Chapter 14

Simulation Modeling

To accompany
Quantitative Analysis for Management, Eleventh Edition,
by Render, Stair, and Hanna
Power Point slides created by Brian Peterson

Learning Objectives

After completing this chapter, students will be able to:

1. Tackle a wide variety of problems by simulation.
2. Understand the seven steps of conducting a simulation.
3. Explain the advantages and disadvantages of simulation.
4. Develop random number intervals and use them to generate outcomes.
5. Understand alternative simulation packages available.

Chapter Outline

Introduction

- ***Simulation*** **is one of the most widely used quantitative analysis tools.**
- **To *simulate* is to try to duplicate the features, appearance, and characteristics of a real system.**
- **We will build a *mathematical model* that comes as close as possible to representing the reality of the system.**
- ***Physical*** **models can also be built to test systems.**

Introduction

Using simulation, a manager should:

1. Define a problem.
2. Introduce the variables associated with the problem.
3. Construct a simulation model.
4. Set up possible courses of action for testing.
5. Run the simulation experiment.
6. Consider the results.
7. Decide what courses of action to take.

Process of Simulation

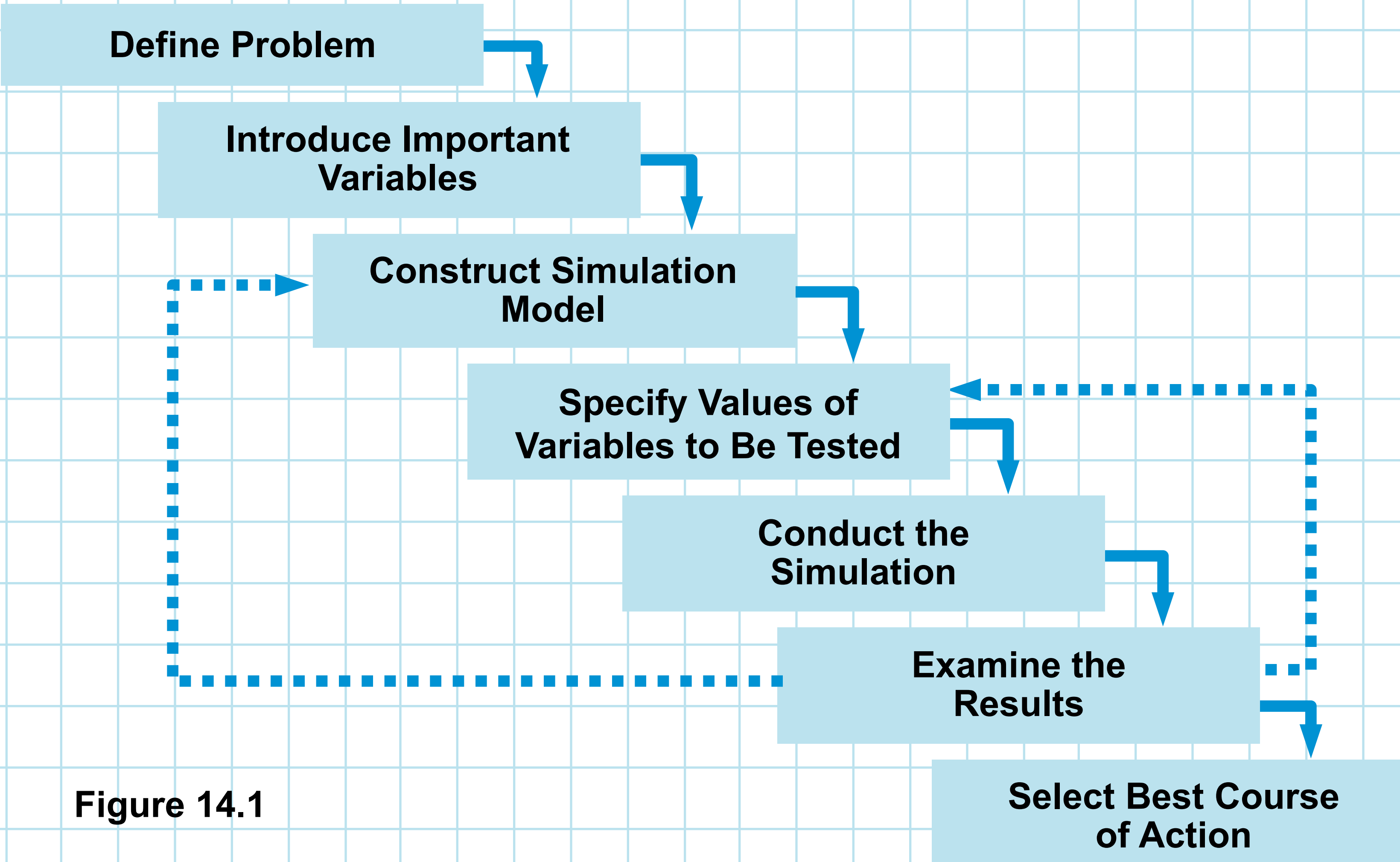

Figure 14.1

Advantages and Disadvantages of Simulation

The main advantages of simulation are:

1. It is relatively straightforward and flexible.
2. Recent advances in computer software make simulation models very easy to develop.
3. Can be used to analyze large and complex real-world situations.
4. Allows “what-if?” type questions.
5. Does not interfere with the real-world system.
6. Enables study of interactions between components.
7. Enables time compression.
8. Enables the inclusion of real-world complications.

Advantages and Disadvantages of Simulation

The main disadvantages of simulation are:

1. It is often expensive as it may require a long, complicated process to develop the model.
2. It does not generate optimal solutions; it is a trial-and-error approach.
3. It requires managers to generate all conditions and constraints of real-world problem.
4. Each model is unique and the solutions and inferences are not usually transferable to other problems.

Monte Carlo Simulation

- When systems contain elements that exhibit chance in their behavior, the Monte Carlo method of simulation can be applied.
- Some examples are:
  1. Inventory demand.
  2. Lead time for inventory.
  3. Times between machine breakdowns.
  4. Times between arrivals.
  5. Service times.
  6. Times to complete project activities.
  7. Number of employees absent.

