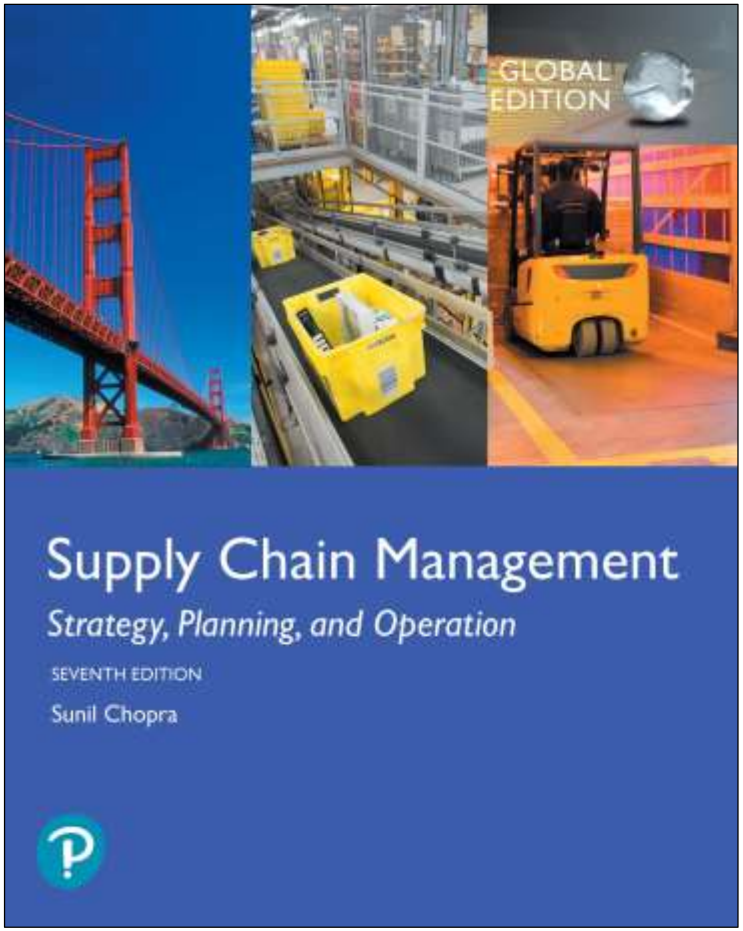
Supply Chain Management: Strategy, Planning, and Operation

Seventh Edition, Global Edition



Chapter 5

Network Design in the Supply Chain

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Learning Objectives (1 of 2)

5.1 Understand the role of network design in a supply chain.

5.2 Identify factors influencing supply chain network design decisions.

5.3 Discuss a framework for making network design decisions.

5.4 Develop an optimization model to design an regional network configuration.

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Learning Objectives (2 of 2)

5.5 Develop an optimization model to identify potential sites in a region.

5.6 Develop an optimization model to locate plants and allocate market demand.

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The Role of Network Design

- Network design decisions
  - How many manufacturing plants, production lines, distribution centers, cross-docking facilities?
  - Where should facilities be located?
  - How much capacity at each facility?
  - Which products?
  - What markets?

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Factors Influencing Network Design Decisions

- Strategic Factors
- Technological Factors (semiconductors vs bottling for coke)
- Macroeconomic Factors
  - ✓ Exchange rate and demand risk
  - ✓ Freight and fuel cost
- Political Factors (Global Political Risk Index)
- Infrastructure Factors
- Customer Response Time and Service Level
- Total Logistics Cost
- Competitive Factors
  - – Positive externalities (competitors open their stores in a same mall)
  - – Locating to split the market

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Competitive Factors

- Locating to split the market
  - Locate to capture largest market share

Figure 5-1 Two Firms Locating on a Line

$$d_1 = a + \frac{1 - b - a}{2} \text{ and } d_2 = \frac{1 + b - a}{2}$$

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Framework for Network Design Decisions (1 of 4)

- Maximize the overall profitability of the supply chain network while providing customers with the appropriate responsiveness
- Many trade-offs during network design
- Network design models used
  – to decide on locations and capacities
  – to assign current demand to facilities and identify transportation lanes

