Find Annual Costs For Life Cycle Cost Calculations Using A Fix-When-Broken-Strategy

Completion of a life cycle cost (LCC) analysis requires expenditures for each year of the project for calculating net present value (NPV). This requires estimating when things will fail and the cost of the failures. A Weibull database is helpful for selecting:

- shape factor beta (β tells about the failure mode) and
- characteristic life eta (η tells about the durability).

The Weibull statistics tell how components fail. Failure costs follow the failures. You need failure costs for the appropriate year to produce NPV details. You can also download an Excel worksheet for computing NPV from this website.

Failures in early years are highly priced in NPV terms. Failures in later years are lower priced because of discounted values. All the following examples use a discount rate = 12%, project time span of 20 years, and a 38% tax provision for calculating the NPVs. Out-of-pocket expenditures refer to the first 20 years which is a typical project life.

Figure 1 produces a **NPV = -$2,992** based on an out-of-pocket expenditure of $17,698.

Figure 1

Monte Carlo Simulation: Weibull β=3.5, η = 10 years
Maintenance Strategy: Fix When It Breaks

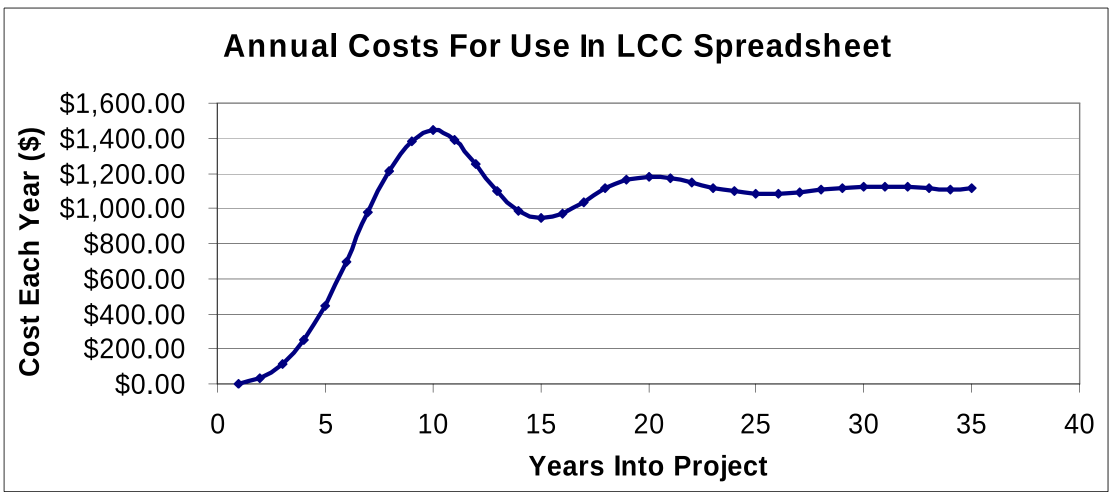


Figure 1 shows the rhythms of replacement. The replacement rhythms make waves of cost over the years for this wear out failure mode. Expenditures deferred to later years have strong, favorable, effects on NPV because of the discount factors; whereas expenditures early in the project life are included at almost current values which are very costly. Of course the costs are driven by the failures, and Table 1 shows the details.

