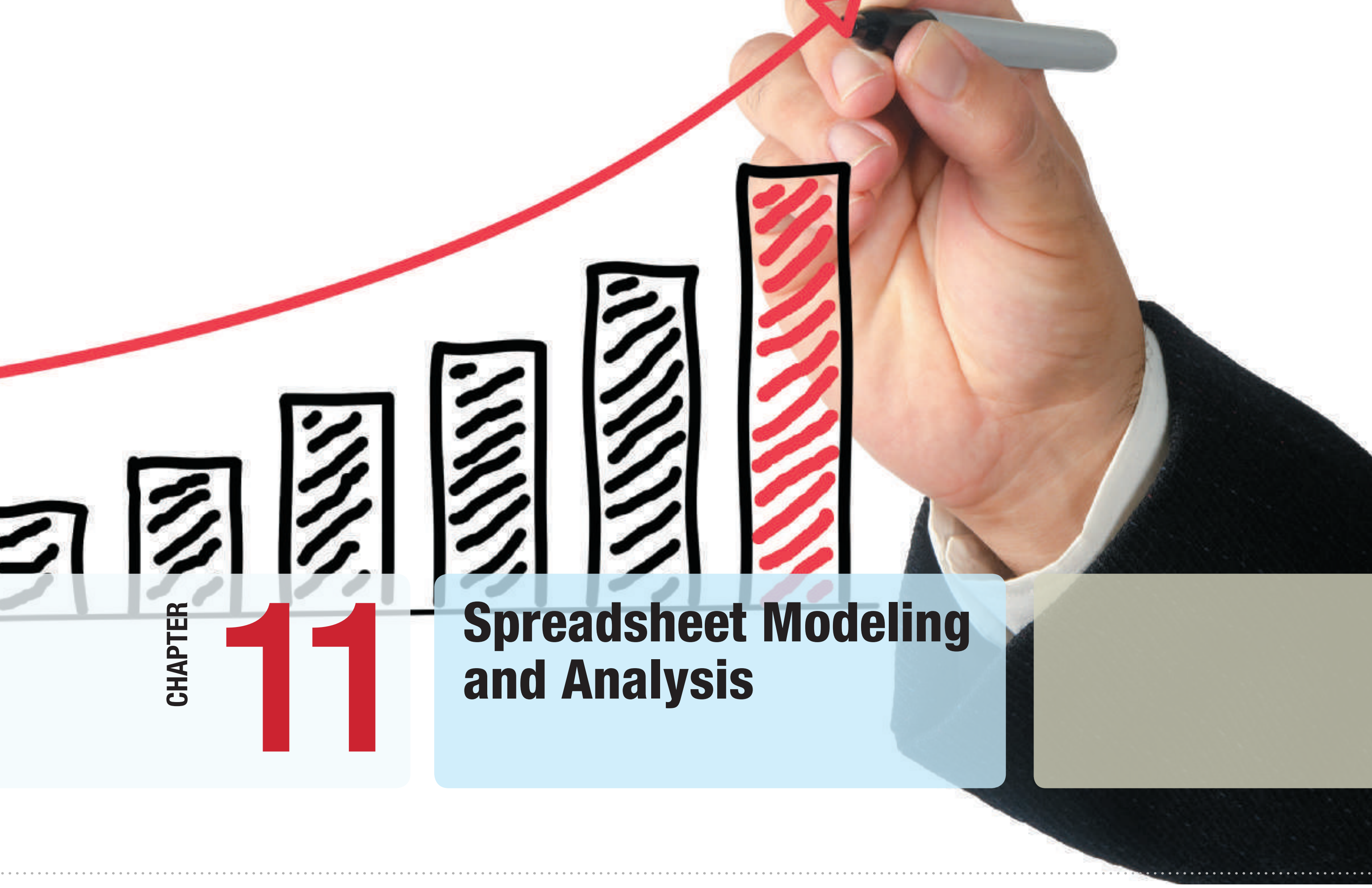


CHAPTER 11 Spreadsheet Modeling and Analysis

Rufous/Shutterstock.com

Learning Objectives

After studying this chapter, you will be able to:

- Explain how to use simple mathematics and influence diagrams to help develop predictive analytic models.
- Apply principles of spreadsheet engineering to designing and implementing spreadsheet models.
- Use Excel features and spreadsheet engineering to ensure the quality of spreadsheet models.
- Develop and implement analytic models for multiple-time-period problems.
- Describe the newsvendor problem and implement it on a spreadsheet.
- Describe how overbooking decisions can be modeled on spreadsheets.
- Explain how model validity can be assessed.
- Perform what-if analysis on spreadsheet models.
- Construct one- and two-way data tables.
- Use data tables to analyze uncertainty in decision models.
- Use the Excel *Scenario Manager* to evaluate different model scenarios.
- Apply the Excel *Goal Seek* tool for break-even analysis and other types of models.
- Create data tables and tornado charts using *Analytic Solver Platform*.
- Use Excel tools to create user-friendly Excel models and applications.

The late management and quality guru Dr. W. Edwards Deming once stated that all management is prediction. What he was implying is that when managers make decisions, they do so with an eye to the future and essentially are predicting that their decisions will achieve certain results. Predictive modeling is the heart and soul of business analytics.

We introduced the concept of a decision model in Figure 1.7 in Chapter 1. Decision models transform inputs—data, uncontrollable variables, and decision variables—into outputs, or measures of performance or behavior. When we build a decision model, we are essentially predicting what outputs will occur based on the model inputs. The model itself is simply a set of assumptions that characterize the relationships between the inputs and the outputs. For instance, in Examples 1.9 and 1.10, we presented two different models for predicting demand as a function of price, each based on different assumptions. The first model assumes that demand is a linear function of price, whereas the second assumes a nonlinear price-elasticity relationship. Which model more accurately predicts demand can be verified only by observing data in the future. Since the future is unknown, the choice of the model must be driven either by sound logic and experience or the analysis of historical data that may be available. These are the two basic approaches that we develop in this chapter. We also describe approaches for analyzing models to evaluate future scenarios and ask what-if types of questions to facilitate better business decisions.

Strategies for Predictive Decision Modeling

Building decision models is more of an art than a science. Creating good decision models requires a solid understanding of basic business principles in all functional areas, such as accounting, finance, marketing, and operations, knowledge of business practice and research, and logical skills. Models often evolve from simple to complex and from deterministic to stochastic (see the definitions in Chapter 1), so it is generally best to start simple and enrich models as necessary.

Building Models Using Simple Mathematics

Sometimes a simple "back-of-the-envelope" calculation can help managers make better decisions and lead to the development of useful models.

EXAMPLE 11.1 The Economic Value of a Customer

Few companies take the time to estimate the value of a good customer (and often spend little effort to keep one). Suppose that a customer at a restaurant spends, on average, \$50 per visit and comes six times each year. Assuming that the restaurant realizes a 40% margin on the average bill for food and drinks, then their gross profit would be (\$50)(6)(.40) = \$120. If 30% of customers do not return each year, then the average lifetime of a customer is 1/0.3 = 3.33 years. Therefore, the average nondiscounted gross profit during a customer's lifetime is \$120(3.33) = \$400.

Although this example calculated the economic value of a customer for one particular scenario, what we've really done is to set the stage for constructing a general decision model. Suppose we define the following variables:

R = revenue per purchase
F = purchase frequency in number per year (e.g., if a customer purchases once every 2 years, then $F = \frac{1}{2} = 0.5$)
M = gross profit margin (expressed as a fraction)
D = defection rate (fraction of customers defecting each year)

Then, the value of a loyal customer, V, would be

$$V = \frac{R \times F \times M}{D} \tag{11.1}$$

In the previous example, $R = \$50$, $F = 6$, $M = 0.4$, and $D = 0.3$. We can use this model to evaluate different scenarios systematically.

Building Models Using Influence Diagrams

Although it can be easy to develop a model from simple numerical calculations, as we illustrated in the previous example, most model development requires a more formal approach. Influence diagrams were introduced in Chapter 1, and are a logical and visual representation of key model relationships, which can be used as a basis for developing a mathematical decision model.

EXAMPLE 11.2 Developing a Decision Model Using an Influence Diagram

We will develop a decision model for predicting profit in the face of uncertain future demand. To help develop the model, we use the influence-diagram approach. We all know that profit = revenue − cost. Using a little "Business 101" logic, revenue depends on the unit price and the quantity sold, and cost depends on the unit cost, quantity produced, and fixed costs of production. However, if demand is uncertain, then the amount produced may be less than or greater than the actual demand. Thus, the quantity sold depends on both the demand and the quantity produced. Putting these facts together, we can build the influence diagram shown in Figure 11.1.

The next step is to translate the influence diagram into a more formal model. Define

P = profit
R = revenue
C = cost
p = unit price
c = unit cost
F = fixed cost
S = quantity sold
Q = quantity produced
D = demand

First, note that cost consists of the fixed cost (F) plus the variable cost of producing Q units (cQ):

$$C = F + cQ$$

Next, revenue equals the unit price (p) multiplied by the quantity sold (S):

$$R = pS$$

The quantity sold, however, must be the smaller of the demand (D) and the quantity produced (Q), or

$$S = \min\{D, Q\}$$

Therefore, $R = pS = p*\min\{D, Q\}$. Substituting these results into the basic formula for profit $P = R - C$, we have

$$P = p*\min\{D, Q\} - (F + cQ) \tag{11.2}$$

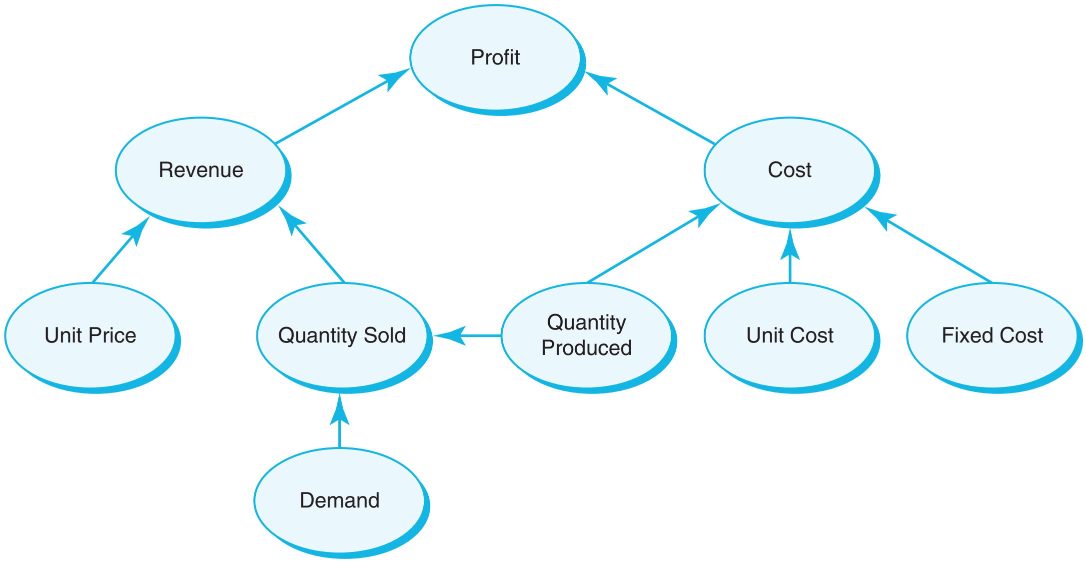


Figure 11.1
An Influence Diagram for Profit

Implementing Models on Spreadsheets

We may creatively apply various Excel tools and capabilities to improve the structure and use of spreadsheet models. In this section, we discuss approaches for developing good, useful, and correct spreadsheet models. Good spreadsheet analytic applications should also be user-friendly; that is, it should be easy to input or change data and see key results, particularly for users who may not be as proficient in using spreadsheets. Good design reduces the potential for errors and misinterpretation of information, leading to more insightful decisions and better results.

Spreadsheet Design

In Chapter 1, Example 1.7, we developed a simple decision model for a break-even analysis situation. Recall that the scenario involves a manufacturer who can produce a part for \$125/unit with a fixed cost of \$50,000. The alternative is to outsource production to a supplier at a unit cost of \$175. We developed mathematical models for the total manufacturing cost and the total cost of outsourcing as a function of the production volume, Q:

$$TC\text{ (manufacturing)} = \$50{,}000 + \$125 \times Q$$
$$TC\text{ (outsourcing)} = \$175 \times Q$$

EXAMPLE 11.3 A Spreadsheet Model for the Outsourcing Decision

Figure 11.2 shows a spreadsheet for implementing the outsourcing decision model (Excel file *Outsourcing Decision Model*). The input data consist of the costs associated with manufacturing the product in-house or purchasing it from an outside supplier and the production volume. The model calculates the total cost for manufacturing and outsourcing. The key outputs in the model are the difference in these costs and the decision that results in the lowest cost. The data are clearly separated from the model component of the spreadsheet.

Observe how the IF function is used in cell B20 to identify the best decision. If the cost difference is negative or zero, then the function returns "Manufacture" as the best decision; otherwise it returns "Outsource." Also observe the correspondence between the spreadsheet formulas and the mathematical model:

$$TC\text{ (manufacturing)} = \$50{,}000 + \$125 \times Q = \text{B6} + \text{B7*B12}$$
$$TC\text{ (outsourcing)} = \$175 \times Q = \text{B12*B10}$$

Thus, if you can write a spreadsheet formula, you can develop a mathematical model by substituting symbols or numbers into the Excel formulas.