Monte Carlo Simulation

- The basis of the Monte Carlo simulation is experimentation on the probabilistic elements through random sampling.
- It is based on the following five steps:
  1. Establishing a probability distribution for important variables.
  2. Building a cumulative probability distribution for each variable.
  3. Establishing an interval of random numbers for each variable.
  4. Generating random numbers.
  5. Actually simulating a series of trials.

Harry's Auto Tire

- A popular radial tire accounts for a large portion of the sales at Harry's Auto Tire.
- Harry wishes to determine a policy for managing this inventory.
- He wants to simulate the daily demand for a number of days.

Step 1: Establishing probability distributions

- One way to establish a probability distribution for a given variable is to examine historical outcomes.
- Managerial estimates based on judgment and experience can also be used.

Harry’s Auto Tire

Historical Daily Demand for Radial Tires at Harry’s Auto Tire and Probability Distribution

DEMAND FOR TIRES	FREQUENCY (DAYS)	PROBAILITY OF OCCURRENCE
0	10	10/200 = 0.05
1	20	20/200 = 0.10
2	40	40/200 = 0.20
3	60	60/200 = 0.30
4	40	40/200 = 0.20
5	30	30/200 = 0.15
	200	200/200 = 1.00

Table 14.1

Harry's Auto Tire

Step 2: Building a cumulative probability distribution for each variable

- Converting from a regular probability to a cumulative distribution is an easy job.
- A cumulative probability is the probability that a variable will be less than or equal to a particular value.
- A cumulative distribution lists all of the possible values and the probabilities, as shown in Table 14.2.

Harry's Auto Tire

Cumulative Probabilities for Radial Tires

DAILY DEMAND	PROBABILITY	CUMULATIVE PROBABILITY
0	0.05	0.05
1	0.10	0.15
2	0.20	0.35
3	0.30	0.65
4	0.20	0.85
5	0.15	1.00

Table 14.2

Harry's Auto Tire

Step 3: Setting random number intervals

- **Assign a set of numbers to represent each possible value or outcome.**
  - **These are *random number intervals.***
  - **A *random number* is a series of digits that have been selected by a totally random process.**
  - **The range of the random number intervals corresponds *exactly* to the probability of the outcomes as shown in Figure 14.2.**

Harry's Auto Tire

Graphical Representation of the Cumulative Probability Distribution for Radial Tires

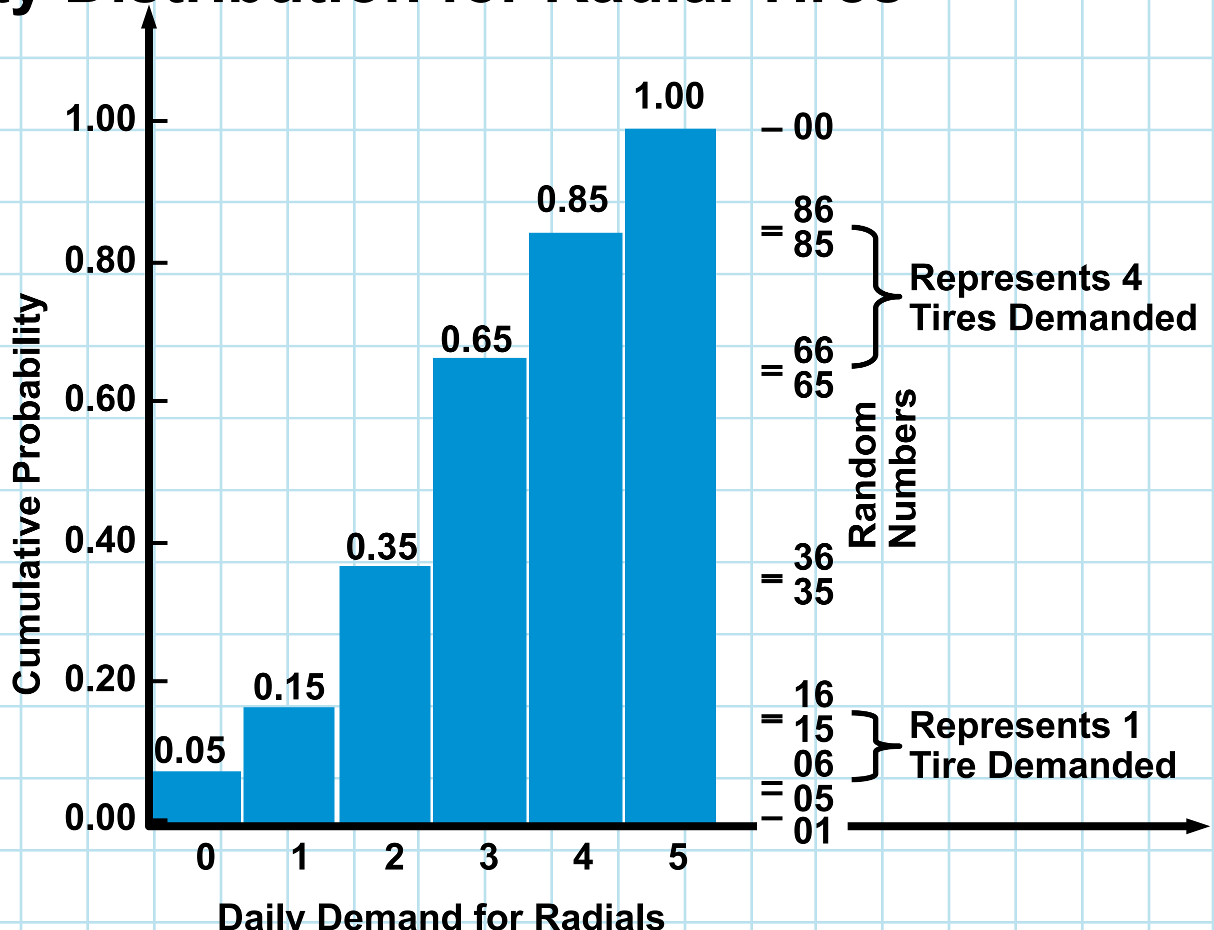

Figure 14.2

Harry's Auto Tire

Assignment of Random Number Intervals for Harry's Auto Tire

DAILY DEMAND	PROBABILITY	CUMULATIVE PROBABILITY	INTERVAL OF RANDOM NUMBERS
0	0.05	0.05	01 to 05
1	0.10	0.15	06 to 15
2	0.20	0.35	16 to 35
3	0.30	0.65	36 to 65
4	0.20	0.85	66 to 85
5	0.15	1.00	86 to 00

Table 14.3

Harry's Auto Tire

Step 4: Generating random numbers

- Random numbers can be generated in several ways.
- Large problems will use computer program to generate the needed random numbers.
- For small problems, random processes like roulette wheels or pulling chips from a hat may be used.
- The most common manual method is to use a random number table.
- Because *everything* is random in a random number table, we can select numbers from anywhere in the table to use in the simulation.

