How To Justify Equipment Improvements Using Life Cycle Cost and Reliability Principles

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Abstract

New Equipment and improvement justifications are based on financial details and alternatives. The datum for all improvements begins with the cost of the status quo, i.e., no improvement as the launching point for alternatives. Justifications require knowing: 1) when things fail, 2) how things fail, and 3) conversions of failures into money statements. Reliability engineering principles help define when and how things fail to provide facts for life cycle costs comparisons to help decide the lowest long-term cost of ownership driven by a single estimator called net present value (NPV). NPV converts hardware issues and alternatives into money issues. Initial first costs are often a bad decision tool for making improvement decisions (lacking details and alternatives from engineering—the first cost may become the only decision criteria). The Engineering Department is responsibility for providing life cycle costs over the project life and they must provide more than a single alternative for the sales department to get the order. Knowledge about times to failure and failure modes are found by reliability technology. A short example illustrates the methodology.

When and How Things Die

Reliability engineering is concerned with predicting and avoiding failures—this is a strategic task. Maintenance engineering is concerned with quickly restoring failures to an operating condition—this is a tactical task. Both reliability engineering and maintenance engineering have roots in each others territory and thus must know about each others roles, responsibilities, and tools Consider this analogy observed in most locale fire departments: *reliability is to the fire marshal as maintenance is to fire fighters*. Reliability technology helps predict failures and the cost of failures.

Preventing failures cost money. Repairing failures cost money. Thus both reliability and maintenance activities are ruled by money. Improvement decisions are always about money and alternative**s**. Improvement projects require engineering details of cost in yearly time buckets for costing cash outflows—many companies use 20 year intervals, some companies use 10 year intervals, and a few companies use 1-3 year intervals with trends toward shorter study periods.

Engineering is responsible for defining when failures will occur so they can be priced-out in NPV worksheets, and this relies on predictions from reliability engineers. Of course the mode of failure also provides information about severity of the failure. The cost of failures must also include gross margin losses from production outages and cutbacks (when appropriate)—this is particularly true for continuous process operations when the production is “sold out”.

Failure of equipment and processes always occur as a natural outgrowth from the laws of physics and changes in entropy of the system. It is easy to kill equipment. It is very difficult to make equipment survive. The three regimes for equipment failure at: 1) infant mortality, 2) chance failures, and 3) old age wear out failures, which are connected to failure rates.

Infant mortality and old age wear out failures are superimposed on chance failures to obtain the typical bathtub failure curve where we typically think of chance failures having a lower failure rate than either wear out failures or infant mortality failures. This idealized bathtub curves is seldom observed for equipment—we have fewer pieces of equipment than we have human failures (deaths) and all human deaths in civilized societies must be reported to government agencies (mandatory reporting for equipment failures is not required).

Thus the death of most equipment must be analyzed from small samples using a very practical reliability technique of Weibull analysis (Abernethy 2000) for each failure mode. In many cases a simple arithmetic technique of MTBF or MTTF is frequently used as a precursor for reliability of equipment considering mixtures of failure modes that occur.

Table 1

Short List Of Reliability Engineering Principles Tools

- **Mean time between failures indices**
- **TPM and reliability principles**
- **Preparing reliability data for analysis**
- **Decision trees merging reliability and costs**
- **Weibull, normal, & log-normal probability plots**
- **Corrective action for Weibull failure**
- **Models & Monte Carlo simulations**
- **Pareto distributions for vital problems**
- **Fault tree analysis**
- **Design review**
- **Load/strength interactions**
- **Software reliability tools**
- **Sudden death and simultaneous testing**
- **Failure recording, analysis and corrective action**
- **Failure mode effect analysis**
- **Bathtub curves for modes of failure**
- **Availability, maintainability, capability**
- **Critical items significantly affecting safety/costs**
- **Quality function deployment**
- **Mechanical components testing for interactions**
- **Electronic device screening and de-rating**
- **Quality function deployment**
- **Reliability testing strategies**
- **Accelerated testing**
- **Contracting for reliability**
- **Reliability growth models and displays**
- **Cost of unreliability**
- **Reliability policies and specifications**
- **Reliability audits**
- **Management's role in reliability improvements**

The short list of reliability tools used for predicting failures and finding cost effective alternatives are shown in Table 1.

Most reliability tools are practical engineering approaches seldom studied in depth at most universities. Usually the tools must be learned as supplements of continuing education either by home study or by short courses (Barringer 2004 a).

Without tools for defining life/death of equipment it is difficult to define costs for life cycle decisions.

Life Cycle Costs

Life cycle costs (LCC) refer to all costs associated with acquisition and ownership of a product or system over its full life. (Fabrycky 1991) The usual figure of merit is net present value (NPV).

NPV is a financial tool for evaluating economic value added. It is the present value of an investment's future net cash flows, minus the initial investment for a given discount rate hurdle. The present values for each year of the project are summed for the net present value. Net cash flows are a measure of a company's financial health. Discount rates are the interest rate used in discounting future cash flows. The discount rates include the cost of money, bank and company administration costs, and risk costs for the lender—they are always larger than Federal Bank rates. For an entire project, the life cycle cost number requires a positive NPV. Bigger positive NPVs are better. In many cases, NPV decisions are made on the least negative values where profit values cannot be included in the calculations. NPV spreadsheets are available on the Internet (Barringer 2004 b).

Project elements cannot easily show profits/savings for each component. Thus decisions are made in selecting equipment is based on the **least negative** NPV. The least negative NPV is better. For many improvement projects the NPV will be positive and most improvement projects also require internal rates of return (IRR) as a second criteria insisting on higher rates of returns on many small projects that must jump a very high hurdle to hold down the expenditure for capital money—particularly if the company lacks access to financial money for improvements.