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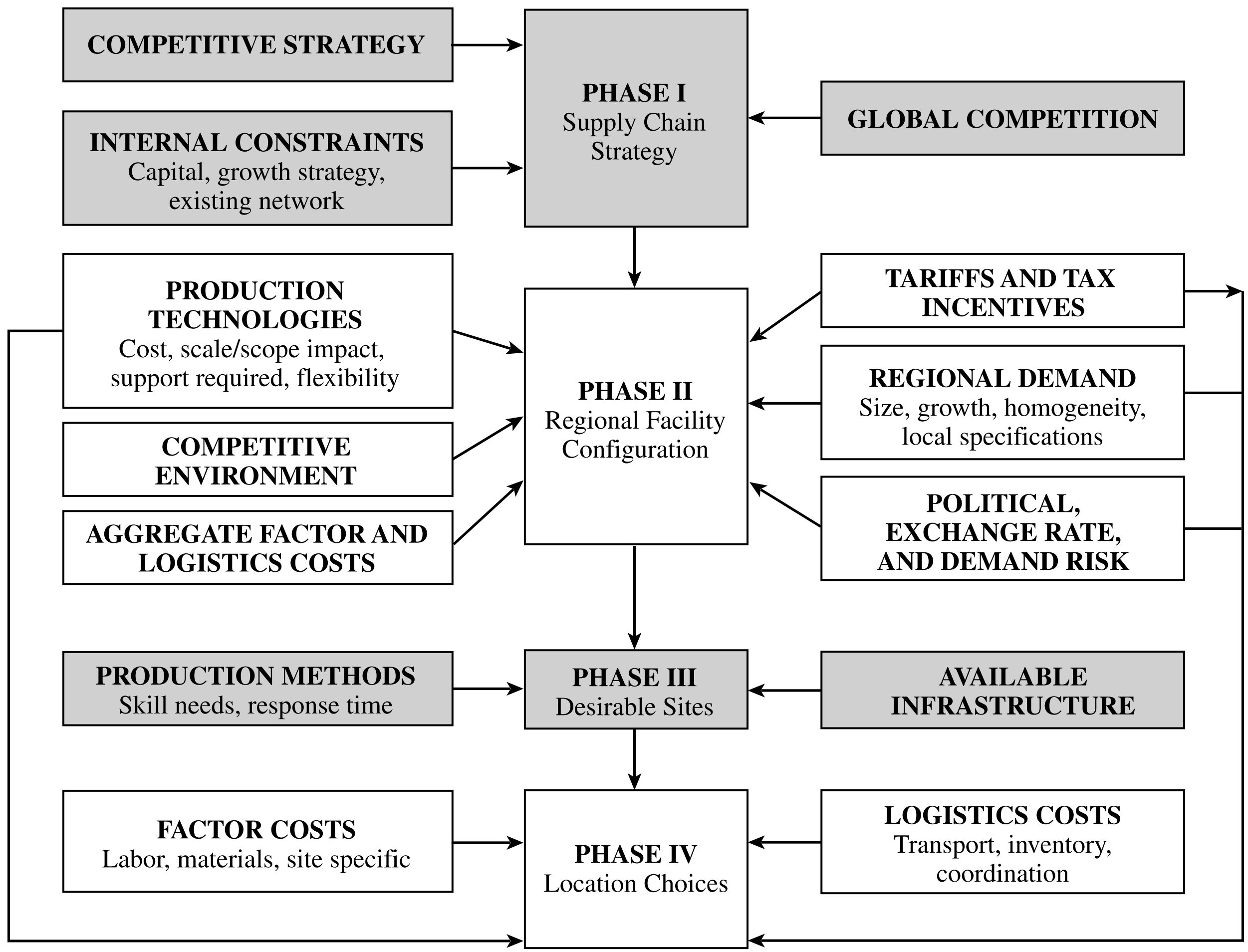
Figure 5-2 Framework for Network Design Decisions



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Framework for Network Design Decisions (2 of 4)

- **Phase I: Define a Supply Chain Strategy/Design**
  - Clear definition of the firm’s competitive strategy
  - Forecast the likely evolution of global competition
  - Identify constraints on available capital
  - Determine broad supply strategy

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Framework for Network Design Decisions (3 of 4)

- **Phase II: Define the Regional Facility Configuration**
  - Forecast of the demand by country or region
  - Identify fixed and variable costs, economies of scale or scope
  - Identify regional tariffs, requirements for local production, tax incentives, and export or import restrictions
  - Identify competitors
  - Identify demand risk, exchange-rate risk, political risk

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Framework for Network Design Decisions (4 of 4)

- **Phase III: Select a Set of Desirable Potential Sites**
  - Hard infrastructure requirements
  - Soft infrastructure requirements
- **Phase IV: Location Choices and Market Allocation**

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Models for Designing a Regional Network Configuration (1 of 2)

- Inputs Required By Region
  - Demand
  - Desired response time
  - Fixed cost of opening a facility
  - Variable cost of labor and material
  - Inventory holding cost
  - Transportation cost between pairs of regions
  - Sale price of product
  - Taxes and tariffs
  - Potential facility capacity

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Models for Designing a Regional Network Configuration (2 of 2)

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region* *Production and Transportation Cost per 1,000,000 Units*					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				

Figure 5-3 Cost Data (in Thousands of Dollars) and Demand Data (in Millions of Units) for SunOil

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Capacitated Plant Location Model (1 of 9)

n = number of potential plant locations/capacity

m = number of markets or demand points

D_j = annual demand from market j

K_i = potential capacity of plant i

f_i = annualized fixed cost of keeping plant i open

c_{ij} = cost of producing and shipping one unit from plant i to market j (cost includes production, inventory, transportation, and tariffs)

y_i = 1 if plant i is open, 0 otherwise

x_{ij} = quantity shipped from plant i to market j

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Capacitated Plant Location Model (2 of 9)

$$Min \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = D_j \quad \text{for} \quad j = 1, \ldots, m$$

$$\sum_{j=1}^{m} x_{ij} = K_i y_i \quad \text{for} \quad i = 1, \ldots, n$$

$$y_i \in \{0,1\} \quad \text{for} \quad i = 1, \ldots, n, x_{ij} \geq 0$$

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Capacitated Plant Location Model (3 of 9)

