- In column G, we simulate the actual duration of each activity by using Crystal Ball's CB.Triangular function. We then round this value to two decimal points, using the ROUND function. For example, the formula in cell G4 is

=ROUND(CB.Triangular(D4, E4, F4), 2)

- In column H, we calculate the actual start time for each activity. In computing this time, we need to ensure that all predecessors for an activity have been completed before that activity can begin. For example, both activities A and B have to finish before activity D can start. Hence, the start time for activity D is set equal to the maximum of the finish times of activities A and B. That is, the formula in cell H7 is

=MAX(I4,I5)

- In column I, we compute the finish time of each activity as the sum of the start time of that activity (column H) and the actual duration of that activity (column G).

In General Foundry's project, the project completion time is the completion time of activity H, shown in cell I11. Based on the single replication shown in Screenshot 10-11, it appears that the project will finish in only 15.35 weeks. However, in order to get a more precise value of this output measure, we use Crystal Ball to replicate the model 3,000 times. Cell I11 is defined as the Forecast cell.

The frequency chart obtained from Crystal Ball is also shown in Screenshot 10-11. Based on this chart, it appears that the average completion time of the project is 16.35 weeks. (To show the mean, click on the graph to get an options window where you can enable this feature.) More importantly for General Foundry, the chart indicates that there is only a 47.63% chance that the project will finish in less than 16 weeks. Based on the results, it appears that Lester Harky should either try to shorten some of the activity durations or, alternatively, negotiate with the EPA for more time.

DISCUSSION QUESTIONS AND PROBLEMS

Discussion Questions

10-1 What are the advantages and limitations of simulation models?

10-2 Why might a manager be forced to use simulation instead of an analytical model in dealing with a problem of

(a) inventory ordering policy?
(b) ships docking in a port to unload?
(c) bank teller service windows?
(d) the U.S. economy?

10-3 What types of management problems can be solved more easily by using decision modeling techniques other than simulation?

10-4 What are the major steps in the simulation process?

10-5 What is Monte Carlo simulation? What principles underlie its use, and what steps are followed in applying it?

10-6 Why is a computer necessary in conducting a real-world simulation?

10-7 What is operational gaming? What is systems simulation? Give examples of how each may be applied.

10-8 Do you think the application of simulation will increase strongly in the next 10 years? Why or why not?

10-9 Would the average output value in a simulation problem change appreciably if a longer period were simulated? Why or why not?

10-10 How might drawing a flow diagram help in developing a simulation model?

10-11 List the advantages of using an Excel add-in program rather than using Excel's built-in functions to develop a simulation model.

10-12 What does Scenario Manager allow you to accomplish in an Excel-based simulation model?

10-13 Do you think we can use Excel's Solver to solve simulation models? Why or why not?

Problems

Notes

- ***Simulation models for all the following problems can be set up by using Excel.***
- ***Wherever necessary, replications can be done either using Data Table or using Crystal Ball.***
- ***In all problems, we have specified the number of replications to use simply as N. Your instructor may specify the actual value of N that he or she wants you to use. If not, we recommend that you try to replicate each simulation model as many***

times as is convenient. If you are using Data Table, 200 to 300 replications should be appropriate to keep the computation time reasonable and the resulting Excel file relatively small (even though the average values may vary from simulation to simulation). However, if you are using Crystal Ball, you should try 3,000 or more replications.

- *Wherever a decision is involved, you can use either Scenario Manager, or Decision Table if you are using Crystal Ball.*

10-14 Clark Property Management is responsible for the maintenance, rental, and day-to-day operation of several large apartment complexes on the east side of New Orleans. George Clark is especially concerned about the cost projections for replacing air conditioner (A/C) compressors. He would like to simulate the number of A/C failures each month. Using data from similar apartment buildings he manages in a New Orleans suburb, Clark establishes the probability of failures during a month as follows:

Number of A/C Failures	Probability
0	0.06
1	0.13
2	0.25
3	0.28
4	0.20
5	0.07
6	0.01

(a) Simulate Clark's monthly A/C failures for a period of three years. Compute the average number of failures per month.
(b) Explain any difference between the simulated average failures and the expected value of failures computed by using the probability distribution.

10-15 Weekly demand for a certain brand of golf ball at The Golf Outlet is normally distributed with a mean of 35 and a standard deviation of 5. The profit per box is $5.00.

(a) Simulate 1 year (52 weeks) of demand and calculate the average weekly profit. Make all demand values integers in your model.
(b) What is the probability that weekly profit will be $200 or more?

10-16 Dan's Electronics sells TVs according to the monthly demand distribution shown in the following table.

Simulate 10 years of demand and compare theoretical and simulated results for the following measures:

(a) Average demand.
(b) Probability that demand will be less than or equal to 30 TVs.

