■ CASE 12.2   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 millionaire.

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 postindustrial, 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 the following list of artists, their pieces, and the price of displaying each piece[1] to Celeste.

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

[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
Robert Bayer	"Void"	An all black oil painting	$150,000
	"Sun"	An all yellow oil painting	$150,000
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.

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 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 among 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 BIP model 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 BIP model 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 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?

Note: A data file for this case is included on this website for your convenience.

■ CASE 12.3   STOCKING SETS

Daniel Holbrook, an expediter at the local warehouse for Furniture City, sighed as he moved boxes and boxes of inventory to the side in order to reach the shelf where the particular item he needed was located. He dropped to his hands and knees and squinted at the inventory numbers lining the bottom row of the shelf. He did not find the number he needed. He worked his way up the shelf until he found the number matching the number on the order slip. Just his luck! The item was on the top row of the shelf! Daniel walked back through the warehouse to find a ladder, stumbling over boxes of inventory littering his path. When he finally climbed the ladder to reach the top shelf, his face crinkled in frustration. Not again! The item he needed was not in stock! All he saw above the inventory number was an empty space covered with dust!

Daniel trudged back through the warehouse to make the dreadful phone call. He dialed the number of Brenda Sims, the saleswoman on the kitchen showroom floor of Furniture

City, and informed her that the particular light fixture the customer had requested was not in stock. He then asked her if she wanted him to look for the rest of the items in the kitchen set. Brenda told him that she would talk to the customer and call him back.

Brenda hung up the phone and frowned. Mr. Davidson, her customer, would not be happy. Ordering and receiving the correct light fixture from the regional warehouse would take at least two weeks.

Brenda then paused to reflect upon business during the last month and realized that over 80 percent of the orders for kitchen sets could not be filled because items needed to complete the sets were not in stock at the local warehouse. She also realized that Furniture City was losing customer goodwill and business because of stockouts. The furniture megastore was gaining a reputation for slow service and delayed deliveries, causing customers to turn to small competitors that sold furniture directly from the showroom floor.

Brenda decided to investigate the inventory situation at the local warehouse. She walked the short distance to the building next door and gasped when she stepped inside the warehouse. What she saw could only be described as chaos. Spaces allocated for some items were overflowing into the aisles of the warehouse while other spaces were completely bare. She walked over to one of the spaces overflowing with inventory to discover the item that was overstocked. She could not believe her eyes! The warehouse had at least 30 rolls of pea-green wallpaper! No customer had ordered pea-green wallpaper since 1973!

Brenda marched over to Daniel demanding an explanation. Daniel said that the warehouse had been in such a chaotic state since his arrival one year ago. He said the inventory problems occurred because management had a policy of stocking every furniture item on the showroom floor

in the local warehouse. Management only replenished inventory every three months, and when inventory was replenished, management ordered every item regardless of if it had been sold. Daniel also said that he had tried to make management aware of the problems with overstocking unpopular items and understocking popular items, but that management would not listen to him because he was simply an expeditor.

Brenda understood that Furniture City required a new inventory policy. Not only was the megastore losing money by making customers unhappy with delivery delays, but it was also losing money by wasting warehouse space. By changing the inventory policy to stock only popular items and replenish them immediately when they are sold, Furniture City would ensure that the majority of customers receive their furniture immediately and that the valuable warehouse space was utilized effectively.

Brenda needed to sell her inventory policy to management. Using her extensive sales experience, she decided that the most effective sales strategy would be to use her kitchen department as a model for the new inventory policy. She would identify all kitchen sets comprising 85 percent of customers orders. Given the fixed amount of warehouse space allocated to the kitchen department, she would identify the items Furniture City should stock in order to satisfy the greatest number of customer orders. She would then calculate the revenue from satisfying customer orders under the new inventory policy, using the bottom line to persuade management to accept her policy.

Brenda analyzed her records over the past three years and determined that 20 kitchen sets were responsible for 85 percent of the customer orders. These 20 kitchen sets were composed of up to eight features in a variety of styles. Brenda listed each feature and its popular styles:

Floor Tile	Wallpaper	Light Fixtures	Cabinets
(T1) White textured tile	(W1) Plain ivory paper	(L1) One large rectangular frosted fixture	(C1) Light solid wood cabinets
(T2) Ivory textured tile	(W2) Ivory paper with dark brown pinstripes	(L2) Three small square frosted fixtures	(C2) Dark solid wood cabinets
(T3) White checkered tile with blue trim	(W3) Blue paper with marble texture	(L3) One large oval frosted fixture	(C3) Light wood cabinets with glass doors
(T4) White checkered tile with light yellow trim	(W4) Light yellow paper with marble texture	(L4) Three small frosted globe fixtures	(C4) Dark wood cabinets with glass doors