	A	B
1	Outsourcing Decision Model	
2		
3	Data	
4		
5	Manufactured in-house	
6	Fixed cost	$50,000
7	Unit variable cost	$125
8		
9	Purchased from supplier	
10	Unit cost	$175
11		
12	Production volume	1500
13		
14	Model	
15		
16	Total manufacturing cost	$237,500
17	Total purchased cost	$262,500
18		
19	Cost difference (Manufacture - Purchase)	-$25,000
20	Best Decision	Manufacture

	A	B
1	Outsourcing Decision Model	
2		
3	Data	
4		
5	Manufactured in-house	
6	Fixed cost	50000
7	Unit variable cost	125
8		
9	Purchased from supplier	
10	Unit cost	175
11		
12	Production volume	1500
13		
14	Model	
15		
16	Total manufacturing cost	=B6+B7*B12
17	Total purchased cost	=B12*B10
18		
19	Cost difference (Manufacture - Purchase)	=B16-B17
20	Best Decision	=IF(B19<=0, "Manufacture", "Outsource")

Figure 11.2

Outsourcing Decision Model Spreadsheet

Because decision models characterize the relationships between inputs and outputs, it is useful to separate the data, model calculations, and model outputs clearly in designing a spreadsheet. It is particularly important not to use input data in model formulas, but to *reference* the spreadsheet cells that contain the data. In this way, if the data change or you want to experiment with the model, you need not change any of the formulas, which can easily result in errors.

EXAMPLE 11.4 Pricing Decision Spreadsheet Model

Another model we developed in Chapter 1 is one in which a firm wishes to determine the best pricing for one of its products to maximize revenue. The model was developed by incorporating an equation for sales into a total revenue calculation:

$$
\begin{aligned}
\text{sales} &= -2.9485 \times \text{price} + 3{,}240.9 \\
\text{total revenue} &= \text{price} \times \text{sales} \\
&= \text{price} \times (-2.9485 \times \text{price} + 3{,}240.9) \\
&= -2.9485 \times \text{price}^2 + 3{,}240.9 \times \text{price}
\end{aligned}
$$

Figure 11.3 shows a spreadsheet for calculating both sales and revenue as a function of price.

Figure 11.3

Pricing Decision Spreadsheet Model

	A	B
1	Pricing Decision Model	
2		
3	Data	
4		
5	Price	$500.00
6		
7	Model	
8		
9	Sales Function Slope	-2.9485
10	Sales Function Intercept	3240.9
11	Sales	1766.65
12		
13	Total Revenue	$883,325.00

	A	B
1	Pricing Decision Model	
2		
3	Data	
4		
5	Price	500
6		
7	Model	
8		
9	Sales Function Slope	-2.9485
10	Sales Function Intercept	3240.9
11	Sales	=B9*B5+B10
12		
13	Total Revenue	=B5*B11

Mathematical models are easy to manipulate; for example, we showed in Chapter 1 that it was easy to find the break-even point by setting TC (manufacturing) $=$ TC (outsourcing) and solving for Q. In contrast, it is more difficult to find the break-even volume using trial and error on the spreadsheet without knowing some advanced tools and approaches. However, spreadsheets have the advantage of allowing you to easily modify the model inputs and calculate the numerical results. We will use both spreadsheets and analytical modeling approaches in our model-building applications—it is important to be able to "speak both languages."

EXAMPLE 11.5 Spreadsheet Implementation of the Profit Model

The analytical model we developed in Example 11.2 can easily be implemented in an Excel spreadsheet to evaluate profit (Excel file *Profit Model*). Let us assume that unit price = \$40, unit cost = \$24, fixed cost = \$400,000, and demand = 50,000. The decision variable is the quantity produced; for the purposes of building a spreadsheet model, we assume a value of 40,000 units. Figure 11.4 shows a spreadsheet implementation of this model. To better understand the model, study the relationships between the spreadsheet formulas, the influence diagram, and the mathematical model. A manager might use the spreadsheet to evaluate how profit would be expected to change for different values of the uncertain future demand and/or the quantity produced, which is a decision variable that the manager can control. We do this later in this chapter.

Spreadsheet Quality

Building spreadsheet models, often called **spreadsheet engineering**, is part art and part science. The quality of a spreadsheet can be assessed both by its logical accuracy and its design. Spreadsheets need to be accurate, understandable, and user-friendly.

First and foremost, spreadsheets should be accurate. **Verification** is the process of ensuring that a model is accurate and free from logical errors. Spreadsheet errors can be disastrous. A large investment company once made a \$2.6 billion error. They notified holders of one mutual fund to expect a large dividend; fortunately, they caught the error before sending the checks. One research study of 50 spreadsheets found that fewer than 10% were error free.[1] Significant errors in business have resulted from mistakes in copying and pasting, sorting, numerical input, and spreadsheet-formula references. Industry research has found that more than 90% of spreadsheets with more than 150 rows were incorrect by at least 5%.

There are three basic approaches to spreadsheet engineering that can improve spreadsheet quality:

Figure 11.4

Spreadsheet Implementation of Profit Model

	A	B	C
1	Profit Model		
2			
3	Data		
4			
5	Unit Price	\$40.00	
6	Unit Cost	\$24.00	
7	Fixed Cost	\$400,000.00	
8	Demand	50000	
9			
10			
11	Model		
12			
13	Unit Price	\$40.00	
14	Quantity Sold	40000	
15	Revenue		\$1,600,000.00
16			
17	Unit Cost	\$24.00	
18	Quantity Produced	40000	
19	Variable Cost		\$960,000.00
20	Fixed Cost		\$400,000.00
21			
22	Profit		\$240,000.00

	A	B	C
1	Profit Model		
2			
3	Data		
4			
5	Unit Price	40	
6	Unit Cost	24	
7	Fixed Cost	400000	
8	Demand	50000	
9			
10			
11	Model		
12			
13	Unit Price	=B5	
14	Quantity Sold	=MIN(B8,B18)	
15	Revenue		=B13*B14
16			
17	Unit Cost	=B6	
18	Quantity Produced	40000	
19	Variable Cost		=B17*B18
20	Fixed Cost		=B7
21			
22	Profit		=C15-C19-C20

[1] S. Powell, K. Baker, and B. Lawson, "Errors in Operational Spreadsheets," *Journal of End User Computing*, 21 (July–September 2009): 24–36.

1. *Improve the design and format of the spreadsheet itself.* After the inputs, outputs, and key model relationships are well understood, you should sketch a logical design of the spreadsheet. For example, you might want the spreadsheet to resemble a financial statement to make it easier for managers to read. It is good practice to separate the model inputs from the model itself and to reference the input cells in the model formulas; that way, any changes in the inputs will be automatically reflected in the model. We have done this in the examples.

   Another useful approach is to break complex formulas into smaller pieces. This reduces typographical errors, makes it easier to check your results, and also makes the spreadsheet easier to read for the user. Finally, it is also important to set up the spreadsheet in a form that the end user—who may be a financial manager, for example—can easily interpret and use. Example 11.6 illustrates these ideas.
2. *Improve the process used to develop a spreadsheet.* If you sketched out a conceptual design of the spreadsheet, work on each part individually before moving on to the others to ensure that each part is correct. As you enter formulas, check the results with simple numbers (such as 1) to determine if they make sense, or use inputs with known results. Be careful in using the *Copy* and *Paste* commands in Excel, particularly with respect to relative and absolute addresses. Use the Excel function wizard (the f_x button on the formula bar) to ensure that you are entering the correct values in the correct fields of the function.
3. *Inspect your results carefully and use appropriate tools available in Excel.* For example, the Excel *Formula Auditing* tools (in the *Formulas* tab) help you validate the logic of formulas and check for errors. Using *Trace Precedents* and *Trace Dependents*, you can visually show what cells affect or are affected by the value of a selected cell, similar to an influence diagram. The Formula Auditing tools also include *Error Checking*, which checks for common errors that occur when using formulas, and *Evaluate Formula*, which helps to debug a complex formula by evaluating each part of the formula individually. We encourage you to learn how to use these tools.

EXAMPLE 11.6 Modeling Net Income on a Spreadsheet

The calculation of net income is based on the following formulas:

- gross profit = sales − cost of goods sold
- operating expenses = administrative expenses + selling expenses + depreciation expenses
- net operating income = gross profit − − operating expenses
- earnings before taxes = net operating income − interest expense
- net income = earnings before taxes − taxes

We could develop a simple model to compute net income using these formulas by substitution:

net income = sales − cost of goods sold − administrative expenses − selling expenses − depreciation expenses − interest expense − taxes

We can implement this model on a spreadsheet, as shown in Figure 11.5. This spreadsheet provides only the end result and, from a financial perspective, provides little information to the end user.

An alternative is to break down the model by writing the preceding formulas in separate cells in the spreadsheet using a data-model format, as shown in Figure 11.6. This clearly shows the individual calculations and provides better information. However, although both of these models are technically correct, neither is in the form to which most accounting and financial employees are accustomed.

A third alternative is to express the calculations as a **pro forma income statement** using the structure and formatting that accountants are used to, as shown in Figure 11.7. Although this has the same calculations as in Figure 11.6, note that the use of negative dollar amounts requires a change in the formulas (i.e., addition of negative amounts rather than subtraction of positive amounts). The Excel workbook *Net Income Models* contains each of these examples in separate worksheets.

Figure 11.5

Simple Spreadsheet Model for Net Income

	A	B	C
1	Net Income Model		
2			
3	Data		
4			
5	Sales	$ 5,000,000	
6	Cost of Goods Sold	$ 3,200,000	
7	Administrative Expenses	$ 250,000	
8	Selling Expenses	$ 450,000	
9	Depreciation Expenses	$ 325,000	
10	Interest Expense	$ 35,000	
11	Taxes	$ 296,000	
12			
13	Model		
14			
15	Net Income	$ 444,000	=B5-SUM(B6:B11)

Figure 11.6

Data-Model Format for Net Income

	A	B	C
1	Net Income Model - Data Model Format		
2			
3	Data		
4			
5	Sales	$ 5,000,000	
6	Cost of Goods Sold	$ 3,200,000	
7	Administrative Expenses	$ 250,000	
8	Selling Expenses	$ 450,000	
9	Depreciation Expenses	$ 325,000	
10	Interest Expense	$ 35,000	
11	Taxes	$ 296,000	
12			
13	Model		
14			
15	Gross Profit	$ 1,800,000	=B5-B6
16	Operating Expenses	$ 1,025,000	=SUM(B7:B9)
17	Net Operating Income	$ 775,000	=B15-B16
18	Earnings Before Taxes	$ 740,000	=B17-B10
19			
20	Net Income	$ 444,000	=B18-B11

Figure 11.7

Pro Forma Income Statement Format

	A	B	C	D
1	Pro Forma Income Statement			
2				
3	Sales		$ 5,000,000	
4	Cost of Goods Sold		$(3,200,000)	
5	Gross Profit		$ 1,800,000	=C3+C4
6				
7	Operating Expenses			
8	Administrative Expenses	$250,000		
9	Selling Expenses	$450,000		
10	Depreciation Expenses	$325,000		
11	Total		$(1,025,000)	=-(SUM(B8:B10))
12				
13	Net Operating Income		$ 775,000	=C5+C11
14	Interest Expense		$ (35,000)	
15				
16	Earnings Before Taxes		$ 740,000	=C13+C14
17	Taxes		$ (296,000)	
18				
19	Net Income		$ 444,000	=C16+C17

Analytics in Practice: Spreadsheet Engineering at Procter & Gamble[2]

In the mid-1980s, Procter & Gamble (P&G) needed an easy and consistent way to manage safety stock inventory. P&G's Western European Business Analysis group created a spreadsheet model that eventually grew into a suite of global inventory models. The model was designed to help supply chain planners better understand inventories in supply chains and to provide a quick method for setting safety stock levels. P&G also developed several spin-off models based on this application that are used around the world.

In designing the model, analysts used many of the principles of spreadsheet engineering. For example, they separated the input sections from the calculation and results sections by grouping the appropriate cells and using different formatting. This speeded up the data entry process. In addition, the spreadsheet was designed to display all relevant data on one screen so the user does not need to switch between different sections of the model.

Analysts also used a combination of data validation and conditional formatting to highlight errors in the data input. They also provided a list of warnings and errors that a user should resolve before using the results of the model. The list flags obvious mistakes such as negative transit times and input data that may require checking and forecast errors that fall outside the boundaries of the model's statistical validity

At the basic level, all input fields had comments attached; this served as a quick online help function for the planners. For each model, they also provided a user manual that describes every input and result and explains the formulas in detail. The model templates and all documentation were posted on an intranet site that was accessible to all P&G employees. This ensured that all employees had access to the most current versions of the models, supporting material, and training schedules.

ZUMA Archive/ZUMA Press/Newscom

Spreadsheet Applications in Business Analytics

A wide variety of practical problems in business analytics can be modeled using spreadsheets. In this section, we present several examples and families of models that illustrate different applications. One thing to note is that a useful spreadsheet model need not be complex; often, simple models can provide managers with the information they need to make good decisions. Example 11.7 is adapted from a real application in the banking industry.

EXAMPLE 11.7 A Predictive Model for Staffing[3]

Staffing is an area of any business where making changes can be expensive and time-consuming. Thus, it is quite important to understand staffing requirements well in advance. In many cases, the time to hire and train new employees can be 90 to 180 days, so it is not always possible to react quickly to staffing needs. Hence, advance planning is vital so that managers can make good decisions about overtime or reductions in work

[2]Based on Ingrid Farasyn, Koray Perkoz, Wim Van de Velde, "Spreadsheet Models for Inventory Target Setting at Procter & Gamble," *Interfaces*, 38, 4 (July–August 2008): 241–250.
[3]The author is indebted to Mr. Craig Zielanzy of BlueNote Analytics, LLC, for providing this example.

hours, or adding or reducing temporary or permanent staff. Planning for staffing requirements is an area where analytics can be of tremendous benefit.