Table for Problem 10-16

Demand	Probability
10	0.03
15	0.07
20	0.09
25	0.12
30	0.20
35	0.18
40	0.21
45	0.08
50	0.02

10-17 Vincent Maruggi, an MBA student at Northern Massachusetts University, has been having problems balancing his checkbook. His monthly income is derived from a graduate research assistantship; however, he also makes extra money in most months by tutoring undergraduates in their decision modeling course. His chances of various income levels are shown here (assume that this income is received at the beginning of each month):

Monthly Income	Probability
$750	0.40
$800	0.20
$850	0.30
$900	0.10

Maruggi's expenditures also vary from month to month, and he estimates that they will follow this distribution:

Monthly Expenses	Probability
$ 700	0.10
$ 800	0.45
$ 900	0.30
$1,000	0.15

Maruggi begins his final year with $1,000 in his checking account. Simulate the cash flow for 12 months and identify Maruggi's (a) ending balance at the end of the year and (b) probability that he will have a negative balance in any month. Replicate your model N times and discuss Maruggi's financial picture based on the average values for these two measures.

10-18 Sunrise Bakery has decided to bake 20 loaves of its famous sourdough bread at the beginning of the day. The store has determined that daily demand will follow the distribution shown in the following table:

Daily Demand	Probability
5	0.08
10	0.12
15	0.25
20	0.20
25	0.20
30	0.15

Each loaf costs Sunrise $1.50 and can be sold for $3.00. Sunrise can sell any unsold loaves for $0.75 the next day.

(a) Simulate 1 month (25 days) of operation to calculate the bakery's total monthly profit. Replicate this calculation N times to compute the average total monthly profit.
(b) Sunrise Bakery would like to investigate the profitability of baking 15, 20, 25, or 30 loaves at the start of the day. Which quantity would you recommend? Why?

10-19 Jeff Park sells newspapers on Sunday morning in an area surrounded by three busy churches. Demand for newspapers is distributed as per the following table:

Demand	Probability
50	0.05
75	0.10
100	0.25
125	0.30
150	0.20
175	0.10

Jeff has decided to order 100 papers from his supplier. Jeff pays $1.25 for each paper he orders and sells each paper for $2.00. Unsold newspapers have no resale value.

(a) Simulate 1 year (52 Sundays) of operation to calculate Jeff's total yearly profit. Replicate this calculation N times. What is the average yearly profit?
(b) Jeff would like to investigate the profitability of ordering 50, 100, 150, and 175 papers at the start of each Sunday. Which order quantity would you recommend? Why?

10-20 Robert's Raft Rentals leases rafts each day from a supplier and rents them to customers who use them to float down the Delaware River. Each day, Robert leases 30 rafts from his supplier, at a cost of $14 per raft. He rents them to his customers for $25 per day. Rental demand follows the normal distribution, with a mean of 30 rafts and a standard deviation of 6 rafts. (Make all demands integers in your model.)

(a) Simulate this leasing policy for a month (30 days) of operation to calculate the total monthly profit. Replicate this calculation N times. What is the average monthly profit?
(b) Robert would like to evaluate the average monthly profit if he leases 25, 30, 35, and 40 rafts. What is your recommendation? Why?

10-21 The Brennan Aircraft Division of TLN Enterprises operates a large number of computerized plotting machines. For the most part, the plotting devices are used to create line drawings of complex wing airfoils and fuselage part dimensions. The engineers operating the automated plotters are called loft lines engineers.

The computerized plotters consist of a minicomputer system connected to a 4- by 5-foot flat table with a series of ink pens suspended above it. When a sheet of clear plastic or paper is properly placed on the table, the computer directs a series of horizontal and vertical pen movements until the desired figure is drawn.

The plotting machines are highly reliable, with the exception of the four sophisticated ink pens that are built in. The pens constantly clog and jam in a raised or lowered position. When this occurs, the plotter is unusable.

Currently, Brennan Aircraft replaces each pen as it fails. The service manager has, however, proposed replacing all four pens every time one fails. This should cut down the frequency of plotter failures. At present, it takes one hour to replace one pen. All four pens could be replaced in two hours. The total cost of a plotter being unusable is $50 per hour. Each pen costs $8. The following breakdown data are thought to be valid:

Hours Between Failures (One Pen Replaced)	Probability	Hours Between Failures (Four Pens Replaced)	Probability
10	0.05	70	0.10
20	0.15	100	0.15
30	0.15	110	0.25
40	0.20	120	0.35
50	0.20	130	0.20
60	0.15	140	0.05

(a) For each option (replacing one pen at a time and replacing all four pens at a time), simulate the average total time a plotter would operate before it would have 20 failures. Then compute the total cost per hour for each option to determine which option Brennan Aircraft should use. Use N replications.
(b) Compute the total cost per hour analytically for each option. How do these results compare to the simulation results?

