A Life Cycle Cost Summary

H. Paul Barringer, P.E.
Barringer & Associates, Inc.
Humble, Texas
USA

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SUMMARY: Life cycle costs (LCC) are cradle to grave costs summarized as an economics model of evaluating alternatives for equipment and projects. Engineering details drive LCC cost numbers for the economic calculations. The economics of proposals drives the scenario selection process. Good engineering proposals without economic justification are often uneconomical. Good engineering with good economics provide business successes. The LCC economic model provides better assessment of long-term cost effectiveness of projects than can be obtained with only first costs decisions.

Keywords: life cycle cost, net present value, lowest long term cost of ownership, economics

1. LIFE CYCLE COST DEFINITIONS

Life cycle cost is the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission (SAE 1999). LCC are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced in annual time increments during the project life with consideration for the time value of money. The objective of LCC analysis is to choose the most cost effective approach from a series of alternative**s** (note alternatives is a plural word) to achieve the lowest long-term cost of ownership. LCC is an economic model over the project life span. Usually the cost of operation, maintenance, and disposal costs exceed all other first costs many times over (supporting costs are often 2-20 times greater than the initial procurement costs). The best balance among cost elements is achieved when the total LCC is minimized (Landers 1996). As with most engineering tools, LCC provides best results when both engineering art and science are merged with good judgment to build a sound business case for action.

Businesses must summarize LCC results in net present value (NPV) format considering depreciation, taxes and the time value of money. Government organizations do not require inclusion of depreciation or taxes for LCC decisions but they must consider the time value of money.

2. INTRODUCTION

Procurement costs are widely used as the primary (and sometimes only) criteria for equipment or system selection based on a simple payback period. LCC analysis is required to demonstrate that operational savings are sufficient to justify the investment costs (often the investment costs, for the lowest long term cost of ownership, are greater than for the simple payback period).

Simple payback criteria are a relative measure for only one case. The more complicated LCC analysis works for comparing alternatives. The simple payback method is frequently used for small capital expenditures which are so clearly economical that the time and expense of a full LCC analysis is not worthwhile. Thus many companies demand short payback periods (1-1.5 years) to keep everything simple with a large financial hurdle for a short time payback which discourages capital projects unless they are big winners. The payback method uses the ($capital cost)/($benefit/year) ratio as a screen for a single project alternative (it is not particularly useful for sorting out multiple alternatives with variations in cost profiles and variations in capital).

Remember the adage attributed to John Ruston: “It’s unwise to pay too much, but it’s foolish to spend too little”—this is the operating principle of LCC. For capital expenditures above $10,000-$25,000 it is wise to consider the use of LCC. Procurement costs are only the tip of the iceberg but the damaging portion of the iceberg relates to the bulk of other costs associated with life cycle costing for equipment and systems.

Life cycle cost was strong in the 1960s when LCC was the subject of considerable interest and publications. Many original works on LCC are out of print. Newer publications are emerging such as:

1) **RMS Guidebook** (SAE 1995) for a life cycle cost summary,
2) **Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment** (SAE 1999) for introducing details on how equipment survives and how it is restored to operating conditions as a method for decreasing life cycle costs by way of both a strategy and tactics for how reliability tools, used up-front, can reduce costs and
3) **Life-Cycle Costing Manual for the Federal Energy Management Program NIST Handbook 135** (US Government 1995) for background and methodology for US Government calculations along with annual supplements for discount factors (US Government 2002).

SAE advocates reducing life cycle costs for equipment in the automotive sector by showing show/why reliability and maintainability must be included in upfront decisions for strategic and tactical issues of achieving the lowest long term cost on ownership. LCC concepts are resurging with US Government efforts to minimize energy costs.

Remember this adage when considering LCC limitations: "In the land of the blind, a one-eyed man is king!" LCC improves our blinded sight—we don't need the most wonderful sight in the world, it just needs to be more acute than our fiercest competitor so that we have an improvement in the cost of operating our plants. USA Department of Defense (DOD) tools and techniques are frequently used effectively in commercial areas and this is true of life-cycle costing. Numerous references to LCC papers are listed in cumulative indexes for a major symposium (RAMS 2001). Major references for LCC in the DOD area are MIL-HDBK-259 for LCC details, MIL-HDBK-276-1 and MIL-HDBK-276-2 as form guides for details and for importing data into specific software.