All LCC tasks require comparisons of alternative**s**—note the word alternatives is plural. In every LCC task, conflicting issues are obvious:

- Project engineers want to minimize capital expenditures
- Accounting wants to maximize NPV
- Shareholders want to maximize dividends/share price
- Production wants to maximize uptime hours
- Maintenance engineers want to minimize repair hours
- Reliability engineers want to avoid failures

All parties want someone else to put the numbers together to justify their love affair with the project or equipment, which justifies their decisions.

Business is about: time, money, and alternative**s**. Time and money are in short supply. A single alternative is without choice and thus unwise because the default position is to do nothing.

A comparison of ridiculous alternative**s** is also unwise because of credibility issues. Alternative**s** are often as numerous as fleas but give pros and cons for making selections. The LCC concept merges time and money together to arrive at a single indicator called NPV for each alternative. NPV numbers prioritize the projects to select the winner from the alternative**s** so you buy right rather than only buying cheap.

The road map of elements going into the LCC is shown in Figure 1 as a memory jogger for the details used in the alternatives.

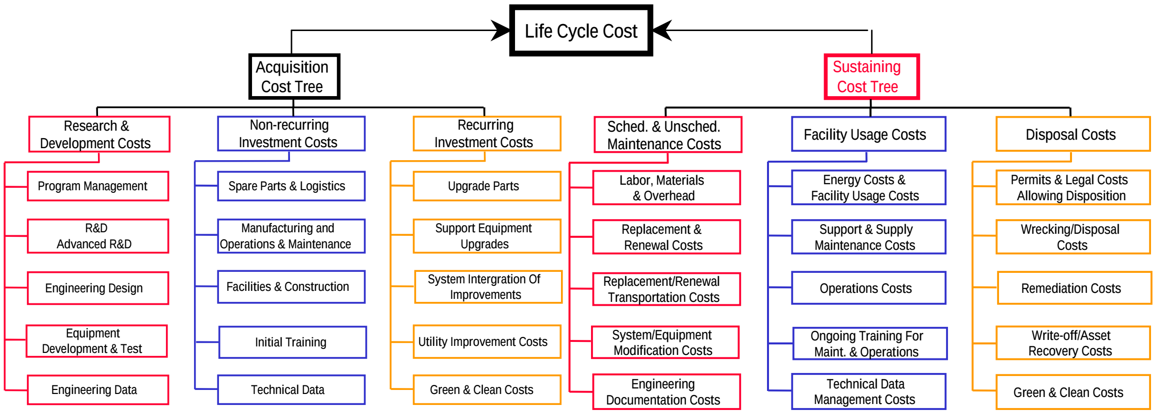


Figure 1: Details Required For Life Cycle Costs

Figure 1 shows items for inclusion in NPV calculations. Not all items are required for each evaluation—particularly if conditions are "same as but…" Cost details from Figure 1 are put into simple spreadsheets with elements by year of the expenditure. The spreadsheet calculations are simple additions, subtractions, multiplications, and calculations of the time effects of money.

Engineers should avoid writing NPV spreadsheets using built-in spreadsheet operators. Rather, make the spreadsheet entries in a "foot and tic" method learned by every accountant so as to build trust and rapport with the auditors who will validate the calculations. Many accountants will not validate the complicated build-in functions but they know how to "foot and tic" the results using old fashioned, time proven methods of accounting.

Life Cycle Cost and Reliability Models—The Example

Consider these questions of acquisition and sustaining costs for three alternatives:

We have two pumps of equal size and capability in parallel. Years ago we needed one pump out of two. We've been de-bottlenecking, and now we need two pumps out of two to make production commitments. This is a high temp application. Space for equipment is cramped.

One pump is correctly installed with long life. We analyze the failure data and find a predominate Weibull failure mode with β = 2.067 (a shape factor), η = 478 days (a scale factor). Repair time is lognormal with 1.6667 days downtime and 2.0 standard deviations (actually for log normal distributions it is a shape factor) for repairs. Typical maintenance repair cost is $10,000/failure.

The second pump has a poor installation/use/sizing situation and demonstrates short life. Predominate Weibull failure modes shows β = 0.667, η = 154 days. Repair time is lognormal with 1.6667 days downtime and 2.0 standard deviations for repair. We cannot afford to spend time to correct the fatal flaws in this installation right now because of the high cutback costs.

Production losses: Cutbacks in output when one pump is off-line are $3,000/hr (when 1 out of 2 survive) and total failure costs are $10,000/hr (when both pumps are down—that means we're less than 1 out of 2 surviving).

If we installed a large pump to act in parallel with the two small pumps can we afford the $75,000 cost for a new, large, pump installation? We need an IRR of at least 50%. Expect the new pump will show β = 2.067, η = 478 days (maybe even better for the new installation). Repair time is lognormal with 1.6667 days downtime and 2.0 std. deviations for repairs. The repair cost is expected to be $12,000 for the large new pump.

If we installed a third small pump for a two out of three situation, can we afford to spend $50,000 cost for the redundant pump installation? We need an IRR of at least 50%. Expect the new pump will show β = 2.067, η = 478 days (maybe even better for the new installation). Repair time is lognormal with 1.6667 days downtime and 2.0 std. deviations for repairs. The repair cost is expected to be $10,000.

Using arithmetic, the no-cost RAPTOR reliability and maintainability (RAM) block diagram software (Barringer 2004c), and make NPV calculations to decide what actions to take during the 20 year project life using a discount rate of 12% and IRR = 50%.

The alternatives are:

1) Do nothing and live with two old pumps where we need 2-out-of-2 for daily operation,
2) Add one large pump so the two existing pumps are in parallel with the new big pump,
3) Add one small pump so the conditions are 2 small pumps required out of 3 small pumps.

