UNIT 15 SIMULATION

Objectives

After studying this unit, you will be able to :

- discuss the need for simulation -in management problems where it will not be possible to use precise mathematical techniques
- explain that simulation may be the only method in situations where it will be extremely difficult to observe actual environment
- describe the process of simulation based on a sound conceptual framework
- apply simulation techniques in solving queuing and inventory control problems.

Structure

15.1 INTRODUCTION

Simulation is a quantitative procedure which describes a process by developing a model of that process and then conducting a series of organized experiments to predict the behaviour of the process over time. Observing the experiments is very much like observing the process in operation. To find out how the real process would react to certain changes, we can produce these changes in our model and simulate the reaction of the real process to them.

For instance, in designing an airplane, the designer can solve various equations describing the aerodynamics of the plane. Or, if these equations are very difficult and complex to solve, scale model can be built and its behaviour observed in a wind tunnel. In simulation, we build mathematical models which we cannot solve and run them on sample data to simulate the behaviour" of the-system. Thus, simulation involves performing experiments on the model of a system.

15.2 REASONS FOR USING SIMULATION

In the case of number of problems, we have been able to find through straight forward techniques, mathematical solutions to the situation. The economic order quantity, the simplex solution to a linear programming problem, and a branch-and-bound solution to an integer programming problem are some of the typical examples we can cite. However, in each of those cases the problem was simplified by certain assumptions so that the appropriate mathematical techniques could be employed. It is not difficult to think of managerial situations so complex that mathematical solution is impossible given the current state of the art in mathematics. In these cases, simulation offers a good alternative,

If we insist that all managerial problems have to be solved mathematically, then we may find ourselves simplifying the situation so that it can he solved; sacrificing realism to solve the problem can get us in real trouble. Whereas the assumption of normality-in dealing with a distribution of inventory demand may he reasonable, the assumption of linearity in a specific linear programming environment may he totally unrealistic.

While in some cases the solutions which result from simplifying assumptions are suitable for the decision-maker, in other cases, they simply are not. Simulation is an appropriate substitute for mathematical evaluation of a model in many situations. Although it also involves assumptions, they are manageable. The use of simulation enables us to provide insight into certain management problems where mathematical evaluation of a model is not possible.

Among the reasons why management scientists would consider using simulation to solve management problems are the following:

1. Simulation may be the only method available because it is difficult to observe the actual environment. (In space flight or the charting of satellite trajectories, it is widely used.)
2. It is not possible to develop a mathematical solution.
3. Actual observation of a system may be too expensive. (The operation of a large computer centre under a number of different operating alternatives might be too expensive to be feasible.)
4. There may not be sufficient time to allow the system to operate extensively. (If we were studying long-run trends in world population, for instance, we simply could not wait the required number of years to see results.)
5. Actual operation and observation of a system may be too disruptive. (If you are comparing two ways of providing food service in a hospital, the confusion that would result from operating two different systems for long enough to get valid observations might be too great.)

15.3 LIMITATIONS OF' SIMULATION

Use of simulation in place of other techniques, like everything else, involves a trade-off, and we should be mindful of the disadvantages involved in the simulation approach. These include the facts that

1. Simulation is not precise. It is not optimization and does not yield an answer but merely provides a set of the system's responses to different operating conditions. In many cases, this lack of precision is difficult to measure.
2. A good simulation model may-be very expensive. Often it takes years to develop a usable corporate planning model.
3. Not all situations can be evaluated using simulation; only situations involving uncertainty are candidates, and without a random component, all simulated experiments would produce the same answer.
4. Simulation generates a way of evaluating solutions but does not generate solutions themselves. Managers must still generate the solutions they want to test.

Activity 1

Explain briefly what do you understand by simulation.

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Activity 2

Describe one practical situation from your experience, where simulation is the only way out.

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Activity 3

Succinctly bring out the limitations of simulation.