3. WHY USE LCC?

LCC helps change provincial perspectives for business issues with emphasis on enhancing economic competitiveness by working for the lowest long term cost of ownership which is not an easy answer to obtain. Consider these typical problems and conflicts observed in most companies:

1. **Project Engineering** wants to minimize capital costs as the only criteria,
2. **Maintenance Engineering** wants to minimize repair hours as the only criteria,
3. **Production** wants to maximize uptime hours as the only criteria,
4. **Reliability Engineering** wants to avoid failures as the only criteria,
5. **Accounting** wants to maximize project net present value as the only criteria, and
6. **Shareholders** want to increase stockholder wealth as the only criteria.

Management is responsible for harmonizing these potential conflicts under the banner of operating for the lowest long term cost of ownership. LCC can be used as a management decision tool for harmonizing the never ending conflicts by focusing on facts, money, and time. Why should engineers be concerned about cost details for LCC? It is important to help engineers <u>think like MBAs</u> and <u>act like engineers</u> for profit making enterprises--It's all about the money!

Economic calculations are well defined but the discount rate is important (US Government 2002). Accounting and finance organizations set internal discount rates (which often change) to make economic decisions easy for engineers. Discount factors reflect a host of relationships and considerations which include very low risk investment returns such as Government T-bills, factors for projects such as estimated uncertainty errors, internal rates of returns, and so forth. In general, consider a typical discount value of 12% which is neither very low nor very high for calculations which will follow (the discount rate can also be used for inflation/deflation factors):

1. **What is the present value (PV) of US$1.00 today over time?** *[Think what will be the real value of the loan made to your no-good brother-in-law if it every gets repaid.]*
2. **What is the future value (FV) of US$1.00 received over time?** *[Think what will be the value of your pension if you can live long enough to collect on it.]*

Cash flows into/out of a business. The discounting method summarizes transactions over the life of the investment in terms of present or future dollars. Table 1 discount rates (used as multipliers or dividers) put financial transactions into the present value of money to answer the two questions posed above.

Table 1: Present Value and Future Value

Discount Rate = 12%																					
Years hence	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Present value of US$1.00	1.00	0.89	0.80	0.71	0.64	0.57	0.51	0.45	0.40	0.36	0.32	0.29	0.26	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.10
Future value of US$1.00	1.00	1.12	1.25	1.40	1.57	1.76	1.97	2.21	2.48	2.77	3.11	3.48	3.90	4.36	4.89	5.47	6.13	6.87	7.69	8.61	9.65

Engineering always want a simple, single value, criteria for a project—the answer for LCC is called net present value (NPV). NPV is the present value of proceeds minus present value of outlays. Projects and processes with the greatest NPV is usually the winner. Often for incremental changes on a project or within a plant, you lack enough details to arrive at a positive NPV. Thus many improvement projects must be selected on the **least negative NPV** values from many alternatives. So once again, we can have the single number engineers always want—it's NPV but in this case, it's the **least negative NPV**.

Most fixed assets and other projects have a limited useful life. All equipment has a finite life based on both deterioration and obsolescence. The most common depreciation methods is straight line depreciation based on acquisition cost less salvage. Straight line depreciation is based on consumption of a fixed percentage of the equipment cost. Often straight line depreciation is used for internal accounting reports of profit/loss and for calculating NPV.

Income tax rates vary and may require inclusion of state as well as federal taxes. For calculation purposes, consider the tax rate is 38% based on the profit before tax numbers. Profit before taxes may be positive or negative. When profit before tax is negative, the company receives a tax credit either a carry-back or carry-forward. When profit before tax is positive, the company pays taxes. For a project or process, tax numbers are used to calculate cash flows. After the tax is included, the cash flow is discounted to get present value, and the sum of all present values gives the NPV.