Table 1: Monte Carlo Simulation: Weibull β = 3.5, η = 10 years Maintenance Strategy: Fix When It Breaks Cost Per Failure = $10,000										
Project Year-->	1	2	3	4	5	6	7	8	9	10
Failures Expected-->	0.000315	0.003196	0.011409	0.025175	0.044770	0.069866	0.097385	0.121152	0.137998	0.144578
Cum Failures Expected-->	0.000315	0.003511	0.014920	0.040095	0.084865	0.154731	0.252116	0.373268	0.511266	0.655844
Failure Cost For LCC-->	$ 3.15	$ 31.96	$ 114.09	$ 251.75	$ 447.70	$ 698.66	$ 973.85	$ 1,211.52	$ 1,379.98	$ 1,445.78
Project Year-->	11	12	13	14	15	16	17	18	19	20
Failures Expected-->	0.139237	0.125282	0.110102	0.098732	0.094354	0.098630	0.103805	0.111213	0.116418	0.118029
Cum Failures Expected-->	0.795081	0.920363	1.030465	1.129197	1.223551	1.322181	1.425986	1.537199	1.653617	1.771646
Failure Cost For LCC-->	$ 1,392.37	$ 1,252.82	$ 1,101.02	$ 987.32	$ 943.54	$ 986.30	$ 1,038.05	$ 1,112.13	$ 1,164.18	$ 1,180.29
Project Year-->	21	22	23	24	25	26	27	28	29	30
Failures Expected-->	0.117232	0.114603	0.111834	0.109751	0.108104	0.108018	0.109186	0.110983	0.111704	0.111941
Cum Failures Expected-->	1.888878	2.003481	2.115315	2.225066	2.333170	2.441188	2.550374	2.661357	2.773061	2.885002
Failure Cost For LCC-->	$ 1,172.32	$ 1,146.03	$ 1,118.34	$ 1,097.51	$ 1,081.04	$ 1,080.18	$ 1,091.86	$ 1,109.83	$ 1,117.04	$ 1,119.41
Project Year-->	31	32	33	34	35					
Failures Expected-->	0.112387	0.111949	0.111266	0.110899	0.111125					
Cum Failures Expected-->	2.997389	3.109338	3.220604	3.331503	3.442628					
Failure Cost For LCC-->	$ 1,123.87	$ 1,119.49	$ 1,112.66	$ 1,108.99	$ 1,111.25					

You can find the annual costs to include in life cycle cost NPV spreadsheets by use of simple Monte Carlo simulations. Download the Excel simulation as a ZIP file, un-ZIP, run in your version of Excel. Find the cost details where the cost is $10,000 per failure. How many iterations are required for a reasonable NPV number? Pretty good, consistent results are found with ~10,000 iterations but the curves produced are jaggy; whereas 1,000,000 iterations produce very smooth curves. Remember that every time you run a Monte Carlo simulation, you get slightly different results for large number of iterations, and if few iterations are used, you see large differences from run to run.

Notice in Table 1 the first failure takes ~13 years to accumulate which is equal to 91.8% of the Weibull CDF. The second and third failures each take ~9 years which is not surprising since the calculated mean time to failure is 8.998 years for β = 3.5 and η = 10 years. The cumulative failures are shown in Table 1 with red numbers for failures near whole numbers.