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15.4 STEPS IN THE SIMULATION JQROCEWS

All effective simulations require a great deal of planning and organization. Although simulations vary in complexity from situation to situation, in general you will have to go through these steps:

1. Define the problem or system you intended to simulate.
2. Formulate the model you intend to use.
3. Test the model; compare its behaviour with the behaviour of the actual problem.
4. Identify and collect the data needed to test the model.
5. Run the simulation.
6. Analyze the results of the simulation and, if desired, change the solution you are evaluating.
7. Rerun the simulation to test the new solution.
8. Validate the simulation; this involves increasing the chances of the inferences you may draw about the real situation from running the simulation to become valid.

15.5 SOME PRACTICAL APPLICATIONS OF SIMULATION

The problems to which simulation has been applied successfully are far too numerous to list here. It is useful at this point, however, to give you some idea of the variety of managerial situations in which this technique has been able to aid the decision process. Each of the situations which we will now describe represents a typical problem area in which simulation can be successfully applied.

1. The Home Heating Oil Simulation

The president of a petroleum products distribution firm attended a management seminar in quantitative techniques. He became interested in the possibility of using simulation to test the relative effectiveness of several alternative methods of dispatching his eight home-heating-oil delivery trucks.. He served over three thousand residential customers in his marketing area; these residences had oil tanks ranging in capacity from 55 to 1900 gallons. The trucks ranged in sizes from 1000 to 5600 gallons, and his bulk plant (the terminal where he stored his heating oil) had a tank capacity of 150,000 gallons. The firm had one transport truck (used to haul heating oil from the port) but could lease others if necessary.

The president was well aware that periods of low temperature put a strain on his whole delivery system. His eight trucks could not keep up with residential usage; - there was confusion and inefficiency around the bulk plant; and additional transport trucks had to be leased at unfavourable short-term rates. There, seemed to be three alternatives. One was to increase truck and bulk plant equipment and personnel so that capacity would be equal to the maximum cold-weather demand. The president knew this would be quite expensive and had already calculated the additional investment in equipment alone to be near Rs 140,0000.A second alternative was to deliver heating oil to residences more frequently-that is, to keep customers" tanks mere nearly full so that demand during low-temperature, periods would be decreased. A third alternative was to replace all small 55 gallon tanks (at company expense) to significantly increase the efficiency of the delivery trucks, (Fewer stops per day and more gallons delivered per stop would significantly increase the capacity of the delivery fleet.) He also knew that combinations of alternatives two and three were another possibility.

It seems clear to us that solving this, problem mathematically is impossible (or at least beyond our mathematical abilities) therefore we should develop a simulation model for this problem which should include these elements:

1. The bulk plant

2. The customers
3. Varying residential tank sites
4. Local delivery trucks
5. Transport trucks (owned and leased)
6. Employees
7. Heating-oil consumption based on temperature

We should simulate several alternative, delivery systems over a wide range of demand conditions. The results then would enable us to adopt the best course of action amongst the alternatives.

2. The Carpet-cutting Application

The production vice-president bf a regional carpet manufacturing company attended an executive development programme. One day he asked the faculty members if they had ever done any work with "carpet-cutting". Soon after that they were in the mill observing the operation. Carpet was manufactured in 175-foot rolls, all 12 feet wide. This company stocked over two hundred different styles and colours of carpet; usually there were multiple rolls or pieces of rolls of each styles and colour on hand in the warehouse. Incoming orders for carpet called for lengths ranging from about 8 feet all the way up to an entire roll (175 feet). Incoming orders were delivered to the cutting room, where cutting machine operators attempted to match existing rolls with incoming orders in such a way that the unusable piece left at the end of the roll (the remnant) would be as small as possible. You can get an idea of the significance of unusable remnants if you consider that the average price per lineal foot of the carpet was about Rs. 200 and that any remnant under 3 feet was thrown away; remnants between 3 feet and 6 feet were sold for about a third of the regular price. The cost of unusable remnants was amounting to almost Rs. 250,0000 a year.