10-22 Zuckerman Wiring and Electric is a company that installs wiring and electrical fixtures in residential construction. John Zuckerman has been concerned with the amount of time it takes to complete wiring jobs because some of his workers are very unreliable. For each wiring job, a list of activities, their mean duration times, standard deviation of duration times, and immediate predecessors are given in the following table:

Activity	Days		Immediate Predecessors
	Mean	Standard Deviation	
A	5.83	0.83	—
B	3.67	0.33	—
C	2.00	0.33	—
D	7.00	0.33	C
E	4.00	0.67	B, D
F	10.00	1.33	A, E
G	2.17	0.50	A, E
H	6.00	1.00	F
I	11.00	0.33	G
J	16.33	1.00	G
K	7.33	1.33	H, I

Assume that all activity durations follow a normal distribution, with the means and standard deviations shown.

Use simulation to determine the probability that Zuckerman will finish the project in 40 days or less.

10-23 Dr. Mark Greenberg practices dentistry in Topeka, Kansas. Greenberg tries hard to schedule appointments so that patients do not have to wait beyond their appointment time. His October 20 schedule is shown in the following table:

Patient	Scheduled Appointment	Time Needed (min.)
Adams	9:30 A.M.	15
Brown	9:45 A.M.	20
Crawford	10:15 A.M.	15
Dannon	10:30 A.M.	10
Erving	10:45 A.M.	30
Fink	11:15 A.M.	15
Graham	11:30 A.M.	20
Hinkel	11:45 A.M.	15

Unfortunately, not every patient arrives exactly on schedule. Also, some examinations take longer than planned, and some take less time than planned. Greenberg's experience dictates the following: 20% of the patients will be 20 minutes early, 10% of the patients will be 10 minutes early, 40% of the patients will be on time, 25% of the patients will be 10 minutes late, and 5% of the patients will be 20 minutes late.

He further estimates that there is a 15% chance that an appointment will take 20% less time than planned, 50% chance it will take exactly the planned time, 25% chance it will take 20% more time than planned, and 10% chance it will take 40% more time than planned.

Dr. Greenberg has to leave at 12:15 P.M. on October 20 to catch a flight to a dental convention in New York. Assuming that he is ready to start his workday at 9:30 A.M. and that patients are treated in order of their scheduled exam (even if one late patient arrives after an early one), will he be able to make the flight? Comment on this simulation. Use N replications.

10-24 Pelnor Corporation is the nation's largest manufacturer of industrial-size washing machines. A main ingredient in the production process is 8- by 10-foot sheets of stainless steel. The steel is used for both interior washer drums and outer casings. Due to an existing contract, Pelnor must place an order for steel with the Smith-Layton Foundry each week, regardless of on-hand inventory. As per the contract, the foundry can ship either 8,500 or 9,500 square feet of steel each week, depending on availability. Based on past history, there is a 45% chance that 8,500 square feet will arrive and a 55% chance that the larger-size order will arrive. Pelnor's weekly demand for stainless steel is given in the following table:

Demand (Sq. Ft.)	Probability
6,000	0.05
7,000	0.15
8,000	0.20
9,000	0.30
10,000	0.20
11,000	0.10

Pelnor has a capacity to store no more than 25,000 square feet of steel at any time. If Pelnor does not have space to store all the steel received in any given week, the excess amount is sent back to the foundry.

(a) Simulate stainless steel order arrivals and use for 52 weeks. (Begin the first week with a starting inventory of 5,000 square feet.) If an end-of-week inventory is ever negative, assume that back orders are permitted and fill the demand from the next arriving order.

(b) Should Pelnor add more storage area? If so, how much? If not, comment on the system. Use

N replications of your model in (a) to answer these questions.

10-25 Furniture Depot orders a certain brand of mattress from its supplier and sells the mattresses at its retail location. The store currently orders 40 mattresses whenever the inventory level drops to 20. The cost to hold 1 mattress in inventory for one day is \$0.75. The cost to place an order with the supplier is \$80, and stockout costs are \$150 per mattress. Beginning inventory is 30 mattresses. The daily demand probabilities are shown in the following table:

Daily Demand	Probability
2	0.08
3	0.14
4	0.20
5	0.26
6	0.22
7	0.10

Lead time is discrete uniformly distributed between two and five days (both inclusive). Simulate this inventory policy for a quarter (90 days) and calculate the total quarterly cost. Also calculate the percentage of stockouts for the quarter. Replicate these calculations N times each to calculate the average values for these measures.

10-26 Consider the Furniture Depot problem described in Problem 10-25.

