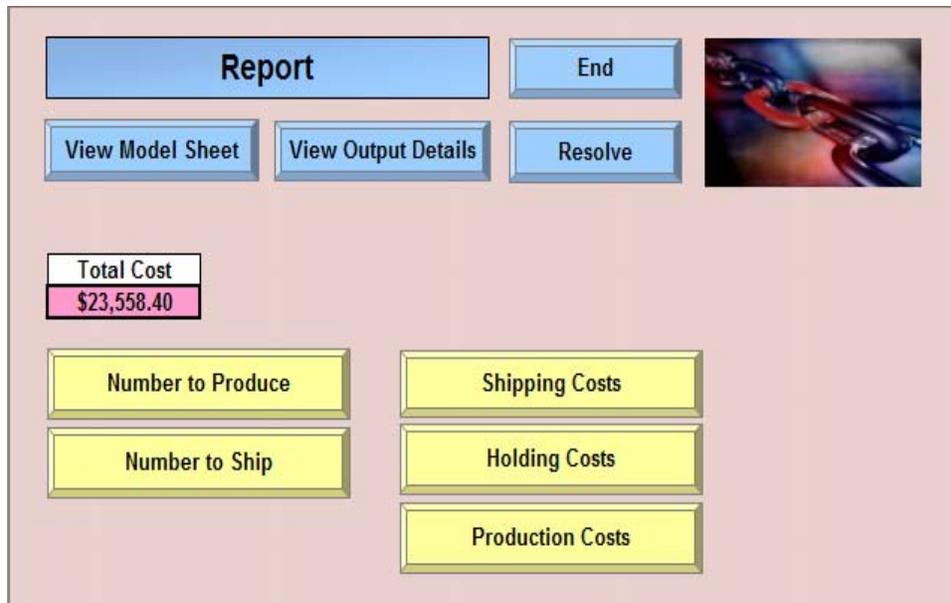


Figure CS11.11 The report sheet.

Number of products produced at each factory per period				Number of products shipped to each customer					Final Shipping Costs			
Product	Factory	Period	Number to Produce	Product	Factory	Customer	Period	Number to Ship	Product	Factory	Customer	Total Shipped
1	1	1	0.00	1	1	1	1	0.00	1	1	1	\$0
1	1	2	0.00	1	1	1	2	0.00	1	1	2	\$0
1	2	1	3999.00	1	1	2	1	0.00	1	1	3	\$0
1	2	2	5868.00	1	1	2	2	0.00	1	2	1	\$48
1	3	1	0.00	1	1	3	1	0.00	1	2	2	\$49
1	3	2	132.00	1	1	3	2	0.00	1	2	3	\$49
2	1	1	2401.00	1	2	1	1	1333.00	1	3	1	\$15
2	1	2	2001.00	1	2	1	2	1868.00	1	3	2	\$0
2	2	1	2265.00	1	2	2	1	1333.00	1	3	3	\$0
2	2	2	4132.00	1	2	2	2	2000.00	2	1	1	\$0
2	3	1	0.00	1	2	3	1	1333.00	2	1	2	\$61
2	3	2	0.00	1	2	3	2	2000.00	2	1	3	\$60
3	1	1	7599.00	1	3	1	1	0.00	2	2	1	\$49
3	1	2	7999.00	1	3	1	2	132.00	2	2	2	\$43
3	2	1	0.00	1	3	2	1	0.00	2	2	3	\$15
3	2	2	0.00	1	3	2	2	0.00	2	3	1	\$0
3	3	1	0.00	1	3	3	1	0.00	2	3	2	\$0
3	3	2	0.00	1	3	3	2	0.00	2	3	3	\$0
2	1	1	0.00	2	1	1	1	0.00	3	1	1	\$69
2	1	1	0.00	2	1	1	2	0.00	3	1	2	\$77
2	1	2	401.00	2	1	2	1	0.00	3	1	3	\$85
2	1	2	0.00	2	1	2	2	0.00	3	2	1	\$0
2	1	3	2000.00	2	1	3	1	2000.00	3	2	2	\$0
2	1	3	2001.00	2	1	3	2	2001.00	3	2	3	\$0
2	2	1	1333.00	2	2	1	1	1333.00	3	3	1	\$0
2	2	1	2000.00	2	2	1	2	2000.00	3	3	2	\$0

Figure CS11.12 The detailed output sheet.

The ten output sheets that the user can view include five output categories, each with a pivot table output sheet and a pivot chart output sheet. We include pivot tables and pivot charts to allow the user to filter and organize the results for greater clarity and analysis. Pivot tables and pivot charts are especially helpful when working with multi-dimensional data. (See Chapter 6.)