The cutting machine operators pointed out that there were hundreds of ways you could fill-an order for a piece- of carpet: (1) cut it from the longest roll of the required style and colour; (2) cut it from the roll which would leave the shortest piece left over; (3) find two orders which would use up an entire roll or piece of a roll; and so on. To complicate matters, one of the faculty members asked to find out whether it would be economical to collect carpet orders for more than 1 day (2 days, 3 days, etc.) before cutting. them, his idea being that the more orders you had, the better match of orders and rolls you could make. Of course, you would have to be willing to risk the wrath of those customers who would be kept waiting longer.

A careful study of the operation at some length may suggest a simulation model of the system with the following components:

1. The production' operation (the manner in which the carpets were delivered to the cutting operation, frequency, etc.)
2. The distribution of incoming orders (size, colour, style)
3. The inventory (rolls in sizes, colours, styles)
4. The cutting process (time, employees)
5. The prioes of sold carpets and remnants

We should simulate the cutting operations under a wide number of different possible "cutting rules"; each simulation run must be say for 1000 days, a period which seems long enough to represent a typical order and production pattern. Then we can choose that cutting rule which results in the least cost and maximum savings per annum.

3. The Public School Planning Application

A faculty member of a management institute had been engaged to conduct a beginning operations research course for the senior administrators of a large metropolitan school system in the country. One day the superintendent (a participant in the course) indicated how difficult it was to deal with his school board on certain long range planning issues and asked whether simulation had anything to offer in such a situation. It seemed that the board was always asking questions like "what would happen if enrolments began to grow at 9% a year instead of 6%v a year?" Or, "How many years do you think it will be before the population shifts enough to warrant making this elementary school into an adult education centre?" There was a whole series of these mathematically impossible "how," "when," and "what if" questions.

We can suggest a large simulation model of the public school system to tackle this problem. With it, the superintendent will be able to do a better job of long range planning in his very complex environment. The model has to accommodate variables like these:

1. Enrolments (by grade, kindergarten through grade 12)
2. Teacher-pupil ratios
3. Classroom capacities
4. Salaries
5. District population
6. Number of schools (including capacities)
7. Number of teachers by subject, function, or grade
8. Construction cost
9. Transportation equipment
10. Warehousing and repair facilities
11. Administrative personnel by grade and function
12. Service personnel (maintenance, custodial, etc.)

15.6 TWO TYPICAL EXAMPLES OF HAND-COMPUTED SIMULATION

In this section, we shall introduce you to simulation by using an example which can be simulated manually, that is, done without using a computer.

Example 1 concerns the scheduling of patients in a hospital operating room.

Table 15.1: Wednesday Operating Schedule, Room No. 3

Time	Activity	Expected time
8:00 AM	Appendectomy	40 min
8:40	Clean-up	20 min
9:00	Laminectomy	90 min
10:30	Clean-up	20 min
10:50	Kidney removal	120 rain
12:50 PM	Clean-up	20 min
1:10	Hysterectomy	60 min
2:10	Clean-up	20 min
2:30	Colostomy	100 min
4:10	Clean-up	20 min
4:30	Lesion removal	10 min
4:40	Clean-up	20 min

Hospital Simulation

Wednesday's schedule for operating room number 3 at a famous hospital is as shown in Table 15.1. From looking at this schedule, the head operating room nurse concludes that it may not he possible to finish with the operating and clean-up - schedule by 5 P.M., the time at which this operating room must be available for emergency night service.

The hospital management analyst, suggests that simulation might indicate whether the schedule for Wednesday is workable and, if not, what change could be made in it. The analyst reviews the operating room records for the past few months and finds that patients do not always arrive at the operating room at the scheduled time. They often have to wait for pre-op medication to be administered, sometimes operating room transportation personnel are late, and from time to time physicians forget to order the patient moved from the floor to the operating room. Investigation of the operating room log indicates that arrival expectations are shown in Table 15.2: The management analyst finds that operating time also vary according to surgical difficulties encountered, differences in, surgical skills, and the effectiveness of the surgical team in general. An analysis of operations scheduled over the past few months produces the results shown in Table 15.3, which gives a good indication of this variation. He also recognizes that any variation in the expected clean-up time Simulation will affect the schedule and checks the records once again. Here he finds that, about half the time, the clean-up crew finishes in 10 minutes. The rest of the time, it take's them 30 minutes. With the data collected, he is ready to begin the simulation.

