FIGURE 7.8
A spreadsheet model for the revised Wyndor problem, where Solver gives the optimal solution shown in the changing cells, UnitsProduced (C14:D14) and Setup? (C17:D17).

	A	B	C	D	E	F	G	H
1	**Wyndor Glass Co. Product-Mix with Setup Costs**							
2								
3			Doors	Windows				
4		Unit Profit	$300	$500				
5		Setup Cost	$700	$1,300				
6								
7					Hours		Hours	
8			Hours Used per Unit Produced		Used		Available	
9		Plant 1	1	0	0	≤	4	
10		Plant 2	0	2	12	≤	12	
11		Plant 3	3	2	12	≤	18	
12								
13			Doors	Windows				
14		Units Produced	0	6				
15			≤	≤	Big Number		Production Profit	$3,000
16		Only if Set Up	0	99	99		−Total Setup Cost	$1,300
17		Setup?	0	1			Total Profit	$1,700

Solver Parameters
Set Objective Cell: TotalProfit
To: Max
By Changing Variable Cells:
UnitsProduced, Setup?
Subject to the Constraints:
Setup? = binary
UnitsProduced = integer
HoursUsed <= HoursAvailable
UnitsProduced <= OnlyIfSetup

Solver Options:
Make Variables Nonnegative
Solving Method: Simplex LP

Range Name	Cells
BigNumber	E16
HoursAvailable	G9:G11
HoursUsed	E9:E11
HoursUsedPerUnitProduced	C9:D11
OnlyIfSetUp	C16:D16
ProductionProfit	H15
Setup?	C17:D17
SetupCost	C5:D5
TotalProfit	H17
TotalSetupCost	H16
UnitProfit	C4:D4
UnitsProduced	C14:D14

	E
7	Hours
8	Used
9	=SUMPRODUCT(C9:D9,UnitsProduced)
10	=SUMPRODUCT(C10:D10,UnitsProduced)
11	=SUMPRODUCT(C11:D11,UnitsProduced)

	B	C	D
16	Only if Set Up	=BigNumber*C17	=BigNumber*D17

	G	H
15	Production Profit	=SUMPRODUCT(UnitProfit,UnitsProduced)
16	−Total Setup Cost	=SUMPRODUCT(SetupCost,Setup?)
17	Total Profit	=ProductionProfit – TotalSetupCost

Review *Questions*

1. How does a mixed BIP problem differ from a pure BIP problem?
2. Why is a linear programming formulation no longer valid for a product-mix problem when there are setup costs for initiating production?
3. How can a binary variable be defined in terms of whether a setup is performed to initiate the production of a certain product?
4. What caused the optimal solution for the revised Wyndor problem to differ from that for the original Wyndor problem?

7.6 Summary

Managers frequently must make yes-or-no decisions, where the only two possible choices are yes, go ahead with a particular option, or no, decline this option. A binary integer programming (BIP) model considers many options simultaneously, with a binary decision variable for each option. Mixed BIP models include some continuous decision variables as well.

The California Manufacturing Co. case study involves yes-or-no decisions on whether a new factory should be built in certain cities and then whether a new warehouse also should be built in certain cities. This case study also introduced the modeling of mutually exclusive alternatives and contingent decisions, as well as the performance of what-if analysis for BIP models.

Many companies have saved millions of dollars by formulating and solving BIP models for a wide variety of applications. We have described and illustrated some of the most important types, including the selection of projects (e.g., research and development projects), the selection of sites for facilities (e.g., emergency services facilities such as fire stations), and crew scheduling in the travel industry (e.g., airlines). We also have discussed how to use mixed BIP to deal with setup costs for initiating production when addressing product-mix problems.

Glossary

binary decision variable A binary variable that represents a yes-or-no decision by assigning a value of 1 for choosing yes and a value of 0 for choosing no. (Introduction), 243

binary integer programming A type of problem or model that fits linear programming except that it uses binary decision variables. (Introduction), 243

binary variable A variable whose only possible values are 0 and 1. (Introduction), 243

BIP Abbreviation for binary integer programming. (Introduction), 243

contingent decision A yes-or-no decision is a contingent decision if it can be yes only if a certain other yes-or-no decision is yes. (Section 7.1), 247

mixed BIP model A BIP model where only some of the variables are restricted to be binary variables. (Introduction), 243

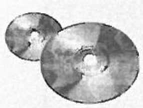
mutually exclusive alternatives A group of alternatives where choosing any one alternative excludes choosing any of the others. (Section 7.1), 246

pure BIP model A BIP model where all the variables are restricted to be binary variables. (Introduction), 243

set covering constraint A constraint that requires the sum of certain binary variables to be greater than or equal to 1. (Section 7.3), 255

set covering problem A type of BIP model where the objective is to minimize some quantity such as total cost and all the functional constraints are set covering constraints. (Section 7.3), 255

yes-or-no decision A decision whose only possible choices are (1) yes, go ahead with a certain option or (2) no, decline this option. (Introduction), 243