The number to produce output sheet contains a pivot table of the amount of each product produced per factory per period. (See Figure CS11.13.) From here, the user can also view the corresponding pivot chart sheet. (See Figure CS11.14.)

Number to Produce				
Number to Produce		Period		
Product	Factory	1	2	Grand Total
1	1	0.00	2000.00	2000.00
	2	3999.00	4000.00	7999.00
	3	0.00	0.00	0.00
<b>1 Total</b>		<b>3999.00</b>	<b>6000.00</b>	<b>9999.00</b>
2	1	2000.00	0.00	2000.00
	2	2666.00	4000.00	6666.00
	3	0.00	2133.00	2133.00
<b>2 Total</b>		<b>4666.00</b>	<b>6133.00</b>	<b>10799.00</b>
3	1	0.00	0.00	0.00
	2	3335.00	2000.00	5335.00
	3	4264.00	5999.00	10263.00
<b>3 Total</b>		<b>7599.00</b>	<b>7999.00</b>	<b>15598.00</b>
<b>Grand Total</b>		<b>16264.00</b>	<b>20132.00</b>	<b>36396.00</b>

Figure CS11.13 The number to produce output sheet with pivot table.

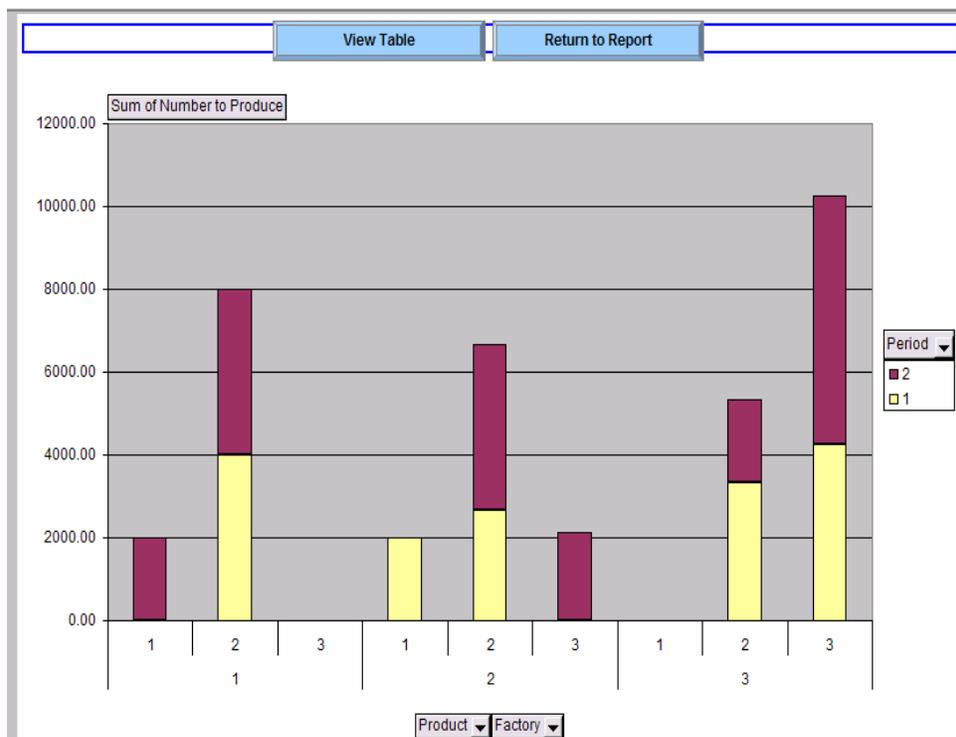


Figure CS11.14 The number to produce output pivot chart.

The number to ship output sheet contains a pivot table of the amount of each product that will ship from each factory to each customer in each period. (See Figure CS11.15.) The corresponding pivot chart appears in Figure CS11.16.

Number to Ship					
Number to Ship			Period		
Product	Factory	Customer	1	2	Grand Total
1	1	1	0.00	2000.00	2000.00
		2	0.00	0.00	0.00
		3	0.00	0.00	0.00
	1 Total		0.00	2000.00	2000.00
	2	1	1333.00	0.00	1333.00
		2	1333.00	2000.00	3333.00
		3	1333.00	2000.00	3333.00
2 Total		3999.00	4000.00	7999.00	
3	1	1	0.00	0.00	0.00
		2	0.00	0.00	0.00
		3	0.00	0.00	0.00
	3 Total		0.00	0.00	0.00
1 Total			3999.00	6000.00	9999.00
2	1	1	0.00	0.00	0.00
		2	0.00	0.00	0.00
		3	2000.00	0.00	2000.00
	1 Total		2000.00	0.00	2000.00
	2	1	1333.00	2000.00	3333.00
		2	1333.00	2000.00	3333.00
		3	0.00	0.00	0.00
	2 Total		2666.00	4000.00	6666.00
	3	1	0.00	0.00	0.00
		2	0.00	0.00	0.00
3		0.00	2133.00	2133.00	
3 Total		0.00	2133.00	2133.00	

Figure CS11.15 The number to ship output sheet with pivot table.