(a) Furniture Depot would like to evaluate ordering 35, 40, 45, and 50 mattresses when the reorder point of 20 is reached. Based on the average total quarterly cost, which order quantity would you recommend?

(b) Furniture Depot would like to evaluate reorder points of 15, 20, 25, and 30 mattresses, with an order quantity of 40 mattresses. Based on the average total quarterly cost, which reorder point would you recommend?

10-27 Video Works is a retail establishment that sells DVD players to its customers. Video Works orders 30 DVD players from its supplier when its inventory reaches 8 units. Daily demand for DVD players is discrete, uniformly distributed between 3 and 6 (both inclusive). The lead time from the supplier also varies for each order and is discrete, uniformly distributed between one and three days (both inclusive). The cost to hold 1 unit in inventory for one day is \$0.50. The cost to place an order is \$100. Stockout cost per unit is estimated at \$40. Initial inventory is 30 units.

Simulate this inventory policy for a quarter (90 days) and calculate the total quarterly cost. Also calculate the percentage of stockouts for the quarter. Replicate these calculations N times each to calculate the average values for these measures.

10-28 Consider the Video Works problem described in Problem 10-27.

(a) Video Works would like to evaluate ordering 25, 30, 35, and 40 DVD players when the reorder point of 8 is reached. Based on the average total quarterly cost, which order quantity would you recommend?

(b) Video Works would like to evaluate reorder points of 6, 8, and 10 DVD players, with an order quantity of 30 players. Based on the average total cost for the quarter, which reorder point would you recommend?

10-29 The Tire Warehouse (TTW) sells a certain brand tire that has a daily demand which is normally distributed with a mean of 15 tires and a standard deviation of 4 tires. (Make all demands integers in your model.) TTW replenishes its inventory by ordering 250 tires from the factory whenever its current inventory reaches 40 tires. The lead time (in days) to receive an order from the factory follows the distribution shown in the following table:

Lead Time	Probability
1	0.10
2	0.22
3	0.28
4	0.15
5	0.15
6	0.10

The cost to hold 1 tire in inventory for one day is \$0.20. The cost to place an order with the factory is \$100. Stockout costs are estimated at \$10 per tire. The initial inventory level is 100 tires.

(a) Simulate 6 months (180 days) of operation to calculate the total semiannual cost and the percentage of stockouts for the period. Replicate these calculations N times each to calculate the average values for these measures.

(b) TTW would like to evaluate the economics of ordering 150, 200, 250, 300, and 350 tires, with a reorder point of 40 tires. Based on the average total semiannual cost, which order quantity would you recommend?

(c) TTW would like to evaluate the economics of ordering 250 tires, with reorder points of 40, 50, 60, 70, and 80 tires. Based on the average total semiannual cost, which reorder point would you recommend?

10-30 ABC Airlines flies a six-passenger commuter fight once a day to Myrtle Beach. A nonrefundable one-way fare with a reservation costs \$79. The daily demand

for this flight is given in the following table, along with the probability distribution of no-shows (a no-show has a reservation but does not arrive at the gate and forfeits the fare):

Demand	Probability	No-shows	Probability
5	0.05	0	0.15
6	0.11	1	0.25
7	0.20	2	0.26
8	0.18	3	0.23
9	0.16	4	0.11
10	0.12		
11	0.10		
12	0.08		

ABC currently overbooks three passengers per flight. If there are not enough seats for a passenger at the gate, ABC Airlines refunds his or her fare and also provides a $100 voucher good on any other trip. The fixed cost for each flight is $350, regardless of the number of passengers.

(a) Set up a simulation model and calculate ABC's profit per flight. Replicate the calculation N times each to calculate the average profit per flight.
(b) ABC Airlines would like to investigate the profitability of overbooking 0, 1, 2, 3, 4, and 5 passengers. What is your recommendation? Why?

10-31 Milwaukee's General Hospital has an emergency room that is divided into six departments: (1) the initial exam station, to treat minor problems and make diagnoses; (2) an x-ray department; (3) an operating room; (4) a cast-fitting room; (5) an observation room for recovery and general observation before final diagnosis or release; and (6) an out-processing department, where clerks check out patients and arrange for payment or insurance forms. The probabilities that a patient will go from one department to another are presented in the following table. (See Table for Problem 10-31.)

Simulate the trail followed by 200 emergency room patients. Process one patient at a time, from each one's entry at the initial exam station until he or she leaves through out-processing. Note that a patient can enter the same department more than once. Based on your simulation, what is the probability that a patient enters the x-ray department more than once?