Harry's Auto Tire

Table of random numbers (partial)

52	06	50	88	53	30	10	47	99	37
37	63	28	02	74	35	24	03	29	60
82	57	68	28	05	94	03	11	27	79
69	02	36	49	71	99	32	10	75	21
98	94	90	36	06	78	23	67	89	85
96	52	62	87	49	56	59	23	78	71
33	69	27	21	11	60	95	89	68	48
50	33	50	95	13	44	34	62	64	39
88	32	18	50	62	57	34	56	62	31
90	30	36	24	69	82	51	74	30	35

Table 14.4

Harry's Auto Tire

Step 5: Simulating the experiment

- **We select random numbers from Table 14.4.**
- **The number we select will have a corresponding range in Table 14.3.**
- **We use the daily demand that corresponds to the probability range aligned with the random number.**

Harry's Auto Tire

Ten-day Simulation of Demand for Radial Tires

DAY	RANDOM NUMBER	SIMULATED DAILY DEMAND
1	52	3
2	37	3
3	82	4
4	69	4
5	98	5
6	96	5
7	33	2
8	50	3
9	88	5
10	90	5
		39 = total 10-day demand
		3.9 = average daily demand for tires

Table 14.5

Harry's Auto Tire

Note that the average demand from this simulation (3.9 tires) is different from the ***expected*** daily demand.

$$\text{Expected daily demand} = \sum_{i=0}^{5} (\text{Probability of } i \text{ tires})(\text{Demand of } i \text{ tires})$$

$$= (0.05)(0) + (0.10)(1) + (0.20)(2) + (0.30)(3) + (0.20)(4) + (0.15)(5)$$

$$= 2.95 \text{ tires}$$

If this simulation were repeated hundreds or thousands of times it is much more likely the average ***simulated*** demand would be nearly the same as the ***expected*** demand.

QM for Windows Output Screen for Simulation of Harry's Auto Tire Example

Once the input screen appears, enter the values and the frequencies. The probabilities will automatically be calculated.

Additional output is available.

This is the average value for this simulation run.

Simulation Results

Harry's Auto Tire Solution

Category name	Value	Frequency	Probability	Cumulative Probability	Value * Frequency	Occurrences	Percentage	Occurences * Value
Category 1	0	10	0.05	0.05	0	42	0.04	0
Category 2	1	20	0.1	0.15	0.1	94	0.09	94
Category 3	2	40	0.2	0.35	0.4	206	0.21	412
Category 4	3	60	0.3	0.65	0.9	287	0.29	861
Category 5	4	40	0.2	0.85	0.8	207	0.21	828
Category 6	5	30	0.15	1	0.75	164	0.16	820
Total		200	1	Expected	2.95	1000	1	3015
							Average	3.02

The expected value is calculated mathematically.

Program 14.1

Simulation with Excel Spreadsheets

Using Excel 2010 to Simulate Tire Demand for Harry's Auto Tire Shop

	A	B	C	D	E	F	G	H	I
1	Harry's Auto Tire Shop								
2		Probability	Probability Range (Lower)	Cumulative Probability	Tires Demand		Day	Random Number	Simulated Demand
3		0.05	0	0.05	0		1	0.628711	3
4		0.1	0.05	0.15	1		2	0.402931	3
5		0.2	0.15	0.35	2		3	0.419694	3
6		0.3	0.35	0.65	3		4	0.645743	3
7		0.2	0.65	0.85	4		5	0.446755	3
8		0.15	0.85	1	5		6	0.022622	0
9							7	0.216480	2
10							8	0.901222	5
11							9	0.794447	4
12							10	0.530363	3
13								**Average =**	2.9
14		Results (Frequency table)							
15		Tires Demanded	Frequency	Percentage	Cumulative %				
16		0	1	10%	10%				
17		1	0	0%	10%				
18		2	1	10%	20%				
19		3	6	60%	80%				
20		4	1	10%	90%				
21		5	1	10%	100%				
22			10	**=Total**					

Program 14.2

Simulation with Excel Spreadsheets

Using Excel 2010 to Simulate Tire Demand for Harry's Auto Tire Shop

	I
13	=AVERAGE(I3:I12)

	C
22	=SUM(C16:C21)

	C	D
3	0	=B3
4	=D3	=D3+B4

	H	I
3	=RAND()	=VLOOKUP(H3,$C$3:$E$8,3,TRUE)

	C
16	=FREQUENCY($I$3:$I$12,$B$16:$B$21)

	D	E
16	=C16/$C$22	=D16
17	=C17/$C$22	=E16+D17

Program 14.2

Simulation with Excel Spreadsheets

Generating Normal Random Numbers in Excel

	A	B	C	D	E
1	**Generating Normal Random Numbers**				
2					
3	Random number		Value	Frenquency	Percentage
4	39.54		26	0	0.0%
5	42.84		28	1	0.5%
6	36.49		30	3	1.5%
7	38.69		32	7	3.5%
8	44.15		34	14	7.0%
9	54.04		36	9	4.5%
10	32.99		38	31	15.5%
11	37.97		40	38	19.0%
12	43.47		42	31	15.5%
13	37.76		44	25	12.5%
14	38.30		46	26	13.0%
15	39.21		48	5	2.5%
16	40.08		50	6	3.0%
17	32.31		52	2	1.0%
18	39.30		54	1	0.5%
19	40.24		56	1	0.5%
20	39.35			**200**	**= Total**
201	41.15				
202	41.03		***(Rows 21-200 are hidden)***		
203	33.02				

Program 14.3

	A
4	=NORMINV(RAND(),40,5)

	E
4	=D4/$D$20

	D
4	=FREQUENCY(A4:A203,C4:C19)

Simulation with Excel Spreadsheets

Excel QM Simulation of Harry's Auto Tire Example

Enter the values and the frequencies. The probabilities and simulation results will then appear.