Engineers must be concerned with life cycle costs for making important economic decisions through engineering actions. Management deplores engineers who are engineering bright but economics dim. Engineers must get the equation balanced to create wealth for stockholders. Often this means: **stop** doing some things the old way, and **start** doing new things in smarter ways such as using NPV decisions via LCC.

4. WHAT GOES INTO LCC?

LCC includes every cost that is appropriate and appropriateness changes with each specific case which is tailored to fit the situation. LCC follows a process (Fabryck 1991—Appendix A) as shown in Figure 1. The steps are:

Step 1-Identify what has to be analyzed and the time period for the project life study along with the appropriate financial criteria.
Step 2-Focus on the technical features by way of the economic consequences to look for alternative solutions.
Step 3-Develop the cost details by year considering memory joggers for cost structures.
Step 4-Select the appropriate cost model, simple discrete, simple with some variability for repairs and replacements, complex with random variations, etc. required by project complexity.
Step 5-Acquire the cost details.
Step 6-Assemble the yearly cost profiles.
Step 7-For key issues prepare breakeven charts to simplify the details into time and money.
Step 8-Sort the big cost items into a Pareto distribution to reconsider further study.
Step 9-Test alternatives for high cost items such as what happens if maintenance cost is ±10% than planned, etc.

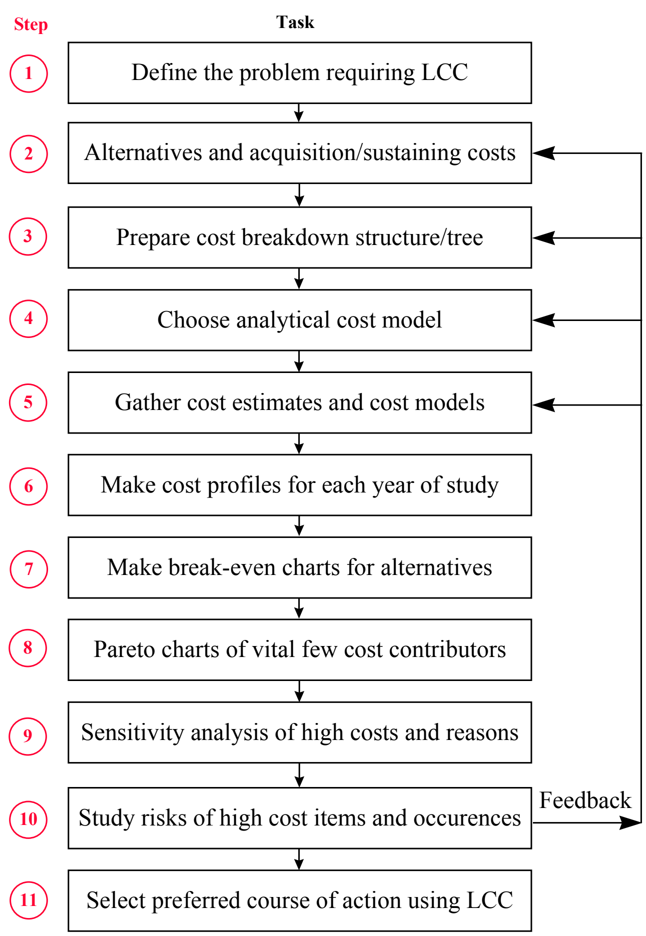

Figure 1: Life Cycle Costing Process

Step 10-Study uncertainty/risk of errors or /alternatives for high cost items as a sanity check and provide feedback to the LCC studies in iterative fashion
Step 11-Select the preferred course of action and plan to defend the decisions with graphics

The basic tree for LCC combines acquisition and sustaining costs as shown in Figure 2.

Acquisition and sustaining costs are not mutually exclusive. If you acquire equipment, you must sustain the acquisition, and you can't sustain without someone having acquired the item.

Acquisition and sustaining costs are found by gathering the correct inputs, building the input database, evaluating the LCC and conducting sensitivity analysis to identify cost drivers.