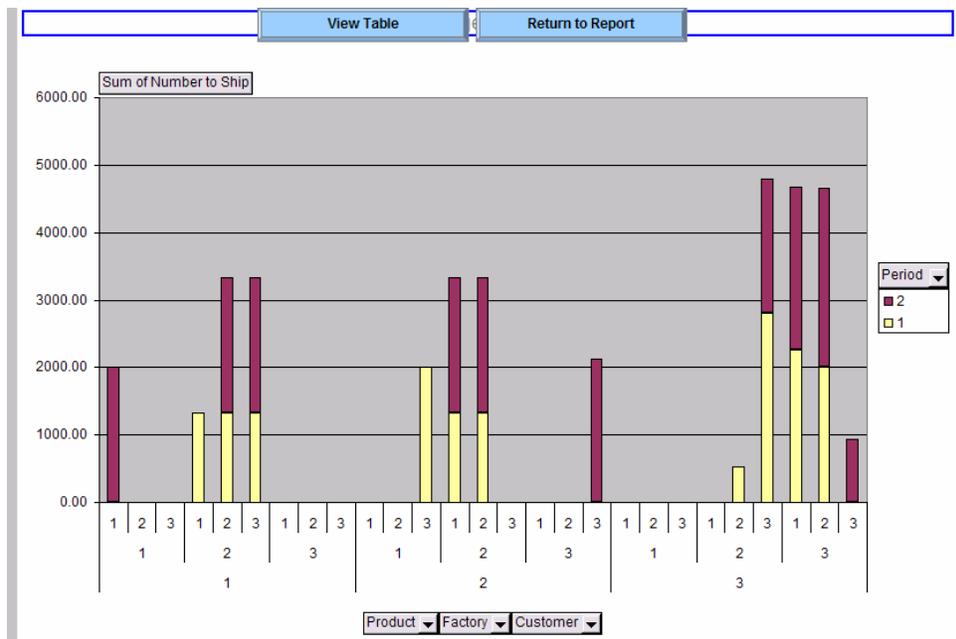


Figure CS11.16 The number to ship output pivot chart.

The shipping costs output sheet contains a pivot table with the total shipping costs for each product from each factory to each customer. (See Figure CS11.17.) There is also an associated pivot chart sheet. (See Figure CS11.18.)

Shipping Costs						Return to Report
Total Shipping Cost		Customer			Grand Total	View Chart
Product	Factory	1	2	3		
1	1	\$300.00	\$0.00	\$0.00	\$300.00	
	2	\$199.95	\$499.95	\$499.95	\$1,199.85	
	3	\$0.00	\$0.00	\$0.00	\$0.00	
<b>1 Total</b>		<b>\$499.95</b>	<b>\$499.95</b>	<b>\$499.95</b>	<b>\$1,499.85</b>	
2	1	\$0.00	\$0.00	\$300.00	\$300.00	
	2	\$499.95	\$499.95	\$0.00	\$999.90	
	3	\$0.00	\$0.00	\$319.95	\$319.95	
<b>2 Total</b>		<b>\$499.95</b>	<b>\$499.95</b>	<b>\$619.95</b>	<b>\$1,619.85</b>	
3	1	\$0.00	\$0.00	\$0.00	\$0.00	
	2	\$0.00	\$80.25	\$720.00	\$800.25	
	3	\$699.90	\$699.60	\$139.95	\$1,539.45	
<b>3 Total</b>		<b>\$699.90</b>	<b>\$779.85</b>	<b>\$859.95</b>	<b>\$2,339.70</b>	
<b>Grand Total</b>		<b>\$1,699.80</b>	<b>\$1,779.75</b>	<b>\$1,979.85</b>	<b>\$5,459.40</b>	

Figure CS11.17 The shipping costs output sheet with pivot table.

