PEARSON NEW INTERNATIONAL EDITION

Discrete-Event System Simulation

Banks Carson II Nelson Nicol

Fifth Edition

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39. Bernie remodels houses and makes room additions. The time it takes to finish a job is normally distributed with a mean of 17 elapsed days and a standard deviation of 3 days. Homeowners sign contracts for jobs at exponentially distributed intervals having a mean of 20 days. Bernie has only one crew. Estimate the mean waiting time (from signing the contract until work begins) for those jobs where a wait occurs. Also estimate the percentage of time the crew is idle. Simulate until 100 jobs have been completed.

40. Parts arrive at a machine in random fashion with exponential interarrival times having a mean of 60 seconds. All parts require 5 seconds to prepare and align for machining. There are three different types of parts, in the proportions shown below. The times to machine each type of part are normally distributed with mean and standard deviation as follows:

Part Type	Percent	Mean (seconds)	σ (seconds)
1	50	48	8
2	30	55	9
3	20	85	12

Find the distribution of total time to complete processing for all types of parts. What proportion of parts take more than 60 seconds for complete processing? How long do parts have to wait, on average? Simulate for one 8-hour day.

41. Shopping times at a department store have been found to have the following distribution:

Shopping Time (minutes)	Number of Shoppers
0–10	90
10–20	120
20–30	270
30–40	145
40–50	88
50–60	28

After shopping, the customers choose one of six checkout counters. Checkout times are normally distributed with a mean of 5.1 minutes and a standard deviation of 0.7 minutes. Interarrival times are exponentially distributed with a mean of 1 minute. Gather statistics for each checkout counter (including the time waiting for checkout). Tabulate the distribution of time to complete shopping and the distribution of time to complete shopping and checkout procedures. What proportion of customers spend more than 45 minutes in the store? Simulate for one 16-hour day.

42. The interarrival time for parts needing processing is given as follows:

Interarrival Time (seconds)	Proportion
10–20	0.20
20–30	0.30
30–40	0.50

There are three types of parts: A, B, and C. The proportion of each part, and the mean and standard deviation of the normally distributed processing times are as follows:

Part Type	Proportion	Mean	Standard Deviation
A	0.5	30 seconds	3 seconds
B	0.3	40 seconds	4 seconds
C	0.2	50 seconds	7 seconds

Each machine processes any type of part, one part at a time. Use simulation to compare one machine with two machines working in parallel, and two machines with three machines working in parallel. What criteria would be appropriate for such a comparison?

43. Orders are received for one of four types of parts. The interarrival time between orders is exponentially distributed with a mean of 10 minutes. The table that follows shows the proportion of the parts by type and the time needed to fill each type of order by the single clerk.

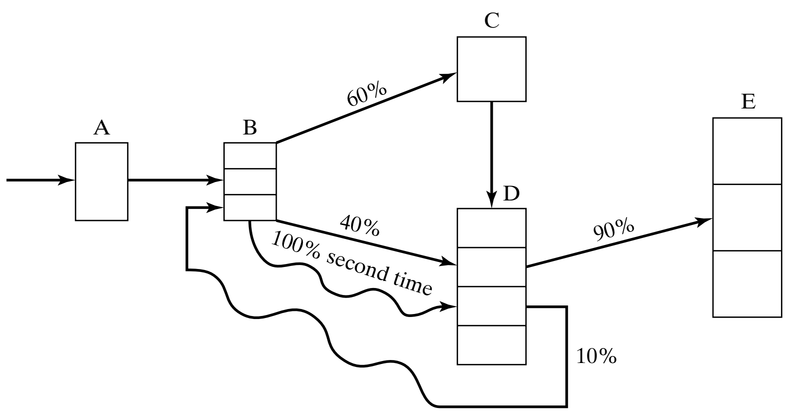
Part Type	Percentage	Service Time (minutes)
A	40	N(6.1, 1.3)
B	30	N(9.1, 2.9)
C	20	N(11.8, 4.1)
D	10	N(15.1, 4.5)

Orders of types A and B are picked up immediately after they are filled, but orders of types C and D must wait 10 ± 5 minutes to be picked up. Tabulate the distribution of time to complete delivery for all orders combined. What proportion take less than 15 minutes? What proportion take less than 25 minutes? Simulate for an 8-hour initialization period, followed by a 40-hour run. Do not use any data collected in the 8-hour initialization period.