Alternative 1—Do Nothing-

Build a RAPTOR RAM model using the Weibull characteristics for age to failure along with the log-normal repair distributions noted above. The model requires two pumps out of two operating. A 2-out-of-2 model will find the statistics for success or failure (green time where everything is operating and red time where conditions are less than 2-out-of-2 operating which defines failure times). A 2 out of 2 model will not find the cutback time, as they will be included into the red times. Therefore, make the model a 1-out-of-2 condition so three conditions are shown: 1) time for no failures where both are operating (green time), 2) time when the pumps are in a cutback condition of 1 out of 2 operating (yellow time), and 3) when both pumps are down (red time). Run the model for 365 days, 730 days, up to 7300 days—look for the failures on an incremental basis from year to year. Price out the failures at $10,000/hr of total system downtime and $3,000/hr for time when only one pump is operating. Here's what you will find:

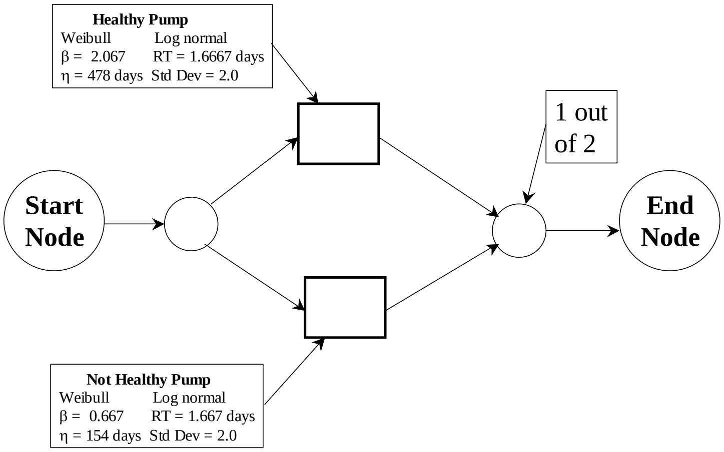
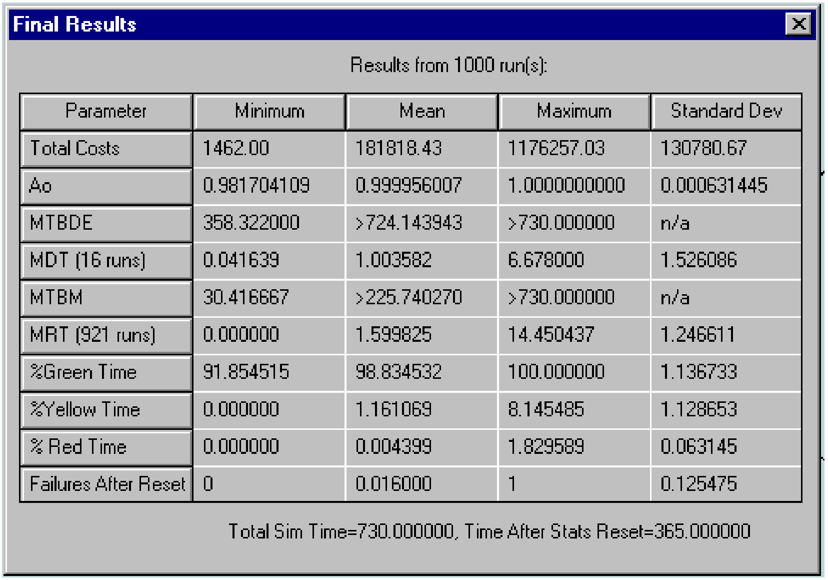


Figure 2: RAPTOR Monte Carlo Model For System Failures

Output from the 1 out of 2 RAPTOR RAM model from Figure 2 produces a summary set of statistics. The mean values will be used for finding the cost numbers in Table 3:

Table 2: Results From RAPTOR Simulations



Final Results

Results from 1000 run(s):

Parameter	Minimum	Mean	Maximum	Standard Dev
Total Costs	1462.00	181818.43	1176257.03	130780.67
Ao	0.981704109	0.999956007	1.0000000000	0.000631445
MTBDE	358.322000	>724.143943	>730.000000	n/a
MDT (16 runs)	0.041639	1.003582	6.678000	1.526086
MTBM	30.416667	>225.740270	>730.000000	n/a
MRT (921 runs)	0.000000	1.599825	14.450437	1.246611
%Green Time	91.854515	98.834532	100.000000	1.136733
%Yellow Time	0.000000	1.161069	8.145485	1.128653
% Red Time	0.000000	0.004399	1.829589	0.063145
Failures After Reset	0	0.016000	1	0.125475

Total Sim Time=730.000000, Time After Stats Reset=365.000000

The RAM report in Table 2 reports the failures during year 2, i.e., between 730 days and 365 days. The entire system is down (red time) 0.004399% of 8760hrs/year = 0.385352 hrs/year and the gross margin lost is 0.385352hrs/yr * $10,000/yr = $3,853.52/yr lost margin. The system is at minimum equipment levels involved in cutback losses (yellow time) for 1 out of 2 operating 1.61069% of 8760hrs/year = 101.7096 hrs/year and the gross margin lost is 101.7096 hrs * $3,000/hr = $305,129/yr lost margin. So the major financial problem is the cutback condition which are $305129/$3854 = 79 fold larger than system outages.

Table 3 shows results of the do nothing alternative for the RAM model, which converts failure data into money.

Table 3
Datum Case: Do Nothing Alternative--Failure Costs For The Status Quo
All results based on 1000 trials for each year---statistical data reported for only the year studied.