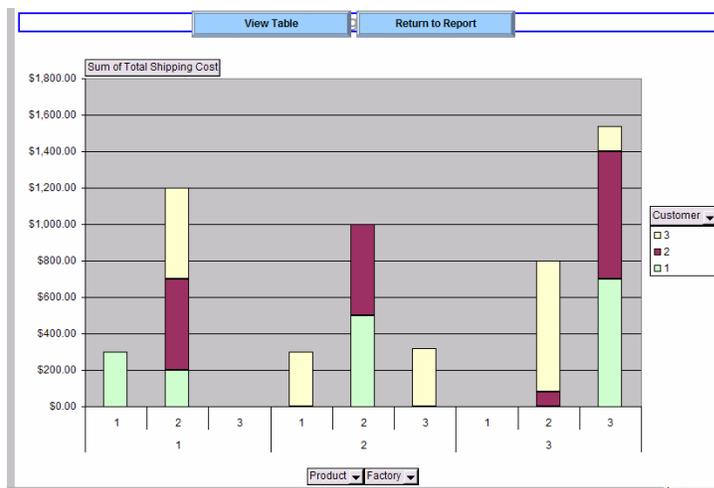


Figure CS11.18 The shipping costs output pivot chart.

The holding costs output sheet contains a pivot table with the total holding costs for each product at each factory in each period. (See Figure CS11.19.) The corresponding pivot chart sheet appears in Figure CS11.20.

Holding Costs					Return to Report
Total Holding Cost		Period		Grand Total	View Chart
Product	Factory	1	2		
1	1	\$500.00	\$500.00	\$1,000.00	
	2	\$500.00	\$500.00	\$1,000.00	
	3	\$500.00	\$500.00	\$1,000.00	
<b>1 Total</b>		<b>\$1,500.00</b>	<b>\$1,500.00</b>	<b>\$3,000.00</b>	
2	1	\$500.00	\$500.00	\$1,000.00	
	2	\$500.00	\$500.00	\$1,000.00	
	3	\$500.00	\$500.00	\$1,000.00	
<b>2 Total</b>		<b>\$1,500.00</b>	<b>\$1,500.00</b>	<b>\$3,000.00</b>	
3	1	\$500.00	\$500.00	\$1,000.00	
	2	\$500.00	\$500.00	\$1,000.00	
	3	\$500.00	\$500.00	\$1,000.00	
<b>3 Total</b>		<b>\$1,500.00</b>	<b>\$1,500.00</b>	<b>\$3,000.00</b>	
<b>Grand Total</b>		<b>\$4,500.00</b>	<b>\$4,500.00</b>	<b>\$9,000.00</b>	

Figure CS11.19 The holding costs output sheet with pivot table.

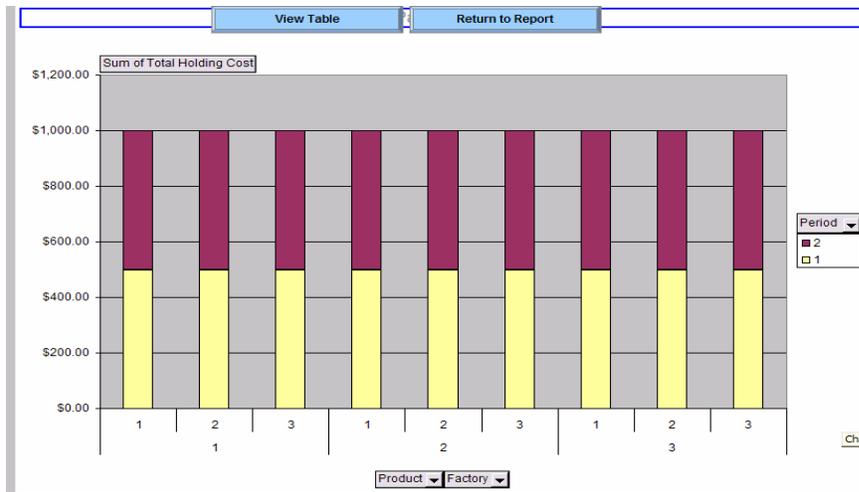


Figure CS11.20 The holding costs output pivot chart.

The production costs output sheet contains a pivot table with the total production costs of each product in each factory for each period. (See Figure CS11.21.) There is also a corresponding pivot chart sheet. (See Figure CS11.22.)