Suppose that the manager of a loan-processing department wants to know how many employees will be needed over the next several months to process a certain number of loan files per month so she can better plan capacity. Let's also suppose that there are different types of products that require processing. A product could be a 30-year fixed rate mortgage, 7/1 ARM, FHA loan, or a construction loan. Each of these loan types vary in their complexity and require different levels of documentation and, consequently, have different times to complete. Assume that the manager forecasts 700 loan applications in May, 750 in June, 800 in July, and 825 in August. Each employee works productively for 6.5 hours each day, and there are 22 working days in May, 20 in June, 22 in July, and 22 in August. The manager also knows, based on historical loan data, the percentage of each product type and how long it takes to process one loan of each type. These data are presented next:

Products	Product Mix (%)	Hours Per File
Product 1	22	3.50
Product 2	17	2.00
Product 3	13	1.50
Product 4	12	5.50
Product 5	9	4.00
Product 6	9	3.00
Product 7	6	2.00
Product 8	5	2.00
Product 9	3	1.50
Product 10	1	3.50
Misc	3	3.00
Total	100	

The manager would like to predict the number of full time equivalent (FTE) staff needed each month to ensure that all loans can be processed.

Figure 11.8 shows a simple predictive model on a spreadsheet to calculate the FTEs required (Excel file *Staffing Model*). For each month, we take the desired throughput and convert thus to the number of files for each product based on the product mix percentages. By multiplying by the hours per file, we then calculate the number of hours required for each product. Finally, we divide the total number of hours required each month by the number of working hours each month (hours worked per day * days in the month). This yields the number of FTEs required.

Figure 11.8

Staffing Model Spreadsheet Implementation

	A	B	C	D	E	F	G	H	I	J	K
1	**Staffing Model**										
2											
3	**Data**										
4		**May**	**June**	**July**	**August**						
5	Desired Throughput	700	750	800	825						
6	Hours Worked Per Day	6.5	6.5	6.5	6.5						
7	Days in Month	22	20	22	22						
8											
9	**Model**										
10				**May**		**June**		**July**		**August**	
11	**Products**	**Product Mix**	**Hours Per File**	**Files/ Month**	**Hours Required**	**Files/ Month**	**Hours Required**	**Files/ Month**	**Hours Required**	**Files/ Month**	**Hours Required**
12	Product 1	22%	3.50	154	539.00	165.00	577.50	176.00	616.00	181.50	635.25
13	Product 2	17%	2.00	119	238.00	127.50	255.00	136.00	272.00	140.25	280.50
14	Product 3	13%	1.50	91	136.50	97.50	146.25	104.00	156.00	107.25	160.88
15	Product 4	12%	5.50	84	462.00	90.00	495.00	96.00	528.00	99.00	544.50
16	Product 5	9%	4.00	63	252.00	67.50	270.00	72.00	288.00	74.25	297.00
17	Product 6	9%	3.00	63	189.00	67.50	202.50	72.00	216.00	74.25	222.75
18	Product 7	6%	2.00	42	84.00	45.00	90.00	48.00	96.00	49.50	99.00
19	Product 8	5%	2.00	35	70.00	37.50	75.00	40.00	80.00	41.25	82.50
20	Product 9	3%	1.50	21	31.50	22.50	33.75	24.00	36.00	24.75	37.13
21	Product 10	1%	3.50	7	24.50	7.50	26.25	8.00	28.00	8.25	28.88
22	Misc	3%	3.00	21	63.00	22.50	67.50	24.00	72.00	24.75	74.25
23	Total	100%		700	2089.50	750.00	2238.75	800.00	2388.00	825.00	2462.63
24			**FTEs Required**		14.61		17.22		16.70		17.22

Figure 11.8

Staffing Model Spreadsheet Implementation (continued)

	A	B	C	D	E
1	**Staffing Model**				
2					
3	**Data**				
4		**May**	**June**	**July**	**August**
5	Desired Througl	700	750	800	825
6	Hours Worked F	6.5	6.5	6.5	6.5
7	Days in Month	22	20	22	22
8					
9	**Model**				
10				**May**	
11	**Products**	**Product Mix**	**Hours Per File**	**Files/Month**	**Hours Required**
12	Product 1	0.22	3.5	=B12*$B$5	=C12*D12
13	Product 2	0.17	2	=B13*$B$5	=C13*D13
14	Product 3	0.13	1.5	=B14*$B$5	=C14*D14
15	Product 4	0.12	5.5	=B15*$B$5	=C15*D15
16	Product 5	0.09	4	=B16*$B$5	=C16*D16
17	Product 6	0.09	3	=B17*$B$5	=C17*D17
18	Product 7	0.06	2	=B18*$B$5	=C18*D18
19	Product 8	0.05	2	=B19*$B$5	=C19*D19
20	Product 9	0.03	1.5	=B20*$B$5	=C20*D20
21	Product 10	0.01	3.5	=B21*$B$5	=C21*D21
22	Misc	=1-SUM(B12:B21)	3	=B22*$B$5	=C22*D22
23	Total	1		=SUM(D12:D22)	=SUM(E12:E22)
24			**FTEs Required**		=E23/(B6*B7)

Models Involving Multiple Time Periods

Most practical models used in business analytics are more complex and involve basic financial analysis similar to the profit model. One example is the decision to launch a new product. In the pharmaceutical industry, for example, the process of research and development is a long and arduous process (see Example 11.8); total development expenses can approach \$1 billion.

Models for these types of applications typically incorporate multiple time periods that are logically linked together, and predictive analytical capabilities are vital to making good business decisions. However, taking a systematic approach to putting the pieces together logically can often make a seemingly difficult problem much easier.

EXAMPLE 11.8 New-Product Development

Suppose that Moore Pharmaceuticals has discovered a potential drug breakthrough in the laboratory and needs to decide whether to go forward to conduct clinical trials and seek FDA approval to market the drug. Total R&D costs are expected to reach \$700 million, and the cost of clinical trials will be about \$150 million. The current market size is estimated to be 2 million people and is expected to grow at a rate of 3% each year. In the first year, Moore estimates gaining an 8% market share, which is anticipated to grow by 20% each year. It is difficult to estimate beyond 5 years because new competitors are expected to be entering the market. A monthly prescription is anticipated to generate revenue of \$130 while incurring variable costs of \$40. A discount rate of 9% is assumed for computing the net present value of the project. The company needs to know how long it will take to recover its fixed expenses and the net present value over the first 5 years.

Figure 11.9 shows a spreadsheet model for this situation (Excel file *Moore Pharmaceuticals*). The model is based on a variety of known data, estimates, and assumptions. If you examine the model closely, you will see that some of the inputs in the model are easily obtained from corporate accounting (e.g., discount rate, unit revenue, and unit cost) using historical data (e.g., project costs), forecasts, or judgmental estimates based on preliminary market research or previous experience (e.g., market size, market share, and yearly growth rates). The model itself is a straightforward application of accounting and financial logic; you should examine the Excel formulas to see how the model is built.

The assumptions used represent the “most likely” estimates, and the spreadsheet shows that the product will begin to be profitable by the fourth year. However, the model is based on some rather tenuous assumptions about the market size and market-share growth rates. In reality, much of the data used in the model are uncertain, and the corporation would be remiss if it simply used the results of this one scenario. The real value of the model would be in analyzing a variety of scenarios that use different values for these assumptions.

Figure 11.9

Spreadsheet Implementation of *Moore Pharmaceuticals Model*

	A	B	C	D	E	F
1	Moore Pharmaceuticals					
2						
3	Data					
4						
5	Market size	2,000,000				
6	Unit (monthly Rx) revenue	$ 130.00				
7	Unit (monthly Rx) cost	$ 40.00				
8	Discount rate	9%				
9						
10	Project Costs					
11	R&D	$ 700,000,000				
12	Clinical Trials	$ 150,000,000				
13	Total Project Costs	$ 850,000,000				
14						
15	Model					
16						
17	Year	1	2	3	4	5
18	Market growth factor		3.00%	3.00%	3.00%	3.00%
19	Market size	2,000,000	2,060,000	2,121,800	2,185,454	2,251,018
20	Market share growth rate		20.00%	20.00%	20.00%	20.00%
21	Market share	8.00%	9.60%	11.52%	13.82%	16.59%
22	Sales	160,000	197,760	244,431	302,117	373,417
23						
24	Annual Revenue	$ 249,600,000	$ 308,505,600	$ 381,312,922	$ 471,302,771	$ 582,530,225
25	Annual Costs	$ 76,800,000	$ 94,924,800	$ 117,327,053	$ 145,016,237	$ 179,240,069
26	Profit	$ 172,800,000	$ 213,580,800	$ 263,985,869	$ 326,286,534	$ 403,290,156
27						
28	Cumulative Net Profit	$ (677,200,000)	$ (463,619,200)	$ (199,633,331)	$ 126,653,203	$ 529,943,358
29						
30	Net Present Value	$ 185,404,860				

	A	B	C	D	E	F
1	Moore Pharmaceuticals					
2						
3	Data					
4						
5	Market size	2000000				
6	Unit (monthly Rx) revenue	130				
7	Unit (monthly Rx) cost	40				
8	Discount rate	0.09				
9						
10	Project Costs					
11	R&D	700000000				
12	Clinical Trials	150000000				
13	Total Project Costs	=B11+B12				
14						
15	Model					
16						
17	Year	1	2	3	4	5
18	Market growth factor		0.03	0.03	0.03	0.03
19	Market size	=B5	=B19*(1+C18)	=C19*(1+D18)	=D19*(1+E18)	=E19*(1+F18)
20	Market share growth rate		0.2	0.2	0.2	0.2
21	Market share	0.08	=B21*(1+C20)	=C21*(1+D20)	=D21*(1+E20)	=E21*(1+F20)
22	Sales	=B19*B21	=C19*C21	=D19*D21	=E19*E21	=F19*F21
23						
24	Annual Revenue	=B22*$B$6*12	=C22*$B$6*12	=D22*$B$6*12	=E22*$B$6*12	=F22*$B$6*12
25	Annual Costs	=B22*$B$7*12	=C22*$B$7*12	=D22*$B$7*12	=E22*$B$7*12	=F22*$B$7*12
26	Profit	=B24-B25	=C24-C25	=D24-D25	=E24-E25	=F24-F25
27						
28	Cumulative Net Profit	=B26-B13	=B28+C26	=C28+D26	=D28+E26	=E28+F26
29						
30	Net Present Value	=NPV(B8,B26:F26)-B13				

Single-Period Purchase Decisions

Banana Republic, a division of Gap, Inc., was trying to build a name for itself in fashion circles as parent Gap shifted its product line to basics such as cropped pants, jeans, and khakis. In one recent holiday season, the company had bet that blue would be the top-selling color in stretch merino wool sweaters. They were wrong; as the company president noted, "The number 1 seller was moss green. We didn't have enough."[4]

This situation describes one of many practical situations in which a one-time purchase decision must be made in the face of uncertain demand. Department store buyers must purchase seasonal clothing well in advance of the buying season, and candy shops must decide on how many special holiday gift boxes to assemble. The general scenario is commonly known as the **newsvendor problem**: A street newsvendor sells daily newspapers and must make a decision about how many to purchase. Purchasing too few results in lost opportunity to increase profits, but purchasing too many results in a loss since the excess must be discarded at the end of the day.

We first develop a general model for this problem and then illustrate it with an example. Let us assume that each item costs \$$C$ to purchase and is sold for \$$R$. At the end of the period, any unsold items can be disposed of at \$$S$ each (the salvage value). Clearly, it makes sense to assume that $R > C > S$. Let D be the number of units demanded during the period and Q be the quantity purchased. Note that D is an uncontrollable input, whereas Q is a decision variable. If demand is known, then the optimal decision is obvious: Choose $Q = D$. However, if D is not known in advance, we run the risk of overpurchasing or underpurchasing. If $Q < D$, then we lose the opportunity of realizing additional profit (since we assume that $R > C$), and if $Q > D$, we incur a loss (because $C > S$).

Notice that we cannot sell more than the minimum of the actual demand and the amount produced. Thus, the quantity sold at the regular price is the smaller of D and Q. Also, the surplus quantity is the larger of 0 and $Q - D$. The net profit is calculated as:

$$\text{net profit} = R \times \text{quantity sold} + S \times \text{surplus quantity} - C \times Q \qquad \textbf{(11.3)}$$

In reality, the demand D is uncertain and can be modeled using a probability distribution based on approaches that we described in Chapter 5. For now, we do not deal with models that involve probability distributions (building the models is enough of a challenge at this point); however, we learn how to deal with them in the next chapter. Another example of an application of predictive analytics that involve probability distributions is overbooking.

EXAMPLE 11.9 A Single-Period Purchase Decision Model

Suppose that a small candy store makes Valentine's Day gift boxes that cost \$12.00 and sell for \$18.00. In the past, at least 40 boxes have been sold by Valentine's Day, but the actual amount is uncertain, and in the past, the owner has often run short or made too many. After the holiday, any unsold boxes are discounted 50% and are eventually sold.

The net profit can be calculated using formula (11.3) for any values of Q and D:

$$\text{net profit} = \$18.00 \times \min\{D, Q\} + \$9.00 \times \max\{0, Q - D\} - \$12.00 \times Q$$

Figure 11.10 shows a spreadsheet that implements this model assuming a demand of 41 and a purchase quantity of 44 (Excel file *Newsvendor Model*).

[4]Louise Lee, "Yes, We Have a New Banana," *BusinessWeek* (May 31, 2004): 70–72.