Table 15-2 : Arrival Expectations

Patient arrives on time	**0.50 probability**
Patient arrives 5 minutes early	0.10 probability
Patient arrives i0 minutes early	0.05 probability
Patient arrives 5 minutes late	0.20 probability
Patient arrives 10 minutes late	0.15probability

Table 15.3: Operation Time Expectations

Operation is completed in the expected time	0.45 probability
Operation is completed in 90% of the expected time	OAS probability
Operation is completed in 80% of the expected time	0.05 probability
Operation is completed in 110% . of the expected time	0.25 probability
Operation is completed in 120% of the expected time	0.10 probability

Generating the Variables in the System (Process Generators)

The analyst needs a way to generate arrival times, operating times, and clean-up times. The methods he uses to dot his are called process generators. He decides to use a random number table. (see Appendix). A random number table is the output we would expect to get from sampling a uniformly distributed random variable where all of its values (digits from 0 through 9 in this case) are equally likely.

Generating Arrival Times

He decides to use the first two digits of each 10-digit number in Appendix as his process generator for arrival times. Since there are 100 possible two-digit numbers from 00 through 99, he relates these two digit numbers to arrival variation like this:

Random numbers		**Arrivals**
00 through 49	On time	(.50 probability)
50 through 59	5 minutes early	(.10 probability)
60 through 64	10 minutes early	(.05 probability)
65 through 84	5 minutes late	(.20 probability)
85 through 99	10 minutes late	(.15 probability)

Generating Operating Times

The analyst now decides to use the last two digits of each 10-digit number in Appendix as his process generator for operating times. He relates these two digits numbers to operating times in this way:

Random numbers				Operating Times
00-44		Oh time completion		(.45 probability)
45-59		Completion in 00% of expected time		(.15 probability)
60-64		Completion in 80% of expected time		(.05 probability)
65-89		Completion in 110% of expected time		(.25 probability)
90-94		Completion in 120% of expected time		(.10 probability)

Generating Clean-up Times

Since there are only two values the random variable takes on here, he decides to use the fourth digit of each 10-digit number in Appendix as his process generator. If it's an odd number, he will let that represent a 10-minute clean-up; an even number- would represent 30-minute clean-up.

The Simulation

The analyst now proceeds with the simulation. First, he generates an arrival-tirne deviation for the first patient: then he generates an operating time deviation for the first operation: finally, he generates a clean-up time for that operation. He continues with this process until the last operation has been performed and the operating room cleaned-up for the final time that day. The results of his simulation are shown in Table 15.4.

From the analyst's simulation, it appears that the scheduled operations can be completed and the mom vacated by 5 PM. In fact, his simulation indicates that the day's schedule ends at 4:45 PM, a few minutes early.

Assumptions

The analyst simulated the day's operation only once, and it may be dangerous for us to draw general conclusions from such a short simulation. If he had repeated the day's simulation several times using different random numbers, then we could feel better about generalizing from his results. He also assumed that the variables in this simulation (arrival deviation, operating time deviation, and clean-up deviation) were independent of each other. If this is not the case, his simulation is not a valid one. Finally, he used discrete distributions of the three variables. In actual practice, were computation time not such a problem, continuously distributed random variables would be appropriate.