Production Costs				
Total Production Cost		Period		Grand Total
Product	Factory	1	2	
1	1	\$0.00	\$500.00	\$500.00
	2	\$999.75	\$1,000.00	\$1,999.75
	3	\$0.00	\$0.00	\$0.00
<b>1 Total</b>		<b>\$999.75</b>	<b>\$1,500.00</b>	<b>\$2,499.75</b>
2	1	\$500.00	\$0.00	\$500.00
	2	\$666.50	\$1,000.00	\$1,666.50
	3	\$0.00	\$533.25	\$533.25
<b>2 Total</b>		<b>\$1,166.50</b>	<b>\$1,533.25</b>	<b>\$2,699.75</b>
3	1	\$0.00	\$0.00	\$0.00
	2	\$833.75	\$500.00	\$1,333.75
	3	\$1,066.00	\$1,499.75	\$2,565.75
<b>3 Total</b>		<b>\$1,899.75</b>	<b>\$1,999.75</b>	<b>\$3,899.50</b>
<b>Grand Total</b>		<b>\$4,066.00</b>	<b>\$5,033.00</b>	<b>\$9,099.00</b>

Figure CS11.21 The production costs output sheet with pivot table.

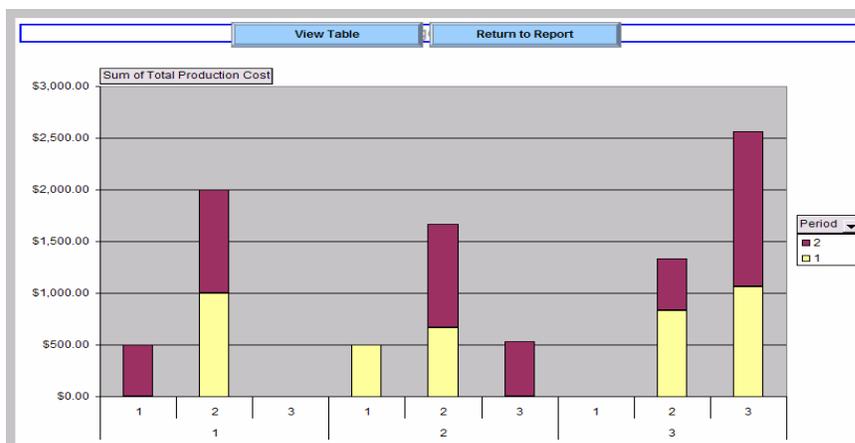


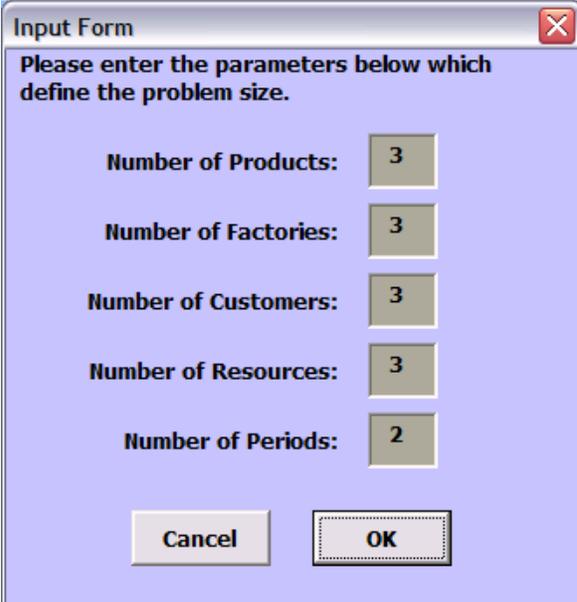
Figure CS11.22 The production costs output pivot chart.

 <b>Summary</b>	<b>Welcome sheet</b>	Contains an application description and the “Start” button.
	<b>Model description sheet</b>	Describes the supply chain model in detail.
	<b>Input sheets</b>	Contain input tables for the demand, the available resources, the resources needed, the holding costs, the production costs, the shipping costs, and the initial inventory.
	<b>Model calculations sheet</b>	Prepares the decision variable cells, the constraint formulas, the right-hand side values, and the objective function formulas for using the Solver.
	<b>Detailed output sheet</b>	Contains detailed results of the model solution.
	<b>Report sheet</b>	Contains the navigational interface for all the output sheets.
	<b>Output sheets</b>	Contain pivot table and pivot chart sheets for the production plan, the shipping plan, the shipping costs, the holding costs, and the production costs.

## CS11.3 *User Interface*

For this application’s user interface, we include navigational and functional buttons as well as two user forms. On the welcome sheet, the “Start” button displays the first user form. The “Model Description” button takes the user to the model description sheet, and the “Return to Application” button on that sheet returns the user to the welcome sheet.

The first user form is the input form. (See Figure CS11.23.) It receives the parameters that define the size of the problem: the number of products, the number of factories, the number of customers, the number of resources, and the number of periods. For this application, we assume these values are fixed as shown.



**Input Form**

Please enter the parameters below which define the problem size.