44. Three independent widget-producing machines all require the same type of vital part, which needs frequent maintenance. To increase production it is decided to keep two spare parts on

hand (for a total of $2 + 3 = 5$ parts). After 2 hours of use, the part is removed from the machine and taken to a single technician, who can do the required maintenance in 30 ± 20 minutes. After maintenance, the part is placed in the pool of spare parts, to be put into the first machine that requires it. The technician has other duties, namely, repairing other items which have a higher priority and which arrive every 60 ± 20 minutes requiring 15 ± 15 minutes to repair. Also, the technician takes a 15-minute break in each 2-hour time period. That is, the technician works 1 hour 45 minutes, takes off 15 minutes, works 1 hour 45 minutes, takes off 15 minutes, and so on. (a) What are the model's initial conditions—that is, where are the parts at time 0 and what is their condition? Are these conditions typical of "steady state"? (b) Make each replication of this experiment consist of an 8-hour initialization phase followed by a 40-hour data-collection phase. Make four statistically independent replications of the experiment all in one computer run (i.e., make four runs with each using a different set of random numbers). (c) Estimate the mean number of busy machines and the proportion of time the technician is busy. (d) Parts are estimated to cost the company \$50 per part per 8-hour day (regardless of how much they are in use). The cost of the technician is \$20 per hour. A working machine produces widgets worth \$100 for each hour of production. Develop an expression to represent total cost per hour which can be attributed to widget production (i.e., not all of the technician's time is due to widget production). Evaluate this expression, given the results of the simulation.

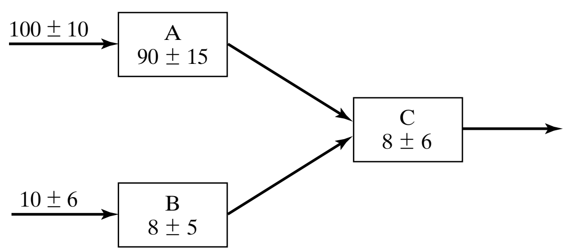
45. The Wee Willy Widget Shop overhauls and repairs all types of widgets. The shop consists of five work stations, and the flow of jobs through the shop is as depicted here:



Regular jobs arrive at station A at the rate of one every 15 ± 13 minutes. Rush jobs arrive every 4 ± 3 hours and are given a higher priority, except at station C, where they are put on a conveyor and sent through a cleaning and degreasing operation along with all other jobs. For jobs the first time through a station, processing and repair times are as follows:

Station	Number of Machines or Workers	Processing and/or Repair Times (minutes)	Description
A	1	12 ± 2	Receiving clerk
B	3	40 ± 20	Disassembly and parts replacement
C	1	20	Degreaser
D	4	50 ± 40	Reassembly and adjustments
E	3	40 ± 5	Packing and shipping

The times listed above hold for all jobs that follow one of the two sequences A $\longrightarrow$ B $\longrightarrow$ C $\longrightarrow$ D $\longrightarrow$ E or A $\longrightarrow$ B $\longrightarrow$ D $\longrightarrow$ E. However, about 10% of the jobs coming out of station D are sent back to B for further work (which takes 30 ± 10 minutes) and then are sent to D and finally to E. The path of these jobs is as follows:



Every 2 hours, beginning 1 hour after opening, the degreasing station C shuts down for routine maintenance, which takes 10 ± 1 minute. However, this routine maintenance does not begin until the current widget, if any, has completed its processing. (a) Make three independent replications of the simulation model, where one replication equals an 8-hour simulation run, preceded by a 2-hour initialization run. The three sets of output represent three typical days. The main performance measure of interest is mean response time per job, where a response time is the total time a job spends in the shop. The shop is never empty in the morning, but the model will be empty without the initialization phase. So run the model for a 2-hour initialization period and collect statistics from time 2 hours to time 10 hours. This "warm-up" period will reduce the downward bias in the estimate of mean response time. Note that the 2-hour warm-up is a device to load a simulation model to some more realistic level than empty. From each of the three independent replications, obtain an estimate of mean response time. Also obtain an overall estimate, the sample average of the three estimates.

