2.3 OTHER EXAMPLES OF SIMULATION

Example 2.5: A Reliability Problem

A milling machine has three different bearings that fail in service. The distribution of the life of each bearing is identical, as shown in Table 2.22. When a bearing fails, the mill stops, a repairperson is called, and a new bearing is installed. The delay time of the repairperson's arriving at the milling machine is also a random variable having the distribution given in Table 2.23.

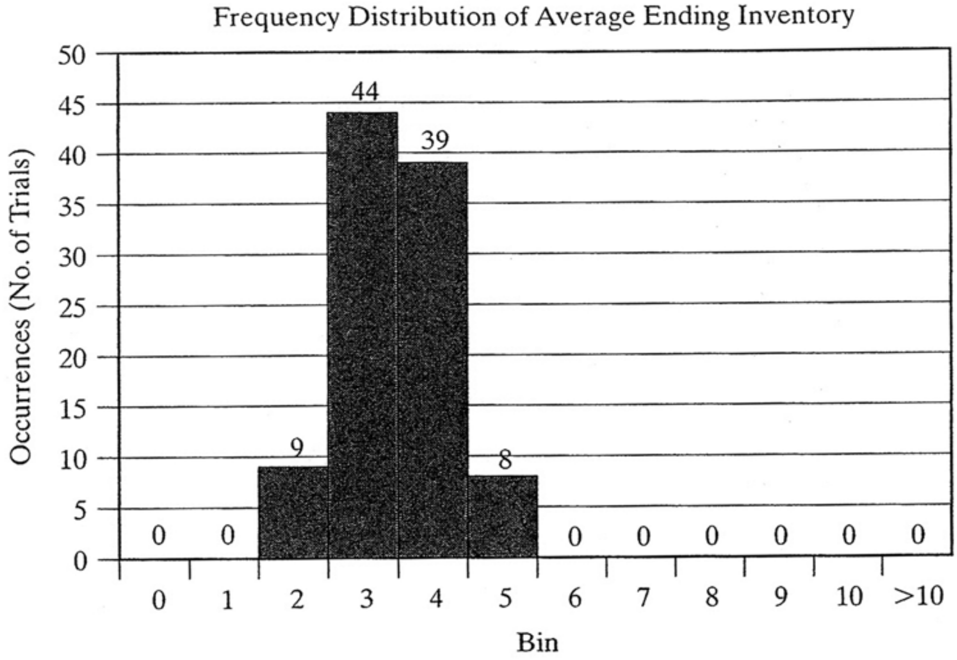

Figure 2.14 Average ending inventory for 100 trials (each 25 days).

Table 2.22 Bearing-Life Distribution

Bearing Life (Hours)	*Probability*	*Cumulative Probability*	*Random Digit Assignment*
1000	0.10	0.10	01–10
1100	0.13	0.23	11–23
1200	0.25	0.48	24–48
1300	0.13	0.61	49–61
1400	0.09	0.70	62–70
1500	0.12	0.82	71–82
1600	0.02	0.84	83–84
1700	0.06	0.90	85–90
1800	0.05	0.95	91–95
1900	0.05	1.00	96–00

Downtime for the mill is estimated at $10 per minute. The direct on-site cost of the repairperson is $30 per hour. It takes 20 minutes to change one bearing, 30 minutes to change two bearings, and 40 minutes to change three bearings. A proposal has been made to replace all three bearings whenever a bearing fails. Management needs an evaluation of the proposal. The total cost per 10,000 bearing-hours will be used as the measure of performance.

Table 2.24 represents a simulation of 15 bearing changes under the current method of operation. Note that there are instances where more than one bearing fails at the same time. This is unlikely to occur in practice and is due to using a rather coarse grid of 100 hours for bearing life. It will be assumed in this example that the times are never exactly the same and thus no more than one

Table 2.23 Delay-Time Distribution

Delay Time (Minutes)	*Probability*	*Cumulative Probability*	*Random Digit Assignment*
5	0.6	0.6	1–6
10	0.3	0.9	7–9
15	0.1	1.0	0