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region Production and Transportation Cost per 1,000,000 Units*					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (1000 Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0	0	0	0	0	0	0		

Figure 5-4 Spreadsheet Area for Decision Variables for SunOil

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Capacitated Plant Location Model (4 of 9)

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region* *Production and Transportation Cost per 1,000,000 Units*					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
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7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (Million Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0	0	0	0	0	0	0		
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacity*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	0								
27		N. America	S. America	Europe	Asia	Africa				
28	*Unmet Demand*	12	8	14	16	7				
29										
30	***Objective Function***									
31	***Cost =***	$ -								

Figure 5-5 Spreadsheet Area for Constraints and Objective Function for SunOil

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Capacitated Plant Location Model (5 of 9)

Cell	Cell Formula	Equation	Copied To
B28	=B9 − SUM(B14:B18)	5.1	C28:F28
B22	= G14 * H4 + H14 * J4 – SUM(B14 : F14)	5.2	B23:B26
B31	=SUMPRODUCT(B14:F18,B4:F8) + SUMPRODUCT(G14:G18,G4:G8) + SUMPRODUCT(H14:H18,I4:I8)	Objective Function	–

Figure 5-5 [Continued]

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Capacitated Plant Location Model (6 of 9)

- Constraints

$$\text{B14:H18} \geq 0 \qquad \{\text{All decision variables are nonnegative}\}$$

$$\text{B22:B26} \geq 0 \qquad \left\{K_i y_i - \sum_{j=1}^{m} x_{ij} \geq 0 \quad \text{for} \quad i = 1, \ldots, 5\right\}$$

$$\text{B28:F28} = 0 \qquad \left\{\text{D}_j - \sum_{i=1}^{n} x_{ij} = 0 \quad \text{for} \quad j = 1, \ldots, 5\right\}$$

$$\text{G14:H18}\ \textbf{binary} \quad \{\text{Location variable } y_i \text{ are binary; that is, 0 or 1}\}$$

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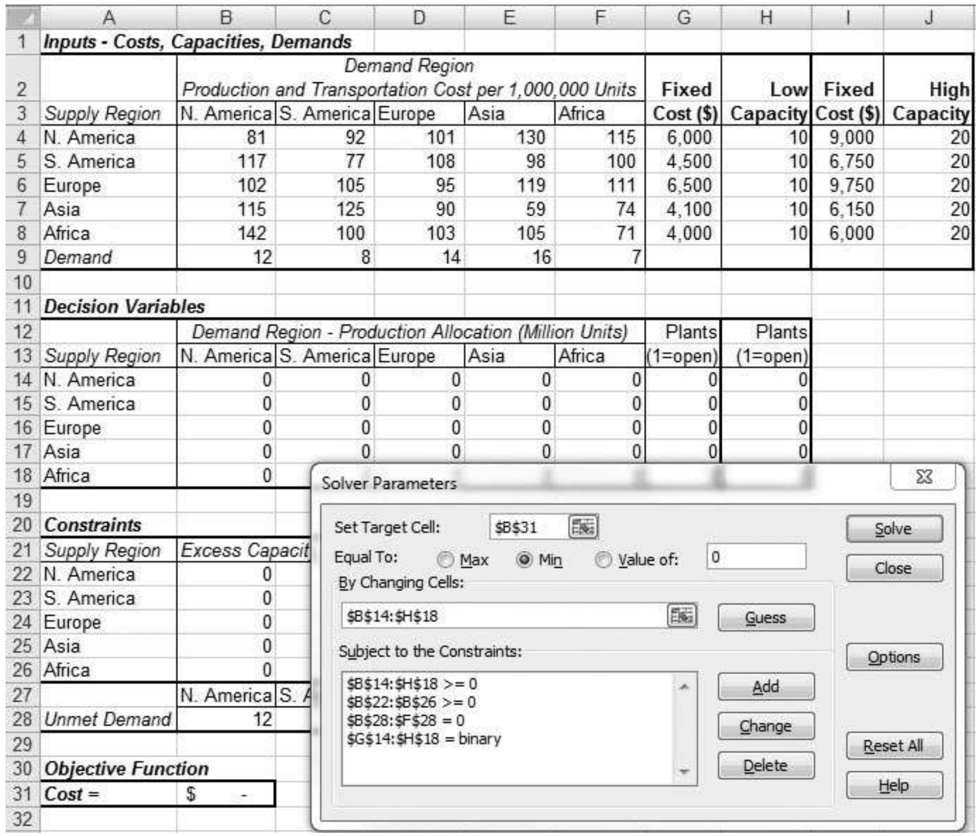
Capacitated Plant Location Model (7 of 9)



	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region Production and Transportation Cost per 1,000,000 Units*					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
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5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (Million Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0								
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacit*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	0								
27		N. America	S. A							
28	*Unmet Demand*	12								
29										
30	***Objective Function***									
31	***Cost =***	$ -								
32										