Table for Problem 10-31

From	To	Probability
Initial exam station	X-ray department	0.45
	Operating room	0.15
	Observation room	0.10
	Out-processing clerk	0.30
X-ray department	Operating room	0.10
	Cast-fitting room	0.25
	Observation room	0.35
	Out-processing clerk	0.30
Operating room	Cast-fitting room	0.25
	Observation room	0.70
	Out-processing clerk	0.05
Cast-fitting room	Observation room	0.55
	X-ray department	0.05
	Out-processing clerk	0.40
Observation room	Operating room	0.15
	X-ray department	0.15
	Out-processing clerk	0.70

10-32 Management of the First Syracuse Bank is concerned about a loss of customers at its main office downtown. One solution that has been proposed is to add one or more drive-through teller windows to make it easier for customers in cars to obtain quick service without parking. Chris Carlson, the bank president, thinks the bank should only risk the cost of installing one drive-through window. He is informed by his staff that the cost (amortized over a 20-year period) of building a drive-through window is $12,000 per year. It also costs $16,000 per year in wages and benefits to staff each new drive-through window.

The director of management analysis, Beth Shader, believes that two factors encourage the immediate construction of two drive-through windows, however. According to a recent article in *Banking Research* magazine, customers who wait in long lines for drive-through service will cost banks an average of $1 per minute in loss of goodwill. Also, adding a second drive-through window will cost an additional $16,000 in staffing, but amortized construction costs can be cut to a total of $20,000 per year if the two drive-through windows are installed together instead of one at a time. To complete her analysis, Shader collected arrival and service rates at a competing downtown bank's drive-through windows for one month. These data are shown in the following table:

Time Between Arrivals (min.)	Occurrences	Service Time (min.)	Occurrences
1	200	1	100
2	250	2	150
3	300	3	350
4	150	4	150
5	100	5	150
		6	100

All times are in minutes.

(a) Simulate a one-hour time period for a system with one drive-through window. Replicate the model N times.
(b) Simulate a one-hour time period for a system with two drive-through windows. Replicate the model N times.
(c) Conduct a cost analysis of the two options. Assume that the bank is open 7 hours per day and 200 days per year.

10-33 Julia Walter owns and operates one of the largest Mercedes-Benz auto dealerships in Washington, DC. In the past 36 months, her sales of this luxury car have ranged from a low of 6 new cars to a high of 12 new cars, as reflected in the following table:

Sales of New Cars per Month	Frequency
6	3
7	4
8	6
9	12
10	9
11	1
12	1

Julia believes that sales will continue during the next 24 months at about the same historical rates and that delivery lead times will also continue to follow this pace (stated in probability form):

Delivery Time (Mos.)	Probability
1	0.44
2	0.33
3	0.16
4	0.07

Julia's current policy is to order 14 cars at a time (two full truckloads, with 7 autos on each truck) and to place a new order whenever the stock on hand reaches 12 autos. Beginning inventory is 14 cars. Julia establishes the following relevant costs: (i) The carrying cost per Mercedes per month is \$600, (ii) the cost of a lost sale averages \$4,350, and (iii) the cost of placing an order is \$570.

(a) Simulate Julia's inventory policy for the next two years. What is the total monthly cost of this policy? Also, what is the average number of stockouts per month? Use N replications of your model.
(b) Julia wishes to evaluate several different ordering quantities—12, 14, 16, 18, and 20. Based on the total monthly cost, what would you recommend? Why? Set $R = 12$ in each case.

10-34 The Alfredo Fragrance Company produces only one product, a perfume called Hint of Elegance. Hint of Elegance consists of two secret ingredients blended into an exclusive fragrance that is marketed in Zurich. An economic expression referred to as the Cobb–Douglas function describes the production of Hint of Elegance as follows:

$$X = \sqrt{(\text{ingredient 1}) \times (\text{ingredient 2})}$$

where X is the amount of perfume produced. The company operates at a level where ingredient 1 is set daily at 25 units and ingredient 2 at 36 units. Although the price Alfredo pays for ingredient 1 is fixed at \$50 per unit, the cost of ingredient 2 and the selling price for the final perfume are both probabilistic. The sales price for Hint of Elegance follows this distribution:

Sales Price	Probability
\$300	0.2
\$350	0.5
\$400	0.3

The cost for ingredient 2 is discrete, uniformly distributed between \$35 and \$45 (in increments of \$1). Simulate the firm's profits for a month (30 days). Use N replications of your model to compute the average monthly profit.

10-35 Janis Miller is considering building a 300-seat theater in a popular tourist destination. After studying the market, Janis has drawn the following conclusions:

- There will be one show every night
- The theater will make a profit of \$2.00 on each occupied seat and suffer a loss of \$0.50 on each unoccupied seat.
- The probability that it rains on any given night is 0.30.
- The number of customers on a dry night is normally distributed, with a mean of 275 and a standard deviation of 30.
- The number of customers on a rainy night is normally distributed, with a mean of 250 and a standard deviation of 45.