Learning Aids for This Chapter

All learning aids are available at **www.mhhe.com/Hillier6e.**

Excel Files:

California Mfg. Case Study

Tazer Corp. Example

Caliente City Example

Southwestern Airways Example

Revised Wyndor Example

Excel Add-in:

Analytic Solver

Supplements to This Chapter:

Advanced Formulation Techniques for Binary Integer Programming

Some Perspectives on Solving Binary Integer Programming Problems

Solved Problems

The solutions are available at **www.mhhe.com/Hillier6e.**

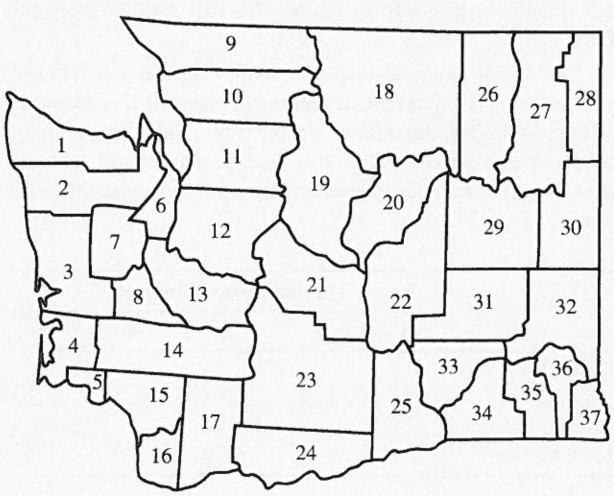
7.S1. Capital Budgeting with Contingency Constraints

A company is planning its capital budget over the next several years. There are eight potential projects under consideration. A calculation has been made of the expected net present value of each project, along with the cash outflow that would be required over the next four years. These data, along with the cash that is available each year, are shown in the next table. There also are the following contingency constraints: (a) at least one of project 1, 2, or 3 must be done, (b) projects 6 and 7 cannot both be done, and (c) project 5 can only be done if project 6 is done. Formulate and solve a BIP model in a spreadsheet to determine which projects should be pursued to maximize the total expected net present value.

	Cash Outflow Required ($million)								Cash Available ($million)
	Project								
	1	2	3	4	5	6	7	8	
Year 1	1	3	0	3	3	7	2	5	20
Year 2	2	2	2	2	2	3	3	4	20
Year 3	2	3	4	2	3	3	6	2	20
Year 4	2	1	0	5	4	2	1	2	20
NPV ($mil)	10	12	11	15	24	17	16	18	

7.S2. Locating Search-and-Rescue Teams

The Washington State legislature is trying to decide on locations at which to base search-and-rescue teams. The teams are expensive, so the legislature would like as few as possible while still providing the desired level of service. In particular, since response time is critical, the legislature would like every county to either have a team located in that county or in an adjacent county. (The locations and names of the counties are shown below.) Formulate and solve a BIP model in a spreadsheet to determine where the teams should be located.



Counties

1. Clallum
2. Jefferson
3. Grays Harbor
4. Pacific
5. Wahkiakum
6. Kitsap
7. Mason
8. Thurston
9. Whatcom
10. Skagit
11. Snohomish
12. King
13. Pierce
14. Lewis
15. Cowlitz
16. Clark
17. Skamania
18. Okanogan
19. Chelan
20. Douglas
21. Kittitas
22. Grant
23. Yakima
24. Klickitat
25. Benton
26. Ferry
27. Stevens
28. Pend Oreille
29. Lincoln
30. Spokane
31. Adams
32. Whitman
33. Franklin
34. Walla Walla
35. Columbia
36. Garfield
37. Asotin

7.S3. Warehouse Site Selection

Consider a small company that produces a single product in two plants and serves customers in five different regions.

The company has been using a make-to-order policy of producing the product only in the quantities needed to fill the orders that have come in from the various regions. However, because of the problems caused by the sporadic production schedule, management has decided to smooth out the production rate and ship the product to one or more storage warehouses, which then will use inventory to fill the incoming regional orders. Management now needs to decide where to locate the company's new warehouse(s). There are three locations under consideration. For each location, there is a fixed monthly cost associated with leasing and operating the warehouse there. Furthermore, each potential warehouse location has a maximum capacity for monthly shipments restricted primarily by the number of trucking docks at the site. The product costs $400 to produce at Plant 1 and $300 to produce at Plant 2. The shipping cost from each plant to each potential warehouse location is shown in the first table below. The fixed leasing and operating cost (if open), the shipping costs, and the capacity (maximum monthly shipments) of each potential warehouse location are shown in the second table below. The monthly demand in each of the customer regions is expected to be 200, 225, 100, 150, and 175 units, respectively. Formulate and solve a BIP model in a spreadsheet to determine which warehouse(s) should be used and how the product should be distributed from plant to warehouse(s) to customer.