Figure 11.10

Spreadsheet Implementation of *Newsvendor Model*

	A	B
1	Newsvendor Model	
2		
3	Data	
4		
5	Selling price	$ 18.00
6	Cost	$ 12.00
7	Discount price	$ 9.00
8		
9	Model	
10		
11	Demand	41
12	Purchase Quantity	44
13		
14	Quantity Sold	41
15	Surplus Quantity	3
16		
17	Profit	$ 237.00

	A	B
1	Newsvendor Model	
2		
3	Data	
4		
5	Selling price	18
6	Cost	12
7	Discount price	9
8		
9	Model	
10		
11	Demand	41
12	Purchase Quantity	44
13		
14	Quantity Sold	=MIN(B11,B12)
15	Surplus Quantity	=MAX(0,B12-B11)
16		
17	Profit	=B14*B5+B15*B7-B12*B6

Overbooking Decisions

An important operations decision for service businesses such as hotels, airlines, and car-rental companies is the number of reservations to accept to effectively fill capacity knowing that some customers may not use their reservations or tell the business. If a hotel, for example, holds rooms for customers who do not show up, they lose revenue opportunities. (Even if they charge a night's lodging as a guarantee, rooms held for additional days may go unused.) A common practice in these industries is to **overbook** reservations. When more customers arrive than can be handled, the business usually incurs some cost to satisfy them (by putting them up at another hotel or, for most airlines, providing extra compensation such as ticket vouchers). Therefore, the decision becomes how much to overbook to balance the costs of overbooking against the lost revenue for underuse.

EXAMPLE 11.10 A Hotel Overbooking Model

Figure 11.11 shows a spreadsheet model (Excel file *Hotel Overbooking Model*) for a popular resort hotel that has 300 rooms and is usually fully booked. The hotel charges $120 per room. Reservations may be canceled by the 6:00 p.m. deadline with no penalty. The hotel has estimated that the average overbooking cost is $100.

The logic of the model is straightforward. In the model section of the spreadsheet, cell B12 represents the decision variable of how many reservations to accept. In this example, we assume that the hotel is willing to accept 310 reservations; that is, to overbook by 10 rooms. Cell B13 represents the actual customer demand (the number of customers who want a reservation). Here we assume that 312 customers tried to make a reservation. The hotel cannot accept more reservations than its predetermined limit, so, therefore, the number of reservations made in cell B13 is the smaller of the customer demand and the reservation limit. Cell B14 is the number of customers who decide to cancel their reservation. In this example, we assume that only 6 of the 310 reservations are cancelled. Therefore, the actual number of customers who arrive (cell B15) is the difference between the number of reservations made and the number of cancellations. If the actual number of customer arrivals exceeds the room capacity, overbooking occurs. This is modeled by the MAX function in cell B17. Net revenue is computed in cell B18. A manager would probably want to use this model to analyze how the number of overbooked customers and net revenue would be influenced by changes in the reservation limit, customer demand, and cancellations.

As with the newsvendor model, the customer demand and the number of cancellations are in reality, random variables that we cannot specify with certainty. We also show how to incorporate randomness into the model in the next chapter.

Figure 11.11

Hotel Overbooking Model Spreadsheet

	A	B
1	Hotel Overbooking Model	
2		
3	Data	
4		
5	Rooms available	300
6	Price	$120
7	Overbooking cost	$100
8		
9	Model	
10		
11	Reservation limit	310
12	Customer demand	312
13	Reservations made	310
14	Cancellations	6
15	Customer arrivals	304
16		
17	Overbooked customers	4
18	Net revenue	$35,600

	A	B
1	Hotel Overbooking Model	
2		
3	Data	
4		
5	Rooms available	300
6	Price	120
7	Overbooking cost	100
8		
9	Model	
10		
11	Reservation limit	310
12	Customer demand	312
13	Reservations made	=MIN(B11,B12)
14	Cancellations	6
15	Customer arrivals	=B13-B14
16		
17	Overbooked customers	=MAX(0,B15-B5)
18	Net revenue	=MIN(B15,B5)*B6-B17*B7

Analytics in Practice: Using an Overbooking Model at a Student Health Clinic

The East Carolina University (ECU) Student Health Service (SHS) provides health-care services and wellness education to enrolled students.[5] Patient volume consists almost entirely of scheduled appointments for non urgent health-care needs. In a recent academic year, 35,050 appointments were scheduled. Patients failed to arrive for over 10% of these appointments. The no-show problem is not unique. Various studies report that no-show rates for health service providers often range as high as 30% to 50%.

To address this problem, a quality-improvement (QI) team was formed to analyze an overbooking option. Their efforts resulted in developing a novel overbooking model that included the effects of employee burnout resulting from the need to see more patients than the normal capacity allowed. The model provided strong evidence that a 10% to 15% overbooking level produces the highest value. The overbooking model was also instrumental in alleviating staff concerns about disruption and pressures that result from large numbers of overscheduled patients. At a 5% overbooking rate, the staff was reassured by model results that predicted 95% of the operating days with no patients being overscheduled; in the worst case, 8 patients would be overscheduled a few days each month. In addition, at a 10% overbooking rate the model predicted that during 85% of the operating days per month, no patients would be overscheduled; a maximum of 16 overscheduled patients would rarely ever occur.


Kurhan/Shutterstock.com

Based on the model predictions, the SHS implemented an overbooking policy and overbooked by 7.3% with plans to increase to 10% in future semesters. The SHS director estimated the actual savings from overbooking during the first semester of implementation would be approximately $95,000.

[5]Based on John Kros, Scott Dellana, and David West, "Overbooking Increases Patient Access at East Carolina University's Student Health Services Clinic," *Interfaces*, Vol. 39, No. 3 May–June 2009, pp. 271–287.

Model Assumptions, Complexity, and Realism

Models cannot capture every detail of the real problem, and managers must understand the limitations of models and their underlying assumptions. **Validity** refers to how well a model represents reality. One approach for judging the validity of a model is to identify and examine the assumptions made in a model to see how they agree with our perception of the real world; the closer the agreement, the higher the validity. Another approach is to compare model results to observed results; the closer the agreement, the more valid the model. A "perfect" model corresponds to the real world in every respect; unfortunately, no such model has ever existed and never will exist in the future, because it is impossible to include every detail of real life in one model. To add more realism to a model generally requires more complexity and analysts have to know how to balance these.

EXAMPLE 11.11 A Retirement-Planning Model

Consider modeling a typical retirement plan. Suppose that an employee starts working after college at age 22 at a starting salary of $50,000. She expects an average salary increase of 3% each year. Her retirement plan requires that she contribute 8% of her salary, and her employer adds an additional 35% of her contribution. She anticipates an annual return of 8% on her retirement portfolio.

Figure 11.12 shows a spreadsheet model of her retirement investments through age 50 (Excel file *Retirement Plan*). There are two validity issues with this model. One, of course, is whether the assumptions of the annual salary increase and return on investment are reasonable and whether they should be assumed to be the same each year. Assuming the same rate of salary increases and investment returns each year simplifies the model but detracts from the realism because these variables will clearly vary each year. A second validity issue is how the model calculates the return on investment. The model in Figure 11.12 assumes that the return on investment is applied to the previous year's balance and not to the current year's contributions (examine the formula used in cell E15). An alternative would be to calculate the investment return based on the end-of-year balance, including current-year contributions, using the formula =(E14 + C15 + D15)*(1 + $B$8) in cell E15 and copying it down the spreadsheet. This will produce a different result.

Neither of these assumptions is quite correct, since the contributions would normally be made on a monthly basis. To reflect this would require a much larger and more-complex spreadsheet model. Thus, building realistic models requires careful thought and creativity, and a good working knowledge of the capabilities of Excel.

Data and Models

Data used in models can come from subjective judgment based on past experience, existing databases and other data sources, analysis of historical data, or surveys, experiments, and other methods of data collection. For example, in the profit model we might query accounting records for values of the unit cost and fixed costs. Statistical methods that we have studied are often used to estimate data required in predictive models. For example, we might use historical data to compute the mean demand; we might also use quartiles or percentiles in the model to evaluate different scenarios. However, even if data are not available, using a good subjective estimate is better than sacrificing the completeness of a model that may be useful to managers.[6]

[6]Glen L. Urban, "Building Models for Decision Makers," *Interfaces*, 4, 3 (May 1974): 1–11.

Figure 11.12

Portion of *Retirement Plan* Spreadsheet

	A	B	C	D	E
1	Retirement Plan Model				
2					
3	Data				
4					
5	Retirement contribution (% of salary)	8%			
6	Employer match	35%			
7	Annual salary increase	3%			
8	Annual return on investment	8%			
9					
10	Model				
11					
12			Employee	Employer	
13	Age	Salary	Contribution	Contribution	Balance
14	22	$50,000	$4,000	$1,400	$5,400
15	23	$ 51,500	$4,120	$1,442	$11,394
16	24	$ 53,045	$4,244	$1,485	$18,034
17	25	$ 54,636	$4,371	$1,530	$25,378
18	26	$ 56,275	$4,502	$1,576	$33,486
19	27	$ 57,964	$4,637	$1,623	$42,425
20	28	$ 59,703	$4,776	$1,672	$52,267
21	29	$ 61,494	$4,919	$1,722	$63,089
22	30	$ 63,339	$5,067	$1,773	$74,977

	A	B	C	D	E
1	Retirement Plan Model				
2					
3	Data				
4					
5	Retirement contribution (% of salary)	0.08			
6	Employer match	0.35			
7	Annual salary increase	0.03			
8	Annual return on investment	0.08			
9					
10	Model				
11					
12			Employee	Employer	
13	Age	Salary	Contribution	Contribution	Balance
14	22	50000	=B14*$B$5	=$B$6*C14	=C14+D14
15	23	= B14*(1+$B$7)	=B15*$B$5	=$B$6*C15	=E14*(1+$B$8) + C15+D15
16	24	= B15*(1+$B$7)	=B16*$B$5	=$B$6*C16	=E15*(1+$B$8) + C16+D16
17	25	= B16*(1+$B$7)	=B17*$B$5	=$B$6*C17	=E16*(1+$B$8) + C17+D17
18	26	= B17*(1+$B$7)	=B18*$B$5	=$B$6*C18	=E17*(1+$B$8) + C18+D18
19	27	= B18*(1+$B$7)	=B19*$B$5	=$B$6*C19	=E18*(1+$B$8) + C19+D19
20	28	= B19*(1+$B$7)	=B20*$B$5	=$B$6*C20	=E19*(1+$B$8) + C20+D20
21	29	= B20*(1+$B$7)	=B21*$B$5	=$B$6*C21	=E20*(1+$B$8) + C21+D21
22	30	= B21*(1+$B$7)	=B22*$B$5	=$B$6*C22	=E21*(1+$B$8) + C22+D22

Let's develop a simple example based on retail markdown pricing decisions that we described in Example 1.1 in Chapter 1.

EXAMPLE 11.12 Modeling Retail Markdown Pricing Decisions

A chain of department stores is introducing a new brand of bathing suit for $70. The prime selling season is 50 days during the late spring and early summer; after that, the store has a clearance sale around July 4 and marks down the price by 70% (to $21.00), typically selling any remaining inventory at the clearance price. Merchandise buyers have purchased 1,000 units and allocated them to the stores prior to the selling season. After a few weeks, the stores reported an average sales of 7 units/day, and past experience suggests that this constant level of sales will continue over the remainder of the selling season. Thus, over the 50-day selling season, the stores would be expected to sell $50 \times 7 = 350$ units at the full retail price and earn a revenue of $\$70.00 \times 350 = \$24{,}500$. The remaining 650 units would be sold at $21.00, for a clearance revenue of $13,650. Therefore, the total revenue would be predicted as $\$24{,}500 + \$13{,}650 = \$38{,}150$.

As an experiment, the store reduced the price to $49 for one weekend and found that the average daily sales were 32.2 units. Assuming a linear trend model for sales as a function of price, as in Example 1.9,

$$\text{daily sales} = a - b \times \text{price}$$

(continued)

we can find values for a and b by solving these two equations simultaneously based on the data the store obtained.

$$7 = a - b \times \$70.00$$
$$32.2 = a - b \times \$49.00$$

This leads to the linear demand model:

$$\text{daily sales} = 91 - 1.2 \times \text{price}$$

We may also use Excel's SLOPE and INTERCEPT functions to find the slope and intercept of the straight line between the two points ($70, 7) and ($49, 32.2); this is incorporated into the Excel model that follows.

Because this model suggests that higher sales can be driven by price discounts, the marketing department has the basis for making improved discounting decisions. For instance, suppose they decide to sell at full retail price for x days and then discount the price by y% for the remainder of the selling season, followed by the clearance sale. What total revenue could they predict?

We can compute this easily. Selling at the full retail price for x days yields revenue of

$$\text{full retail price revenue} = 7\ \text{units/day} \times x\ \text{days} \times \$70.00 = \$490.00x$$

The markdown price applies for the remaining $50 - x$ days:

$$\text{markdown price} = \$70(100\% - y\%)$$
$$\text{daily sales} = a - b \times \text{markdown price} = 91 - 1.2 \times \$70 \text{ x } (100\% - y\%)$$

units sold at markdown = daily sales $\times$ $(50 - x)$ as long as this is less than or equal to the number of units remaining in inventory from full retail sales. If not, this number needs to be adjusted.

Then we can compute the markdown revenue as

$$\text{markdown revenue} = \text{units sold x markdown price}$$

Finally, the remaining inventory after 50 days is

$$\begin{aligned}\text{clearance inventory} &= 1000 - \text{units sold at full retail} - \text{units sold at markdown}\\ &= 1{,}000 - 7x - [91 - 1.2 \times \$70.00 \times (100\% - y\%)] \times (50 - x)\end{aligned}$$

This amount is sold at a price of $21.00, resulting in revenue of

$$\text{clearance price revenue} = [1{,}000 - 7x - [91 - 1.2 \times \$70.00 \times (100\% - y\%)] \times (50 - x)] \times \$21.00$$

The total revenue would be found by adding the models developed for full retail price revenue, discounted price revenue, and clearance price revenue.