Figure 2

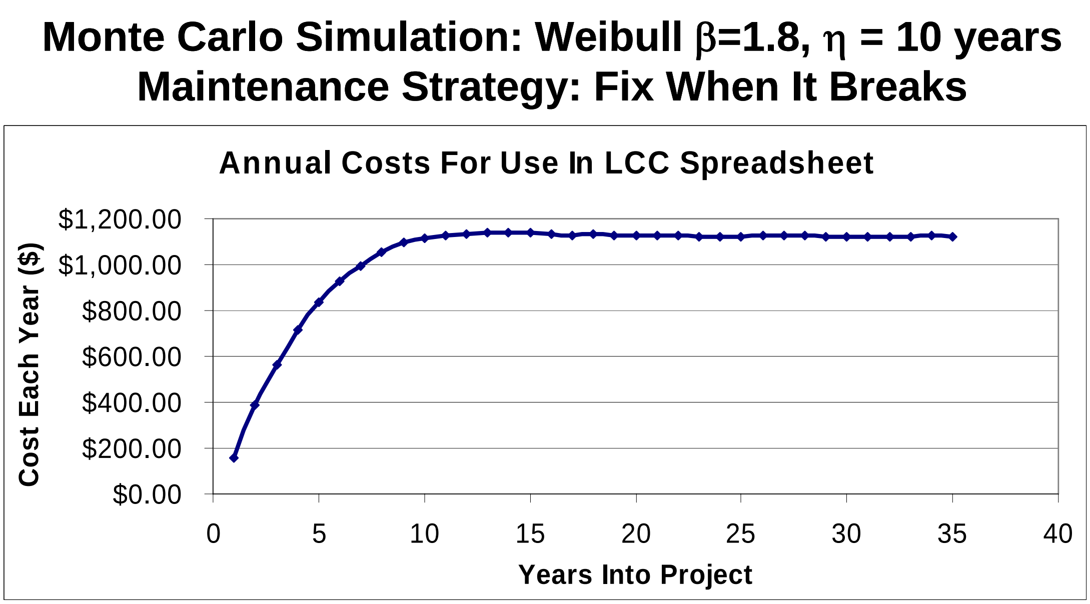


Figure 2 with a β = 1.8, the **NPV = -$3,680** based on an out-of-pocket expenditure of $19,157.

Figure 2's replacement rhythms are not obvious because of the smaller beta value. Table 2 shows the failure costs.

Table 2: Monte Carlo Simulation: Weibull β = 1.8, η = 10 years Maintenance Strategy: Fix When It Breaks Cost Per Failure = $10,000

Project Year-->	1	2	3	4	5	6	7	8	9	10
Failures Expected-->	0.015622	0.038682	0.056408	0.071442	0.083435	0.092472	0.099552	0.105245	0.109455	0.111545
Cum Failures Expected-->	0.015622	0.054304	0.110712	0.182154	0.265589	0.358061	0.457613	0.562858	0.672313	0.783858
Failure Cost For LCC-->	$ 156.22	$ 386.82	$ 564.08	$ 714.42	$ 834.35	$ 924.72	$ 995.52	$ 1,052.45	$ 1,094.55	$ 1,115.45
Project Year-->	11	12	13	14	15	16	17	18	19	20
Failures Expected-->	0.112852	0.113103	0.113909	0.113660	0.113638	0.113306	0.112637	0.113530	0.112468	0.112786
Cum Failures Expected-->	0.896710	1.009813	1.123722	1.237382	1.351020	1.464326	1.576963	1.690493	1.802961	1.915747
Failure Cost For LCC-->	$ 1,128.52	$ 1,131.03	$ 1,139.09	$ 1,136.60	$ 1,136.38	$ 1,133.06	$ 1,126.37	$ 1,135.30	$ 1,124.68	$ 1,127.86
Project Year-->	21	22	23	24	25	26	27	28	29	30
Failures Expected-->	0.112474	0.112781	0.112101	0.111897	0.112408	0.112824	0.112790	0.112626	0.111939	0.112167
Cum Failures Expected-->	2.028221	2.141002	2.253103	2.365000	2.477408	2.590232	2.703022	2.815648	2.927587	3.039754
Failure Cost For LCC-->	$ 1,124.74	$ 1,127.81	$ 1,121.01	$ 1,118.97	$ 1,124.08	$ 1,128.24	$ 1,127.90	$ 1,126.26	$ 1,119.39	$ 1,121.67
Project Year-->	31	32	33	34	35					
Failures Expected-->	0.112404	0.112397	0.112346	0.112460	0.112376					
Cum Failures Expected-->	3.152158	3.264555	3.376901	3.489361	3.601737					
Failure Cost For LCC-->	$ 1,124.04	$ 1,123.97	$ 1,123.46	$ 1,124.60	$ 1,123.76					