Harry's Auto Tire

Enter the values and the frequencies in the top table. Press F9 to run another simulation. If you like, you may enter the random numbers in the column labeled "Random number".

Simulation

Data

Random Number Sorter	Category name	Value	Frequency
0	Category 1	0	10
5	Category 2	1	20
15	Category 3	2	40
35	Category 4	3	60
65	Category 5	4	40
85	Category 6	5	30
	Total		200

Expected Value

Probability	Cumulative Probability	Value * Frequency
0.05	0.05	0
0.1	0.15	20
0.2	0.35	80
0.3	0.65	180
0.2	0.85	160
0.15	1	150
	Expected	

Simulation results

Value	Simulation Occurrences	Percentage	Occurences * Value
0	6	0.03	0
1	22	0.11	22
2	34	0.17	68
3	63	0.315	189
4	49	0.245	196
5	26	0.13	130
Totals	200	1	605
		Average	3.025

Program 14.4

Simulation and Inventory Analysis

- We have seen deterministic inventory models.
- In many real-world inventory situations, demand and lead time are variables.
- Accurate analysis is difficult without simulation.
- We will look at an inventory problem with two decision variables and two probabilistic components.
- The owner of a hardware store wants to establish ***order quantity*** and ***reorder point*** decisions for a product that has probabilistic daily demand and reorder lead time.

Simkin's Hardware Store

- The owner of a hardware store wants to find a good, low cost inventory policy for an electric drill.
- Simkin identifies two types of variables, controllable and uncontrollable inputs.
- The controllable inputs are the order quantity and reorder points.
- The uncontrollable inputs are daily demand and variable lead time.
- The demand data for the drill is shown in Table 14.6.

Simkin's Hardware Store

Probabilities and Random Number Intervals for Daily Ace Drill Demand

(1) DEMAND FOR ACE DRILL	(2) FREQUENCY (DAYS)	(3) PROBABILITY	(4) CUMULATIVE PROBABILITY	(5) INTERVAL OF RANDOM NUMBERS
0	15	0.05	0.05	01 to 05
1	30	0.10	0.15	06 to 15
2	60	0.20	0.35	16 to 35
3	120	0.40	0.75	36 to 75
4	45	0.15	0.90	76 to 90
5	30	0.10	1.00	91 to 00
	300	1.00		

Table 14.6

Simkin's Hardware Store

Probabilities and Random Number Intervals for Reorder Lead Time

(1) LEAD TIME (DAYS)	(2) FREQUENCY (ORDERS)	(3) PROBABILITY	(4) CUMULATIVE PROBABILITY	(5) RANDOM NUMBER INTERVAL
1	10	0.20	0.20	01 to 20
2	25	0.50	0.70	21 to 70
3	15	0.30	1.00	71 to 00
	50	1.00		

Table 14.7

Simkin's Hardware Store

- The third step is to develop a simulation model.
- A **flow diagram**, or **flowchart**, is helpful in this process.
- The fourth step in the process is to specify the values of the variables that we wish to test.
- The first policy that Simkin wants to test is an order quantity of 10 with a reorder point of 5.
- The fifth step is to actually conduct the simulation.
- The process is simulated for a 10 day period.