Countertops	Dishwashers	Sinks	Ranges
(O1) Plain light wood countertops	(D1) White energy-saving dishwasher	(S1) Sink with separate hot and cold water taps	(R1) White electric oven
(O2) Stained light wood countertops	(D2) Ivory energy-saving dishwasher	(S2) Divided sink with separate hot and cold water taps and garbage disposal	(R2) Ivory electric oven
(O3) White lacquer-coated countertops		(S3) Sink with one hot and cold water tap	(R3) White gas oven
(O4) Ivory lacquer-coated countertops		(S4) Divided sink with one hot and cold water tap and garbage disposal	(R4) Ivory gas oven

Brenda then created a table showing the 20 kitchen sets and the particular features composing each set. To simplify the table, she used the codes shown in parentheses above to represent the particular feature and style. The table is given on the next page. For example, kitchen set 1 consists of floor tile T2, wallpaper W2, light fixture L4, cabinet C2, countertop O2, dishwasher D2, sink S2, and range R2. Notice that sets 14 through 20 do not contain dishwashers.

Brenda knew she had only a limited amount of warehouse space allocated to the kitchen department. The warehouse could hold 50 square feet of tile and 12 rolls of wallpaper in the inventory bins. The inventory shelves could hold two light fixtures, two cabinets, three countertops, and two sinks. Dishwashers and ranges are similar in size, so Furniture City stored them in similar locations. The warehouse floor could hold a total of four dishwashers and ranges.

Every kitchen set always includes exactly 20 square feet of tile and exactly five rolls of wallpaper. Therefore, 20 square feet of a particular style of tile and five rolls of a particular style of wallpaper are required for the styles to be in stock.

(a) Formulate and solve a BIP model to maximize the total number of kitchen sets (and thus the number of customer orders) Furniture City stocks in the local warehouse. Assume that when a customer orders a kitchen set, all the particular items composing that kitchen set are replenished at the local warehouse immediately.

(b) How many of each feature and style should Furniture City stock in the local warehouse? How many different kitchen sets are in stock?

(c) Furniture City decides to discontinue carrying nursery sets, and the warehouse space previously allocated to the nursery department is divided between the existing departments at Furniture City. The kitchen department receives enough additional space to allow it to stock both styles of dishwashers and three of the four styles of ranges. How does the optimal inventory policy for the kitchen department change with this additional warehouse space?

(d) Brenda convinces management that the kitchen department should serve as a testing ground for future inventory policies. To provide adequate space for testing, management decides to allocate all the space freed by the nursery department to the kitchen department. The extra space means that the kitchen department can store not only the dishwashers and ranges from part (c), but also all sinks, all countertops, three of the four light fixtures, and three of the four cabinets. How much does the additional space help?

(e) How would the inventory policy be affected if the items composing a kitchen set could not be replenished immediately? Under what conditions is the assumption of immediate replenishment nevertheless justified?

Note: A data file for this case is included on this website for your convenience.

■ CASE 12.4   ASSIGNING STUDENTS TO SCHOOLS (REVISITED AGAIN)

Reconsider Case 4.3.

The Springfield School Board now has made the decision to prohibit the splitting of residential areas among multiple schools. Thus, each of the six areas must be assigned to a single school.

	T1	T2	T3	T4	W1	W2	W3	W4	L1	L2	L3	L4	C1	C2	C3	C4	O1	O2	O3	O4	D1	D2	S1	S2	S3	S4	R1	R2	R3	R4
Set 1		X				X						X		X						X		X	X	X				X		
Set 2		X		X			X								X					X		X	X			X	X			
Set 3	X					X				X			X					X				X			X				X	
Set 4			X			X					X			X					X		X	X	X				X			
Set 5				X			X	X					X						X			X	X		X		X			
Set 6		X			X					X					X				X		X	X		X						X
Set 7	X					X					X		X		X			X			X	X				X				
Set 8		X		X					X		X			X					X			X		X						X
Set 9		X		X					X				X		X			X			X	X			X					
Set 10	X			X					X				X					X	X				X			X		X		
Set 11			X	X						X			X	X				X	X				X					X		
Set 12		X			X				X				X					X			X			X		X	X			
Set 13			X				X			X			X	X				X				X		X				X		
Set 14			X				X				X	X						X				X		X		X				
Set 15		X				X	X						X		X				X						X		X			
Set 16		X				X				X	X							X				X		X		X				
Set 17	X					X	X						X		X							X		X			X			
Set 18		X				X				X		X						X			X			X				X		
Set 19		X					X			X			X					X			X			X						X
Set 20		X				X	X			X			X					X						X						X

(a) Formulate a BIP model for this problem under the current policy of providing bussing for all middle school students who must travel more than approximately a mile.

(b) Referring to part (*a*) of Case 4.3, explain why that linear programming model and the BIP model just formulated are so different when they are dealing with nearly the same problem.

(c) Solve the BIP model formulated in part (*a*).

(d) Referring to part (*c*) of Case 4.3, determine how much the total bussing cost increases because of the decision to prohibit the splitting of residential areas among multiple schools.

(e, f, g, h) Repeat parts (*e, f, g, h*) of Case 4.3 under the new school board decision to prohibit splitting residential areas among multiple schools.