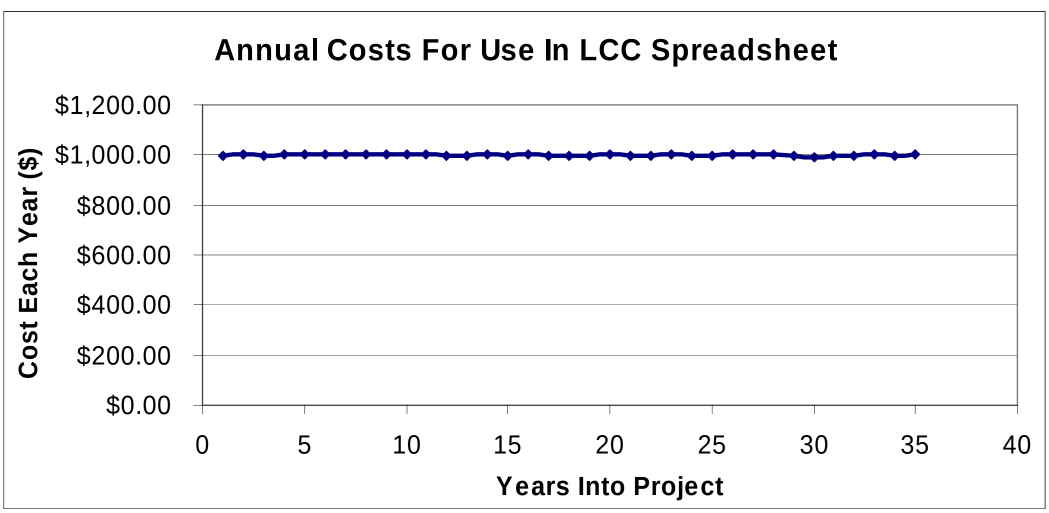
Notice in Table 2 the first failure takes 12 years to accumulate which is 75% of the Weibull CDF. The second and third failures each take ~9 years which is not surprising since the calculated mean time to failure is 8.89 years for β = 1.8 and η = 10 years. The cumulative failures are shown in Table 2 with red numbers for failures near whole numbers.

Figure 3 shows the costs to be used each year for a chance failure mode with β = 1. Frequently this is a simplification decision (i.e., β = 1) on many life cycle cost sheets (unfortunately this decision takes major hits against NPV early in the life of the project).

Figure 3 produces a **NPV = -$4,633** based on an out-of-pocket expenditure of $20,035.

Figure 3

Monte Carlo Simulation: Weibull β= 1, η = 10 years Maintenance Strategy: Fix When It Breaks



When β = 1 and η = 10 years, this describes the exponential type, random failure and the mean time to failure is equal to eta (i.e., 10 years). As you can see from the costs curve we have 1/10 chance for failure each year, i.e., (1/10)*$10,000 = $1000 annual exposure. Detailed results of the simulation, regarding failures is shown in Table 3.

Table 3: Monte Carlo Simulation: Weibull β = 1, η = 10 years Maintenance Strategy: Fix When It Breaks Cost Per Failure = $10,000

Project Year-->	1	2	3	4	5	6	7	8	9	10
Failures Expected-->	0.099872	0.100473	0.099882	0.100345	0.100054	0.100088	0.100118	0.100165	0.099976	0.100231
Cum Failures Expected-->	0.099872	0.200345	0.300227	0.400572	0.500626	0.600714	0.700832	0.800997	0.900973	1.001204
Failure Cost For LCC-->	$ 998.72	$ 1,004.73	$ 998.82	$ 1,003.45	$ 1,000.54	$ 1,000.88	$ 1,001.18	$ 1,001.65	$ 999.76	$ 1,002.31

Project Year-->	11	12	13	14	15	16	17	18	19	20
Failures Expected-->	0.100040	0.099580	0.099541	0.099934	0.099757	0.100237	0.099656	0.099756	0.099640	0.100194
Cum Failures Expected-->	1.101244	1.200824	1.300365	1.400299	1.500056	1.600293	1.699949	1.799705	1.899345	1.999539
Failure Cost For LCC-->	$ 1,000.40	$ 995.80	$ 995.41	$ 999.34	$ 997.57	$ 1,002.37	$ 996.56	$ 997.56	$ 996.40	$ 1,001.94