Flow Diagram for Simkin's Inventory Example

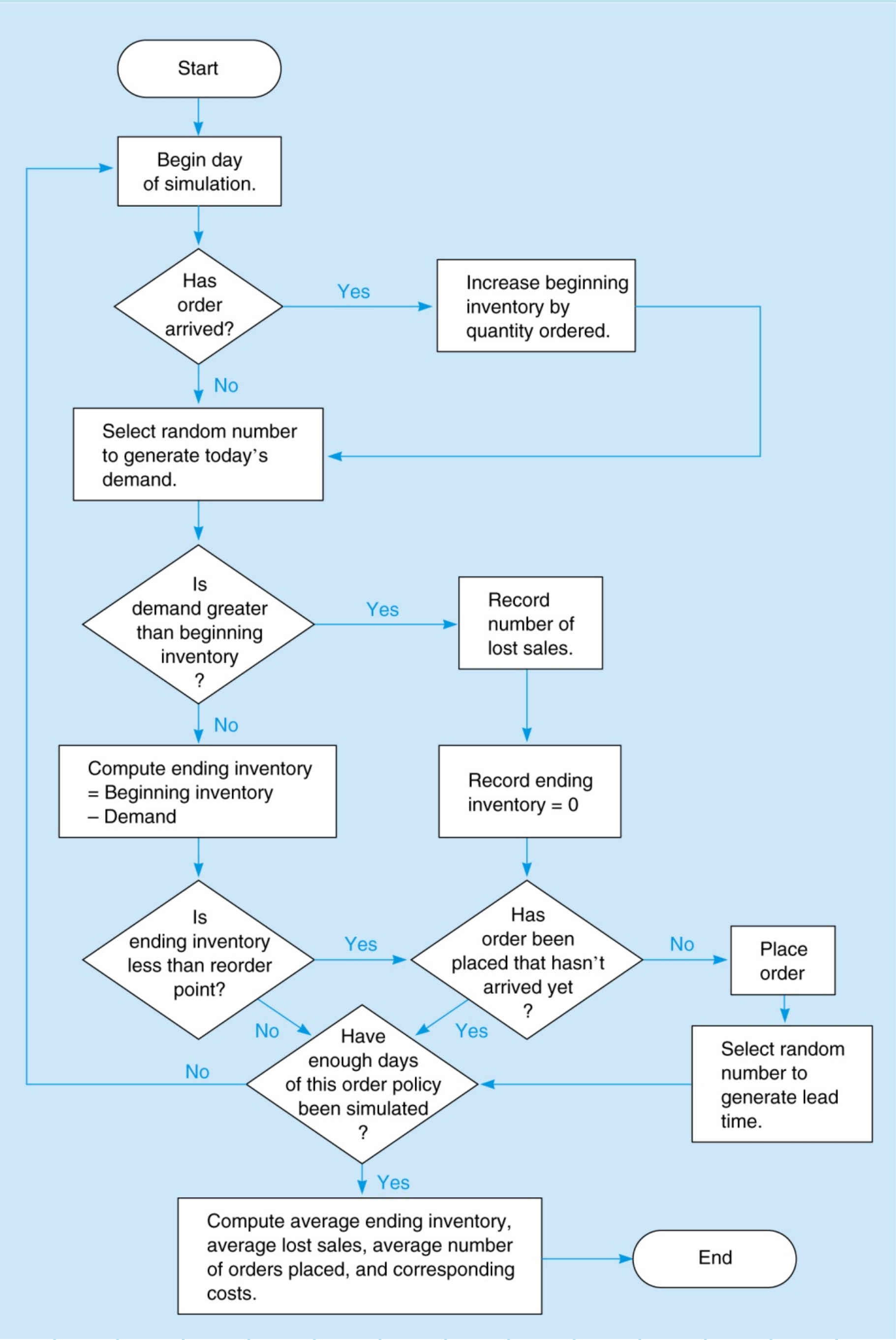

Figure 14.3

Simkin's Hardware Store

Using the table of random numbers, the simulation is conducted using a four-step process:

1. Begin each day by checking whether an ordered inventory has arrived. If it has, increase the current inventory by the quantity ordered.
2. Generate a daily demand from the demand probability by selecting a random number.
3. Compute the ending inventory every day. If on-hand inventory is insufficient to meet the day's demand, satisfy as much as possible and note the number of lost sales.
4. Determine whether the day's ending inventory has reached the reorder point. If necessary place an order.

Simkin's Hardware Store

Simkin Hardware's First Inventory Simulation

ORDER QUANTITY = 10 UNITS			REORDER POINT = 5 UNITS						
(1) DAY	(2) UNITS RECEIVED	(3) BEGINNING INVENTORY	(4) RANDOM NUMBER	(5) DEMAND	(6) ENDING INVENTORY	(7) LOST SALES	(8) ORDER	(9) RANDOM NUMBER	(10) LEAD TIME
1	…	10	06	1	9	0	No		
2	0	9	63	3	6	0	No		
3	0	6	57	3	3	0	Yes	02	1
4	0	3	94	5	0	2	No		
5	10	10	52	3	7	0	No		
6	0	7	69	3	4	0	Yes	33	2
7	0	4	32	2	2	0	No		
8	0	2	30	2	0	0	No		
9	10	10	48	3	7	0	No		
10	0	7	88	4	3	0	Yes	14	1
				Total	41	2			

Table 14.8

Analyzing Simkin's Inventory Cost

- The objective is to find a low-cost solution so Simkin must determine the costs.
- Equations for average daily ending inventory, average lost sales, and average number of orders placed.

$$\text{Average ending inventory} = \frac{41 \text{ total units}}{10 \text{ days}} = 4.1 \text{ units per day}$$

$$\text{Average lost sales} = \frac{2 \text{ sales lost}}{10 \text{ days}} = 0.2 \text{ unit per day}$$

$$\text{Average number of orders placed} = \frac{3 \text{ orders}}{10 \text{ days}} = 0.3 \text{ order per day}$$

Analyzing Simkin's Inventory Cost

- Simkin's store is open 200 days a year.
- Estimated ordering cost is $10 per order.
- Holding cost is $6 per drill per year.
- Lost sales cost $8.

Daily order cost = (Cost of placing one order) x (Number of orders placed per day)
= $10 per order x 0.3 order per day = $3

Daily holding cost = (Cost of holding one unit for one day) x (Average ending inventory)
= $0.03 per unit per day x 4.1 units per day
= $0.12

Analyzing Simkin's Inventory Cost

- Simkin's store is open 200 days a year.
- Estimated ordering cost is $10 per order.
- Holding cost is $6 per drill per year.
- Lost sales cost $8.

Daily stockout cost = (Cost per lost sale) x (Average number of lost sales per day)

= $8 per lost sale x 0.2 lost sales per day

= $1.60

Total daily inventory cost = Daily order cost + Daily holding cost + Daily stockout cost

= $4.72

Analyzing Simkin's Inventory Cost

- For the year, this policy would cost approximately $944.
- This simulation should really be extended for many more days, perhaps 100 or 1,000 days.
- Even after a larger simulation, the model must be verified and validated to make sure it truly represents the situation on which it is based.
- If we are satisfied with the model, additional simulations can be conducted using other values for the variables.
- After simulating all reasonable combinations, Simkin would select the policy that results in the lowest total cost.

Simulation of a Queuing Problem

- **Modeling waiting lines is an important application of simulation.**
- **The assumptions of queuing models are quite restrictive.**
- **Sometimes simulation is the only approach that fits.**
- **In this example, arrivals do not follow a Poisson distribution and unloading rates are not exponential or constant.**

Port of New Orleans

- Fully loaded barges arrive at night for unloading.
- The number of barges each night varies from 0 – 5, and the number of barges vary from day to day.
- The supervisor has information which can be used to create a probability distribution for the daily unloading rate.
- Barges are unloaded first-in, first-out.
- Barges must wait for unloading which is expensive.
- The dock superintendent wants to do a simulation study to enable him to make better staffing decisions.

Port of New Orleans

Overnight Barge Arrival Rates and Random Number Intervals

NUMBER OF ARRIVALS	PROBABILITY	CUMULATIVE PROBABILITY	RANDOM NUMBER INTERVAL
0	0.13	0.13	01 to 13
1	0.17	0.30	14 to 30
2	0.15	0.45	31 to 45
3	0.25	0.70	46 to 70
4	0.20	0.90	71 to 90
5	0.10	1.00	91 to 00

Table 14.9

Port of New Orleans

Unloading Rates and Random Number Intervals

DAILY UNLOADING RATE	PROBABILITY	CUMULATIVE PROBABILITY	RANDOM NUMBER INTERVAL
1	0.05	0.05	01 to 05
2	0.15	0.20	06 to 20
3	0.50	0.70	21 to 70
4	0.20	0.90	71 to 90
5	0.10	1.00	91 to 00
	1.00		