Shipping Costs and Capacity of the Plants

	Shipping Cost (per unit)			Capacity (units/month)
	WH 1	WH 2	WH 3	
Plant 1	$25	$50	$75	500
Plant 2	$50	$75	$25	400

Fixed Cost, Shipping Costs, and Capacity of the Warehouses

	Fixed Cost (per month)	Shipping Cost (per unit) Region 1	Region 2	Region 3	Region 4	Region 5	Capacity (units/month)
WH 1	$50,000	$30	$70	$75	$55	$40	700
WH 2	$30,000	$55	$30	$45	$45	$70	500
WH 3	$70,000	$70	$30	$50	$60	$55	1,000

Problems

We have inserted the symbol AS to the left of each problem (or its parts) where Analytic Solver is required. An asterisk on the problem number indicates that at least a partial answer is given in the back of the book.

7.1. Read the referenced article that fully describes the management science study summarized in the application vignette presented in Section 7.1. Briefly describe how mixed BIP was applied in this study. Then list the various financial and nonfinancial benefits that resulted from this study.

7.2. Reconsider the California Manufacturing Co. case study presented in Section 7.1. The mayor of San Diego now has contacted the company's president, Armando Ortega, to try to persuade him to build a factory and perhaps a warehouse in that city. With the tax incentives being offered the company, Armando's staff estimates that the net present value of building a factory in San Diego would be $7 million and the amount of capital required to do this would be $4 million. The net present value of building a warehouse there would be $5 million and the capital required would be $3 million. (This option will only be considered if a factory also is being built there.)

Armando has asked Steve Chan to revise his previous management science study to incorporate these new alternatives into the overall problem. The objective still is to find the feasible combination of investments that maximizes the total net present value, given that the amount of capital available for these investments is $10 million.

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

7.3.* A young couple, Eve and Steven, want to divide their main household chores (marketing, cooking, dishwashing, and laundering) between them so that each has two tasks but the total time they spend on household duties is kept to a minimum. Their efficiencies on these tasks differ, where the time each would need to perform the task is given by the following table.

	Time Needed per Week (Hours) Marketing	Cooking	Dish Washing	Laundry
Eve	4.5	7.8	3.6	2.9
Steven	4.9	7.2	4.3	3.1

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

7.4. Read the referenced article that fully describes the management science study summarized in the application vignette presented in Section 7.2. Briefly describe how mixed binary integer programming was applied in this study. Then list the various financial and nonfinancial benefits that resulted from this study.

7.5. A real-estate development firm, Peterson and Johnson, is considering five possible development projects. Using units of millions of dollars, the following table shows the estimated long-run profit (net present value) that each project would generate, as well as the amount of investment required to undertake the project.

	Development Project 1	2	3	4	5
Estimated profit (millions)	$1	$1.8	$1.6	$0.8	$1.4
Capital required (millions)	6	12	10	4	8

The owners of the firm, Dave Peterson and Ron Johnson, have raised $20 million of investment capital for these projects. Dave and Ron now want to select the combination of projects that will maximize their total estimated long-run profit (net present value) without investing more than $20 million.

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

AS *c.* Perform what-if analysis on the amount of investment capital made available for the development projects by generating a parameter analysis report with Analytic Solver to solve the model with the following amounts of investment capital (in millions of dollars): 16, 18, 20, 22, 24, 26, 28, and 30. Include both the changing cells and the objective cell as output cells in the parameter analysis report.

7.6. The board of directors of General Wheels Co. is considering seven large capital investments. Each investment can be made only once. These investments differ in the estimated long-run profit (net present value) that they will generate as well as in the amount of capital required, as shown by the following table.

Investment Opportunity	Estimated Profit (millions)	Capital Required (millions)
1	$17	$43
2	10	28
3	15	34
4	19	48
5	7	17
6	13	32
7	9	23

The total amount of capital available for these investments is $100 million. Investment opportunities 1 and 2 are mutually exclusive, and so are 3 and 4. Furthermore, neither 3 nor 4 can be undertaken unless one of the first two opportunities is undertaken. There are no such restrictions on investment opportunities 5, 6, and 7. The objective is to select the combination of capital investments that will maximize the total estimated long-run profit (net present value).

a. Formulate and solve a BIP model on a spreadsheet for this problem.