Set up Janis's problem and simulate total profit for 1 month (30 days). Make all demands integers in your model. Replicate your model N times and calculate Janis's average monthly profit.

10-36 The owner of Dwayne's Concrete Service notes that the number of jobs each month follows a discrete uniform distribution between 10 and 16. The probability that a specific job will be for a residential driveway is 70%, and the probability that it will be for a commercial project is 30%. Revenues for residential driveways follow a normal distribution, with a mean of \$500 and a standard deviation of \$50. Commercial projects, although more lucrative, also have larger

variability. Dwayne estimates that revenues here follow a normal distribution, with a mean of $1,500 and a standard deviation of $400. Set up a simulation model for Dwayne's problem and replicate it N times to calculate the average monthly revenue.

10-37 The Clemson Police Department makes annual door-to-door solicitations for funds. Residents of each visited house are asked to contribute either $15 (and receive a free family portrait package) or $25 (and receive two free family portrait packages). An analysis from previous years' solicitations indicates that

- only 80% of the homes visited have the man or woman of the house at home.
- when someone is home, there is only a 40% chance that he or she will make a donation.
- of the people making donations, there is a 50% chance they will contribute $15 and a 45% chance they will contribute $25. Occasionally (5% chance), a person makes a donation in excess of $25. Such distributions follow a discrete uniform distribution between $30 and $50 (in increments of $1).

The police chief plans to visit 30 houses tomorrow. Set up a simulation model and replicate it N times to determine the probability that the chief will receive more than $250 in donations from these 30 houses.

10-38 A local bank has a single drive-through window with arrival times and service times that follow the distributions from the following table (all times are in minutes):

Time between Arrivals (min.)	Probability	Service Time (min.)	Probability
1	0.15	1	0.15
2	0.24	2	0.35
3	0.27	3	0.22
4	0.22	4	0.28
5	0.12		

Simulate the arrival of 200 customers to compute each of the following measures: (a) average time a customer waits for service, (b) average time a customer is in the system (wait plus service time), and (c) percentage of time the server is busy with customers. Replicate each measure N times to compute the average.

10-39 Ann sells hot dogs at the local peewee league baseball games. For the upcoming championship game, Ann has to decide how many hot dogs to order (170, 190, or 210), at a cost of $0.25 each. Ann sells hot dogs for $1 each. However, any unsold hot dogs must be thrown away.

If the game is interesting, Ann thinks that fewer people will visit her stand. In such a case, Ann estimates that demand will be normally distributed, with a mean of 140 and a standard deviation of 20. However, if the game is a blowout, she expects more people to visit the stand. Demand in this case will be normally distributed, with a mean of 190 and a standard deviation of 15. Based on her familiarity with the two teams, she estimates that there is only a 40% chance that the game will be a blowout.

Set up a simulation model and replicate it N times for each order size to determine Ann's: (a) expected profit and (b) expected percentage of unsold hot dogs. What do you recommend Ann should do?

10-40 Stone Harbor Grocery Store has a single check-out register, with customer arrival distribution shown in the following table (in minutes):

Time between Arrivals (min.)	Probability
1	0.18
2	0.20
3	0.22
4	0.25
5	0.15

Service time is discrete uniformly distributed between one and four minutes.

Simulate the arrival of 200 customers to compute each of the following measures: (a) average time a customer waits for service and (b) probability that a customer waits 3 minutes or longer for service. Replicate each measure N times to compute the average.

10-41 Astro Chemical manufactures chlorine gas by passing electricity through saltwater in a diaphragm cell. The plant has 88 diaphragm cells that operate in parallel. Each cell can produce 5 tons of chlorine gas per day, and each ton of chlorine gas has a profit contribution of $15. Due to the harsh environment, cell failures occur, causing the cell to be taken offline for maintenance. A cell fails, on average, every 30 hours, according to the exponential probability distribution. Only one cell can be repaired at any given time. Using the current maintenance procedure, the repair time follows a truncated normal probability distribution, with a mean of 21 hours, a standard deviation of 6 hours, and a minimum value of 5 hours. A new maintenance procedure is being considered that will require a significant capital investment. If this new procedure is implemented, the repair time will still follow a truncated normal distribution, but the mean time will be 14 hours, the standard deviation will be 4 hours, and the minimum time will be 3 hours. Simulate 200 failures to determine the annual savings in downtime with the new method.