Year	Days	Mean Red Time (two pumps down at same time), **(%)**	Mean Red Time Converted To Down Time For Total System Failures, **(hrs/year)**	Mean Number of Red Event System Failures. **(#)**	Mean Red Time For Complete System Failures Converted To Gross Margin Money Lost	Mean Yellow Time (Cutback zone-one survives out of two) **(%)**	Mean Yellow Time For Cutbacks Converted To Downtown **(hours/yr)**	Mean Repair Time **(days/ failure)**	Average Number of Cutback Failures Per Year **(#/yr)**	Cutback Conditions Gross Margin Failure Cost Losses **($/yr)**	Gross Margin Losses From Cutbacks and Total System Failures **($/yr)**	Pump Mainte-nance Repair Costs **($/yr)**	Sum Of Gross Margin Losses & Repair Costs **($/yr)**
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**I**	**j**	**k**	**l**	**m**	**n**
		From RAPTOR	365*(c/100)*24	From RAPTOR	$10,000*d	From RAPTOR	365*(g/100)*24	From RAPTOR	h/(I*24)	$3,000*h	f + k	$10,000*(e + J)	L + N
1	365	0.002144	0.187814	0.009	$1,878	1.279285	112.0654	1.674760	2.788095	$336,196	$338,074	$27,971	$366,045
2	730	0.004399	0.385352	0.016	$3,854	1.161069	101.7096	1.599825	2.648978	$305,129	$308,982	$26,650	$335,632
3	1095	0.002880	0.252288	0.016	$2,523	1.174653	102.8996	1.646313	2.604294	$308,699	$311,222	$26,203	$337,425
4	1460	0.002312	0.202531	0.013	$2,025	1.218289	106.7221	1.638230	2.714365	$320,166	$322,192	$27,274	$349,465
5	1825	0.002606	0.228286	0.012	$2,283	1.167023	102.2312	1.659235	2.567228	$306,694	$308,977	$25,792	$334,769
6	2190	0.001404	0.122990	0.007	$1,230	1.198115	104.9549	1.700919	2.571034	$314,865	$316,095	$25,780	$341,875
7	2555	0.003302	0.289255	0.02	$2,893	1.191764	104.3985	1.654584	2.629023	$313,196	$316,088	$26,490	$342,578
8	2920	0.001809	0.158468	0.014	$1,585	1.173470	102.7960	1.707165	2.508935	$308,388	$309,973	$25,229	$335,202
9	3285	0.002225	0.194910	0.014	$1,949	1.222295	107.0730	1.712634	2.604980	$321,219	$323,168	$26,190	$349,358
10	3650	0.002040	0.178704	0.007	$1,787	1.188088	104.0765	1.659607	2.612981	$312,230	$314,017	$26,200	$340,216
11	4015	0.005804	0.508430	0.021	$5,084	1.197460	104.8975	1.779037	2.456795	$314,692	$319,777	$24,778	$344,555
12	4380	0.001773	0.155315	0.012	$1,553	1.175174	102.9452	1.707771	2.511686	$308,836	$310,389	$25,237	$335,626
13	4745	0.002105	0.184398	0.009	$1,844	1.224117	107.2326	1.649817	2.708196	$321,698	$323,542	$27,172	$350,714
14	5110	0.001496	0.131050	0.009	$1,310	1.196564	104.8190	1.587960	2.750358	$314,457	$315,768	$27,594	$343,361
15	5475	0.002415	0.211554	0.009	$2,116	1.133094	99.2590	1.619986	2.552981	$297,777	$299,893	$25,620	$325,512
16	5840	0.002512	0.220051	0.013	$2,201	1.160906	101.6954	1.601372	2.646048	$305,086	$307,287	$26,590	$333,877
17	6205	0.005928	0.519293	0.01	$5,193	1.167567	102.2789	1.663234	2.562249	$306,837	$312,030	$25,722	$337,752
18	6570	0.003201	0.280408	0.016	$2,804	1.265275	110.8381	1.725613	2.676297	$332,514	$335,318	$26,923	$362,241
19	6935	0.004091	0.358372	0.015	$3,584	1.122020	98.2890	1.567801	2.612177	$294,867	$298,451	$26,272	$324,722
20	7300	0.004691	0.410932	0.015	$4,109	1.254588	109.9019	1.795161	2.550883	$329,706	$333,815	$25,659	$359,474
			Average =	**0.013**	**$2,590**				**2.614**	**$313,663**	**$316,253**	**$26,267**	**$342,520**

Observations about Table 3: Each year, the number of pump failures is high and thus failure/repair costs are high for the sold-out condition. Also note that the results of each year are different but roughly the same value—this is typical of Monte Carlo simulations where each time you solve the problem, you should expect to see different values because of use random numbers.

Table 3 required the use of Weibull and Log-normal analysis of failure/repair data to fuel the Monte Carlo model. The Monte Carlo RAPTOR model provided the factual data about failures and cut back conditions, which can be priced for the NPV calculations. Thus reliability engineering principles has been merged with the costs of outages and repairs to provide the expected costs for making financial calculations. The conditions can be calculated by hand but the skill level is high, whereas the use of the software allows moderate skill levels to quickly get the results so the method is very productive.

First and last columns of Table 3 are important for the NPV worksheet: time and money for the do nothing alternative—use the last column values as the annual recurring cost values for the life cycle cost worksheet. Table 3 shows average annual cost of **un**reliability for this pump system is $342,520. Before de-bottlenecking the average cost of **un**reliability was $28,857, which is the result of column N minus column K—so we've solved one problem of increasing production but we've encountered another problem of high failure cost from requiring 2 out of 2 operation.

The capital cost for this datum case is a sunk cost at zero value and thus the NPV = -$1,591,363. (Please note the cost of electricity for the pumps should also be added along with a host of other charges as noted in Figure 1!)

Alternative 1—Add a parallel large new pump for $75,000

This alternative simply adds a large pump in parallel as shown in Figure 3 with the failure data described in Figure 3.