AS *b.* Perform what-if analysis on the amount of capital made available for the investment opportunities by generating a parameter analysis report with Analytic Solver to solve the model with the following amounts of capital (in millions of dollars): 80, 90, 100, 110, . . . , and 200. Include both the changing cells and the objective cell as output cells in the parameter analysis report.

7.7. The Fly-Right Airplane Company builds small jet airplanes to sell to corporations for use by their executives. To meet the needs of these executives, the company's customers sometimes order a custom design of the airplanes being purchased. When this occurs, a substantial start-up cost is incurred to initiate the production of these airplanes.

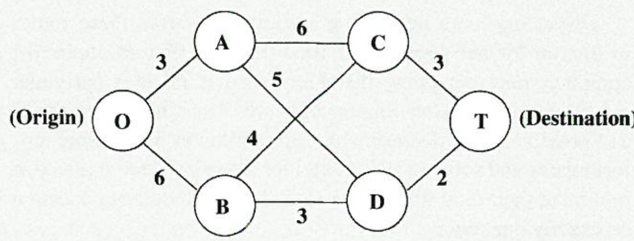
Fly-Right has recently received purchase requests from three customers with short deadlines. However, because the company's production facilities already are almost completely tied up filling previous orders, it will not be able to accept all three orders. Therefore, a decision now needs to be made on the number of airplanes the company will agree to produce (if any) for each of the three customers.

The relevant data are given in the next table. The first row gives the start-up cost required to initiate the production of the airplanes for each customer. Once production is under way, the marginal net revenue (which is the purchase price minus the marginal production cost) from each airplane produced is shown in the second row. The third row gives the percentage of the available production capacity that would be used for each airplane produced. The last row indicates the maximum number of airplanes requested by each customer (but less will be accepted).

	Customer		
	1	**2**	**3**
Start-up cost	$3 million	$2 million	0
Marginal net revenue	$2 million	$3 million	$0.8 million
Capacity used per plane	20%	40%	20%
Maximum order	3 planes	2 planes	5 planes

Fly-Right now wants to determine how many airplanes to produce for each customer (if any) to maximize the company's total profit (total net revenue minus start-up costs). Formulate and solve a spreadsheet model with both integer variables and binary variables for this problem.

7.8.* Consider the following special type of shortest path problem (discussed in Section 6.4) where the nodes are in columns and the only paths considered always move forward one column at a time.



The numbers along the links represent distances (in miles), and the objective is to find the shortest path from the origin to the destination.

This problem also can be formulated as a BIP model involving both mutually exclusive alternatives and contingent decisions. Formulate and solve this BIP model on a spreadsheet. Identify the constraints for (1) mutually exclusive alternatives and (2) contingent decisions.

7.9. Read the referenced article that fully describes the management science study summarized in the application vignette presented in Section 7.4. Briefly describe how BIP and related techniques were applied in this study. Then list the various financial and nonfinancial benefits that resulted from this study.

7.10. Speedy Delivery provides two-day delivery service of large parcels across the United States. Each morning at each collection center, the parcels that have arrived overnight are loaded onto several trucks for delivery throughout the area. Since the competitive battlefield in this business is speed of delivery, the parcels are divided among the trucks according to their geographical destinations to minimize the average time needed to make the deliveries.

On this particular morning, the dispatcher for the Blue River Valley Collection Center, Sharon Lofton, is hard at work. Her three drivers will be arriving in less than an hour to make the day's deliveries. There are nine parcels to be delivered, all at locations many miles apart. As usual, Sharon has loaded these locations into her computer. She is using her company's special software package, a decision support system called Dispatcher. The first thing Dispatcher does is use these locations to generate a considerable number of attractive possible routes for the individual delivery trucks. These routes are shown in the table below (where the numbers in each column indicate the order of the deliveries), along with the estimated time required to traverse the route.

	Attractive Possible Route									
Delivery Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	1				1				1	
B		2		1		2			2	2
C			3	3			3		3	
D	2					1		1		
E			2	2		3				
F		1			2					
G	3						1	2		3
H			1		3					1
I		3		4			2			
Time (in hours)	6	4	7	5	4	6	5	3	7	6

Dispatcher is an interactive system that shows these routes to Sharon for her approval or modification. (For example, the computer may not know that flooding has made a particular route infeasible.) After Sharon approves these routes as attractive possibilities with reasonable time estimates, Dispatcher next formulates and solves a BIP model for selecting three routes that minimize their total time while including each delivery location on exactly one route.

a. Using the data in the table, demonstrate how Dispatcher can formulate and solve this BIP model on a spreadsheet.

b. Describe how the problem addressed in part *a* is analogous to the crew scheduling problem described in Section 7.4.