Figure 11.13 shows a spreadsheet implementation of this model (Excel file *Markdown Pricing Model*). By changing the values in cells B7 and B8, the marketing manager could predict the revenue that could be achieved for different markdown decisions.

Figure 11.13

Markdown Pricing Model Spreadsheet

	A	B	C
1	Markdown Pricing Model		
2			
3	Data		
4	Retail price	$70.00	
5	Inventory	1000	
6	Selling season (days)	50	
7	Days at full retail	40	
8	Intermediate markdown	30%	
9	Clearance markdown	70%	
10			
11	Sales Data	Average	
12	Price (X)	Daily Sales (Y)	
13	$70	7.00	
14	$49	32.20	
15	Demand function parameters		
16	Intercept	91	
17	Slope	-1.2	
18			
19	Model		
20			
21	Full Retail Sales		
22	Retail price	$70.00	
23	Daily sales	7.00	
24	Days at retail price	40	
25	Units sold at retail	280	
26		Retail revenue	$19,600.00
27	Discount Sales		
28	Discount	30%	
29	Discount price	$49.00	
30	Daily sales	32.20	
31	Unit sold	322	
32		Discount revenue	$15,778.00
33	Clearance Sales		
34	Clearance price	$21.00	
35	Units sold at clearance	398	
36		Clearance revenue	$8,358.00
37			
38		Total revenue	$43,736.00

	A	B	C
1	Markdown Pricing Model		
2			
3	Data		
4	Retail price	70	
5	Inventory	1000	
6	Selling season (days)	50	
7	Days at full retail	40	
8	Intermediate markdown	0.3	
9	Clearance markdown	0.7	
10			
11	Sales Data	Average	
12	Price (X)	Daily Sales (Y)	
13	70	7	
14	49	32.2	
15	Demand function parameters		
16	Intercept	=INTERCEPT(B13:B14,A13:A14)	
17	Slope	=SLOPE(B13:B14,A13:A14)	
18			
19	Model		
20			
21	Full Retail Sales		
22	Retail price	=B4	
23	Daily sales	=B16+B17*B22	
24	Days at retail price	=B7	
25	Units sold at retail	=B23*B24	
26		Retail revenue	=B25*B22
27	Discount Sales		
28	Discount	=B8	
29	Discount price	=B22*(1-B28)	
30	Daily sales	=B16 + B17*B29	
31	Unit sold	=MIN(B30*(B6-B24),B5-B25)	
32		Discount revenue	=B31*B29
33	Clearance Sales		
34	Clearance price	=B4*(1-B9)	
35	Units sold at clearance	=MAX(0,B5-B25-B31)	
36		Clearance revenue	=B34*B35
37			
38		Total revenue	=C26+C32+C36

Developing User-Friendly Excel Applications

Using business analytics requires good communication between analysts and the clients or managers who use the tools. In many cases, users may not be as familiar with Excel. Thus, developing user-friendly spreadsheets is vital to gaining acceptance of the tools and making them useful.

Data Validation

One useful Excel tool is the **data validation** feature. This feature allows you to define acceptable input values in a spreadsheet, and provide an error alert if an invalid entry is made. This can help to avoid inadvertent user errors. This can be found in the *Data Tools* Group within the *Data* tab on the Excel ribbon. Select the cell range, click on *Data Validation*, and then specify the criteria that Excel will use to flag invalid data.

Range Names

Use cell and range names to simplify formulas and make them more user-friendly. For example, suppose that the unit price is stored in cell B13 and quantity sold is in cell B14. Suppose you wish to calculate revenue in cell C15. Instead of writing the formula =B13*B14, you could define the name of cell B13 in Excel as "UnitPrice" and the name of cell B14 as "QuantitySold." Then in cell C15, you could simply write the formula =UnitPrice*QuantitySold. (In this book, however, we use cell references so that you can more easily trace formulas in the examples.)

EXAMPLE 11.13 Using Data Validation

Let us use the *Outsourcing Decision Model* spreadsheet as an example. Suppose that an employee is asked to use the spreadsheet to evaluate the manufacturing and purchase cost options and best decisions for a large number of parts used in an automobile system assembly. She is given lists of data that cost accountants and purchasing managers have compiled and printed and must look up the data and enter them into the spreadsheet. Such a manual process leaves plenty of opportunity for error. However, suppose that we know that the unit cost of any item is at least $10 but no more than $100. If a cost is $47.50, for instance, a misplaced decimal would result in either $4.75 or $475, which would clearly be out of range. In the *Data Validation* dialog, you can specify that the value must be a decimal number between 10 and 100 as shown in Figure 11.14. On the *Error Alert* tab, you can also create an alert box that pops up when an invalid entry is made (see Figure 11.15). On the *Input Message* tab, you can create a prompt to display a comment in the cell about the correct input format. Data validation has other customizable options that you might want to explore.

Figure 11.14

Data Validation Dialog

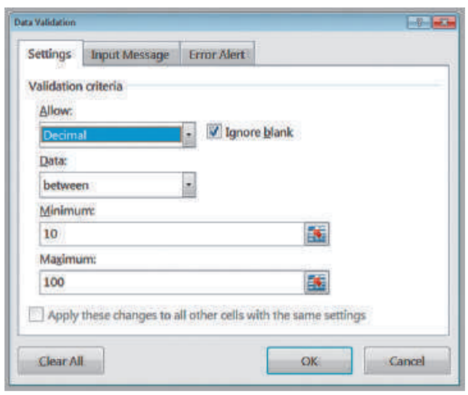
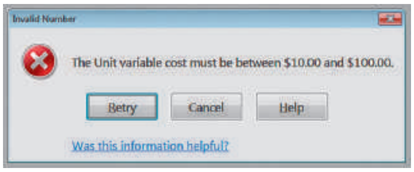


Figure 11.15

Example of an Error Alert



Form Controls

Form controls are buttons, boxes, and other mechanisms for inputting or changing data on spreadsheets easily that can be used to design user-friendly spreadsheets. To use form controls, you must first activate the *Developer* tab on the ribbon. Click the *File* tab, then *Options*, and then *Customize Ribbon*. Under *Customize the Ribbon*, make sure that *Main Tabs* is displayed in the drop-down box, and then click the check box next to *Developer* (which is typically unchecked in a standard Excel installation). You will see the new tab in the Excel ribbon as shown in Figure 11.16.

If you click the *Insert* button in the *Controls* group, you will see the form controls available (do not confuse these with the *Active X Controls* in the same menu). Form controls include

- Button
- Combo box
- Check box
- Spin button
- List box
- Option button
- Group box
- Label
- Scroll bar

These allow the user to more easily interface with models to enter or change data without the potential of inadvertently introducing errors in formulas. With form controls, you can keep the spreadsheets hidden and make them easier to use, especially for individuals without much spreadsheet knowledge. To insert a form control, click the *Insert* button in the *Controls* tab under the *Developer* menu, click on the control you want to use and then click within your worksheet. The following example shows how to use both a spin button and scroll bar in the *Outsourcing Decision Model* Excel file.

Figure 11.16

Excel Developer Tab

EXAMPLE 11.14 Using Form Controls for the Outsourcing Decision Model

We will design a simple spreadsheet interface to allow a user to evaluate different values of the supplier cost and production volume in the *Outsourcing Decision Model* spreadsheet. We will use a spin button for the supplier unit cost (which we will assume might vary between \$150 and \$200 in increments of \$5) and a scroll bar for the production volume (in unit increments between 500 and 3000 units). The completed spreadsheet is shown in Figure 11.17.

First, click the Insert button in the Controls group of the *Developer* tab, select the spin button, click it, and then click somewhere in the worksheet. The spin button (and any form control) can be re-sized by dragging the handles along the edge and moved within the worksheet. Move it to a convenient location, and enter the name you wish to use (such as Supplier Unit Cost) adjacent to it. Next, right click the spin button and select *Format Control*. You will see the dialog box shown in Figure 11.18. Enter the values shown and click *OK*. Now if you click the up or down buttons, the value in cell D3 will change within the specified range. Next, repeat this process by inserting the scroll bar next to the production volume in column D. The next step is to link the values in column D to the model by replacing the value in cell B10 with =D3, and the value in cell B12 with =D8. (We could have assigned the cell link references in the *Format Control* dialogs to cells B10 and B12, but it is easier to see the values next to the form controls.) Now, using the controls, you can easily see how the model outputs change without having to type in new values.

Form controls only allow integer increments, so we have to make some modifications to a spreadsheet if we want to change a number by a fractional value. For example, suppose that we want to use a spin button to change an interest rate in cell B8 from 0% to 10% in increments of 0.1% (i.e., 0.001). Choose some empty cell, say C8 and enter a value between 0 and 100 in it. Then enter the formula =C8/1000 in cell B8. Note that if the value in C8 = 40, for example, then the value in cell B8 will be 40/1000 = 0.04, or 4%. Then as the value in cell C8 changes by 1, the value in cell B8 changes by 1/1000, or 0.1%. In the *Format Control* dialog, specify the minimum value at 0 and the maximum value at 100 and link the button to cell C8. Now as you click the up or down arrows on the spin button, the value in cell C8 changes by 1 and the value in cell B8 changes by 0.1%.

Other form controls can also be used; we encourage you to experiment and identify creative ways to use them. Excel also has many other features that can be used to improve the design and implementation of spreadsheet models. The serious analyst should consider learning about macro recording and Visual Basic for Applications (VBA), but these topics are well-beyond the scope of this book.

Figure 11.17

Outsourcing Decision Model Spreadsheet with Form Controls

	A	B	C	D	E
1	Outsourcing Decision Model				
2				Supplier Unit Cost	
3	Data			\$155	
4					
5	Manufactured in-house				
6	Fixed cost	\$50,000			
7	Unit variable cost	\$125		Production Volume	
8				1489	
9	Purchased from supplier				
10	Unit cost	\$155			
11					
12	Production volume	1489			
13					
14	Model				
15					
16	Total manufacturing cost	\$236,125			
17	Total purchased cost	\$230,795			
18					
19	Cost difference	\$5,330			
20	Decision	Outsource			

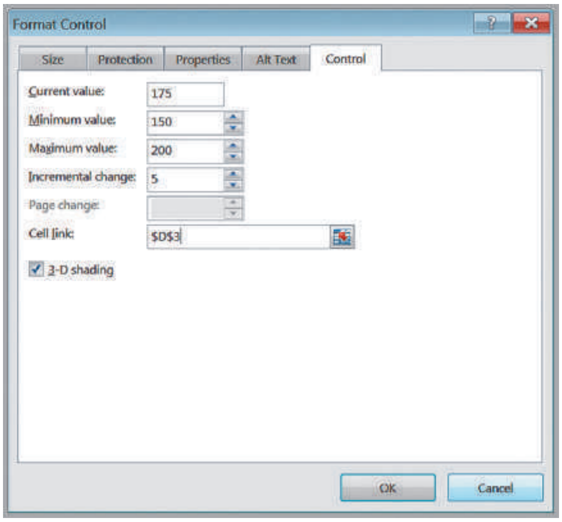


Figure 11.18

Format Control Dialog

Analyzing Uncertainty and Model Assumptions

Because predictive analytical models are based on assumptions about the future and incorporate variables that most likely will not be known with certainty, it is usually important to investigate how these assumptions and uncertainty affect the model outputs. This is one of the most important and valuable activities for using predictive models to gain insights and make good decisions. In this section, we describe several different approaches for doing this.

What-If Analysis

Spreadsheet models allow you to easily evaluate what-if questions—how specific combinations of inputs that reflect key assumptions will affect model outputs. **What-if analysis** is as easy as changing values in a spreadsheet and recalculating the outputs. However, systematic approaches make this process easier and more useful.

In Example 11.2, we developed a model for profit and suggested how a manager might use the model to change inputs and evaluate different scenarios. A more informative way of evaluating a wider range of scenarios is to build a table in the spreadsheet to vary the input or inputs in which we are interested over some range, and calculate the output for this range of values. The following example illustrates this.

EXAMPLE 11.15 Using Excel for What-If Analysis

In the profit model used in Example 11.2, we stated that demand is uncertain. A manager might be interested in the following question: For any fixed quantity produced, how will profit change as demand changes? In Figure 11.19, we created a table for varying levels of demand, and computed the profit. This shows that a loss is incurred for low levels of demand, whereas profit is limited to $240,000 whenever the demand exceeds the quantity produced, no matter how high it is. Notice that the formula refers to cells in the model; thus, the user could change the quantity produced or any of the other model inputs and still have a correct evaluation of the profit for these values of demand. One of the advantages of evaluating what-if questions for a range of values rather than one at a time is the ability to visualize the results in a chart, as shown in Figure 11.20. This clearly shows that profit increases as demand increases until it hits the value of the quantity produced.