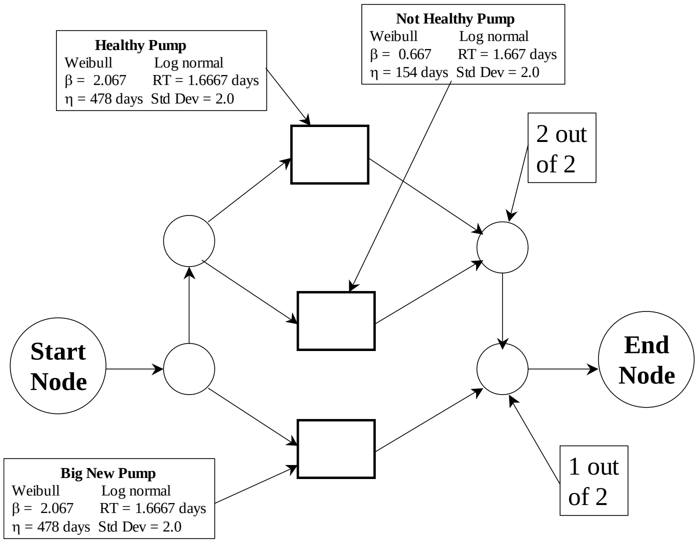


Figure 3: RAPTOR Monte Carlo Model For Addition Of A Large Parallel Pump

Results are summarized in Table 4. Note the system failures roughly the same as for Table 3 but the failure costs are substantially different because the parallel spare mitigates failures.

Table 4 - Failure Cost Details

Alternate #1: Add Large New Pump For $75,000 Capital Addition

All results based on 1000 trials for each year---statistical data reported for only the year studied.

Year	Days	Mean Red Time (two pumps down at same time), **(%)**	Mean Red Time Converted To Down Time For Total System Failures, **(hrs/year)**	Mean Number of Red Event System Failures. **(#)**	Mean Red Time For Complete System Failures Converted To Gross Margin Money Lost **($/year)**	Mean Yellow Time (System survives on 1 out of two) **(%)**	Mean Yellow Time For Cutbacks Converted To Downtown **(hours/yr)**	Mean Repair Time **(days/ failure)**	Maintenance Actions From Table 3 **(#/yr)**	Cutback Conditions Gross Margin Failure Cost Losses **($/yr)**	Gross Margin Losses From Cutbacks and Total System Failures **($/yr)**	Pump Mainte-nance Repair Costs **($/yr)**	Sum Of Gross Margin Losses & Repair Costs **($/yr)**
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**I**	**j**	**k**	**l**	**m**	**n**
		From RAPTOR	365*(c/100)*24	From RAPTOR	$10,000*d	From RAPTOR	365*(g/100)*24	From RAPTOR	h/(I*24)	$3,000*h	f + k	$10,000*(e + J)	L + N
1	365	0.002808	0.245981	0.009	$2,460	1.496662	0.0000	1.621665	2.788095	$0	$2,460	$27,971	$30,431
2	730	0.003180	0.278568	0.018	$2,786	1.525694	0.0000	1.645328	2.648978	$0	$2,786	$26,670	$29,455
3	1095	0.002636	0.230914	0.016	$2,309	1.523991	0.0000	1.591735	2.604294	$0	$2,309	$26,203	$28,512
4	1460	0.002888	0.252989	0.013	$2,530	1.540243	0.0000	1.641320	2.714365	$0	$2,530	$27,274	$29,804
5	1825	0.003342	0.292759	0.018	$2,928	1.558373	0.0000	1.658373	2.567228	$0	$2,928	$25,852	$28,780
6	2190	0.005548	0.486005	0.024	$4,860	1.652372	0.0000	1.680495	2.571034	$0	$4,860	$25,950	$30,810
7	2555	0.003415	0.299154	0.019	$2,992	1.588985	0.0000	1.692783	2.629023	$0	$2,992	$26,480	$29,472
8	2920	0.006000	0.525600	0.019	$5,256	1.676827	0.0000	1.759163	2.508935	$0	$5,256	$25,279	$30,535
9	3285	0.004139	0.362576	0.025	$3,626	1.534075	134.3850	1.708342	2.604980	$0	$3,626	$26,300	$29,926
10	3650	0.002161	0.189304	0.016	$1,893	1.586171	138.9486	1.618912	2.612981	$0	$1,893	$26,290	$28,183
11	4015	0.008591	0.752572	0.034	$7,526	1.530274	134.0520	1.643702	2.456795	$0	$7,526	$24,908	$32,434
12	4380	0.003305	0.289518	0.019	$2,895	1.507384	132.0468	1.568182	2.511686	$0	$2,895	$25,307	$28,202
13	4745	0.004369	0.382724	0.018	$3,827	1.560153	136.6694	1.629170	2.708196	$0	$3,827	$27,262	$31,089
14	5110	0.004655	0.407778	0.023	$4,078	1.607977	140.8588	1.725438	2.750358	$0	$4,078	$27,734	$31,811
15	5475	0.005434	0.476018	0.022	$4,760	1.678712	147.0552	1.694653	2.552981	$0	$4,760	$25,750	$30,510
16	5840	0.005960	0.522096	0.019	$5,221	1.566482	137.2238	1.145008	2.646048	$0	$5,221	$26,650	$31,871
17	6205	0.005148	0.450965	0.019	$4,510	1.566820	137.2534	1.641916	2.562249	$0	$4,510	$25,812	$30,322
18	6570	0.005380	0.471288	0.23	$4,713	1.500112	131.4098	1.612780	2.676297	$0	$4,713	$29,063	$33,776
19	6935	0.005484	0.480398	0.019	$4,804	1.556089	136.3134	1.646546	2.612177	$0	$4,804	$26,312	$31,116
20	7300	0.002263	0.198239	0.013	$1,982	1.525871	133.6663	1.696846	2.550883	$0	$1,982	$25,639	$27,621
			Average =	**0.030**	**$3,798**				**2.614**	**$0**	**$3,798**	**$26,435**	**$30,233**