Figure 5-6 Using Solver to Set Regional Configuration for SunOil

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Capacitated Plant Location Model

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region Production and Transportation Cost per 1,000,000 Units*					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (Million Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	12	8	0	0	0	0	1		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	4	16	0	0	1		
18	Africa	0	0	10	0	7	0	1		
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacity*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	3								
27		N. America	S. America	Europe	Asia	Africa				
28	*Unmet Demand*	0	0	0	0	0				
29										
30	***Objective Function***									
31	***Cost =***	$ 23,751								

Figure 5-7 Optimal Regional Network Configuration for SunOil

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Accounting for Taxes, Tariffs, and Customer Requirements

- Networks should be structured to maximize profit after taxes while meeting customer service requirements
- Objective function maximizes profits

$$Max \sum_{j=1}^{m} r_j \sum_{i=1}^{n} x_{ij} - \sum_{i=1}^{n} F_i y_i - \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

- Constraint Equation 5.1 becomes

$$\sum_{i=1}^{n} x_{ij} \le D_j \ for \ j = 1, \ldots, m$$

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Summary of Learning Objective 4

The capacitated plant location model can be used to obtain a regional configuration that minimizes total cost or maximizes total profits. The model provides optimal plant locations while ensuring that no plant supplies more than its capacity and each market obtains enough supply to meet demand.

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Models for Identifying Potential Sites

- Gravity Location Models
  - Inputs required

x_n, y_n : coordinate location of either a market or supply source *n*

F_n : cost of shipping one unit for one mile between the facility and either market or supply source *n*

D_n : quantity to be shipped between facility and market or supply source *n*

(*x*, *y*) is the location selected for the facility, the distance d_n between the facility at location (*x*, *y*) and the supply source or market *n* is given by

$$d_n = \sqrt{(x - x_n)^2 + (y - y_n)^2}$$

The total transportation cost is given by

$$TC = \sum_{n=1}^{k} d_n D_n F_n$$

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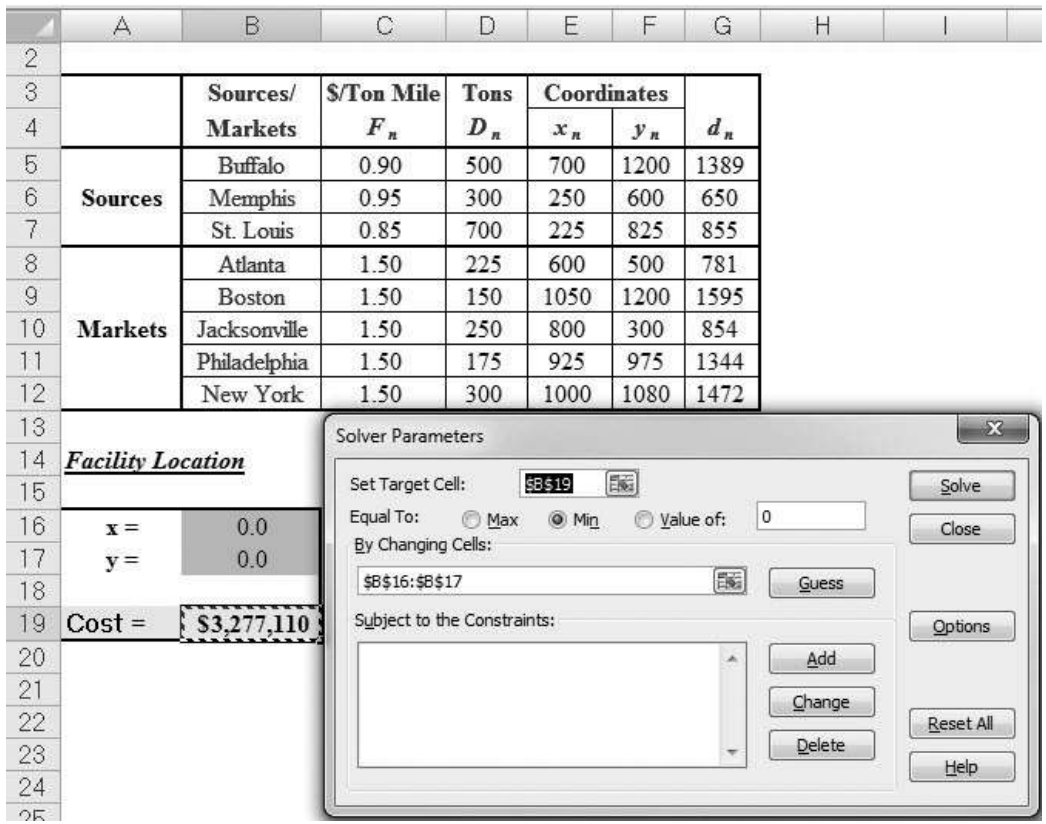
Gravity Model (1 of 3)