Table 14.10

Queuing Simulation of Port of New Orleans Barge Unloadings

(1) DAY	(2) NUMBER DELAYED FROM PREVIOUS DAY	(3) RANDOM NUMBER	(4) NUMBER OF NIGHTLY ARRIVALS	(5) TOTAL TO BE UNLOADED	(6) RANDOM NUMBER	(7) NUMBER UNLOADED
1	—	52	3	3	37	3
2	0	06	0	0	63	0
3	0	50	3	3	28	3
4	0	88	4	4	02	1
5	3	53	3	6	74	4
6	2	30	1	3	35	3
7	0	10	0	0	24	0
8	0	47	3	3	03	1
9	2	99	5	7	29	3
10	4	37	2	6	60	3
11	3	66	3	6	74	4
12	2	91	5	7	85	4
13	3	35	2	5	90	4
14	1	32	2	3	73	3
15	0	00	5	5	59	3
	20		41			39
	Total delays		Total arrivals			Total unloadings

Table 14.11

Port of New Orleans

Three important pieces of information:

$$\text{Average number of barges delayed to the next day} = \frac{20 \text{ delays}}{15 \text{ days}}$$

$$= 1.33 \text{ barges delayed per day}$$

$$\text{Average number of nightly arrivals} = \frac{41 \text{ arrivals}}{15 \text{ days}} = 2.73 \text{ arrivals}$$

$$\text{Average number of barges unloaded each day} = \frac{39 \text{ unloadings}}{15 \text{ days}} = 2.60 \text{ unloadings}$$

Excel Model for the Port of New Orleans Queuing Simulation

Port of New Orleans Barge Unloadings

Day	Previously delayed	Random number	Arrivals	Total to be unoaded	Random Number	Possibly unloaded	Unloaded
1	0	0.4122	2	2	0.44942	3	2
2	0	0.1801	1	1	0.89542	4	1
3	0	0.7886	4	4	0.83696	4	4
4	0	0.6198	3	3	0.65745	3	3
5	0	0.7517	4	4	0.65671	3	3
6	1	0.3591	2	3	0.01266	1	1
7	2	0.3651	2	4	0.60660	3	3
8	1	0.2075	1	2	0.77510	4	2
9	0	0.1506	1	1	0.96885	5	1
10	0	0.5876	3	3	0.19753	2	2

Barge Arrivals

Demand	Probability	Lower	Cumulative	Demand
0	0.13	0.00	0.13	0
1	0.17	0.13	0.30	1
2	0.15	0.30	0.45	2
3	0.25	0.45	0.70	3
4	0.20	0.70	0.90	4
5	0.10	0.90	1.00	5

Unloading rates

Number	Probability	Lower	Cumulative	Unloading
1	0.05	0.00	0.05	1
2	0.15	0.05	0.20	2
3	0.50	0.20	0.70	3
4	0.20	0.70	0.90	4
5	0.10	0.90	1.00	5

Program 14.5

Excel Model for the Port of New Orleans Queuing Simulation

	C	D
17	=0	=B17
18	=C17+B17	=D17+B18

	I	J
17	=0	=H17
18	=I17+H17	=J17+H18

	B	C	D	E	F	G	H
4	=RAND()	=VLOOKUP(B4,$C$17:$E$22,3,TRUE)	=C4	=D4	=RAND()	=VLOOKUP(F4,$I$17:$K$19,3,TRUE)	=E4+G4
5	=RAND()	=VLOOKUP(B5,$C$17:$E$22,3,TRUE)	=D4+C5	=MAX(D5,H4)	=RAND()	=VLOOKUP(F5,$I$17:$K$19,3,TRUE)	=E5+G5

Program 14.5

Simulation Model for a Maintenance Policy

- **Simulation can be used to analyze different maintenance policies before actually implementing them.**
- **Many options regarding staffing levels, parts replacement schedules, downtime, and labor costs can be compared.**
- **This can include completely shutting down factories for maintenance.**

Three Hills Power Company

- Three Hills provides power to a large city through a series of almost 200 electric generators.
- The company is concerned about generator failures because a breakdown costs about $75 per generator per hour.
- Their four repair people earn $30 per hour and work rotating 8 hour shifts.
- Management wants to evaluate the:
  1. Service maintenance cost.
  2. Simulated machine breakdown cost.
  3. Total cost.

Three Hills Power Company

- There are two important maintenance system components:
  - Time between successive generator breakdowns which varies from 30 minutes to three hours.
  - The time it takes to repair the generators which ranges from one to three hours in one hour blocks
- A next event simulation is constructed to study this problem.