Alternate 2—Add a new small pump for $50,000 for 2 out of 3 service

This alternative simply adds a small pump into a 2 out of 3 condition as shown in Figure 4 with the failure data described in the figure

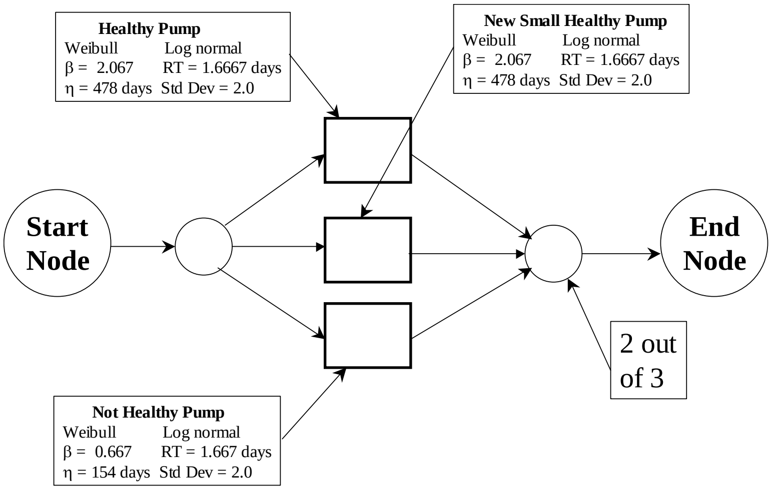


Figure 4: RAPTOR Monte Carlo Model For Addition Of A Small Pump For 2 Out Of 3 Operation

The results are summarized in Table 5. Note the system failures are roughly the same as for Table 3 and the costs are roughly the same for Table 4, however the capital costs are much lower.

Table 5-Failure Cost Details By Year

Alternate #2: Add Third Small Pump For $50,000 capital addition

All results based on 1000 trials for each year---statistical data reported for only the year studied.

Year	Days	Mean Red Time (two pumps down at same time), **(%)**	Mean Red Time Converted To Down Time For Total System Failures, **(hrs/year)**	Mean Number of Red Event System Failures. **(#)**	Mean Red Time For Complete System Failures Converted To Gross Margin Money Lost **($/year)**	Mean Yellow Time (System survives on 1 out of two) **(%)**	Mean Yellow Time For Cutbacks Converted To Downtown **(hours/yr)**	Mean Repair Time **(days/ failure)**	Maintenance Actions From Table 3 **(#/yr)**	Cutback Conditions Gross Margin Failure Cost Losses **($/yr)**	Gross Margin Losses From Cutbacks and Total System Failures **($/yr)**	Pump Mainte-nance Repair Costs **($/yr)**	Sum Of Gross Margin Losses & Repair Costs **($/yr)**
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**I**	**j**	**k**	**l**	**m**	**n**
		From RAPTOR	365*(c/100)*24		$10,000*d	From RAPTOR	365*(g/100)*24	From RAPTOR	h/(I*24)	$3,000*h	f + k	$10,000*(e + J)	L + N
1	365	0.005631	0.493276	0.024	$4,933	1.493357	0.0000	1.621734	2.788095	$0	$4,933	$28,121	$33,054
2	730	0.006598	0.577985	0.034	$5,780	1.522276	0.0000	1.645328	2.648978	$0	$5,780	$26,830	$32,610
3	1095	0.006315	0.553194	0.027	$5,532	1.511053	0.0000	1.588076	2.604294	$0	$5,532	$26,313	$31,845
4	1460	0.005134	0.449738	0.023	$4,497	1.542650	0.0000	1.641561	2.714365	$0	$4,497	$27,374	$31,871
5	1825	0.007489	0.656036	0.029	$6,560	1.557925	0.0000	1.626821	2.567228	$0	$6,560	$25,962	$32,523
6	2190	0.008598	0.753185	0.041	$7,532	1.640525	0.0000	1.679492	2.571034	$0	$7,532	$26,120	$33,652
7	2555	0.006485	0.568086	0.03	$5,681	1.585399	0.0000	1.692950	2.629023	$0	$5,681	$26,590	$32,271
8	2920	0.007761	0.679864	0.032	$6,799	1.646099	0.0000	1.748673	2.508935	$0	$6,799	$25,409	$32,208
9	3285	0.006247	0.547237	0.038	$5,472	1.506308	131.9526	1.669873	2.604980	$0	$5,472	$26,430	$31,902
10	3650	0.004558	0.399281	0.032	$3,993	1.561381	136.7770	1.621280	2.612981	$0	$3,993	$26,450	$30,443
11	4015	0.011695	1.024482	0.05	$10,245	1.534922	134.4592	1.644482	2.456795	$0	$10,245	$25,068	$35,313
12	4380	0.008187	0.717181	0.035	$7,172	1.548677	135.6641	1.609311	2.511686	$0	$7,172	$25,467	$32,639
13	4745	0.007047	0.617317	0.028	$6,173	1.557050	136.3976	1.643827	2.708196	$0	$6,173	$27,362	$33,535
14	5110	0.008371	0.733300	0.036	$7,333	1.606874	140.7622	1.707090	2.750358	$0	$7,333	$27,864	$35,197
15	5475	0.012698	1.112345	0.042	$11,123	1.643722	143.9900	1.690501	2.552981	$0	$11,123	$25,950	$37,073
16	5840	0.009475	0.830010	0.028	$8,300	1.598046	139.9888	1.654809	2.646048	$0	$8,300	$26,740	$35,041
17	6205	0.010576	0.926458	0.035	$9,265	1.558653	0.0000	1.634686	2.562249	$0	$9,265	$25,972	$35,237
18	6570	0.007056	0.618106	0.036	$6,181	1.506175	0.0000	1.612697	2.676297	$0	$6,181	$27,123	$33,304
19	6935	0.005098	0.446585	0.025	$4,466	1.560881	0.0000	1.641412	2.612177	$0	$4,466	$26,372	$30,838
20	7300	0.009203	0.806183	0.038	$8,062	1.604712	140.5728	1.675225	2.550883	$0	$8,062	$25,889	$33,951
			Average =	**0.033**	**$6,755**				**2.614**	**$0**	**$6,755**	**$26,470**	**$33,225**

Life Cycle Cost Details-

Table 6 summarizes the alternatives in terms of money. The two columns on the right hand side of the table go into the life cycle cost work sheet. The simple concept of payback shows the big new pump has a payback of $75,000/($312,287/yr) = 0.240 years or less than 3 months, and the small pump has a payback of $50,000/$309,295/yr) = 0.162 years or less than 2 months.