Figure 11.19

What-If Table for Uncertain Demand

	A	B	C	D	E	F	G	H	I
1	Profit Model								
2									
3	Data				Demand	Qty. Sold	Revenue	Cost	Profit
4					25000	25000	$ 1,000,000	$1,360,000	$(360,000)
5	Unit Price	$40.00			30000	30000	$ 1,200,000	$1,360,000	$(160,000)
6	Unit Cost	$24.00			35000	35000	$ 1,400,000	$1,360,000	$ 40,000
7	Fixed Cost	$400,000.00			40000	40000	$ 1,600,000	$1,360,000	$ 240,000
8	Demand	50000			45000	40000	$ 1,600,000	$1,360,000	$ 240,000
9					50000	40000	$ 1,600,000	$1,360,000	$ 240,000
10					55000	40000	$ 1,600,000	$1,360,000	$ 240,000
11	Model				60000	40000	$ 1,600,000	$1,360,000	$ 240,000
12									
13	Unit Price	$40.00							
14	Quantity Sold	40000							
15	Revenue		$1,600,000.00						
16									
17	Unit Cost	$24.00							
18	Quantity Produced	40000							
19	Variable Cost		$960,000.00						
20	Fixed Cost		$400,000.00						
21									
22	Profit		$240,000.00						

	A	B	C	D	E	F	G	H	I
1	Profit Model								
2									
3	Data				Demand	Qty. Sold	Revenue	Cost	Profit
4					25000	=MIN(E4,$B$18)	=$B$13*F4	=$C$19+$C$20	=G4-H4
5	Unit Price	40			30000	=MIN(E5,$B$18)	=$B$13*F5	=$C$19+$C$20	=G5-H5
6	Unit Cost	24			35000	=MIN(E6,$B$18)	=$B$13*F6	=$C$19+$C$20	=G6-H6
7	Fixed Cost	400000			40000	=MIN(E7,$B$18)	=$B$13*F7	=$C$19+$C$20	=G7-H7
8	Demand	50000			45000	=MIN(E8,$B$18)	=$B$13*F8	=$C$19+$C$20	=G8-H8
9					50000	=MIN(E9,$B$18)	=$B$13*F9	=$C$19+$C$20	=G9-H9
10					55000	=MIN(E10,$B$18)	=$B$13*F10	=$C$19+$C$20	=G10-H10
11	Model				60000	=MIN(E11,$B$18)	=$B$13*F11	=$C$19+$C$20	=G11-H11
12									
13	Unit Price	=B5							
14	Quantity Sold	=MIN(B8,B18)							
15	Revenue		=B13*B14						
16									
17	Unit Cost	=B6							
18	Quantity Produced	40000							
19	Variable Cost		=B17*B18						
20	Fixed Cost		=B7						
21									
22	Profit		=C15-C19-C20						

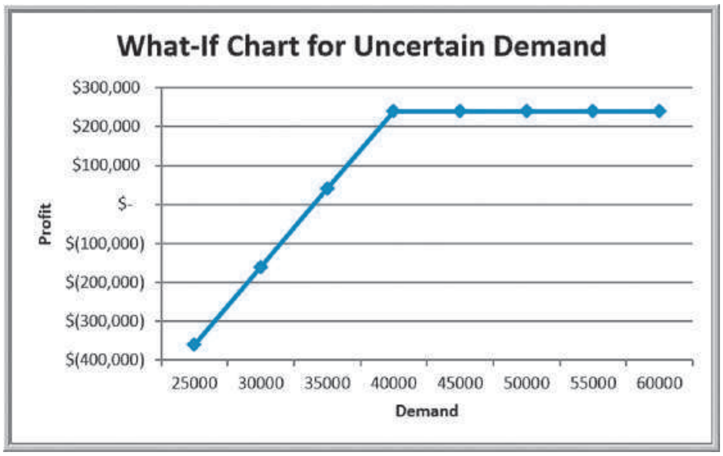


Figure 11.20

Chart of What-If Analysis

Conducting what-if analysis in this fashion can be quite tedious. Fortunately, Excel provides several tools—data tables, *Scenario Manager*, and *Goal Seek*—that facilitate what-if and other types of decision model analyses. These can be found within the *What-If Analysis* menu in the *Data* tab.

Data Tables

Data tables summarize the impact of one or two inputs on a specified output. Excel allows you to construct two types of data tables. A **one-way data table** evaluates an output variable over a range of values for a single input variable. **Two-way data tables** evaluate an output variable over a range of values for two different input variables.

To create a one-way data table, first create a range of values for some input cell in your model that you wish to vary. The input values must be listed either down a column (column oriented) or across a row (row oriented). If the input values are column oriented, enter the cell reference for the output variable in your model that you wish to evaluate in the row *above* the first value and one cell to the *right* of the column of input values. Reference any other output variable cells to the right of the first formula. If the input values are listed across a row, enter the cell reference of the output variable in the column to the *left* of the first value and one cell *below* the row of values. Type any additional output cell references below the first one. Next, select the range of cells that contains *both* the formulas and values you want to substitute. From the *Data* tab in Excel, select *Data Table* under the *What-If Analysis* menu. In the dialog box (see Figure 11.21), if the input range is column oriented, type the cell reference for the input cell in your model in the *Column input cell* box. If the input range is row oriented, type the cell reference for the input cell in the *Row input cell* box.

EXAMPLE 11.16 A One-Way Data Table for Uncertain Demand

In this example, we create a one-way data table for profit for varying levels of demand. First, create a column of demand values in column E exactly as we did in Example 11.15. Then in cell F3, enter the formula = C22. This simply references the output of the profit model. Highlight the range E3:F11 (note that this range includes both the column of demand as well as the cell reference to profit), and select *Data Table* from the *What-If Analysis* menu. In the Column input cell field, enter B8; this tells the tool that the values in column E are different values of demand in the model. When you click OK, the tool produces the results (which we formatted as currency) shown in Figure 11.22.

We may evaluate multiple outputs using one-way data tables.

EXAMPLE 11.17 One-Way Data Tables with Multiple Outputs

Suppose that we want to examine the impact of the uncertain demand on revenue in addition to profit. We simply add another column to the data table. For this case, insert the formula = C15 into cell G3. Also, add the labels "Profit" in F2 and "Revenue" in G2 to identify the results. Then, highlight the range E3:G11 and proceed as described in the previous example. This process results in the data table shown in Figure 11.23.

Figure 11.21

Data Table Dialog

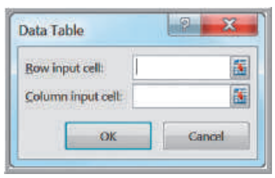


Figure 11.22

One-Way Data Table for Uncertain Demand

	A	B	C	D	E	F
1	Profit Model					
2						
3	Data				Demand	$240,000.00
4					25000	$(360,000.00)
5	Unit Price	$40.00			30000	$(160,000.00)
6	Unit Cost	$24.00			35000	$ 40,000.00
7	Fixed Cost	$400,000.00			40000	$ 240,000.00
8	Demand	50000			45000	$ 240,000.00
9					50000	$ 240,000.00
10					55000	$ 240,000.00
11	Model				60000	$ 240,000.00
12						
13	Unit Price	$40.00				
14	Quantity Sold	40000				
15	Revenue		$1,600,000.00			
16						
17	Unit Cost	$24.00				
18	Quantity Produced	40000				
19	Variable Cost		$960,000.00			
20	Fixed Cost		$400,000.00			
21						
22	Profit		$240,000.00			

Figure 11.23

One-Way Data Table with Two Outputs

E	F	G
	Profit	Revenue
Demand	$240,000	$1,600,000
25000	$(360,000)	$1,000,000
30000	$(160,000)	$1,200,000
35000	$ 40,000	$1,400,000
40000	$ 240,000	$1,600,000
45000	$ 240,000	$1,600,000
50000	$ 240,000	$1,600,000
55000	$ 240,000	$1,600,000
60000	$ 240,000	$1,600,000

To create a two-way data table, type a list of values for one input variable in a column and a list of input values for the second input variable in a row, starting one row above and one column to the right of the column list. In the cell in the upper left-hand corner immediately above the column list and to the left of the row list, enter the cell reference of the output variable you wish to evaluate. Select the range of cells that contain this cell reference and both the row and column of values. On the *What-If Analysis* menu, click *Data Table.* In the *Row input cell* of the dialog box, enter the reference for the input cell in the model that corresponds to the input values in the row. In the *Column input cell* box,

EXAMPLE 11.18 A Two-Way Data Table for the Profit Model

In most models, the assumptions used for the input data are often uncertain. For example, in the profit model, the unit cost might be affected by supplier price changes and inflationary factors. Marketing might be considering price adjustments to meet profit goals. We use a two-way data table to evaluate the impact of changing these assumptions. First, create a column for the unit prices you wish to evaluate and a row for the unit costs in the form of a matrix. In the upper left corner enter the formula =C22, which references the profit in the model. Select the range of all the data (not including the descriptive titles) and then select the data table tool in the *What-If Analysis* menu. In the *Data Table* dialog, enter B6 for the *Row input cell* since the unit cost corresponds to cell B6 in the model, and enter B5 for the *Column input cell* since the unit price corresponds to cell B5. Figure 11.24 shows the completed result.

Figure 11.24

Two-Way Data Table

		Unit Cost			
Profit	$240,000.00	$22.00	$23.00	$24.00	$25.00
Unit Price	$35.00	$ 120,000.00	$ 80,000.00	$ 40,000.00	$ -
	$36.00	$ 160,000.00	$ 120,000.00	$ 80,000.00	$ 40,000.00
	$37.00	$ 200,000.00	$ 160,000.00	$ 120,000.00	$ 80,000.00
	$38.00	$ 240,000.00	$ 200,000.00	$ 160,000.00	$ 120,000.00
	$39.00	$ 280,000.00	$ 240,000.00	$ 200,000.00	$ 160,000.00
	$40.00	$ 320,000.00	$ 280,000.00	$ 240,000.00	$ 200,000.00
	$41.00	$ 360,000.00	$ 320,000.00	$ 280,000.00	$ 240,000.00
	$42.00	$ 400,000.00	$ 360,000.00	$ 320,000.00	$ 280,000.00
	$43.00	$ 440,000.00	$ 400,000.00	$ 360,000.00	$ 320,000.00
	$44.00	$ 480,000.00	$ 440,000.00	$ 400,000.00	$ 360,000.00
	$45.00	$ 520,000.00	$ 480,000.00	$ 440,000.00	$ 400,000.00

enter the reference for the input cell in the model that corresponds to the input values in the column. Then click *OK*.

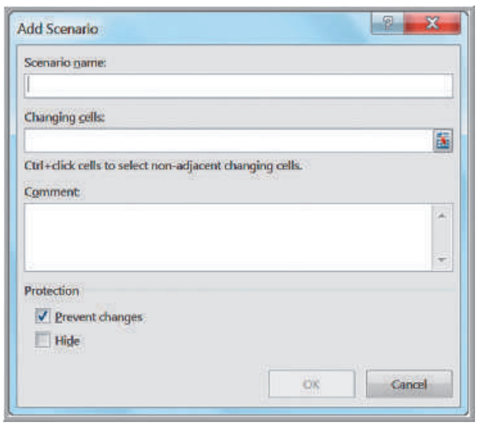
Two-way data tables can evaluate only one output variable. To evaluate multiple output variables, you must construct multiple two-way tables.

Scenario Manager

The Excel *Scenario Manager* tool allows you to create **scenarios**—sets of values that are saved and can be substituted automatically on your worksheet. Scenarios are useful for conducting what-if analyses when you have more than two output variables (which data tables cannot handle). The Excel *Scenario Manager* is found under the *What-If Analysis* menu in the *Data Tools* group on the *Data* tab. When the tool is started, click the *Add* button to open the *Add Scenario* dialog and define a scenario (see Figure 11.25). Enter the name of the scenario in the *Scenario name* box. In the *Changing cells* box, enter the references, separated by commas, for the cells in your model that you want to include in the scenario (or hold down the *Ctrl* key and click on the cells). In the *Scenario Values* dialog that appears next, enter values for each of the changing cells. If you have put these into your spreadsheet, you can simply reference them. After all scenarios are added, they can be selected by clicking on the name of the scenario and then the *Show* button. Excel will change all values of the cells in your spreadsheet to correspond to those defined by the scenario for you to see the results within the model. When you click the *Summary* button on the *Scenario Manager* dialog, you will be prompted to enter the result cells and choose either a summary or a PivotTable report. The *Scenario Manager* can handle up to 32 variables.

Figure 11.25

Add Scenario Dialog



EXAMPLE 11.19 Using the Scenario Manager for the Markdown Pricing Model

In the *Markdown Pricing Model* spreadsheet, suppose that we wish to evaluate four different strategies, which are shown in Figure 11.26. In the *Add Scenario* dialog, enter Ten/ten as the scenario name, and specify the changing cells as B7 and B8 (that is, the number of days at full retail price and the intermediate markdown). In the *Scenario Values* dialog, enter the values for these variables in the appropriate fields, or enter the formulas for the cell references; for instance, enter =E2 for the changing cell B7 or =E3 for the changing cell B8. Repeat this process for each scenario. Click the *Summary* button. In the *Scenario Summary* dialog that appears next, enter C33 (the total revenue) as the result cell. The *Scenario Manager* evaluates the model for each combination of values and creates the summary report shown in Figure 11.27. The results indicate that the largest profit can be obtained using the twenty/twenty markdown strategy.

Goal Seek

If you know the result that you want from a formula but are not sure what input value the formula needs to get that result, use the *Goal Seek* feature in Excel. *Goal Seek* works only with one variable input value. If you want to consider more than one input value or wish to maximize or minimize some objective, you must use the *Solver* add-in, which is discussed in other chapters. On the *Data* tab, in the *Data Tools* group, click *What-If Analysis*, and then click *Goal Seek*. The dialog shown in Figure 11.28 will appear. In the *Set cell* box, enter the reference for the cell that contains the formula that you want to resolve. In the *To value* box, type the formula result that you want. In the *By changing cell* box, enter the reference for the cell that contains the value that you want to adjust.

	A	B	C	D	E	F	G	H
1	Markdown Pricing Model			Scenarios	Ten/ten	Twenty/twenty	Thirty/thirty	Forty/forty
2				Days at full retail price	10	20	30	40
3	Data			Intermediate markdown	10%	20%	30%	40%
4	Retail price	$70.00						
5	Inventory	1000						
6	Selling season (days)	50						
7	Days at full retail	40						
8	Intermediate markdown	30%						
9	Clearance markdown	70%						

Figure 11.26

Markdown Pricing Model with Scenarios

Figure 11.27

Scenario Summary for the Markdown Pricing Model

Scenario Summary	Current Values:	Ten/ten	Twenty/twenty	Thirty/thirty	Forty/forty
Changing Cells:					
$B$7	40	10	20	30	40
$B$8	40%	10%	20%	30%	40%
Result Cells:					
$C$33	$43,246.00	$50,302.00	$52,850.00	$49,322.00	$43,246.00

Notes: Current Values column represents values of changing cells at time Scenario Summary Report was created. Changing cells for each scenario are highlighted in gray.