Three Hills Flow Diagram

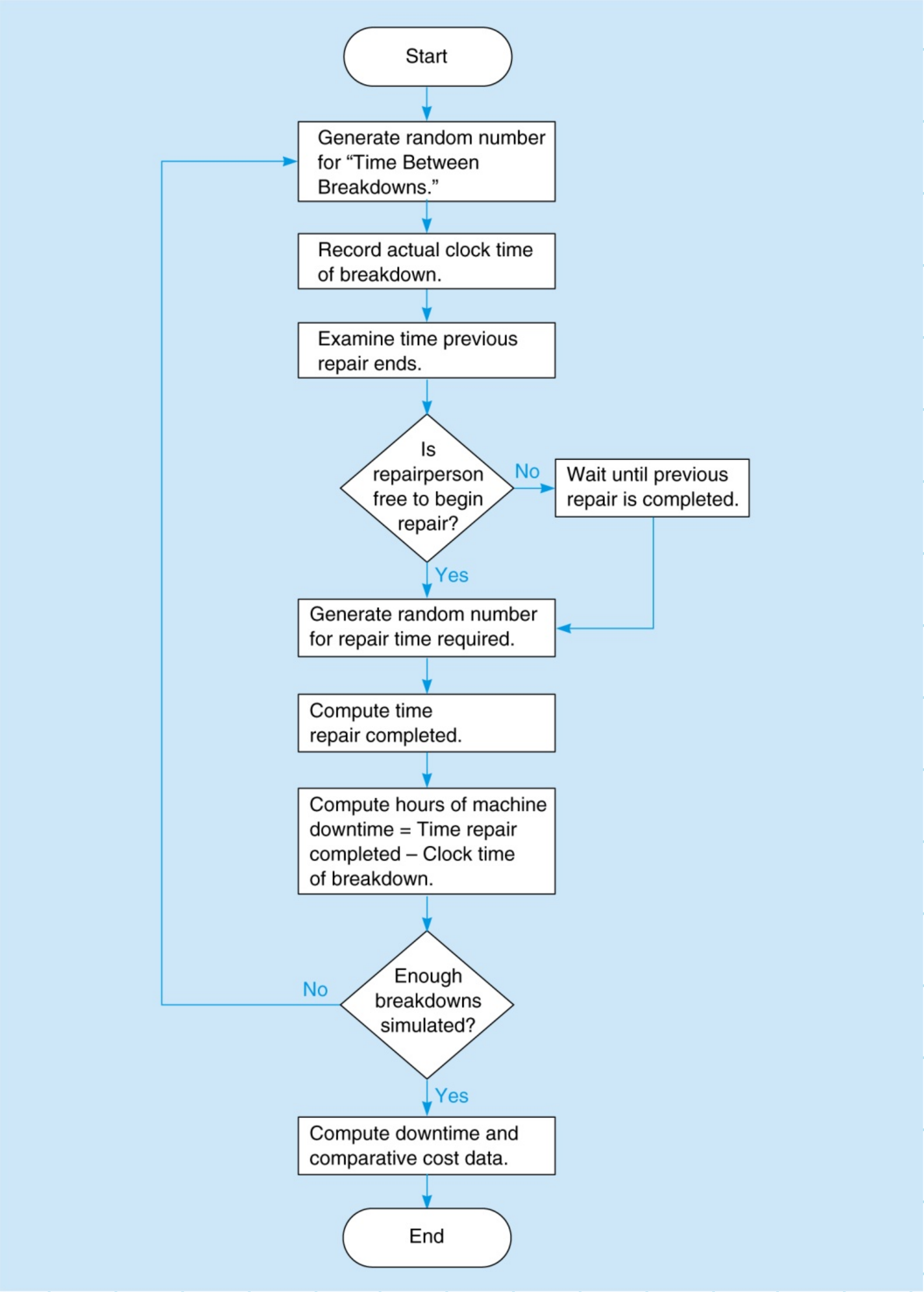

Figure 14.4

Three Hills Power Company

Time between generator breakdowns at Three Hills Power

TIME BETWEEN RECORDED MACHINE FAILURES (HRS)	NUMBER OF TIMES OBSERVED	PROBABILITY	CUMULATIVE PROBABILITY	RANDOM NUMBER INTERVAL
0.5	5	0.05	0.05	01 to 05
1.0	6	0.06	0.11	06 to 11
1.5	16	0.16	0.27	12 to 27
2.0	33	0.33	0.60	28 to 60
2.5	21	0.21	0.81	61 to 81
3.0	19	0.19	1.00	82 to 00
Total	100	1.00		

Table 14.12

Three Hills Power Company

Generator repair times required

REPAIR TIME REQUIRED (HRS)	NUMBER OF TIMES OBSERVED	PROBABILITY	CUMULATIVE PROBABILITY	RANDOM NUMBER INTERVAL
1	28	0.28	0.28	01 to 28
2	52	0.52	0.80	29 to 80
3	20	0.20	1.00	81 to 00
Total	100	1.00		

Table 14.13

Three Hills Power Company

Simulation of generator breakdowns and repairs

(1) BREAKDOWN NUMBER	(2) RANDOM NUMBER FOR BREAKDOWNS	(3) TIME BETWEEN BREAKDOWNS	(4) TIME OF BREAKDOWN	(5) TIME REPAIR-PERSON IS FREE TO BEGIN THIS REPAIR	(6) RANDOM NUMBER FOR REPAIR TIME	(7) REPAIR TIME REQUIRED	(8) TIME REPAIR ENDS	(9) NUMBER OF HOURS MACHINE DOWN
1	57	2	02:00	02:00	07	1	03:00	1
2	17	1.5	03:30	03:30	60	2	05:30	2
3	36	2	05:30	05:30	77	2	07:30	2
4	72	2.5	08:00	08:00	49	2	10:00	2
5	85	3	11:00	11:00	76	2	13:00	2
6	31	2	13:00	13:00	95	3	16:00	3
7	44	2	15:00	16:00	51	2	18:00	3
8	30	2	17:00	18:00	16	1	19:00	2
9	26	1.5	18:30	19:00	14	1	20:00	1.5
10	09	1	19:30	20:00	85	3	23:00	3.5
11	49	2	21:30	23:00	59	2	01:00	3.5
12	13	1.5	23:00	01:00	85	3	04:00	5
13	33	2	01:00	04:00	40	2	06:00	5
14	89	3	04:00	06:00	42	2	08:00	4
15	13	1.5	05:30	08:00	52	2	10:00	4.5
							Total	44

Table 14.14

Cost Analysis of the Simulation

- The simulation of 15 generator breakdowns covers 34 hours of operation.
- The analysis of this simulation is:

Service maintenance cost	= 34 hours of worker service time x \$30 per hour
	= \$1,020
Simulated machine breakdown cost	= 44 total hours of breakdown x \$75 lost per hour of downtime
	= \$3,300
Total simulated maintenance cost of the current system	= Service cost + Breakdown cost
	= \$1,020 + \$3,300
	= \$4,320

Cost Analysis of the Simulation

- The cost of $4,320 should be compared with other alternative plans to see if this is a "good" value.
- The company might explore options like adding another repairperson.
- Strategies such as *preventive maintenance* might also be simulated for comparison.