Table 6: Cost Summary Data For Life Cycle Cost Calculations

	Cost Details				**Savings**	
Year	Original Installation	After debottle-necking	Big new pump @ $75K	Little new pump @ $50K	Big new pump @ $75K	Little new pump @ $50K
1	$29,849	$366,045	$30,431	$33,054	$335,614	$332,991
2	$30,503	$335,632	$29,455	$32,610	$306,177	$303,023
3	$28,726	$337,425	$28,512	$31,845	$308,913	$305,580
4	$29,299	$349,465	$29,804	$31,871	$319,662	$317,594
5	$28,075	$334,769	$28,780	$32,523	$305,989	$302,246
6	$27,010	$341,875	$30,810	$33,652	$311,064	$308,223
7	$29,383	$342,578	$29,472	$32,271	$313,107	$310,307
8	$26,814	$335,202	$30,535	$32,208	$304,667	$302,994
9	$28,139	$349,358	$29,926	$31,902	$319,432	$317,456
10	$27,987	$340,216	$28,183	$30,443	$312,034	$309,774
11	$29,862	$344,555	$32,434	$35,313	$312,121	$309,242
12	$26,790	$335,626	$28,202	$32,639	$307,424	$302,987
13	$29,016	$350,714	$31,089	$33,535	$319,625	$317,179
14	$28,904	$343,361	$31,811	$35,197	$311,550	$308,165
15	$27,735	$325,512	$30,510	$37,073	$295,002	$288,439
16	$28,791	$333,877	$31,871	$35,041	$302,006	$298,837
17	$30,915	$337,752	$30,322	$35,237	$307,430	$302,515
18	$29,727	$362,241	$33,776	$33,304	$328,465	$328,937
19	$29,855	$324,722	$31,116	$30,838	$293,607	$293,885
20	$29,768	$359,474	$27,621	$33,951	$331,853	$325,523
Average=	$28,857	**$342,520**	$30,233	$33,225	**$312,287**	**$309,295**
	Cost Data				**Savings From Debottlnecking Datum**	

Using the cost numbers by year for the life cycle cost calculations shows a clear winner in Table 7: you can reduce the cost of unreliability about $309,295 per year---**add the third small pump** for a NPV = +$1,400,134 with an IRR = 354.1%. This is a run (don't walk) improvement project—please note the brief approach shown above does not include power cost savings, and other costs such as project management, etc which logically should be included to get the correct prospective. All of the cost details were not included to keep the example simple.

Table 7: Financial Summary

Project Summary Based On Failure Data

	NPV	**IRR**
Big New Pump @ $75K	$1,388,368	233.1%
Small New Pump @ $50K	$1,400,134	354.1%

Where Do You Find Data For Acquisition Cost?

Assembling data for acquisition cost is performed fairly well on most projects using the memory jogger of Figure 1. Often acquisition cost is the only number in the life cycle cost analysis, which is well defined by a bid price.

Other details of acquisition cost must be estimated from facts usually available within the business system. Scaling data up/down for specific cases is a well-established method. Assembling cost details by year of expenditure within the project life is never easy, but it must be done fairly meticulously as front-end money has greater impact than the same money spend in the last year of the project such as occurs with end of life issues.

Where Do You Find Data For Sustaining Cost?

Making the life cycle cost calculations is easy when you have the data. The difficult effort is how to resolve the chicken or egg dilemma for finding failure data, maintenance data, and other details involved in the sustaining cost section of Figure 1. You need reliability engineering details to find when things die. Failure data and repair time data can be converted into statistical format using WinSMITH Weibull software for use in reliability calculations. (Fulton 2004) Other Weibull databases are available on the Internet (Barringer 2004d).

Few individuals claim knowledge of sustaining cost facts until someone else puts numbers on the table—then the critics are numerous for “correcting” the proposed numbers. Follow the scientific method: build a hypothesis for failures and their cost and then test the hypothesis. When in doubt about the failure data or cost, make an estimate and test the estimate for validity.

Much data needed for Figure 1 comes from operating costs (including electricity, etc.) and maintenance records which show times between failure and repair times. These details are often associated with the field of reliability and maintainability with a direct relationship with finding lower life cycle costs. (SAE 1999) The cost details should also include costs for lost gross margin for outages of systems when it is appropriate. Reference lists for books and databases with extensive failure details are available on the Internet (Barringer 2004a) and training manuals (Barringer 2004 a&d) and from technical societies (SAE 1999). Some of the failure data is from simple arithmetic calculations and other data follows the preferred method from Weibull databases. (Abernethy 2000)

Failures and failure costs can be influenced by operating conditions, installation conditions, and maintenance conditions. These are different grades of influences for or against longer life. Often variable conditions require Monte Carlo simulations to find how costs will vary with time and the different grades of influences (Barringer 2004f). The Monte Carlo technique uses random numbers to solve the problems and spreadsheets are available at no cost to download from the Internet.