7.11. An increasing number of Americans are moving to a warmer climate when they retire. To take advantage of this trend, Sunny Skies Unlimited is undertaking a major real-estate development project. The project is to develop a completely new retirement community (to be called Pilgrim Haven) that will cover several square miles. One of the decisions to be made is where to locate the two paramedic stations that have been allocated to the community to respond to medical emergencies. For planning purposes, Pilgrim Haven has been divided into five tracts, with no more than one paramedic station to be located in any given tract. Each station is to respond to *all* the medical emergencies that occur in the tract in which it is located as well as in the other tracts that are assigned to this station. Thus, the decisions to be made consist of (1) the tracts to receive a paramedic station and (2) the assignment of each of the other tracts to one of the paramedic stations. The objective is to minimize the overall average of the *response times* to medical emergencies.

The following table gives the average response time to a medical emergency in each tract (the rows) if that tract is served by a station in a given tract (the columns). The last column gives the forecasted average number of medical emergencies that will occur in each of the tracts per day.

		Paramedic Station in Tract					Average Frequency of Medical Emergencies per Day
		1	**2**	**3**	**4**	**5**	
Response	**1**	5	20	15	25	10	2
times (min.)	**2**	12	4	20	15	25	1
to a medical	**3**	30	15	6	25	15	3
emergency	**4**	20	10	15	4	12	1
in tract	**5**	15	25	12	10	5	3

Formulate and solve a BIP model on a spreadsheet for this problem. Identify any constraints that correspond to mutually exclusive alternatives or contingent decisions.

7.12. Reconsider Problem 7.11. The management of Sunny Skies Unlimited now has decided that the decision regarding the locations of the paramedic stations should be based mainly on costs.

The cost of locating a paramedic station in a tract is \$200,000 for tract 1, \$250,000 for tract 2, \$400,000 for tract 3, \$300,000 for tract 4, and \$500,000 for tract 5. Management's objective now is to determine which tracts should receive a station to minimize the total cost of stations while ensuring that each tract has at least one station close enough to respond to a medical emergency in no more than 15 minutes. In contrast to the original problem, note that the total number of paramedic stations is no longer fixed. Furthermore, if a tract without a station has more than one station within 15 minutes, it is no longer necessary to assign this tract to just one of these stations.

a. Formulate the algebraic form of a pure BIP model with five binary variables for this problem.

b. Display and solve this model on a spreadsheet.

7.13. Reconsider the Southwestern Airways crew scheduling problem presented in Section 7.4. Because of a blizzard in the Chicago area, all the flights into and out of Chicago (including flights 4, 6, 7, and 9 in Table 7.5) have been canceled for the time being, so a new crew scheduling plan needs to be developed to cover the seven remaining flights in Table 7.5.

The 12 feasible sequences of flights still are the ones shown in Table 7.5 after deleting the canceled flights. When flights into and out of Chicago had originally been part of a sequence, a crew now would fly as passengers on a Southwestern Airways flight to the next city in the sequence to cover the remaining flights in the sequence. For example, flight sequence 4 now would be San Francisco to Los Angeles to Denver to San Francisco, where a crew would fly as passengers on a flight from Los Angeles to Denver (not shown in the table) to enable serving as the crew from Denver to San Francisco. (Since the original sequence 5 included a round-trip from Denver to Chicago and back, a crew assigned to this sequence now would simply lay over in Denver to await the flight from Denver to San Francisco.) The cost of assigning a crew to any sequence still would be the same as shown in the bottom row of Table 7.5.

The objective still is to minimize the total cost of the crew assignments that cover all the flights. The fact that only 7 flights now need to be covered instead of 11 increases the chance that fewer than three crews will need to be assigned to a flight sequence this time. (The flights where these crews fly as passengers do not need to be covered since they already are assigned to crews that are not based in San Francisco.)

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this problem on a spreadsheet.

7.14. Yakima Construction Corporation (YCC) is considering a number of different development projects. The cash outflows that would be required to complete each project are indicated in the table in the right column, along with the expected net present value of each project (all values in millions of dollars).

	Project				
	1	**2**	**3**	**4**	**5**
Year 1	$8	$10	$12	$4	$14
Year 2	6	8	6	3	6
Year 3	3	7	6	2	5
Year 4	0	5	6	0	7
NPV	$12	$15	$20	$9	$23

Each project must be done in full (with the corresponding cash flows for all four years) or not done at all. Furthermore, there are the following additional considerations. Project 1 cannot be done unless Project 2 is also undertaken, and projects 3 and 4 would compete with each other, so they should not both be chosen. YCC expects to have the following cash available to invest in these projects: $40 million for year 1, $25 million for year 2, $16 million for year 3, and $12 million for year 4. Any available money not spent in a given year is then available to spend the following year. YCC's policy is to choose their projects so as to maximize their total expected NPV.