10-42 Custom Tee Shirts is planning to print and sell specially designed tee shirts for the upcoming World Series. The shirts will cost $8 each to produce and can be sold for $21 each until the World Series. After the

World Series, the price will be reduced to $10 per shirt. The demand at the $21 price is expected to be normally distributed, with a mean of 10,000 shirts and a standard deviation of 2,000 shirts. The demand for the $10 price is expected to be normally distributed, with a mean of 4,000 shirts and a standard deviation of 800 shirts. Any shirts left over will be discarded. Because of the high setup costs, Custom Tee Shirts is planning on producing one run of 12,000 shirts. Make all demand values integers in your model.

(a) Simulate N setups to calculate the average profit for this quantity of shirts.
(b) Custom Tee Shirts would like to evaluate producing 10,000, 12,000, and 14,000 shirts. Which would you recommend? Why?

10-43 George Foster is responsible for the warehouse operation for a local discount department store chain. The warehouse has only one unloading dock that is currently operated by a single three-person crew. Trucks arrive at an average rate of five per hour and follow the exponential probability distribution. The average time for one of the crews to unload a truck tends to follow a normal distribution, with a mean of 9 minutes and standard deviation of 3 minutes (minimum time is 1 minute). George has estimated the cost of operating a truck at $40 per hour. George pays each person on the unloading crew $11 per hour. The unloading dock operates 8 hours each day. Simulate 100 days of this operation to calculate the total daily cost. Replicate this calculation N times to compute the expected total cost per day of this operation.

10-44 A customer service counter at a local department store is normally staffed by a single employee. The probabilities of arrival times and service times are shown in the following table (all times are in minutes):

Time Between Arrivals (min.)	Probability	Service Time (min.)	Probability
1	0.07	1	0.07
2	0.25	2	0.24
3	0.23	3	0.28
4	0.26	4	0.28
5	0.19	5	0.13

Simulate the arrival of 100 customers to compute each of the following measures: (a) average number of customers in line and (b) probability that a customer will have to wait 3 or more minutes for service to begin. Replicate each measure N times to compute the average.

10-45 A plant engineering group needs to set up an assembly line to produce a new product. The following table describes the relationships between the activities that need to be completed for this product to be manufactured:

Activity	Days a	Days m	Days b	Immediate Predecessors
A	3	6	8	—
B	5	8	10	A
C	5	6	8	A
D	1	2	4	B, C
E	7	11	17	D
F	7	9	12	D
G	6	8	9	D
H	3	4	7	F, G
I	3	5	7	E, F, H

Assume that the actual duration of each activity follows a triangular distribution, with the three time estimates shown for that activity. Round off all activity times to two decimal points.

(a) Use simulation to determine the probability that the project will finish in 37 days or less.
(b) Use simulation to determine the probability that the project will take more than 32 days.

10-46 Tom Schriber, director of personnel of Management Resources, Inc., is in the process of designing a program that its customers can use in the job-finding process. Some of the activities include preparing resumés, writing letters, making appointments to see prospective employers, researching companies and industries, and so on. Information on the activities is shown in the following table:

Activity	Days Mean	Days Standard Deviation	Immediate Predecessors
A	10.00	0.67	—
B	7.17	0.50	—
C	3.17	0.17	—
D	20.00	3.33	A
E	7.00	0.33	C
F	10.00	0.33	B, D, E
G	7.33	0.67	B, D, E
H	15.00	0.33	F
I	11.17	0.50	F
J	7.00	0.33	G, H
K	6.67	0.67	I, J
L	2.17	0.50	G, H

Assume that all activity durations follow a normal distribution, with the means and standard deviations shown. Round off all activity times to two decimal points.

Use simulation to determine the average project completion time and the probability that the project will take at least 75 days.

10-47 Laura Thompson needs to plan and manage a local construction project. The following table describes the relationships between the activities that need to be completed:

Activity	Days			Immediate Predecessors
	a	*m*	*b*	
A	4	8	13	—
B	4	10	15	A
C	7	14	20	B
D	9	16	19	B
E	6	9	11	B
F	2	4	5	D, E
G	4	7	11	C, F
H	3	5	9	G
I	2	3	4	G, H

Assume that the actual duration of each activity follows a triangular distribution, with the three time estimates shown for that activity. Round off all activity times to one decimal point. Use simulation to determine the probability that the project will take at least 50 days.

10-48 David Stockman is responsible for developing a supervisory training program for his organization. The following table describes the relationships between the activities that need to be completed:

Activity	Days		Immediate Predecessors
	Minimum	Maximum	
A	3	13	—
B	5	17	—
C	3	8	A, B
D	5	14	C
E	2	9	C
F	2	15	E
G	5	12	F
H	6	12	D
I	3	8	F, H
J	4	10	G, I

Assume that the actual duration of each activity follows a discrete uniform distribution between the minimum and maximum times shown for that activity.

Use simulation to determine the probability that the project will be finished in less than 49 days.