(b) Management is considering putting one additional worker at the busiest station (A, B, D, or E). Would this significantly improve mean response time? (c) As an alternative to part (b), management is considering replacing machine C with a faster one that processes a widget in only 14 minutes. Would this significantly improve mean response time?

46. A building-materials firm loads trucks with two payloader tractors. The distribution of truck-loading times has been found to be exponential, with a mean loading time of 6 minutes. The truck interarrival time is exponentially distributed with an arrival rate of 16 per hour. The waiting time of a truck and driver is estimated to cost \$50 per hour. How much (if any) could the firm save (per 10-hour day) if an overhead hopper system that would fill any truck in a constant time of 2 minutes is installed? (Assume that the present tractors could and would adequately service the conveyors loading the hoppers.)

47. A milling-machine department has 10 machines. The runtime until failure occurs on a machine is exponentially distributed with a mean of 20 hours. Repair times are uniformly distributed between 3 and 7 hours. Select an appropriate run length and appropriate initial conditions. (a) How many repair people are needed to ensure that the mean number of machines running is greater than eight? (b) If there are two repair people, estimate the number of machines that are either running or being serviced.

48. Forty people are waiting to pass through a turnstile that takes 2.5 ± 1.0 seconds to traverse. Simulate this system 10 times, each one independent of the others, and determine the range and the average time for all 40 people to traverse.

49. People borrow *Gone with the Wind* from the local library and keep it for 21 ± 10 days. There is only one copy of the book in the library. You are the sixth person on the reservation list (five are ahead of you). Simulate 50 independent cycles of book borrowing to determine the probability that you will receive the book within 100 days.

50. Jobs arrive every 300 ± 30 seconds to be handled by a process that consists of four operations: OP10 requires 50 ± 20 seconds, OP20 requires 70 ± 25 seconds, OP30 requires 60 ± 15 seconds, OP40 requires 90 ± 30 seconds. Simulate this process until 250 jobs are completed; then combine the four operations of the job into one with the distribution 240 ± 100 seconds and simulate the process with this distribution. Does the average time in the system change for the two alternatives?

51. Two types of jobs arrive to be processed on the same machine. Type 1 jobs arrive every 50 ± 30 seconds and require 35 ± 20 seconds for processing. Type 2 jobs arrive every 100 ± 40 seconds and require 20 ± 15 seconds for processing. For an 8-hour simulation, what is the average number of jobs waiting to be processed?

52. Two types of jobs arrive to be processed on the same machine. Type 1 jobs arrive every 80 ± 30 seconds and require 35 ± 20 seconds for processing. Type 2 jobs arrive every 100 ± 40 seconds and require 20 ± 15 seconds for processing. Engineering has judged that there is excess capacity on the machine. For a simulation of 8 hours of operation of the system, find X for Type 3 jobs that arrive every $X \pm 0.4X$ seconds and require a time of 30 seconds on the machine so that the average number of jobs waiting to be processed is two or less.

53. Using spreadsheet software, generate 1000 uniformly distributed random values with mean 10 and spread 2. Plot these values with intervals of width 0.5 between 8 and 12. How close did the simulated set of values come to the expected number in each interval?

54. Using a spreadsheet, generate 1000 exponentially distributed random values with a mean of 10. What is the maximum of the simulated values? What fraction of the generated values is less than the mean of 10? Plot a histogram of the generated values. [*Hint*: If you cannot find an exponential generator in the spreadsheet you use, use the formula -10*LOG($1 - R$), where R is a uniformly distributed random number from 0 to 1 and LOG is the natural logarithm.]

55. There are many "boids" simulations on the internet. Search the internet for two examples of a boids simulation. For each one, find a description of the rules that each boid follows. Compare and contrast the two sets of rules. At a minimum, answer the following questions regarding each model. (a) Are the boids flying in a 2-D or 3-D space? Are they flying in a world with boundary, or without boundary? [*Hint*: Do they turn at edges or walls? Or do they re-appear on the other side? If so, this implies that two apparent boundaries are glued together and are not really boundaries at all.] Describe the world or universe in which the boids are flying. (b) Does the model have user-adjustable parameters? Such parameters may include the number of boids, the closeness factor (how close one boid must be to other boids before it's affected by the other's behavior), speed, and so forth. Make a list of all such parameters. (c) How long does it take for flocking behavior to emerge?

List of Materials Available on www.bcnn.net

Base classes for programming-language based simulations