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

7.15. Read the referenced article that fully describes the management science study summarized in the application vignette presented in Section 7.5. Briefly describe how mixed BIP was applied in this study. Then list the various financial and nonfinancial benefits that resulted from this study.

7.16. An electrical utility needs to generate 6,500 megawatts of electricity today. It has five generators. If any electricity is generated by a given generator, that generator must be started up and a fixed start-up cost is incurred. There is an additional cost for each megawatt generated by a generator. These costs, as well as the maximum capacity of each generator, are shown in the above table. The objective is to determine the minimum cost plan that meets the electrical needs for today.

	Generator				
	A	**B**	**C**	**D**	**E**
Fixed start-up cost	$3,000	$2,000	$2,500	$1,500	$1,000
Cost per megawatt/day generated	$5	$4	$6	$6	$7
Maximum capacity (MW/day)	2,100	1,800	2,500	1,500	3,000

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

7.17. The school board for the Bellevue School District has made the decision to purchase 1,350 additional Macintosh computers for computer laboratories in all its schools. Based on past experience, the school board also has directed that these computers should be purchased from some combination of three companies—Educomp, Macwin, and McElectronics. In all three cases, the companies charge a discounted variable cost per computer and a fixed delivery and installation cost for these large sales to school districts. The next table shows these charges as well as the capacity (the maximum number of computers that can be sold from the limited inventory) for each of the companies.

	Educomp	Macwin	McElectronics
Capacity	700	700	1,000
Fixed cost	$45,000	$35,000	$50,000
Variable cost	$750	$775	$700

The school board wants to determine the minimum-cost plan for meeting its computer needs.

a. Formulate a BIP model in algebraic form for this problem.

b. Formulate and solve this model on a spreadsheet.

AS *c.* Now suppose that Macwin has not submitted its final bid yet, so the per computer cost is not known with certainty. Generate a parameter analysis report with Analytic Solver to show the optimal order quantities and total cost of the optimal solution when the cost per computer for Macwin is $680, $690, $700, $710, . . . , $790, or $800.

7.18. Noble Amazon sells books online. Management is trying to determine the best sites for the company's warehouses. The five potential sites under consideration are listed in the first column of the following table. Most of the sales come from customers in the United States. The average weekly demand from each region of the country, the average shipping cost from each warehouse site to each region of the country, the fixed cost per week of each warehouse if it is operated, and the maximum capacity of each warehouse (if it is operated) are shown in the following table. Formulate and solve a mixed BIP model in a spreadsheet to determine which warehouse sites Noble Amazon should operate and how books should be distributed from each warehouse to each region of the country to minimize total cost.

	Average Shipping Cost ($/book)					Fixed Cost	Warehouse Capacity
Warehouse Site	**Northwest**	**Southwest**	**Midwest**	**Southeast**	**Northeast**	**(per week)**	**(books/week)**
Spokane, WA	$2.40	$3.50	$4.80	$6.80	$5.75	$40,000	20,000
Reno, NV	$3.25	$2.30	$3.40	$5.25	$6.00	$30,000	20,000
Omaha, NE	$4.05	$3.25	$2.85	$4.30	$4.75	$25,000	15,000
Harrisburg, PA	$5.25	$6.05	$4.30	$3.25	$2.75	$40,000	25,000
Jacksonville, FL	$6.95	$5.85	$4.80	$2.10	$3.50	$30,000	15,000
Customer demand (per week)	8,000	12,000	9,000	14,000	17,000		

7.19. Aberdeen Computer Corp. (ACC) is located in Aberdeen, Washington. The company has developed Jeeves, a voice-activated Internet assistant for the home. This product is manufactured at four plants, located in Atlanta, Kansas City, Aberdeen, and Austin. After production, the units are shipped to three warehouses, located in Nashville, San Jose, and Houston. ACC sells through the retail channel. In particular, five different retailers currently sell Jeeves—Sears, Best Buy, Fry's, Walmart, and Office Depot. ACC makes weekly shipments to the main warehouses of these five retailers. The shipping cost from each plant to each warehouse, along with the production cost and weekly production capacity at each plant, are given in the table below.