Figure 11.28

Goal Seek Dialog

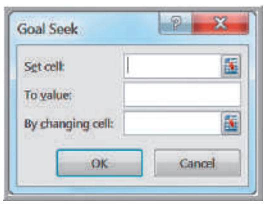


Figure 11.29

Break-Even Analysis Using Goal Seek

	A	B
1	Outsourcing Decision Model	
2		
3	Data	
4		
5	Manufactured in-house	
6	Fixed cost	$50,000
7	Unit variable cost	$125
8		
9	Purchased from supplier	
10	Unit cost	$175
11		
12	Production volume	1000
13		
14	Model	
15		
16	Total manufacturing cost	$175,000
17	Total purchased cost	$175,000
18		
19	Cost difference (Manufacture - Purchase)	$0
20	Best Decision	Manufacture

EXAMPLE 11.20 Finding the Break-Even Point in the Outsourcing Model

In the outsourcing decision model we introduced in Chapter 1 and developed a spreadsheet for in Example 11.3 p. 352, we might wish to find the break-even point. The break-even point is the value of demand volume for which total manufacturing cost equals total purchased cost, or, equivalently, for which the difference is zero. Therefore, you seek to find the value of production volume in cell B12 that yields a value of zero in cell B19. In the *Goal Seek* dialog, enter B19 for the *Set cell*, enter 0 in the *To value* box, and enter B12 in the *By changing cell* box. The *Goal Seek* tool determines that the break-even volume is 1,000 and enters this value in cell B12 in the model, as shown in Figure 11.29.

Model Analysis Using *Analytic Solver Platform*

Analytic Solver Platform (see the section in Chapter 2 regarding spreadsheet add-ins) provides sensitivity analysis capabilities to explore a spreadsheet model and identify and visualize the key input parameters that have the greatest impact on model results.

Parametric Sensitivity Analysis

Parametric sensitivity analysis is the term used by *Analytic Solver Platform* for systematic methods of what-if analysis. A parameter is simply a piece of input data in a model. With *Analytic Solver Platform* you can easily create one- and two-way data tables and a special type of chart, called a *tornado chart*, that provides useful what-if information.

EXAMPLE 11.21 Creating Data Tables with *Analytic Solver Platform*

Suppose that we wish to create a one-way data table to evaluate the profit as the unit price in cell B5 is varied between $35 and $45 in the profit model (see Figure 11.4). First, define this cell as a parameter in *Analytic Solver Platform*. Select cell B5 and then click the *Parameters* button in the ribbon (Figure 11.30), and select *Sensitivity*. This opens a *Function Arguments* dialog (Figure 11.31), in which you specify a set of values or a range. To create the data table, select the result cell that corresponds to the model output—in this case, cell C22. Then click the *Reports* button and click on *Parameter Analysis* from the *Sensitivity* menu. This displays a *Sensitivity Report* dialog

(Figure 11.32). You may use the arrows to move cells into the panes on the right; this is useful if you have defined multiple input parameters and want to conduct different sensitivity analyses. *Analytic Solver Platform* will create a new worksheet with the data table, as shown in Figure 11.33.

To create a two-way data table, define two inputs as parameters and in the *Sensitivity Report* dialog. For example, we might want to change both the unit price as well as the unit cost. With two parameters, be sure to check the box *Vary Parameters Independently* near the bottom.

You can also create charts to visualize the data tables by selecting the results cell, clicking the *Charts* button, and then clicking *Parameter Analysis* from the *Sensitivity* menu. Figure 11.34 shows a two-way data table and a three-dimensional chart when both the unit price and unit cost are varied. We encourage you to replace the cell references ($B$5, $B$6, and $C$22) by descriptive names to facilitate understanding the results.

Figure 11.30

Analytic Solver Platform Ribbon

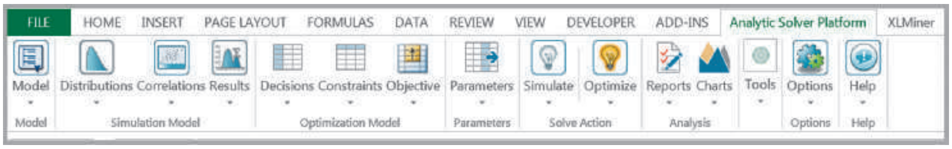


Figure 11.31

Analytic Solver Platform Function Arguments Dialog

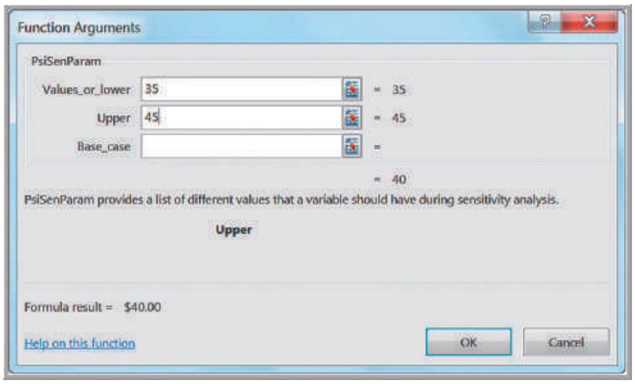


Figure 11.32

Sensitivity Report Dialog

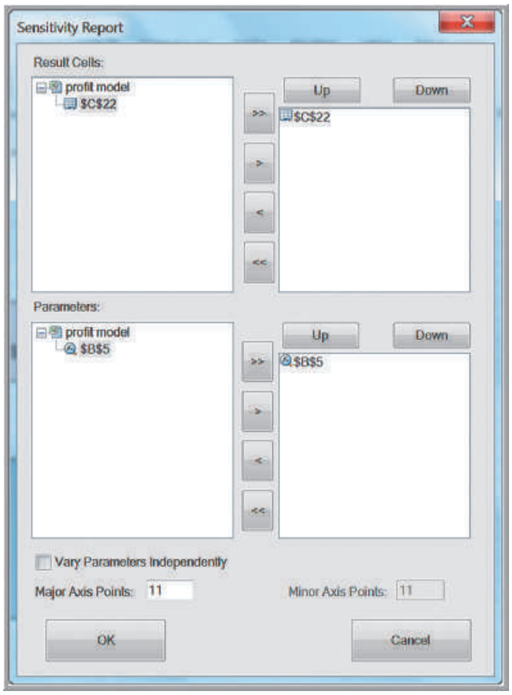


Figure 11.33

Sensitivity Analysis Report—One-Way Data Table

	A	B
1	$B$5	[Profit Model.xlsx]profit model'!$C$22
2	$35.00	$40,000.00
3	$36.00	$80,000.00
4	$37.00	$120,000.00
5	$38.00	$160,000.00
6	$39.00	$200,000.00
7	$40.00	$240,000.00
8	$41.00	$280,000.00
9	$42.00	$320,000.00
10	$43.00	$360,000.00
11	$44.00	$400,000.00
12	$45.00	$440,000.00

	A	B	C	D	E	F	G
1	**$C$22 : $B$5 by $B$6**						
2							
3							
4	**$B$5**	**$B$6**					
5		**$20.00**	**$21.60**	**$23.20**	**$24.80**	**$26.40**	**$28.00**
6	**$35.00**	$200,000.00	$136,000.00	$72,000.00	$8,000.00	-$56,000.00	-$120,000.00
7	**$37.00**	$280,000.00	$216,000.00	$152,000.00	$88,000.00	$24,000.00	-$40,000.00
8	**$39.00**	$360,000.00	$296,000.00	$232,000.00	$168,000.00	$104,000.00	$40,000.00
9	**$41.00**	$440,000.00	$376,000.00	$312,000.00	$248,000.00	$184,000.00	$120,000.00
10	**$43.00**	$520,000.00	$456,000.00	$392,000.00	$328,000.00	$264,000.00	$200,000.00
11	**$45.00**	$600,000.00	$536,000.00	$472,000.00	$408,000.00	$344,000.00	$280,000.00

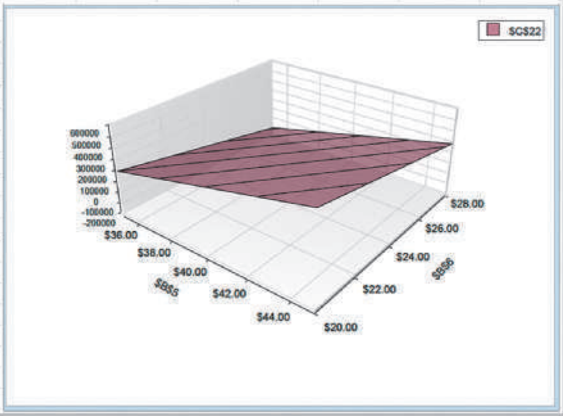


Figure 11.34

Two-Way Data Table and Chart

Tornado Charts

As we have seen, charts, graphs, and other visual aids play an important part in analyzing data and models. One useful tool is a *tornado chart*. A **tornado chart** graphically shows the impact that variation in a model input has on some output while holding all other inputs constant. Typically, we choose a base case and then vary the inputs by some percentage, say plus or minus 10% or 20%. As each input is varied, we record the values of the output and chart the ranges of the output in a bar chart in descending order. This usually results in a funnel shape, hence the name.

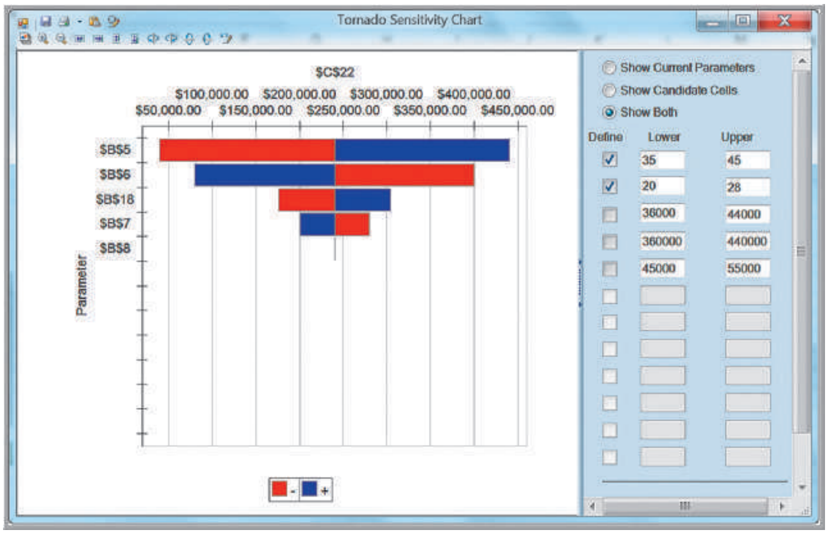
A tornado chart shows which inputs are the most influential on the output and which are the least influential. If these inputs are uncertain, then you would probably want to study the more influential ones to reduce uncertainty and its effect on the output. If the effects are small, you might ignore any uncertainty or eliminate those effects from the model. They are also useful in helping you select the inputs that you would want to analyze further with data tables or scenarios.

EXAMPLE 11.22 Creating a Tornado Chart in *Analytic Solver Platform*

Creating a tornado chart in *Analytic Solver Platform* is extremely easy to do. *Analytic Solver Platform* automatically identifies all the data input cells on which the output cell depends and creates the chart. In the *Profit Model* spreadsheet, select cell C22; then click the *Parameters* button and choose *Identify*. Figure 11.35 shows the results. We see that a 10% change in cell B5, the unit price, affects profit the most, followed by the unit cost, quantity produced, fixed cost, and demand. If you don't want to vary all parameters by the same percentage, you may define ranges in the same fashion as we did for the data table examples.

Figure 11.35

Tornado Sensitivity Chart for the Profit Model



Key Terms

Data table
Data validation
Form controls
Newsvendor problem
One-way data table
Overbook
Parametric sensitivity analysis
Pro forma income statement
Scenarios
Spreadsheet engineering
Tornado chart
Two-way data table
Validity
Verification
What-if analysis

Problems and Exercises

1. Develop a spreadsheet model for gasoline usage scenario, Problem 4 in Chapter 1, using the data provided. Apply the principles of spreadsheet engineering in developing your model.

2. Develop a spreadsheet model for Problem 5 in Chapter 1. Apply the principles of spreadsheet engineering in developing your model. Use the spreadsheet to create a table for a range of prices to help you identify the price that results in the maximum revenue.

3. Develop a spreadsheet model to determine how much a person or a couple can afford to spend on a house.[7] Lender guidelines suggest that the allowable monthly housing expenditure should be no more than 28% of monthly gross income. From this, you must subtract total nonmortgage housing expenses, which would include insurance and property taxes and any other additional expenses. This defines the affordable monthly mortgage payment. In addition, guidelines also suggest that total affordable monthly debt payments, including housing expenses, should not exceed 36% of gross monthly income. This is calculated by subtracting total nonmortgage housing expenses and any other installment debt, such as car loans, student loans, credit-card debt, and so on, from 36% of total monthly gross income. The smaller of the affordable monthly mortgage payment and the total affordable monthly debt payments is the affordable monthly mortgage. To calculate the maximum that can be borrowed, find the monthly payment per $1,000 mortgage based on the current interest rate and duration of the loan. Divide the affordable monthly mortgage amount by this monthly payment to find the affordable mortgage. Assuming a 20% down payment, the maximum price of a house would be the affordable mortgage divided by 0.8. Use the

[7]Based on Ralph R. Frasca, *Personal Finance*, 8th ed. (Boston: Prentice Hall, 2009).

following data to test your model: total monthly gross income = \$6,500; nonmortgage housing expenses = \$350; monthly installment debt = \$500; monthly payment per \$1,000 mortgage = \$7.25.