Table 15.4 : Results of Simulation of Activity in Operating Room No. 3

Random number	First two digits	Last two digits	Fourth digit	Meaning	Outcome
15	X			On-time arrival of appendectomy patient	Appendectomy began at 8 A.M.
96		X		Appendectomy completed in 120% of expected time (48 min)	Appendectomy completed at 8:48 A.M.
1			X	Clean-up done in 10 min	Room ready for second operation at 8:58 A.M.
9	X			On-time arrival of laminectomy patient (9 A.M.)	Laminectomy began at 9 A.M.
82		X		Laminectomy completed in 110% of expected time (99 min)	Laminectomy completed at 10:39 A.M.
8			X	Clean-up done in 30 min	Room ready for third operation at 11.09 A.M.
41	X			On-time arrival of kidney patient (10:50 A.M.)	Kidney removal began at 11:09 A.M.
56		X		Kidney removal completed in 90% of expected time (108 min)	Kidney removal completed at 12:57 P.M.
2			X	Clean-up done in 30 min	Room ready for fourth operation at 1:27 P.M.
75	X			Hysterectomy patient arrives 5 min late (1:15 P.M.)	Hysterectomy began at 1:27 P.M.
68		X		Hysterectomy completed in 110% of expected time (66 min)	Hysterectomy completed at 2:33 P.M.

Random number	First two digits	Last two digits	Fourth digit	Meaning	Outcome
7			X	Clean-up done in 10 min	Room ready for fifth operation at 2:43 P.M.
00	X			On-time arrival of colostomy patient (2:30 P.M.)	Colostomy began at 2:43 P.M.
58		X		Colostomy completed in 90% of expected time (90 min)	Colostomy completed at 4:13 P.M.
9			X	Clean-up done in 10 min	Room ready sixth operation at 4:23 P.M.
72	X			Lesion patient arrivals 5 min late (4:35 P.M.)	Lesion operation begun at 4:35 P.M.
40		X		On-time completion of lesion operation (10 min)	Lesion operation completed at 4:45 P.M.
5			X	Clean-up done in 10 min	Operating room schedule for Wednesday completed at 4:55 P.M.

Activity 4

Repeat above simulation exercise with different set of random numbers.

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Simulation and Inventory Control

In order to provide -adequate service to customers i , the .reorder point must be chosen with consideration for the demand during lead time. If both the lead time and demand of inventory per unit of time are random variables, then simulation technique earl be used to investigate the effect of different inventory policies (e.g. different combinations of order quantity and reorder point) on a probabilistic inventory system basis.

Example 2 : The wholesaler dealing in stationery items wants to determine the order size for desk calendars. The demand and lead time are probabilistic and their distributions are given below :,

demand/week (thousand)	probability	lead time (weeks)	probability
0	0.2	2	0.3
1	0.4	3	0.4
2	0.3	4	0.3
3	0.1		

The cost of placing an order is Rs. 50 per order and the holding cost for 1000 calendars is Rs. 2 per week. The shortage cost is Rs. 10 per thousand. The inventory manager is considering the policy: whenever the inventory level is equal to or below 2000, an order is pl4ced equal to the difference between the current inventory balance and specified maximum replenishment level of 4000.

Simulate the policy for 20 weeks period assuming that (a) the beginning inventory is 3000 units; N no back orders are permitted; (c) each order is placed at the beginning of the week following the drop in inventory level to (or below) the reorder point; (d) the replenishment orders are received at the beginning of the week.

Solution : Using the weekly demand and lead time distributions, assign an appropriate set of random numbers to represent value or range of values of variables shown in tables 15.5 anti 15.6 respectively.

Table 15.5

Demand/week (thousand)	Probability	Cumulative Probability	Random Numbers
0	0.2	0.2	00-19
1	0.4	0.6	20-59
2	0.3	0.9	60-89
3	0.1	1.0	90-99

Table 15.6

Lead time (weeks)	Probability	Cumulative Probability	Random Numbers
2	0.3	0.3	00-29
3	0.4	0.7	30-69
4	0.3	1.0	70-99