CASE STUDY

Alabama Airlines

Alabama Airlines opened its doors in June 2004 as a commuter service, with its headquarters and only hub located in Birmingham. A product of airline deregulation, Alabama Air joined the growing number of successful short-haul, point-to-point airlines, including Lone Star, Comair, Atlantic Southeast, Skywest, and Business Express.

Alabama Air was started and managed by two former pilots, David Douglas (who had been with the defunct Eastern Airlines) and Michael Hanna (formerly with Pan Am). It acquired a fleet of 12 used prop-jet planes and the airport gates vacated by Delta Air Lines' 2003 downsizing.

With business growing quickly, Douglas turned his attention to Alabama Air's toll-free reservations system. Between midnight and 6:00 A.M., only one telephone reservations agent had been on duty. The time between incoming calls during this period is distributed as shown in Table 10.8. Douglas carefully observed and timed the agent and estimated that the time taken to process passenger inquiries is distributed as shown in Table 10.9.

All customers calling Alabama Air go on hold and are served in the order of the calls unless the reservations agent is available for immediate service. Douglas is deciding whether a second agent should be on duty to cope with customer demand. To maintain customer satisfaction, Alabama Air does not want a customer on hold for more than three to four minutes and also wants to maintain a "high" operator utilization.

Further, the airline is planning a new TV advertising campaign. As a result, it expects an increase in toll-free line phone

TABLE 10.8

Current Incoming Call Distribution

Time Between Calls (min.)	Probability
1	0.11
2	0.21
3	0.22
4	0.20
5	0.16
6	0.10

TABLE 10.9

Service Time Distribution

TIME TO PROCESS ENQUIRIES (MIN.)	PROBABILITY
1	0.20
2	0.19
3	0.18
4	0.17
5	0.13
6	0.10
7	0.03

TABLE 10.10

Revised Incoming Call Distribution

TIME BETWEEN CALLS (MIN.)	PROBABILITY
1	0.22
2	0.25
3	0.19
4	0.15
5	0.12
6	0.07

enquiries. Based on similar campaigns in the past, the incoming call distribution from midnight to 6 A.M. is expected to be as shown in Table 10.10. (The same service time distribution will apply.)

Discussion Questions

1. What would you advise Alabama Air to do for the current reservation system, based on the original call distribution? Create a simulation model to investigate the scenario. Describe the model carefully and justify the duration of the simulation, assumptions, and measures of performance.
2. What are your recommendations regarding operator utilization and customer satisfaction if the airline proceeds with the advertising campaign?

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CASE STUDY

Abjar Transport Company

In 2004, Samir Khaldoun, after receiving an MBA degree from a leading university in the United States, returned to Jeddah, Saudi Arabia, where his family has extensive business holdings. Samir's first assignment was to stabilize and develop a newly formed, family-owned transport company—Abjar Transport.

An immediate problem Samir faces is the determination of the number of trucks needed to handle the forecasted freight volume. Before now, trucks were added to the fleet on an "as-needed" basis, without comprehensive capacity planning. This approach has created problems of driver recruitment, truck service and maintenance, and excessive demurrage (i.e., port fees) because of delays at unloading docks and retention of cargo containers.

Samir forecasts that Abjar's freight volume should average 160,000 tons per month, with a standard deviation of 30,000 tons. Freight is unloaded on a uniform basis throughout the month. Based on past experience, the amount handled per month is assumed to be normally distributed.

After extensive investigation, Samir concludes that the fleet should be standardized to 40-foot Mercedes 2624 2 × 4 tractor-trailer rigs, which are each suitable for carrying two 20-foot containers, one 30-foot container, or one 40-foot container. Cargo capacity is approximately 60 tons per rig. Each tractor-trailer unit is estimated to cost 240,000 riyals. Moreover, they must meet Saudi Arabian specifications—double cooling fans, oversized radiators, and special high-temperature tires. Historical evidence suggests that these Mercedes rigs will operate 96% of the time.

Approximately 25% of the freight handled by these tractor-trailer rigs is containerized in container lengths of 20, 30, and 40 feet. (The balance of the freight—75%—is not containerized.) The 20-foot containers hold approximately 20 tons of cargo, the 30-foot containers hold 45 tons, and the 40-foot containers hold 60 tons of freight. Approximately 60% of the containerized freight is shipped in 40-foot units, 20% is shipped in 30-foot units, and 20% is transported in 20-foot units.

Abjar Transport picks up freight at the dock and delivers it directly to customers or to warehouses for later delivery. Based on his study of truck routing and scheduling patterns, Samir concludes that each rig should pick up freight at the dock three times each day.

Discussion Question

How many tractor-trailer rigs should make up the Abjar Transport fleet?