	Sources/ Markets	$/Ton Mile F_n	Tons D_n	Coordinates x_n	Coordinates y_n	d_n
Sources	Buffalo	0.90	500	700	1200	1389
	Memphis	0.95	300	250	600	650
	St. Louis	0.85	700	225	825	855
Markets	Atlanta	1.50	225	600	500	781
	Boston	1.50	150	1050	1200	1595
	Jacksonville	1.50	250	800	300	854
	Philadelphia	1.50	175	925	975	1344
	New York	1.50	300	1000	1080	1472

Facility Location

x =	0.0
y =	0.0
Cost =	$3,277,110

Figure 5-8 Using Solver to Optimize Location for Steel Appliances

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Gravity Model (2 of 3)

Cell	Cell Formula	Equation	Copied to
G5	=SQRT((B16 – E5)^2 + (B17 – F5)^2)	5.5	G6:G12
B19	= SUMPRODUCT(G5:G12,D5:D12,C5:C12)	5.6	–

Figure 5-8 [Continued]

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Gravity Model (3 of 3)

1. For each supply source or market n, evaluate d_n
2. Obtain a new location (x', y') for the facility, where

$$x' = \frac{\sum_{n=1}^{k} \frac{D_n F_n x_n}{d_n}}{\sum_{n=1}^{k} \frac{D_n F_n}{d_n}} \quad \text{and} \quad y' = \frac{\sum_{n=1}^{k} \frac{D_n F_n y_n}{d_n}}{\sum_{n=1}^{k} \frac{D_n F_n}{d_n}}$$

3. If the new location (x', y') is almost the same as (x, y) stop. Otherwise, set (x, y) = (x', y') and go to step 1

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Summary of Learning Objective 5

The gravity model can be used to identify potential facility locations in each region. Given the quantity coming from supply sources and market demand, the model identifies the geographic location in a region that minimizes the total transportation cost. This geographic location can be used to identify nearby potential sites that satisfy both hard and soft infrastructure requirements.

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Models for Demand Allocation and Plant Location

Table 5-1 Capacity, Demand, and Cost Data for TelecomOne and HighOptic

Demand City Production and Transportation Cost per Thousand Units (Thousand $)

Supply City	**Atlanta**	**Boston**	**Chicago**	**Denver**	**Omaha**	**Portland**	**Monthly Capacity (Thousand Units)** K	**Monthly Fixed Cost (Thousand $)** f
Baltimore	1,675	400	985	1,630	1,160	2,800	18	7,650
Cheyenne	1,460	1,940	970	100	495	1,200	24	3,500
Salt Lake City	1,925	2,400	1,450	500	950	800	27	5,000
Memphis	380	1,355	543	1,045	665	2,321	22	4,100
Wichita	922	1,646	700	508	311	1,797	31	2,200
Monthly demand (thousand units) D_j	10	8	14	6	7	11		

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Allocating Demand to Existing Production Facilities (1 of 8)

- Inputs required

n = number of factory locations

m = number of markets or demand points

D_j = annual demand from market j

K_i = capacity of factory i

c_{ij} = cost of producing and shipping one unit from factory i to market j

x_{ij} = quantity shipped from factory i to market j

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Allocating Demand to Existing Production Facilities

$$Min \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = D_j \quad \textbf{for} \quad j = 1, \ldots, m$$

$$\sum_{j=1}^{m} x_{ij} \leq K_i \quad \textbf{for} \quad i = 1, \ldots, n$$

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Allocating Demand to Existing Production Facilities (3 of 8)

Table 5-2 Optimal Demand Allocation for TelecomOne and HighOptic

		Atlanta	Boston	Chicago	Denver	Omaha	Portland
TelecomOne	Baltimore	0	8	2			
	Memphis	10	0	12			
	Wichita	0	0	0			
HighOptic	Salt Lake				0	0	11
	Cheyenne				6	7	0

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Allocating Demand to Existing Production Facilities (4 of 8)

	A	B	C	D	E	F	G	H	I
1	***Inputs - Costs, Capacities, Demands (for TelecomOptic)***								
2		*Demand City Production and Transportation Cost per 1000 Units*						**Fixed**	
3	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Cost ($)**	**Capacity**
4	Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
5	Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
6	Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
7	Memphis	380	1,355	543	1,045	665	2,321	4,100	22
8	Wichita	922	1,646	700	508	311	1,797	2,200	31
9	*Demand*	10	8	14	6	7	11		
11	***Decision Variables***								
12		*Demand City - Production Allocation (1000 Units)*						**Plants**	
13	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)	
14	Baltimore	0	0	0	0	0	0	0	
15	Cheyenne	0	0	0	0	0	0	0	
16	Salt Lake	0	0	0	0	0	0	0	
17	Memphis	0	0	0	0	0	0	0	
18	Wichita	0	0	0	0	0	0	0	

Figure 5-9 Spreadsheet Area for Decision Variables for TelecomOptic

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Allocating Demand to Existing Production Facilities (5 of 8)