The simulation for a period of ' 20 weeks concerning the inventory system and the related costs with a replenishment level of 4000 units and reorder level of 2000 units, is shown in table 117. At the start of the simulation, the first random number 31 generates a demand of 1000 units, as determined from the cumulative probability values of calendar demand in table 115, leaving 2000 units on hand at the end of the first week. Since it is equal to the reorder level, an order for 4000-2000=2000 units is placed. With a random number 29, the lead time is 2 weeks; refer to the lead time cumulative probability values in table 15.6. With 2000 units to be held, the holding cos'k is Rs, 4 and there is no shortage cost. In the next week, the random number 70 results in a demand of 2000 units, from table 15.5, and 2000 units available in inventory at the beginning of the second week are reduced to zero unit-,:by the end of the week. In the third week, demand is for 1000 units but as the available inventory is zero this results in the shortage cost of its. 10. The 2000 units ordered in the first Week are received in the beginning of the fourth week. The demand in the fourth week is also for 2000 units. and, hence ending inventory is zero. The second shortage thus occurs in the' fifth week and continues till the end of eighth week. The units ordered at the end of fourth week are received only in the beginning of the ninth week. In this way, the simulation is continued for a period of 20 weeks.

The evaluate the performance of the policy simulated; we need to ' know the number of orders placed, the average inventory, and the number of units short. From table 15.7, we note that 5 times orders were placed during the course of simulation.

Table 15.7

REPLENISHMENT LEVEL = 4000 UNITS

Week	Beginning Inventory ('000)	Demand R.N.	Demand Units	Ending Inventory ('000)	Lead Time R.N.	Lead Time Weeks	Quantity Ordered ('000)	Costs (Rs.) Holding	Costs (Rs.) Shortage
0				3	—	—	—	—	—
1	3	31	1	2	29	2	2	4	—
2	2	70	2	0	—	—	—	—	—
3	0	53	1	-1	—	—	—	—	10
4	2*	86	2	0	83	4	4	—	—
5	0	32	1	-1	—	—	—	—	10
6	0	78	2	-2	—	—	—	—	20
7	0	26	1	-1	—	—	—	—	10
8	0	64	2	-2	—	—	—	—	20
9	4*	45	1	3	—	—	—	—	—
10	3	12	0	3	—	—	—	6	—
11	3	99	3	0	58	3	4	6	—
12	0	52	1	-1	—	—	—	—	10
13	0	43	1	-1	—	—	—	—	10
14	0	84	2	-2	—	—	—	—	20
15	4*	38	1	3	—	—	—	6	—
16	3	40	1	2	41	3	2	4	—
17	2	19	0	2	—	—	—	4	—
18	2	87	2	0	—	—	—	—	—
19	0	83	2	-2	—	—	—	—	20
20	2*	73	2	0	13	2	4	—	—

* Includes order quantity just received.

The average inventory can be calculated by adding the weekly ending inventory balances (ignoring negative balances) and dividing by the number of weeks. Thus

$$\text{Average inventory} = \frac{15000}{20} = 750 \text{ units per week}$$

The total average weekly cost can be calculated as follows :

Weekly average cost = Ordering cost + Inventory holding cost + Shortage cost.

$$= \frac{(\text{Rs. } 50)(5)}{20} + \frac{(\text{Rs. } 2)(750)}{1000} + \frac{(\text{Rs. } 10)(13)}{20}$$

$$= \frac{250}{20} + 1.50 + \frac{130.0}{20}$$

$$= \text{Rs. } 12.50 + 1.50 + 6.50$$

$$= \text{Rs. } 20.50$$

In this case the average shortage cost is high as compared to holding cost. This shortage cost can be reduced by increasing the reorder level.

The two decision variable, replenishment level and reorder level, interact -with each other and influence the three. cost elements. Since replenishment level and reorder level depend on each other, experiments conducted with the simulation model should be so designed as to list the various combinations of both variables. In the prose yt problem, the average lead time is -2.8 weeks and the average demand per week is 1400 units. Hence average demand during lead time is 3920 units. On the other hand, maximum lead time is 4 weeks and maximum weekly demand is 3000 units. Thus, maximum demand during lead time is 12000 units. It follows that the best reorder point, irrespective of the replenishment level, should be somewhere in the range of 3920 to 12000 units.

Activity 5

Do the above problem on simulation with another set, of random numbers and compare your result with previous solution.