Number of Products: 3

Number of Factories: 3

Number of Customers: 3

Number of Resources: 3

Number of Periods: 2

Cancel OK

Figure CS11.23 The input form.

The second user form is a navigational form for the input sheets. (See Figure CS11.24.) Each button on the form takes the user to the respective input sheet. The “Solve” button on the bottom of the form is a functional button that calls the procedures to solve the problem.



Figure CS11.24 The navigation form for the input sheets.

A “Return to Form” button on every input sheet takes the user back to the navigational form for the input sheets. On the report sheet, the “View Model Sheet” button takes the user to the model calculations sheet, and the “View Detailed Output” button takes the user to the detailed output sheet. In Section CS13.5, we will discuss the “Re-solve” button. The other buttons take the user to the respective output sheets, and the “End” button returns the user to the welcome sheet. Each output sheet contains two buttons: “Return to Report” and “View Chart.” Each pivot chart sheet also contains two buttons: “Return to Table” and “Return to Report.”

 <p><b>Summary</b></p>	<p><b>Navigational buttons</b></p>	<p>“Start” and “Model Description” on welcome sheet, “Return to Application” on model description sheet, buttons for input sheets, “Return to Form” on input sheets, “View Model Sheet” and “View Detailed Output” on report sheet, buttons for output sheets, “Return to Report” and “View Chart” on pivot table output sheets, and “Return to Table” and “Return to Report” on pivot chart sheets.</p>
	<p><b>Functional buttons</b></p>	<p>“Solve” on the navigational user form and “Re-solve” on the report sheet.</p>
	<p><b>Input form</b></p>	<p>Receives the number of products, the number of factories, the number of customers, the number of resources, and the number of periods.</p>
	<p><b>Navigational form for input sheets</b></p>	<p>Navigates the user to all the input sheets; the “Solve” button runs the model calculation procedures.</p>

## CS11.4 *Procedures*

We will now outline the procedures for this application beginning with the initial sub procedures and variable definitions. (See Figure CS11.25.) The “Start” button calls the *Main* procedure, which begins by calling the *ClearPrev* procedure. (We have currently put a comment mark in front of this code so the user can use the default values if desired.) It then initializes some variables and presents the input form. If the application is dynamic, it would then need to call a procedure to create the tables using the size values provided on the input form. Finally, it calls the navigation form for the input sheets.

```
Option Explicit

Public i As Integer, j As Integer, _
NFac As Integer, NProd As Integer, NCust As Integer, NRes As Integer, NPer As Integer, _
result As Variant, ws As Worksheet

Sub MAIN() 'called from Start button on welcome sheet
    'Call ClearPrev

    NFac = 3
    NProd = 3
    NCust = 3
    NRes = 3
    NPer = 2

    frmInput.Show
    'Call CreateTables
    frmSheets.Show
End Sub

Sub ClearPrev() 'optional for clearing data values on input sheets
    Application.ScreenUpdating = False
    'Demand sheet
    Range(Range("DemandStart").Offset(1, 3), Range("DemandStart").Offset(1, 3).End(xlDown)).ClearContents
    'Available Resources sheet
    Range(Range("AmountRes").Offset(1, 3), Range("AmountRes").Offset(1, 3).End(xlDown)).ClearContents
    'Resources Needed Sheet
    Range(Range("ResNeeded").Offset(1, 2), Range("ResNeeded").Offset(1, 2).End(xlDown)).ClearContents
    'Holding Cost sheet
    Range(Range("HoldCost").Offset(1, 2), Range("HoldCost").Offset(1, 2).End(xlDown)).ClearContents
    'Production Cost sheet
    Range(Range("ProdCost").Offset(1, 3), Range("ProdCost").Offset(1, 3).End(xlDown)).ClearContents
    'Shipping Cost sheet
    Range(Range("ShipCost").Offset(1, 3), Range("ShipCost").Offset(1, 3).End(xlDown)).ClearContents
    'Initial Inventory Sheet
    Range(Range("InitInv").Offset(1, 2), Range("InitInv").Offset(1, 2).End(xlDown)).ClearContents
    Application.ScreenUpdating = True
End Sub
```

Figure CS11.25 The variable declarations and the *Main* and *ClearPrev* procedures.

The procedures for the input form simply display the default values for the problem size. (See Figure CS11.26.) If the application allowed the user to change these values, the new sizes would need to be recorded.

```

Sub cmdCancel_Click()
    Worksheets("Welcome").Visible = True
    Unload Me
End Sub

Sub cmdOK_Click()
    'no change to default values is allowed
    Unload Me
End Sub

Private Sub UserForm_Initialize()
    txtNumFac.Value = NFac
    txtNumProd.Value = NProd
    txtNumCust.Value = NCust
    txtNumRes.Value = NRes
    txtNumPer.Value = NPer
End Sub

```

Figure CS11.26 The procedures for the input form.