	A	B	C	D	E	F	G	H	I
1	*Inputs - Costs, Capacities, Demands (for TelecomOptic)*								
2		*Demand City Production and Transportation Cost per 1000 Units*						**Fixed**	
3	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Cost ($)**	**Capacity**
4	Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
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9	*Demand*	10	8	14	6	7	11		
11	***Decision Variables***								
12		*Demand City - Production Allocation (1000 Units)*						**Plants**	
13	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)	
14	Baltimore	0	0	0	0	0	0	0	
15	Cheyenne	0	0	0	0	0	0	0	
16	Salt Lake	0	0	0	0	0	0	0	
17	Memphis	0	0	0	0	0	0	0	
18	Wichita	0	0	0	0	0	0	0	
20	***Constraints***								
21	*Supply City*	*Excess Capacity*							
22	Baltimore	0							
23	Cheyenne	0							
24	Salt Lake	0							
25	Memphis	0							
26	Wichita	0							
28		Atlanta	Boston	Chicago	Denver	Omaha	Portland		
29	*Unmet Demand*	10	8	14	6	7	11		
31	***Objective Function***								
32	***Cost =***	$ -							

Figure 5-10 Spreadsheet Area for Constraints for TelecomOptic

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Allocating Demand to Existing Production Facilities (6 of 8)

Cell	Formula	Equation	Copied to
B22	=I4*H14 – SUM(B14:G14)	5.1	B23:B26
B29	= B9 − SUM(B14:B18)	5.2	C29:G29
B32	= SUMPRODUCT(B4:G8, B14:G18) + SUMPRODUCT(H4:H8, H14:H18)	Objective function	–

Figure 5-10 Spreadsheet Area for Constraints for TelecomOptic

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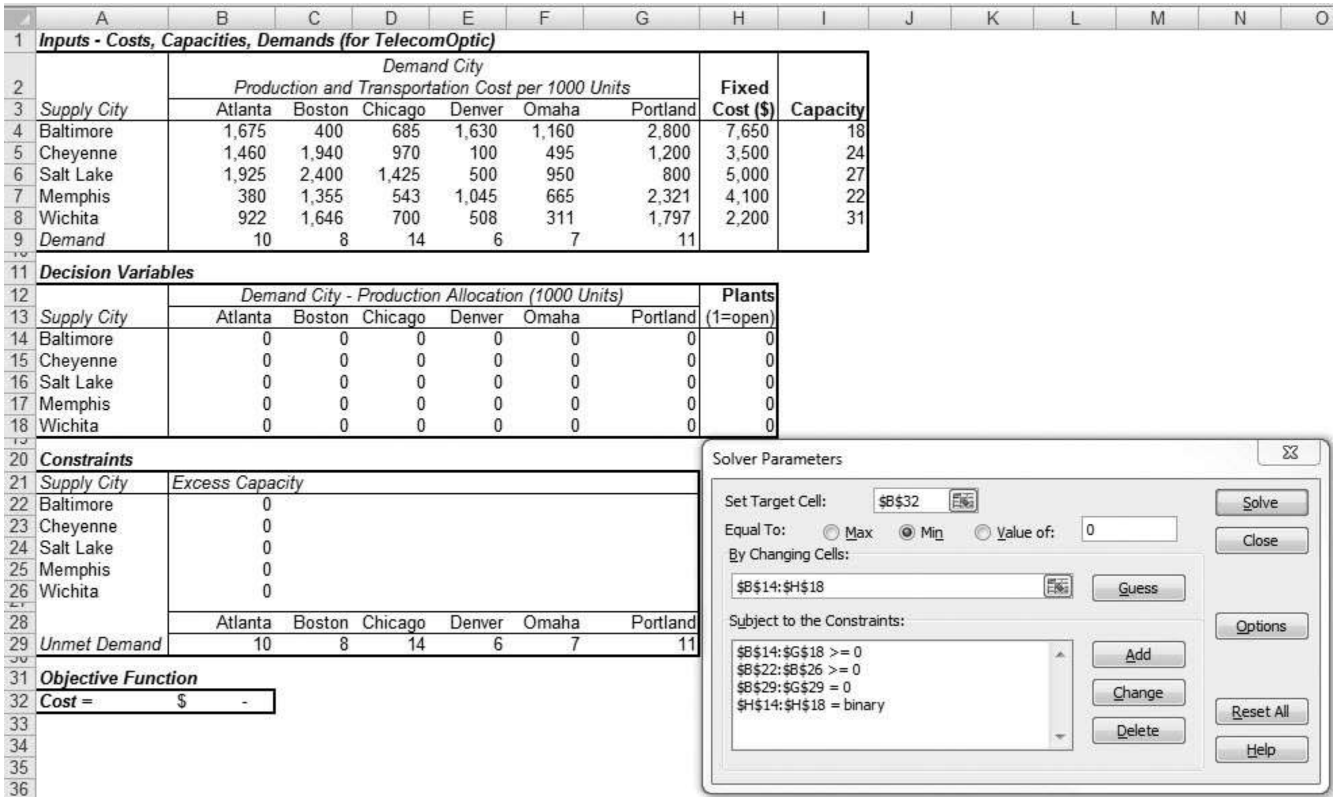
Allocating Demand to Existing Production Facilities (7 of 8)