Project Year-->	21	22	23	24	25	26	27	28	29	30
Failures Expected-->	0.099852	0.099863	0.100275	0.099832	0.099757	0.100207	0.100380	0.099985	0.099470	0.099166
Cum Failures Expected-->	2.099391	2.199254	2.299529	2.399361	2.499118	2.599325	2.699705	2.799690	2.899160	2.998326
Failure Cost For LCC-->	$ 998.52	$ 998.63	$ 1,002.75	$ 998.32	$ 997.57	$ 1,002.07	$ 1,003.80	$ 999.85	$ 994.70	$ 991.66

Project Year-->	31	32	33	34	35
Failures Expected-->	0.099326	0.099689	0.099939	0.099676	0.100305
Cum Failures Expected-->	3.097652	3.197341	3.297280	3.396956	3.497261
Failure Cost For LCC-->	$ 993.26	$ 996.89	$ 999.39	$ 996.76	$ 1,003.05

It's easy to see that failures are occurring every 10 years in the simplified model of chance failures which is equal to 63.2% of the Weibull CDF. The simulated numbers for cost are ±0.2% of the expected value of $1000.

Figure 4 shows the costs to be used each year for the Weibull statistic with β = 0.7. These infant mortality failure modes (i.e., β < 1) incur high costs in the early years where expenditures carry a high value. Thus the NPV is worse than other conditions in Figure 1-3.

Figure 4

Monte Carlo Simulation: Weibull β= 0.7, η = 10 years Maintenance Strategy: Fix When It Breaks

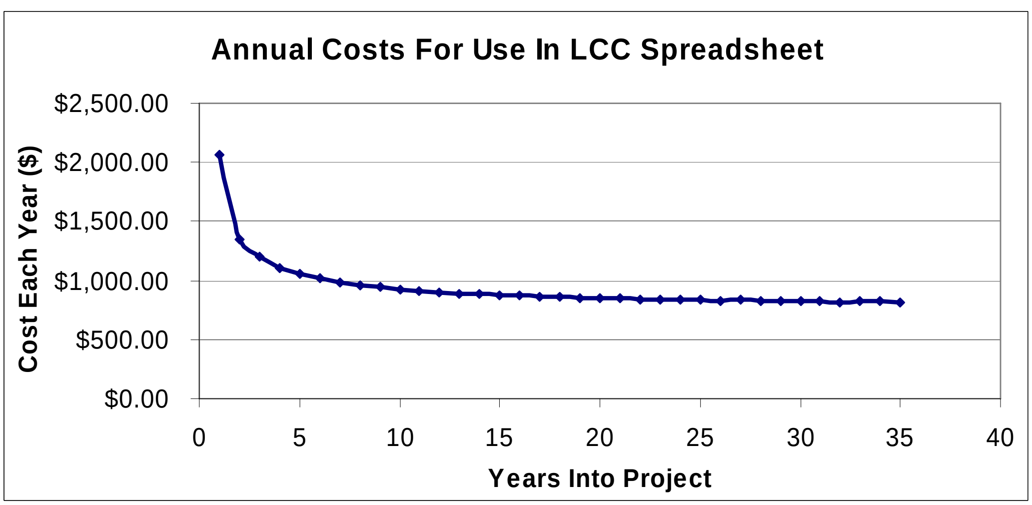


Figure 4 produces a **NPV = -$5,374** with an out-of-pocket expenditure of $20,386.

The early high cost failures from infant mortality have major cost impact on NPV. The failure details and cost numbers are shown in Table 4 with the first failure accumulating in 8+ years.