The procedures for the second user form include several navigational procedures to take the user to the various input sheets. (See Figure CS11.27.)

```

Sub cmdHoldCost_Click()
    Worksheets("HoldingCost").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Sub cmdInitInv_Click()
    Worksheets("InitialInv").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Private Sub cmdProdCost_Click()
    Worksheets("ProductionCost").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Sub cmdResNeed_Click()
    Worksheets("ResNeeded").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Sub cmdShipCost_Click()
    Worksheets("ShippingCost").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Sub cmdDemand_Click()
    Worksheets("Demand").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

Sub cmdAvailRes_Click()
    Worksheets("AvailRes").Visible = True
    Worksheets("Welcome").Visible = False
    Unload Me
End Sub

```

Figure CS11.27 The navigational procedures for the input sheets' navigational form.

Several additional procedures for this form perform some error checking and call the main procedure that solves the model, *SolveSCM*. (See Figure CS11.28.) The user is then taken to the report sheet.

```

Sub cmdCancel_Click()
Worksheets("Welcome").Visible = True
Unload Me
End
End Sub

Sub cmdSolve_Click()
'check that input has been inserted to tables on all sheets
If Range("DemandStart").Offset(1, 3).Value = "" Or Range("AmountRes").Offset(1, 3).Value = "" _
Or Range("ResNeeded").Offset(1, 2).Value = "" Or Range("HoldCost").Offset(1, 2).Value = "" _
Or Range("ProdCost").Offset(1, 3).Value = "" Or Range("ShipCost").Offset(1, 3).Value = "" _
Or Range("InitInv").Offset(1, 2).Value = "" Then
MsgBox "Please provide input values on all sheets."
Exit Sub
End If

Call SolveSCM

Worksheets("Report").Visible = True
Worksheets("Welcome").Visible = False
Unload Me
End Sub

```

Figure CS11.28 The additional procedures for the input sheets' navigational form.

The *SolveSCM* procedure is the main procedure of the application. (See Figure CS11.29.) Before the model can be solved, the model sheet must be prepared. However, since we assume this application is of a fixed parameter size, the necessary formulas and references have already been prepared in Excel. Therefore, we can simply activate this sheet and run the Solver commands. These commands set the objective function as the overall costs and the decision variables as the amount per product to produce and ship. Notice that the corresponding ranges have already been named in Excel to simplify the Solver references. The shipping, resources, inventory, and demand constraints are also set with the Solver commands. As the final Solver commands run, the feasibility of the problem is checked and the problem is solved.

```

Sub SolveSCM() 'called to run Solver for SCM model
Application.ScreenUpdating = False

'model sheet already prepared
Worksheets("Model").Visible = True
Worksheets("Model").Activate

'set Solver Input
SolverReset
SolverOK SetCell:=Range("OFTotalCost"), MaxMinVal:=2, ByChange:=Range("AllDV")
SolverAdd CellRef:=Range("ConShip"), Relation:=1, FormulaText:=Range("DVTtoProd")
SolverAdd CellRef:=Range("ConRes"), Relation:=1, FormulaText:=Range("RHSRes")
SolverAdd CellRef:=Range("ConInv"), Relation:=3, FormulaText:=Range("RHSInv")
SolverAdd CellRef:=Range("ConDemand"), Relation:=3, FormulaText:=Range("RHSDemand")

SolverOptions AssumeNonNeg:=True, AssumeLinear:=True
result = SolverSolve(UserFinish:=True)
If result = 5 Then
MsgBox "This problem is infeasible."
End If

Worksheets("Model").Visible = False
Application.ScreenUpdating = True
End Sub

```

Figure CS11.29 The *SolveSCM* procedure.

The report sheet requires several navigational procedures. (See Figure CS11.30.) These include procedures for the “View Model Sheet” and “View Detailed Output” buttons as well as the five buttons to view the output sheets.

```

.....
'navigational procedures for Report sheet
.....
Sub ViewModel() 'for View Model button
  Worksheets("Model").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewDetails() 'for View Details button
  Worksheets("Results").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewProd() 'for Production output sheet
  Worksheets("NumProd").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewShip() 'for Shipping output sheet
  Worksheets("NumShip").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewShipCost() 'for Shipping Costs output sheet
  Worksheets("ShipCost").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewHoldCost() 'for Holding Costs output sheet
  Worksheets("HoldCost").Visible = True
  Worksheets("Report").Visible = False
End Sub

Sub ViewProdCost() 'for Production Costs output sheet
  Worksheets("ProdCost").Visible = True
  Worksheets("Report").Visible = False
End Sub

```

Figure CS11.30 The navigational procedures for the report sheet.