	Shipping Cost ($/unit)			Production	Capacity
Plant	**Nashville**	**San Jose**	**Houston**	**Cost ($/unit)**	**(units/week)**
Atlanta	$30	$40	$50	$208	200
Kansas City	$25	$45	$40	$214	300
Aberdeen	$45	$30	$55	$215	300
Austin	$30	$50	$30	$210	400

The shipping cost from each warehouse to each customer, the variable cost (cost per unit moved through the warehouse), the capacity (maximum number of units that can be moved through the warehouse per week) for each warehouse, and the weekly demand for each customer are given in the table below.

	Shipping Cost ($/unit)					Variable Cost	Capacity
Warehouse	**Sears**	**Best Buy**	**Fry's**	**Comp USA**	**Office Max**	**($/unit)**	**(units/week)**
Nashville	$40	$45	$30	$25	$20	$4	300
San Jose	$15	$50	$25	$15	$40	$5	500
Houston	$50	$35	$15	$40	$50	$5	500
Customer demand (per week)	100	50	75	300	150		

a. Formulate and solve a linear programming model in a spreadsheet to determine the plan for weekly production and distribution of Jeeves from the various plants, through the warehouses, to the customers that will minimize total costs.

b. Now suppose that ACC is considering saving money by closing some of its production facilities and/or warehouses. Suppose there is a fixed cost to operate each plant and each warehouse as indicated in the following tables. Add binary variables to your model in part *a* to incorporate the decision of which plants and warehouses to keep open so as to minimize total cost (including the fixed costs for any plant or warehouse that is operated).

Plant	Fixed Cost ($/week)
Atlanta	$8,000
Kansas City	$9,000
Aberdeen	$9,000
Austin	$10,000

Warehouse	Fixed Cost ($/week)
Nashville	$4,000
San Jose	$5,000
Houston	$5,000

Case 7-1

Assigning Art

It had been a dream come true for Ash Briggs, a struggling artist living in the San Francisco Bay area. He had made a trip to the corner grocery store late one Friday afternoon to buy some milk, and, on impulse, he had also purchased a California lottery ticket. One week later, he was a multimillionaire.

Ash did not want to squander his winnings on materialistic, trivial items. Instead he wanted to use his money to support his true passion: art. Ash knew all too well the difficulties of gaining recognition as an artist in this post-industrial, technological society where artistic appreciation is rare and financial support even rarer. He therefore decided to use the money to fund an exhibit of up-and-coming modern artists at the **San Francisco Museum of Modern Art.**

Ash approached the museum directors with his idea, and the directors became excited immediately after he informed them that he would fund the entire exhibit in addition to donating $1 million to the museum. Celeste McKenzie, a museum director, was assigned to work with Ash in planning the exhibit. The exhibit was slated to open one year from the time Ash met with the directors, and the exhibit pieces would remain on display for two months.

Ash began the project by combing the modern art community for potential artists and pieces. He presented a list (shown below) of artists, their pieces, and the price of displaying each piece[1] to Celeste.

Ash possesses certain requirements for the exhibit. He believes the majority of Americans lack adequate knowledge of art and artistic styles, and he wants the exhibit to educate Americans. Ash wants visitors to become aware of the collage as an art form, but he believes collages require little talent. He therefore decides to include only one collage. Additionally, Ash wants viewers to compare the delicate lines in a three-dimensional wire mesh sculpture to the delicate lines in a two-dimensional computer-generated drawing. He therefore wants at least one wire-mesh sculpture displayed if a computer-generated drawing is displayed. Alternatively, he wants at least one computer-generated drawing displayed if a wire-mesh sculpture

Artist	Piece	Description of Piece	Price
Colin Zweibell	*Perfection*	A wire-mesh sculpture of the human body	$300,000
	Burden	A wire-mesh sculpture of a mule	250,000
	The Great Equalizer	A wire-mesh sculpture of a gun	125,000
Rita Losky	*Chaos Reigns*	A series of computer-generated drawings	400,000
	Who Has Control?	A computer-generated drawing intermeshed with lines of computer code	500,000
	Domestication	A pen-and-ink drawing of a house	400,000
	Innocence	A pen-and-ink drawing of a child	550,000
Norm Marson	*Aging Earth*	A sculpture of trash covering a larger globe	700,000
	Wasted Resources	A collage of various packaging materials	575,000
Candy Tate	*Serenity*	An all-blue watercolor painting	200,000
	Calm before the Storm	A painting with an all-blue watercolor background and a black watercolor center	225,000
Robert Bayer	*Void*	An all-black oil painting	150,000
	Sun	An all-yellow oil painting	150,000

(*Continued*)

[1] The display price includes the cost of paying the artist for loaning the piece to the museum, transporting the piece to San Francisco, constructing the display for the piece, insuring the piece while it is on display, and transporting the piece back to its origin.

