Source: BCNN

5.1 Simulation of a Reliability Problem

The next example compares two replacement policies for replacing bearings in a milling machine. The example is a Monte Carlo simulation, not a dynamic event-based model, since events and clock times are not included. Each bearing life is randomly generated 15 times and the resulting costs computed.

Example 9: Replacing Bearings in a Milling Machine

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 22. When a bearing fails, the mill stops, a mechanic is called, and he or she installs a new bearing (costing \$32 per bearing). The delay time for the mechanic to arrive varies randomly, having the distribution given in Table 23. Downtime for the mill is estimated to cost \$10 per minute. The direct on-site cost of the mechanic is \$30 per hour. The mechanic takes 20 minutes to change one bearing, 30 minutes to change two bearings, and 40 minutes to change three bearings. The engineering staff has proposed a new policy to replace all three bearings whenever one bearing fails. Management needs an evaluation of the proposal, using total cost per 10,000 bearing-hours as the measure of performance.

Table 22 Distribution for Bearing Life

	B	C	D
3	Distribution of Bearing-Life		
4–5	Bearing Life	Probability	Cumulative Probability
6	1000	0.10	0.1
7	1100	0.13	0.23
8	1200	0.25	0.48
9	1300	0.13	0.61
10	1400	0.09	0.70
11	1500	0.12	0.82
12	1600	0.02	0.84
13	1700	0.06	0.90
14	1800	0.05	0.95
15	1900	0.05	1.00

Table 24 Bearing Replacement under Current Method

	B	C	D	E	F	G	H
17	Simulation Table						
18		Bearing 1		Bearing 2		Bearing3	
19–20	Step	Life (Hours)	Delay (minutes)	Life (Hours)	Delay (minutes)	Life (Hours)	Delay (minutes)
21	1	1000	5	1700	10	1300	10
22	2	1200	5	1100	5	1100	5
23	3	1200	10	1000	10	1300	10
24	4	1500	5	1000	10	1100	15
25	5	1700	5	1900	15	1200	5
26	6	1200	5	1200	10	1500	10
27	7	1300	5	1500	5	1100	10
28	8	1700	5	1700	5	1400	15
29	9	1000	5	1300	5	1800	15
30	10	1800	10	1300	5	1200	5
31	11	1200	5	1100	5	1500	5
32	12	1100	5	1800	5	1100	10
33	13	1300	10	1200	5	1700	10
34	14	1300	10	1100	5	1300	10
35	15	1100	5	1300	5	1300	10
36	TOTALS	19,600	95	20,200	105	19,900	145

The simulation table for the current policy, shown in Table 24 and taken from the spreadsheet "Example2.9CurrentBearings.xls", represents a simulation of 15 bearing changes under the current policy of replacing only the single bearing that fails. 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 the crude simplifying assumption that bearing life is a multiple of 100 hours (so that we could have a simple discrete distribution rather than a more realistic one). Here, we assume that the times are never exactly the same and thus no more than one bearing is changed at any breakdown.

From this single trial (or replication) of the simulation, the cost of the current system is estimated as follows:

$$\begin{aligned}
\text{Cost of bearing} &= 45 \text{ bearings} \times \$32/\text{bearing} \\
&= \$1{,}440 \\
\text{Cost of delay time} &= (95 + 105 + 145) \text{ minutes} \times \$10/\text{minute} \\
&= \$3{,}450 \\
\text{Cost of downtime during repair} &= 45 \text{ bearings} \times 20 \text{ minutes/bearing} \times \$10/\text{minute} \\
&= \$9{,}000 \\
\text{Cost of mechanics} &= 45 \text{ bearings} \times 20 \text{ minutes/bearing} \times \$30/60 \text{ minutes} \\
&= \$450 \\
\text{Total cost} &= \$1{,}440 + \$3{,}450 + \$9{,}000 + \$450 \\
&= \$14{,}340
\end{aligned}$$

The total life of all 45 bearings is $(19{,}600 + 20{,}200 + 19{,}900) = 59{,}700$ hours. Therefore, the total cost per 10,000 bearing-hours is $(\$14{,}340/5.97) = \$2{,}402$.

The simulation table for the proposed method, shown in Table 25, is taken from the spreadsheet "Example2.9ProposedBearings.xls". For the first set of bearings, the earliest failure is at 1,100 hours.

Table 23 Distribution of Delay until Mechanic Arrives

	F	G	H
4	Distribution of Delay Time		
5–6	Delay Time	Probability	Cumulative Probability
7	5	0.60	0.60
8	10	0.30	0.90
9	15	0.10	1.00

Table 25 Bearing Replacement under Proposed Method

	B	C	D	E	F	G
17	Simulation Table					
18		Bearing 1	Bearing 2	Bearing 3	First	
19–20	Step	Life (Hours)	Life (Hours)	Life (Hours)	Failure (Hours)	Delay (minutes)
21	1	1300	1100	1300	1,100	10
22	2	1100	1200	1500	1,100	5
23	3	1100	1400	1800	1,100	15
24	4	1200	1500	1100	1,100	10
25	5	1700	1300	1300	1,300	5
26	6	1700	1100	1000	1,000	10
27	7	1000	1900	1200	1,000	10
28	8	1500	1700	1300	1,300	15
29	9	1300	1100	1800	1,100	5
30	10	1200	1100	1300	1,100	5
31	11	1000	1200	1200	1,000	15
32	12	1500	1700	1200	1,200	10
33	13	1300	1700	1000	1,000	10
34	14	1800	1200	1100	1,100	10
35	15	1300	1300	1100	1,100	10
36	TOTALS				16600	145

All three bearings are replaced at that time, even though the remaining bearings had more life in them. For example, Bearing 1 would have lasted 200 additional hours.

From this single trial (or replication) of the model, the cost of the proposed policy is estimated as follows:

$$\begin{aligned}
\text{Cost of bearings} &= 45 \text{ bearings} \times \$32/\text{bearing} \\
&= \$1{,}440 \\
\text{Cost of delay time} &= 145 \text{ minutes} \times \$10/\text{minute} \\
&= \$1{,}450 \\
\text{Cost of downtime during repairs} &= 15 \text{ sets} \times 40 \text{ minutes/set} \times \$10/\text{minute} \\
&= \$6{,}000 \\
\text{Cost of mechanics} &= 15 \text{ sets} \times 40 \text{ minutes/set} \times \$30/60 \text{ minutes} \\
&= \$300 \\
\text{Total cost} &= \$1{,}440 + \$1{,}450 + \$6{,}000 + \$300 \\
&= \$9{,}190
\end{aligned}$$

The total life of the bearings is $(16{,}600 \times 3) = 49{,}800$ hours. Therefore, the total cost per 10,000 bearing-hours is $(\$9{,}190/4.98) = \$1{,}845$. The new policy generates a savings of \$557 per 10,000 hours of bearing-life.

The spreadsheet solutions for Example 9 are in: "Example2.9CurrentBearings.xls" for the current policy and "Example2.9ProposedBearings.xls" for the proposed policy. In each spreadsheet, a user can change a number of inputs: the distribution of bearing life, the distribution of delay time until mechanic arrival, the cost parameters, and the repair time per bearing or set of bearings.