Additionally navigational procedures are required for the output sheets and other sheets. (See Figure CS11.31.) The “Return to Report,” “View Chart,” and “Return to Table” buttons all need the output sheet procedures. Notice that we use a worksheet variable type here to avoid repeating these procedures for various sets of output sheets. The other navigational procedures are for the “Model Description,” “Return to Application,” “Return to Form,” “Re-solve,” and “End” buttons. Notice that the *Re-solve* procedure is used for the “Return to Application,” “Return to Form,” and “Re-solve” buttons.

```

.....
'navigational procedures for output sheets
.....
Sub ViewChart() 'for all View Chart buttons
  Set ws = ActiveSheet
  Sheets(ws.Name & "C").Visible = True
  ws.Visible = False
End Sub

Sub ReturnTable() 'for all Return Table buttons
  ws.Visible = True
  ActiveSheet.Visible = False
End Sub

Sub ReturntoReport() 'for all Return to Report buttons
  Worksheets("Report").Visible = True
  ActiveSheet.Visible = False
End Sub

.....
'other navigational procedures
.....
Sub Resolve() 'for Resolve button on Report sheet and all Return buttons on input sheets
  Worksheets("Welcome").Visible = True
  ActiveSheet.Visible = False
  frmSheets.Show
End Sub

Sub EndProg() 'for End button and Return to Application buttons
  Worksheets("Welcome").Visible = True
  ActiveSheet.Visible = False
End Sub

Sub ModelDescrip() 'for viewing Model Descrip sheet
  Worksheets("Descrip").Visible = True
  Worksheets("Welcome").Visible = False
End Sub

```

Figure CS11.31 The navigational procedures for the output sheets and other sheets.

 <b>Summary</b>	<b>Main</b>	Initializes the application and takes the user to the historical data sheet.
	<b>ClearPrev</b>	Clears the previous values on all the sheets.
	<b>Input form procedures</b>	Initialize and record the size parameters.
	<b>Navigational form for input sheets procedures</b>	Navigates to various input sheets, performs error checking, and calls the <i>SolveSCM</i> procedure.
	<b>SolveSCM</b>	Prepares the model sheet and runs the Solver commands.
	<b>Navigational procedures for report sheet</b>	Apply to the “View Model Sheet” and “View Detailed Output” buttons as well as to the five buttons for viewing the output sheets.
	<b>Navigational procedures for output sheets</b>	Apply to the “Return to Report,” “View Chart,” and “Return to Table” buttons.
	<b>Other navigational procedures</b>	Apply to the “Model Description,” “Return to Application,” “Return to Form,” “Re-solve,” and “End”

## CS11.5 *Re-solve Options*

The user can re-solve this application by pressing the “Re-solve” button on the report sheet. This button is assigned to the *Re-solve* procedure, which brings the user back to the welcome sheet and re-displays the navigational form for the input sheets. (See Figure CS11.31.) This procedure allows the user to change the input values and re-solve the model calculations. He or she can then return to the report sheet to view all of the output.

 <b>Summary</b>	<b>“Re-solve” button</b> After pressing it, the user returns to the navigational form for the input sheets to modify some or all of the input. The application is then re-solved, and the user return to the report sheet.
---	---

## CS11.6 *Summary*

- In this application, we seek the best production and shipping schedule that minimizes the supply chain’s costs. These costs include the production costs, the holding costs, and the shipping costs.
- This application requires over twenty worksheets: the welcome sheet, a model description sheet, seven input sheets, the model calculations sheet, a report sheet, a detailed output sheet, and ten output sheets that include pivot tables and pivot charts.
- For this application’s interface, we use navigational and functional buttons as well as two user forms.
- Several procedures in this application initialize and perform the model calculations to find the optimal production and shipping plans that minimize overall costs.

- The user can re-solve the application by pressing the “Re-solve” button on the report sheet; he or she revisits the input sheets, modifies the values, and re-solves the model.

## CS11.7 *Extensions*

---

- If the user were able to change the size parameters of the problem, which sheets would this affect?
- If the user were able to change the size parameters of the problem, which procedures would this affect?
- If the user were able to change the size parameters of the problem, what are some new procedures that would need to be created? Make these changes to the application so it is dynamic. What other re-solve options are now possible?