Artist	Piece	Description of Piece	Price
David Lyman	*Storefront Window*	A photo-realistic painting of a jewelry store display window	850,000
	Harley	A photo-realistic painting of a Harley-Davidson motorcycle	750,000
Angie Oldman	*Consumerism*	A collage of magazine advertisements	400,000
	Reflection	A mirror (considered a sculpture)	175,000
	Trojan Victory	A wooden sculpture of a condom	450,000
Rick Rawls	*Rick*	A photo-realistic self-portrait (painting)	500,000
	Rick II	A cubist self-portrait (painting)	500,000
	Rick III	An expressionist self-portrait (painting)	500,000
Bill Reynolds	*Beyond*	A science fiction oil painting depicting Mars colonization	650,000
	Pioneers	An oil painting of three astronauts aboard the space shuttle	650,000
Bear Canton	*Wisdom*	A pen-and-ink drawing of an Apache chieftain	250,000
	Superior Powers	A pen-and-ink drawing of a traditional Native American rain dance	350,000
	Living Land	An oil painting of the Grand Canyon	450,000
Helen Row	*Study of a Violin*	A cubist painting of a violin	400,000
	Study of a Fruit Bowl	A cubist painting of a bowl of fruit	400,000
Ziggy Lite	*My Namesake*	A collage of Ziggy cartoons	300,000
	Narcissism	A collage of photographs of Ziggy Lite	300,000
Ash Briggs	*All That Glitters*	A watercolor painting of the Golden Gate Bridge	50,000*
	The Rock	A watercolor painting of Alcatraz	50,000*
	Winding Road	A watercolor painting of Lombard Street	50,000*
	Dreams Come True	A watercolor painting of the San Francisco Museum of Modern Art	50,000*

*Ash does not require personal compensation, and the cost for moving his pieces to the museum from his home in San Francisco is minimal. The cost of displaying his pieces therefore only includes the cost of constructing the display and insuring the pieces.

is displayed. Furthermore, Ash wants to expose viewers to all painting styles, but he wants to limit the number of paintings displayed to achieve a balance in the exhibit between paintings and other art forms. He therefore decides to include at least one photo-realistic painting, at least one cubist painting, at least one expressionist painting, at least one watercolor painting, and at least one oil painting. At the same time, he wants the number of paintings to be no greater than twice the number of other art forms.

Ash wants all his own paintings included in the exhibit since he is sponsoring the exhibit and since his paintings celebrate the San Francisco Bay area, the home of the exhibit.

Ash possesses personal biases for and against some artists. Ash is currently having a steamy affair with Candy Tate, and he wants both of her paintings displayed. Ash counts both David Lyman and Rick Rawls as his best friends, and he does not want to play favorites between these two artists. He therefore decides to display as many pieces from David Lyman as from Rick Rawls and to display at least one piece from each of them. Although Ziggy Lite is very popular within art circles, Ash believes Ziggy makes a mockery of art. Ash will therefore only accept one display piece from Ziggy, if any at all.

Celeste also possesses her own agenda for the exhibit. As a museum director, she is interested in representing a diverse population of artists, appealing to a wide audience, and creating a politically correct exhibit. To advance feminism, she decides to include at least one piece from a female artist for every two pieces included from a male artist. To advance environmentalism, she decides to include either one or both of the pieces *Aging Earth* and *Wasted Resources.* To advance Native American rights, she decides to include at least one piece by Bear Canton. To advance science, she decides to include at least one of the following pieces: *Chaos Reigns, Who Has Control?, Beyond,* and *Pioneers.*

Celeste also understands that space is limited at the museum. The museum only has enough floor space for four sculptures and enough wall space for 20 paintings, collages, and drawings.

Finally, Celeste decides that if *Narcissism* is displayed, *Reflection* should also be displayed since *Reflection* also suggests narcissism.

Please explore the following questions independently except where otherwise indicated.

a. Ash decides to allocate $4 million to fund the exhibit. Given the pieces available and the specific requirements from Ash and Celeste, formulate and solve a binary integer programming problem to maximize the number of pieces displayed in the exhibit without exceeding the budget. How many pieces are displayed? Which pieces are displayed?

b. To ensure that the exhibit draws the attention of the public, Celeste decides that it must include at least 20 pieces. Formulate and solve a binary integer programming problem to minimize the cost of the exhibit while displaying at least 20 pieces and meeting the requirements set by Ash and Celeste. How much does the exhibit cost? Which pieces are displayed?

c. An influential patron of Rita Losky's work who chairs the museum's board of directors learns that Celeste requires at least 20 pieces in the exhibit. He offers to pay the minimum amount required on top of Ash's $4 million to ensure that exactly 20 pieces are displayed in the exhibit and that all of Rita's pieces are displayed. How much does the patron have to pay? Which pieces are displayed?