4. A company records the following components of fixed and variable costs for a product.

Fixed Cost (in dollars):	Plaint Maintenance – 15,000
	Salaries – 40,000
	Depreciation – 100,000
	Rent – 8,000
	Manufacturing expenses – 12,000
	Advertising – 5,000
	Administrative expenses – 20,000
Variable Cost per unit:	Labor – 3.00, Materials – 5.00, Sales Commission – 2.00

Assuming Sales Price per unit = \$15, develop a spreadsheet model to calculate the break-even point using the above. Design your spreadsheet using effective spreadsheet-engineering principles.

5. For inventory problems, the cost is a function of the order size. A company has collected the following data for one of its product.

Annual requirement, R = 12,000

Ordering cost per order, S = 150

Cost per unit, C = 4

Carrying cost per unit, I = 0.20

Quantity ordered per order, Q = 100

Develop a general model for computing ordering cost, carrying cost, and total cost functions. Use the following formulas:

Ordering cost = (R/Q)*S

Carrying Cost = (Q/2)*I*C

Total Cost = Ordering cost + Carrying Cost

6. A (greatly) simplified model of the national economy can be described as follows. The national income is the sum of three components: consumption, investment, and government spending. Consumption is related to the total income of all individuals and to the taxes they pay on income. Taxes depend on total income and the tax rate. Investment is also related to the size of the total income.

a. Use this information to draw an influence diagram by recognizing that the phrase "*A* is related to *B*" implies that *A* influences *B* in the model.

b. If we assume that the phrase "*A* is related to *B*" can be translated into mathematical terms as $A = kB$, where k is some constant, develop a mathematical model for the information provided.

7. Thomas wants to predict the sales figures of his company for the upcoming year. On the basis of historical data, he concludes that a linear function passes through the observed data points for the first and sixth years. The sales figure for the first year is \$24,000, and for the sixth year is \$2,000. Develop a spreadsheet model to find intercept and slope of the linear function and predict sales for the seventh year.

8. The Radio Shop sells two popular models of portable sport radios, model A and model B. The sales of these products are not independent of each other (in economics, we call these substitutable products, because if the price of one increases, sales of the other will increase). The store wishes to establish a pricing policy to maximize revenue from these products. A study of price and sales data shows the following relationships between the quantity sold (N) and prices (P) of each model:

$$N_A = 20 - 0.62P_A + 0.30P_B$$
$$N_B = 29 + 0.10P_A - 0.60P_B$$

a. Construct a model for the total revenue and implement it on a spreadsheet.

b. What is the predicted revenue if P_A = \$18 and P_B = \$30? What if the prices are P_A = \$25 and P_B = \$50?

9. For a new product, sales volume in the first year is estimated to be 80,000 units and is projected to grow at a rate of 4% per year. The selling price is \$12 and will increase by \$0.50 each year. Per-unit variable costs are \$3, and annual fixed costs are \$400,000. Per-unit costs are expected to increase 5% per year. Fixed costs are expected to increase 8% per year. Develop a spreadsheet model to calculate the net present value of profit over a 3-year period, assuming a 4% discount rate.

10. A stockbroker calls on potential clients from referrals. For each call, there is a 10% chance that the client will decide to invest with the firm. Fifty-five

[8]Based on an example of the Parfitt-Collins model in Gary L. Lilien, Philip Kotler, and K. Sridhar Moorthy, *Marketing Models* (Englewood Cliffs, NJ: Prentice Hall, 1992): 483.

percent of those interested are found not to be qualified, based on the brokerage firm's screening criteria. The remaining are qualified. Of these, half will invest an average of $5,000, 25% will invest an average of $20,000, 15% will invest an average of $50,000, and the remainder will invest $100,000. The commission schedule is as follows:

Transaction Amount	Commission
Up to $25,000	$50 + 0.5% of the amount
$25,001 to $50,000	$75 + 0.4% of the amount
$50,001 to $100,000	$125 + 0.3% of the amount

The broker keeps half the commission. Develop a spreadsheet to calculate the broker's commission based on the number of calls per month made. What is the expected commission based on making 600 calls?

11. The director of a nonprofit ballet company in a medium-sized U.S. city is planning its next fundraising campaign. In recent years, the program has found the following percentages of donors and gift levels:

Gift Level	Amount	Average Number of Gifts
Benefactor	$10,000	3
Philanthropist	$5,000	10
Producer's Circle	$1,000	25
Director's Circle	$500	50
Principal	$100	7% of solicitations
Soloist	$50	12% of solicitations

Develop a spreadsheet model to calculate the total amount donated based on this information if the number of the company contacts 1000 potential donors to donate at the $100 level or below.

12. A gasoline mini-mart orders 25 copies of a monthly magazine. Depending on the cover story, demand for the magazine varies. The gasoline mini-mart purchases the magazines for $1.50 and sells them for $4.00. Any magazines left over at the end of the month are donated to hospitals and other health-care facilities. Modify the newsvendor example spreadsheet to model this situation. Investigate the financial implications of this policy if the demand is expected to vary between 10 and 30 copies each month. How many must be sold to at least break even?

13. Koehler Vision Associates (KVA) specializes in laser-assisted corrective eye surgery. Prospective patients make appointments for prescreening exams to determine their candidacy for the surgery: if they qualify, a $250 charge is applied as a deposit for the actual procedure. The weekly demand is 150, and about 12% of prospective patients fail to show up or cancel their exam at the last minute. Patients that do not show up are refunded the prescreening fee less a $25 processing fee. KVA can handle 125 patients per week and is considering overbooking its appointments to reduce the lost revenue associated with cancellations. However, any patient that is overbooked may spread unfavorable comments about the company; thus, the overbooking cost is estimated to be $125. Develop a spreadsheet model for calculating net revenue. Find the net revenue and number overbooked if 140 through 150 appointments are taken.

14. Tanner Park is a small amusement park that provides a variety of rides and outdoor activities for children and teens. In a typical summer season, the number of adult and children's tickets sold are 20,000 and 10,000, respectively. Adult ticket prices are $18 and the children's price is $10. Revenue from food and beverage concessions is estimated to be $60,000, and souvenir revenue is expected to be $25,000. Variable costs per person (adult or child) are $3, and fixed costs amount to $150,000. Determine the profitability of this business.

15. With the growth of digital photography, a young entrepreneur is considering establishing a new business, Cruz Wedding Photography. He believes that the average number of wedding bookings per year is 15. One of the key variables in developing his business plan is the life he can expect from a single digital single lens reflex (DSLR) camera before it needs to be replaced. Due to heavy usage, the shutter life expectancy is estimated to be 150,000 clicks. For each booking, the average number of photographs taken is assumed to be 2,000. Develop a model to determine the camera life (in years).

16. The Executive Committee of Reder Electric Vehicles is debating whether to replace its original model, the REV-Touring, with a new model, the REV-Sport, which would appeal to a younger audience. Whatever vehicle chosen will be produced for the next 4 years, after which time a reevaluation will be necessary. The REV-Sport has passed through the concept and initial design phases and is ready for final design and manufacturing. Final development costs are estimated to be $75 million, and the new fixed costs for tooling and manufacturing are estimated to be $600 million. The REV-Sport is expected to sell for $30,000. The first year sales for the REV-Sport is estimated to be 60,000, with a sales growth for the subsequent years of 6% per year. The variable cost per vehicle is uncertain until the design and supply-chain decisions are finalized, but is estimated to be $22,000. Next-year sales for the REV-Touring are estimated to be 50,000, but the sales are expected to decrease at a rate of 10% for each of the next 3 years. The selling price is $28,000. Variable costs per vehicle are $21,000. Since the model has been in production, the fixed costs for development have already been recovered. Develop a 4-year model to recommend the best decision using a net present value discount rate of 5%. How sensitive is the result to the estimated variable cost of the REV-Sport? How might this affect the decision?

17. The Schoch Museum is embarking on a 5-year fundraising campaign. As a nonprofit institution, the museum finds it challenging to acquire new donors as many donors do not contribute every year. Suppose that the museum has identified a pool of 8,000 potential donors. The actual number of donors in the first year of the campaign is estimated to be 65% of this pool. For each subsequent year, the museum expects that 35% of current donors will discontinue their contributions. In addition, the museum expects to attract some percentage of new donors. This is assumed to be 10% of the pool. The average contribution in the first year is assumed to be $50, and will increase at a rate of 2.5%. Develop a model to predict the total funds that will be raised over the 5-year period, and investigate the impacts of the percentage assumptions used in the model.

18. Apply the data-validation tool to the *Bank Data* Excel file with an error alert message box to ensure that a two-digit number is correctly entered under Age, the data entered under ZipCode should not exceed 5 digits, and the Education field takes the values 1, 2 and 3 for 'undergraduate', 'graduate' and 'post graduate' respectively. Enter some fictitious additional data to verify that your results are correct.

19. Insert a spin button and scroll bar in the *Outsourcing Decision Model* to allow the user to easily change the production volume in cell B12 from 500 to 3000. Which one is easier to use? Discuss the pros and cons of each.

20. Insert a spin button in the car lease purchase model to change the discount rate in cell F8 from 1% to 10% in increments of one-tenth.

21. For the Pro Forma Income Statement model in the Excel file *Net Income Models* (Figure 11.7), add a scroll bar form control to allow the user to easily change the level of sales from 3,000,000 to 10,000,000 in increments of 1,000 and recalculate the spreadsheet. (Hint: the scroll values must be between 0 and 30,000 so you will need to modify the spreadsheet to make it work correctly.)

22. Create a new worksheet in the *Retirement Portfolio* workbook. In this worksheet, add a list box form control to allow the user to select one of the mutual funds on the original worksheet, and display a summary of the net asset value, number of shares, and total value using the VLOOKUP function. (Hint: your list box should show the fund names, but you will need to modify the original spreadsheet to use VLOOKUP correctly!)

23. The Excel sheet *Travelling Salesman* contains data on cost incurred by salesman on travelling from one city to another. Using this data matrix, add list box controls so that manager can choose two cities and find the cost of travelling between them. (Hint: Set the cell links to be any blank cells as the list boxes return the number of position in the list; then use VLOOKUP to find the cost).

24. Problem 15 in Chapter 1 posed the following situation: A manufacturer of mp3 players is preparing to set the price on a new model. Demand is thought to depend on the price and is represented by the model

$$D = 2{,}500 - 3P$$

The accounting department estimates that the total costs can be represented by

$$C = 5{,}000 + 5D$$

Implement your model on a spreadsheet and construct a one-way data table to estimate the price for which profit is maximized.

25. Problem 16 in Chapter 1 posed the following situation: The demand for airline travel is quite sensitive to price. Typically, there is an inverse relationship between demand and price; when price decreases, demand increases, and vice versa. One major airline has found that when the price (p) for a round trip between Chicago and Los Angeles is $600, the demand ($D$) is 500 passengers per day. When the price is reduced to \$400, demand is 1,200 passengers per day. You were asked to develop an appropriate model. Implement your model on a spreadsheet and use a data table to estimate the price that maximizes total revenue.

26. Develop a spreadsheet model for determining value, using the simple valuation function Value = D/(r − g), where r is the discount rate = 10% and g is the growth rate = 4% and D is dividend = 1.25. Use a two-way data table to determine value if g varies from 1% to 5% in increments of 1, and r varies from 8% to 16% in increments of 2%.

27. The booking price for motivational seminar (held every week) is charged at \$650 per booking, with maximum seats = 100. The total cost for arranging such a seminar comes to \$35,000 per week. The manager offers 10% discount on group bookings, allowing 5 seats per group. On an average, he receives 2 to 10 (maximum allowed in a seminar) group booking orders. Construct a spreadsheet model to determine the profit all seats are booked, and none of which is group booking.

a. Use data tables to evaluate the profit for the specified range of booked group seats.

b. Suppose the manager is considering lowering or increasing the group booking discount by 5%. How will profit be affected?

28. For the Koehler Vision Associates model you developed in Problem 13, use data tables to study how revenue is affected by changes in the number of appointments accepted and patient demand.

29. For the stockbroker model you developed in Problem 10, use data tables to show how the commission is a function of the number of calls made.

30. For the nonprofit ballet company fundraising model you developed in Problem 11, use a data table to show how the amount varies based on the number of solicitations.

31. For the garage-band model you developed in Problem 7, define and run some reasonable scenarios using the *Scenario Manager* to evaluate profitability for the following scenarios:

Scenarios for Problem 31	Likely	Optimistic	Pessimistic
Expected Crowd	3000	4500	2500
Concession Expenditure	\$15	\$20	\$12.50
Fixed cost	\$10,000	\$8,500	\$12,500

32. Think of any retailer that operates many stores throughout the country, such as Old Navy, Hallmark Cards, or Radio Shack, to name just a few. The retailer is often seeking to open new stores and needs to evaluate the profitability of a proposed location that would be leased for 5 years. An Excel model is provided in the *New Store Financial Model* spreadsheet. Use *Scenario Manager* to evaluate the cumulative discounted cash flow for the fifth year under the following scenarios:

Scenarios for Problem 32	Scenario 1	Scenario 2	Scenario 3
Inflation rate	1%	5%	3%
Cost of merchandise (% of sales)	25%	30%	26%
Labor cost	\$150,000	\$225,000	\$200,000
Other expenses	\$300,000	\$350,000	\$325,000
First-year sales revenue	\$600,000	\$600,000	\$800,000
Sales growth year 2	15%	22%	25%
Sales growth year 3	10%	15%	18%
Sales growth year 4	6%	11%	14%
Sales growth year 5	3%	5%	8%