Your can build simple, low cost Monte Carlo reliability models using software available from the Internet which are useful for driving life cycle cost decisions. The reason for building reliability models is to find where failure cost is occurring and to search for the lowest long term cost of ownership as shown in Figure 2 where system details, when priced-out, provide a clear leading alternative for solving the problems. The reliability models show what’s affordable and the less desirable alternatives.

Reliability models, using actual failure data and repair times give system availability, reliability, maintainability, and other operating system details which allow construction of costs and tradeoffs. The reliability models provide evidence for tradeoff boxes. Engineers need graphics for understanding what’s happening to their systems. The tradeoff box has life cycle cost on the vertical axis and effectiveness on the horizontal axis. Effectiveness is the product of availability, reliability, maintainability, and capability of the system to perform. Complex items become simple when you see the results shown in Figure 5. The left hand of Figure 5 symbolizes the case of the datum resulting from de-bottlenecking without enhancing the equipment. The right hand of Figure 5 symbolizes the case of adding big equipment. The sweet spot in Figure 5 is symbolized by adding the small pump for a case of operating 2-out-of-3.

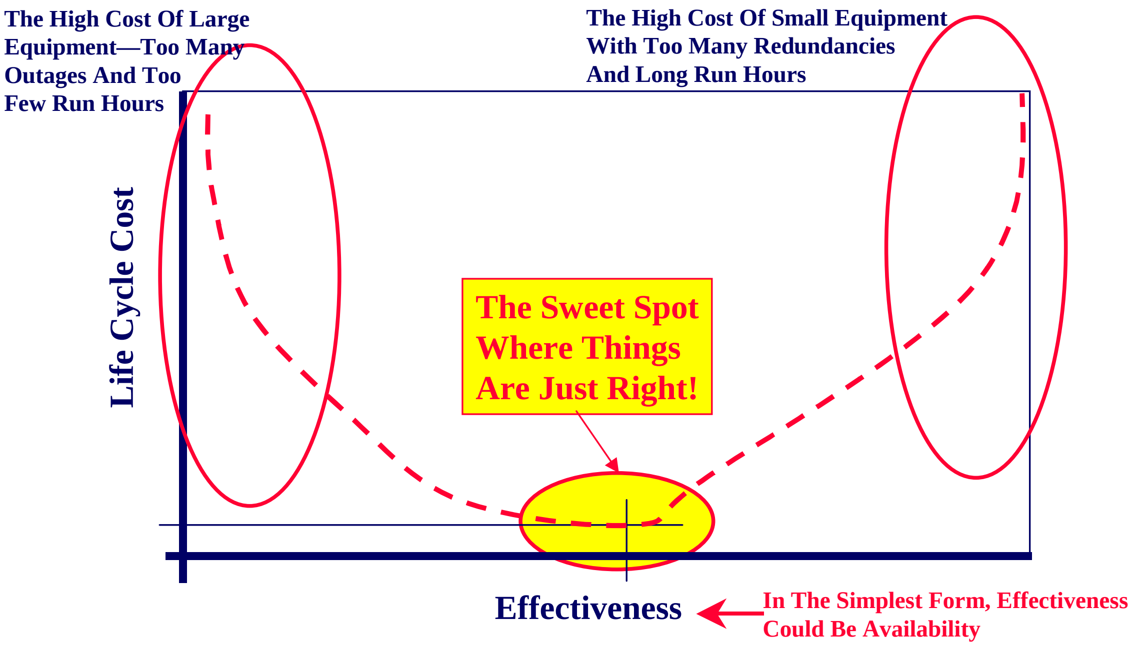


Figure 5: The Trade Off Box

What most companies need is the money and not perfect solutions! Life cycle cost helps provide the answers when driven by the tools of reliability engineering. When you have concepts and features on a product or process that generates value, the value must be quantified for inclusion in the life cycle cost model. Sometimes the view must be from the buyer's position and other times from the seller's position—the key issue is to quantify for inclusion into the model.

Engineers must provide sales people with life cycle cost calculations for their use as a sales tool. Rainmakers (sales people who can produce orders from a cloudless sky) in the Sales Department need the life cycle cost details to sell based on facts to produce orders it's a simple relationship.

Summary

Life cycle costs merge engineering details into a cost format that considers the time value of money. The life cycle concept relies heavily on reliability and maintainability technology issues to convert ideas into hard, cold engineering facts so the results can be converted into a monetary value.

The first cost for procurement is not the last cost. Procurement cost may represent only a small fraction of the total cost during the life of an item, and in other cases, it may be a large portion of the total life cycle costs—general rules of thumb have much variance.

The engineering facts must be converted into financial details of NPV and IRR with a selection of the best alternative from several courses of action. The decisions you make up front will be with you for many years so it's important to justify improvements using the best tools available.

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Biography

Paul Barringer, P.E. is a manufacturing, engineering, and reliability consultant with more than thirty-five years of engineering and manufacturing experience in design, production, quality, maintenance, and reliability of technical products. Experienced in both the technical and bottom-line aspects of operating a business with management experience in manufacturing and engineering for an ISO 9001 facility. Industrial experience includes the oil and gas services business for high pressure and deep holes, super alloy manufacturing, and isotope separation using ultra high speed rotating devices.

He is author of training courses: **Reliability Engineering Principles** for calculating the life of equipment and predicting the failure free interval**, Process Reliability** for finding the reliability of processes and quantifying production losses, and **Life Cycle Cost** for finding the most cost effective alternative from many equipment scenarios using reliability concepts.

Barringer is a Registered Professional Engineer, Texas. Inventor named in six U.S.A. Patents and numerous foreign patents. He is a contributor to **The New Weibull Handbook**, a reliability handbook, published by Dr. Robert B. Abernethy.

His education includes a MS and BS in Mechanical Engineering from North Carolina State University. He participated in Harvard University's three-week Manufacturing Strategy conference.

December 23, 2004