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15.7 COMPUTER SIMULATION

It is difficult, if not impossible, to perform •simulations without a computer. Consider the hospital simulation in this unit. Imagine what work would be involved if the analyst simulated that one operating room for a month or simulated the entire 12-opemtkg rooms in the hospital for a months time Because hand-computed simulations are so expensive and so tedious, real simulations are done almost exclusively on a computer.

One of the most effective computer simulation languages is GPSS (General Purpose System Simulation) developed by IBM. One can also use computer language like FORTRAN to perform simulation experiments..

Activity 6

Why do you need a computer to do simulation? Explain briefly.

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15.8 SUMMARY

At the outset, a comprehensive overview of simulation has been provided through an introduction. We then moved on to the question of "why do you need simulation?" Here reasons for resorting to the technique of simulation have been given.

Every method has certain strengths and limitations. It is important for any one to understand the merits and shortcomings of a tool before actually using it. The limitations of simulation have also been covered.

After providing the steps of simulation in a sequential manner, some typical applications of simulation have been illustrated which include—Home-Heating oil simulation, Carpet-cutting application, and Public School Planning system.

Then two typical examples have been manually solved using the standard method of simulation from the area of queuing and inventory in a step by step manner. The idea here, is to provide a conceptual framework of solving a simulation model.

We have mentioned in a brief manner, the role of computers in simulation and emphasized the paramount importance of resorting to simulation solution through standard computer package like GPSS of IBM. It is impossible to do a complex simulation exercise without a computer in-practice.

15.9 SEI.F-ASSESSMENT' EXERCISES

1. Distinguish between solutions derived from simulation models and from analytical models.
2. "When it becomes difficult to use an optimization technique for solving a problem, one has to resort to simulation technique." Discuss.
3. Explain clearly the advantages and limitations of simulation.
4. Delineate the steps of performing simulation.
5. Can you solve in all situations, simulation exercise without a computer? Discuss.
6. One hundred unemployed people were found to arrive at a one-person state unemployment office to obtain their unemployment compensation cheque according to the following frequency distribution.

Inter-arrival Time (min)	Frequency	Service Time (min)	Frequency
2	10	2	10
3	20	3	20
4	40	4	40
5	20	5	20
6	10	6	10

The state office is interested in predicting the operating characteristics of this one person state unemployment office during a typical operating day from 10.00 a.m. to 11.00 a.m. Use simulation to determine the average waiting time and total time in the system, and the maximum queue length.

15.10 FURTHER READINGS

Ackoff. R.L. and M.W. Sasieni-*Fundamentals of Operations Research*, New York: John Wiley & Sons, 1968.

Levin R. and. C.A. Kirkpatrick-*Quantitative Approaches to Management*, New York: Mcgraw Hill Book Company, 1975.

M.P. Gupta and J.K. Sharma *Operations Research for Management,* National Publishing House, New Delhi, 1987.

Appendix 1

Random Number Table (2500 Random Digits)

1581922396	2068577984	8262130892	8374856049	4637567488
0928105582	7295088379	9586111652	7055508767	6472382934
4112077556	3440672486	1882412963	0684012006	0933147914
7457477468	5435810788	9670852913	1291265730	4890031305
0099520858	3090908872	2039593181	5973470495	9776135501
7245174840	2275698645	8416549348	4676463101	2229367983
6749420382	4832630032	5670984959	5432114610	2966095680
5503161011	7413686599	1198757693	0414294470	0140121398
7164238934	7666127259	5263097712	5133648980	4011966963
3593969523	0272759769	0385998136	9999089966	7544056832
4192054466	0700014629	5169439659	8408705169	1074373131
9697426117	6488888550	4031652526	8123543276	0927534537
2007950579	9564268448	3457416988	1531027886	7016633739
4584768758	2389278610	3859431781	3643768456	4141314518
3840145867	9120831830	7228367652	1267173884	4020651657
0190453442	4800088084	1165628559	5407921254	3768932478
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