Inputs - Costs, Capacities, Demands (for TelecomOptic)

	Demand City: Production and Transportation Cost per 1000 Units							
Supply City	Atlanta	Boston	Chicago	Denver	Omaha	Portland	Fixed Cost ($)	Capacity
Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
Memphis	380	1,355	543	1,045	665	2,321	4,100	22
Wichita	922	1,646	700	508	311	1,797	2,200	31
Demand	10	8	14	6	7	11		

Decision Variables

	Demand City - Production Allocation (1000 Units)						
Supply City	Atlanta	Boston	Chicago	Denver	Omaha	Portland	Plants (1=open)
Baltimore	0	0	0	0	0	0	0
Cheyenne	0	0	0	0	0	0	0
Salt Lake	0	0	0	0	0	0	0
Memphis	0	0	0	0	0	0	0
Wichita	0	0	0	0	0	0	0

Constraints

Supply City	Excess Capacity
Baltimore	0
Cheyenne	0
Salt Lake	0
Memphis	0
Wichita	0

	Atlanta	Boston	Chicago	Denver	Omaha	Portland
Unmet Demand	10	8	14	6	7	11

Objective Function

Cost = $ -

Figure 5-11 Solver Dialog Box for TelecomOptic

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Allocating Demand to Existing Production Facilities (8 of 8)

Inputs - Costs, Capacities, Demands (for TelecomOptic)

	Demand City — Production and Transportation Cost per 1000 Units						**Fixed**	
Supply City	Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Cost ($)**	**Capacity**
Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
Memphis	380	1,355	543	1,045	665	2,321	4,100	22
Wichita	922	1,646	700	508	311	1,797	2,200	31
Demand	10	8	14	6	7	11		

Decision Variables

	Demand City - Production Allocation (1000 Units)						**Plants**
Supply City	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)
Baltimore	0	8	2	0	0	0	1
Cheyenne	0	0	0	6	7	11	1
Salt Lake	0	0	0	0	0	0	0
Memphis	10	0	12	0	0	0	1
Wichita	0	0	0	0	0	0	0

Constraints

Supply City	*Excess Capacity*
Baltimore	8
Cheyenne	0
Salt Lake	0
Memphis	0
Wichita	0

	Atlanta	Boston	Chicago	Denver	Omaha	Portland
Unmet Demand	0	0	0	0	0	0

Objective Function

Cost =	$ 47,401

Figure 5-12 Optimal Network Design for TelecomOptic

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Models for Locating Production Facilities

- Capacitated plant location model
  - Merge the companies
  - Solve using location-specific costs

y_i = 1 if factory i is open, 0 otherwise

x_{ij} = quantity shipped from factory i to market j

$$Min \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

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Capacitated Plant Location Model (9 of 9)

$$\text{B14:G18} \geq 0 \quad \{\text{All decision variables are nonnegative}\}$$

$$\text{B22:B26} \geq 0 \quad \left\{ K_i y_i - \sum_{j=1}^{m} x_{ij} \geq 0 \quad \text{for} \quad i = 1, \ldots, 5 \right\}$$

$$\text{B29:G29} = 0 \quad \left\{ D_j - \sum_{i=1}^{n} x_{ij} = 0 \quad \text{for} \quad j = 1, \ldots, 6 \right\}$$

$$\text{H14:H18 } \textbf{binary} \quad \{\text{Location variables } y_i \text{ are binary; that is, 0 or 1}\}$$

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More Complex Capacitated Plant Location Model (1 of 2)

- Capacitated plant location model with single sourcing

y_i = 1 if factory i is located at site i, 0 otherwise
x_{ij} = 1 if market j is supplied by factory i, 0 otherwise

$$Min \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} D_j c_{ij} x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = 1 \textbf{ for } j = 1, \ldots, m$$

$$\sum_{j=1}^{m} D_j x_{ij} \leq K_i y_i \textbf{ for } i = 1, \ldots, n$$

$$x_{ij}, y_i \in \{0,1\}$$

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More Complex Capacitated Plant Location Model (2 of 2)

Table 5-3 Optimal Network Configuration for TelecomOptic with Single Sourcing

	Open/Closed	Atlanta	Boston	Chicago	Denver	Omaha	Portland
Baltimore	Closed	0	0	0	0	0	0
Cheyenne	Closed	0	0	0	0	0	0
Salt Lake	Open	0	0	0	6	0	11
Memphis	Open	10	8	0	0	0	0
Wichita	Open	0	0	14	0	7	0

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Locating Plants and Warehouses Simultaneously