Excel Spreadsheet Model for Three Hills Power Company Maintenance Problem

Three Hills Power Company

Breakdown number	Random number	Time between breakdowns	Time of breakdowns	Time repairperson is free	Random Number	Repair time	Repair ends
1	0.4250	2	2	2	0.5263	2	4
2	0.0279	0.5	2.5	4	0.0466	1	5
3	0.9666	3	5.5	5.5	0.2342	1	6.5
4	0.9527	3	8.5	8.5	0.1482	1	9.5
5	0.2316	1.5	10	10	0.6001	2	12
6	0.3460	2	12	12	0.4528	2	14
7	0.3648	2	14	14	0.1964	1	15
8	0.8095	2.5	16.5	16.5	0.2554	1	17.5
9	0.7553	2.5	19	19	0.6737	2	21
10	0.4003	2	21	21	0.4339	2	23

Demand Table

Time between breakdowns	Probability	Lower	Cumulative	Demand
0.5	0.05	0	0.05	0.5
1.0	0.06	0.05	0.11	1
1.5	0.16	0.11	0.27	1.5
2.0	0.33	0.27	0.6	2
2.5	0.21	0.6	0.81	2.5
3.0	0.19	0.81	1	3

Repair times

Time	Probability	Lower	Cumulative	Lead time
1	0.28	0.00	0.28	1
2	0.52	0.28	0.80	2
3	0.20	0.80	1.00	3

Program 14.6

Excel Spreadsheet Model for Three Hills Power Company Maintenance Problem

	C	D	E
17	=0	=B17	=A17
18	=C17+B17	=D17+B18	=A18

	I	J	K
17	=0	=H17	=G17
18	=I17+H17	=J17+H18	=G18
19	=I18+H18	=J18+H19	=G19

	B	C	D	E	F	G	H
4	=RAND()	=VLOOKUP(B4,$C$17:$E$22,3,TRUE)	=C4	=D4	=RAND()	=VLOOKUP(F4,$I$17:$K$19,3,TRUE)	=E4+G4
5	=RAND()	=VLOOKUP(B5,$C$17:$E$22,3,TRUE)	=D4+C5	=MAX(D5,H4)	=RAND()	=VLOOKUP(F5,$I$17:$K$19,3,TRUE)	=E5+G5

Program 14.6

Other Simulation Models

- Simulation models are often broken into three categories:
  - The Monte Carlo method.
  - Operational gaming.
  - Systems simulation.
- Though theoretically different, computerized simulation has tended to blur the differences.

Operational Gaming

- *Operational gaming* refers to simulation involving two or more competing players.
- The best examples of this are military games and business games.
- These types of simulation allow the testing of skills and decision-making in a competitive environment.

Systems Simulation

- *Systems simulation* is similar in that allows users to test various managerial policies and decisions to evaluate their effect on the operating environment.
- This models the dynamics of *large* systems.
- A *corporate operating system* might model sales, production levels, marketing policies, investments, union contracts, utility rates, financing, and other factors.
- *Economic simulations*, often called econometric models, are used by governments, bankers, and large organizations to predict inflation rates, domestic and foreign money supplies, and unemployment levels.

Systems Simulation

Inputs and Outputs of a Typical Economic System Simulation

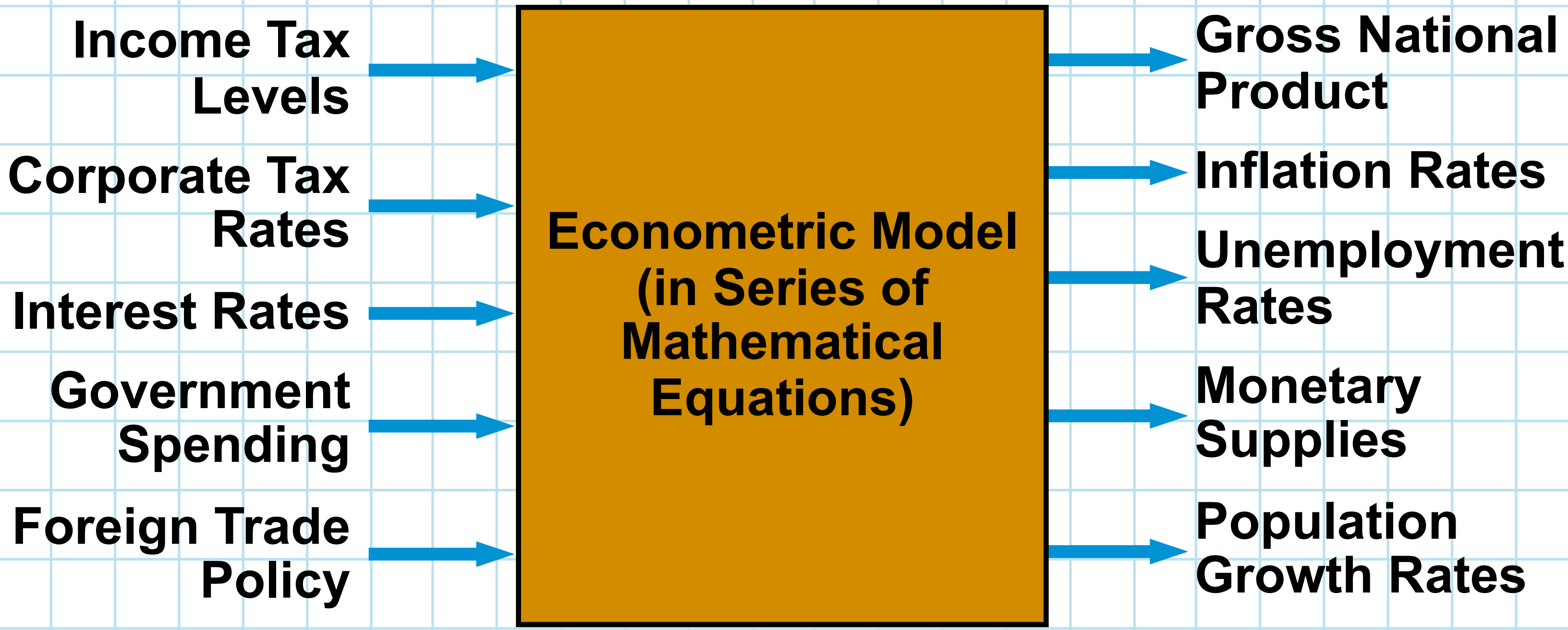

Figure 14.5

Verification and Validation

- It is important that a simulation model be checked to see that it is working properly and providing good representation of the real world situation.
- The *verification* process involves determining that the computer model is internally consistent and following the logic of the conceptual model.
- Verification answers the question “Did we build the model right?”
- *Validation* is the process of comparing a simulation model to the real system it represents to make sure it is accurate.
- Validation answers the question “Did we build the right model?”

Role of Computers in Simulation

- Computers are critical in simulating complex tasks.
- General-purpose programming languages can be used for simulation, but a variety of simulation software tools have been developed to make the process easier:
  - Arena
  - ProModel
  - SIMUL8
  - ExtendSim
  - Proof 5
- Excel and add-ins can also be used for simulation problems

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