Table 2.24 Bearing Replacement under Current Method

	Bearing 1				*Bearing 2*				*Bearing 3*			
	RD[a]	*Life (Hours)*	*RD*	*Delay (Minutes)*	*RD*	*Life (Hours)*	*RD*	*Delay (Minutes)*	*RD*	*Life (Hours)*	*RD*	*Delay (Minutes)*
1	67	1,400	7	10	71	1,500	8	10	18	1,100	6	5
2	55	1,300	3	5	21	1,100	3	5	17	1,100	2	5
3	98	1,900	1	5	79	1,500	3	5	65	1,400	2	5
4	76	1,500	6	5	88	1,700	1	5	03	1,000	9	10
5	53	1,300	4	5	93	1,800	0	15	54	1,300	8	10
6	69	1,400	8	10	77	1,500	6	5	17	1,100	3	5
7	80	1,500	5	5	08	1,000	9	10	19	1,100	6	5
8	93	1,800	7	10	21	1,100	8	10	09	1,000	7	10
9	35	1,200	0	15	13	1,100	3	5	61	1,300	1	5
10	02	1,000	5	5	03	1,100	2	5	84	1,600	0	15
11	99	1,900	9	10	14	1,000	1	5	11	1,100	5	5
12	65	1,400	4	5	05	1,000	0	15	25	1,200	2	5
13	53	1,300	7	10	29	1,200	2	5	86	1,700	8	10
14	87	1,700	1	5	07	1,000	4	5	65	1,400	3	5
15	90	1,700	2	5	20	1,100	3	5	44	1,200	4	5
Total				110				110				105

[a]RD, random digits.

bearing is changed at any breakdown. The cost of the current system is estimated as follows:

Cost of bearing = 45 bearings × \$32/bearing = \$1,440
Cost of delay time = (110 + 110 + 105) minutes × \$10/minute = \$3,250
Cost of downtime during repair = 45 bearings × 20 minutes/bearing × \$10 minute
= \$9,000
Cost of repairpersons = 45 bearings × 20 minutes/bearing × \$30/60 minutes
= \$450
Total cost = \$1,440 + \$3,250 + \$9,000 + \$450 = \$14,140

The total life of the bearings is (22,300 + 18,700 + 18,600) 59,600 hours. Therefore, the total cost per 10,000 bearing-hours is (\$14,140/5.96) = \$2,372.

Table 2.25 is a simulation of the proposed method. Note that the random digits are not shown. For the first set of bearings, the earliest failure is at 1,000 hours. All three bearings are replaced

Table 2.25 Bearing Replacement under Proposed Method

	Bearing 1 Life (Hours)	*Bearing 2 Life (Hours)*	*Bearing 3 Life (Hours)*	*First Failure (Hours)*	*Delay (Minutes)*
1	1,700	1,100	1,000	1,000	10
2	1,000	1,800	1,200	1,000	5
3	1,500	1,700	1,300	1,300	5
4	1,300	1,100	1,800	1,100	5
5	1,200	1,100	1,300	1,100	5
6	1,000	1,200	1,200	1,000	10
7	1,500	1,700	1,200	1,200	5
8	1,300	1,700	1,000	1,000	10
9	1,800	1,200	1,100	1,100	15
10	1,300	1,300	1,100	1,100	5
11	1,400	1,300	1,900	1,300	10
12	1,500	1,300	1,400	1,300	5
13	1,500	1,800	1,200	1,200	10
14	1,000	1,900	1,400	1,000	5
15	1,300	1,700	1,700	1,300	5
Total					110

at that time, even though the remaining bearings had more life in them. For example, Bearing 1 would have lasted 700 additional hours.

The cost of the proposed system is estimated as follows:

Cost of bearings = 45 bearings × \$32/bearing = \$1,440
Cost of delay time = 110 minutes × \$10/minute = \$1,100
Cost of downtime during repairs = 15 sets × 40 minutes/set × \$10/minute
= \$6,000
Cost of repairpersons = 15 sets × 40 minutes/set × \$30/60 minutes
= \$300
Total cost = \$1,440 + \$1,100 + \$6,000 + \$300 = \$8,840

The total life of the bearings is (17,000 × 3) 51,000 hours. Therefore, the total cost per 10,000 bearing-hours is (\$8,840/5.1) = \$1,733.

The new policy generates a savings of \$634 per 10,000 hours of bearing-life. If the machine runs continuously, the savings are about \$556 per year.

There are two Excel spreadsheet models for Example 2.5 at www.bcnn.net. These are Example 2.5C (the current system) and Example 2.5P (the proposed system). Much flexibility is offered with respect to the inputs on these models. The user can change the distribution of bearing life (making sure that the cumulative probability is exactly 1.00). The distribution of delay time can be changed (again, making sure that the cumulative probability is exactly 1.00). Also, the parameters of the problem can be changed (bearing cost per unit, and so forth). As in other spreadsheet models, the number of trials can be varied from 1 to 400. Finally, in the Experiment sheet, the endpoints of the bins can be changed for observing the frequency of total cost for 10000 hours of bearing life.