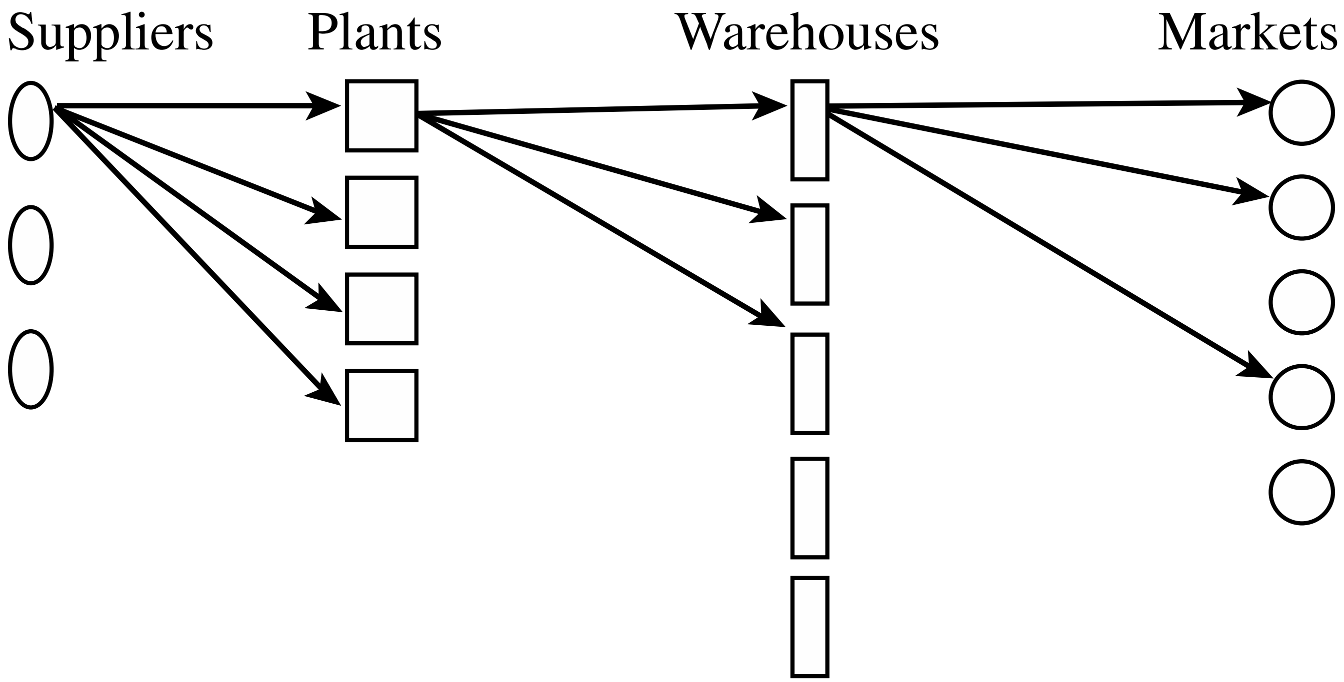

Figure 5-13 Stages in a Supply Network

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Locating Plants and Warehouses Simultaneously (2 of 5)

- Inputs

m = number of markets or demand points

n = number of potential factory locations

l = number of suppliers

t = number of potential warehouse locations

D_j = annual demand from market j

K_i = potential capacity of factory at location i

S_h = supply capacity at supplier h

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Locating Plants and Warehouses Simultaneously (3 of 5)

W_e = potential warehouse capacity at location *e*

F_i = fixed cost of locating plant at location *I*

f_e = fixed cost of locating a warehouse at location *e*

c_{hi} = cost of shipping one unit from supply source *h* to factory *I*

c_{ie} = cost of producing and shipping one unit from factory *I* to warehouse *e*

c_{ej} = cost of shipping one unit from warehouse *e* to market *j*

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Locating Plants and Warehouses Simultaneously (4 of 5)

- Decision variables

  y_i = 1 if factory is located at location *i*, 0 otherwise

  y_e = 1 if factory is located at location *e*, 0 otherwise

  x_{ej} = quantity shipped from warehouse *e* to market *j*

  x_{ie} = quantity shipped from factory at location *i* to warehouse *e*

  x_{hi} = quantity shipped from supplier *h* to factory at location *i*

- Objective function

$$Min \sum_{i=1}^{n} F_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l} \sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n} \sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t} \sum_{j=1}^{m} c_{ej} x_{ej}$$

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Locating Plants and Warehouses Simultaneously (5 of 5)

- Constraint equations

$$\sum_{i=1}^{n} x_{hi} \le S_h \quad for \quad h = 1,\ldots,l$$

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \ge 0 \quad for \quad i = 1,\ldots,n$$

$$\sum_{e=1}^{t} x_{ie} \le K_i y_i \quad for \quad i = 1,\ldots,n$$

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \le 0 \quad for \quad e = 1,\ldots,t$$

$$\sum_{j=1}^{m} x_{ej} \le W_e y_e \quad for \quad e = 1,\ldots,t$$

$$\sum_{e=1}^{t} x_{ej} + D_j \quad for \quad j = 1,\ldots,m$$

$$y_i, y_e \in \{0,1\}, x_{ej}, x_{ie}, x_{hi} \ge 0$$

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Summary of Learning Objective 6

The capacitated plant location model can be used to locate production facilities and ware- houses to minimize total network costs or maximize network profits. A similar model can also be used to allocate market demand across an existing set of facilities in a supply chain network. Both models optimize the objective function while ensuring that capacity constraints are satisfied and market demand is served.

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