Table 4: Monte Carlo Simulation: Weibull β = 0.7, η = 10 years Maintenance Strategy: Fix When It Breaks Cost Per Failure = $10,000

Project Year-->	1	2	3	4	5	6	7	8	9	10
Failures Expected-->	0.205885	0.134721	0.119813	0.111034	0.105547	0.101669	0.098733	0.096334	0.094598	0.092718
Cum Failures Expected-->	0.205885	0.340606	0.460419	0.571453	0.677000	0.778669	0.877402	0.973736	1.068334	1.161052
Failure Cost For LCC-->	$ 2,058.85	$ 1,347.21	$ 1,198.13	$ 1,110.34	$ 1,055.47	$ 1,016.69	$ 987.33	$ 963.34	$ 945.98	$ 927.18
Project Year-->	11	12	13	14	15	16	17	18	19	20
Failures Expected-->	0.091256	0.090346	0.089181	0.088445	0.087618	0.086825	0.086690	0.086745	0.085203	0.085162
Cum Failures Expected-->	1.252308	1.342654	1.431835	1.520280	1.607898	1.694723	1.781413	1.868158	1.953361	2.038523
Failure Cost For LCC-->	$ 912.56	$ 903.46	$ 891.81	$ 884.45	$ 876.18	$ 868.25	$ 866.90	$ 867.45	$ 852.03	$ 851.62
Project Year-->	21	22	23	24	25	26	27	28	29	30
Failures Expected-->	0.084852	0.084314	0.083651	0.083140	0.083784	0.083105	0.083269	0.082759	0.082696	0.082022
Cum Failures Expected-->	2.123375	2.207689	2.291340	2.374480	2.458264	2.541369	2.624638	2.707397	2.790093	2.872115
Failure Cost For LCC-->	$ 848.52	$ 843.14	$ 836.51	$ 831.40	$ 837.84	$ 831.05	$ 832.69	$ 827.59	$ 826.96	$ 820.22
Project Year-->	31	32	33	34	35					
Failures Expected-->	0.082026	0.081738	0.082289	0.081969	0.081677					
Cum Failures Expected-->	2.954141	3.035879	3.118168	3.200137	3.281814					
Failure Cost For LCC-->	$ 820.26	$ 817.38	$ 822.89	$ 819.69	$ 816.77					

The first failure occurs in 8 years which is 57.5% of the Weibull CDF, the second failure 12 years later, and the third failure is also 12 years later.

These four examples show:

1. how to find failure costs for each project year with different failure modes
2. how early failure costs are killers for NPV
3. the need for Weibull failure statistics to be able to find failures and costs
4. why it's important to know how equipment will live and die to get correct cost profiles by year

In summary, here is a comparison of these examples for **repair when broken**:

Table 1: LCC Summary

$10,000/failure, 20 year project, 38% taxes, 12% discount rate

Fig.	β	η (years)	NPV ($)	Out-of-pocket ($)
1	3	10	-$2,992	$17,698
2	1.8	10	-$3,680	$19,157
3	1	10	-$4,633	$20,035
4	0.7	10	-$5,374	$20,386

Figure 1's results are the least negative and thus the preferred case. The least preferred case is shown in Figure 4 and Table 4.

You can find other LCC resources on this website:

1. Find Annual Cost For Life Cycle Cost Calculations With Planned Replacements

2. Optimizing Equipment Reliability Data for End-Users and Equipment Suppliers.
3. Life Cycle Cost Tutorial
4. Life Cycle Cost & Reliability for Process Equipment
5. Life Cycle Cost And Good Practices
6. How to Justify Machinery Improvements Using Reliability Engineering Principles
7. Why You Need Practical Reliability Details To Define Life Cycle Costs For Your Products and Competitors Products!
8. How To Justify Equipment Improvements Using Life Cycle Cost and Reliability Principles
9. Reliability Issues From A Management Perspective
10. A Life Cycle Cost Summary
11. Life Cycle Cost Analysis—Who Does What?
12. Reliability And Life Cycle Cost
13. Life Cycle Cost Issues
14. Life Cycle Cost Training

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