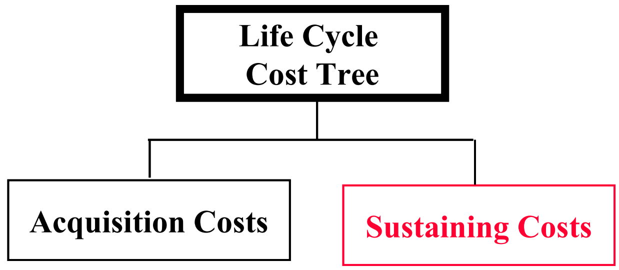

Figure 2: Top Level Of LCC Tree

Acquisition costs have branches for the cost tree shown in Figure 3 as a memory jogger.

Sustaining costs have branches for the tree as shown in Figure 4 which is also a memory jogger.

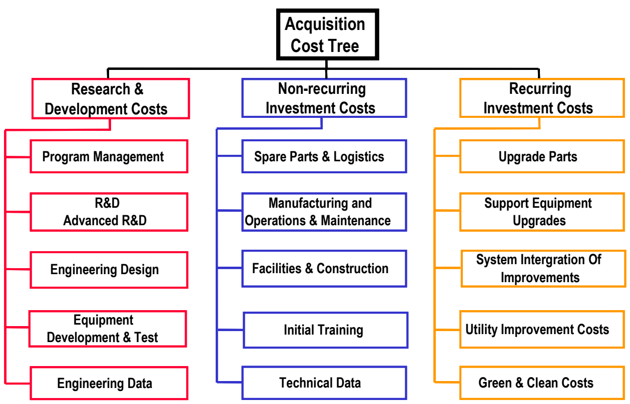

Figure 3: Acquisition Cost Tree

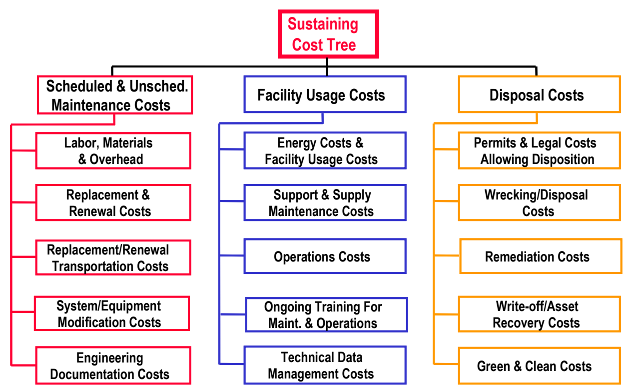

Figure 4: Sustaining Cost Tree

What cost goes into each branch of the acquisition and sustaining branches? It all depends on the specific case and is generally driven by common sense. Building a nuclear power plant to generate electricity requires special categories under each item of acquisition cost and sustaining cost. Building a pulp and paper mill or modifying coke drums at a refinery to prevent characteristic over-stress which occurs during coke drum quench cycles have different cost structures. Include the appropriate cost elements and discard the trivial elements which do not substantially influence LCC. Engineering sizes and aims the LCC cost funnel; production/maintenance pour money into the LCC money funnel.

5. ENGINEERING FACTS

LCC requires facts driven by data. Most engineers say they lack data. In fact, data is widely available as a starting point for LCC (Bloch 1995). Often data resides in local computer files but it has not been analyzed or put to effective use. Analysis can start with arithmetic analysis and grow to more complicated statistical analysis (Barringer 1996). Follow guidelines for each step listed in Figure 1 to work-out a typical engineering problem (remember, a single right or wrong method/solution does not exist--many methods and routes can be used to find LCC). If you disagree with the cost or life data, substitute your hypothesis values determined by local operating conditions, local costs, and local grades of equipment. Consider the following LCC example.

Step 1: Define the problem. A solo pump is operating without an online spare. At pump failure, the process shuts down and financial losses are incurred as each hour of down time results in a gross margin loss of US$4,000/hour of outage. Find an effective LCC alternative as the plant has an estimated 10 years of remaining life and is expected to be sold-out during this interval.

Step 2: Alternatives and acquisitions/sustaining costs. Consider three obvious alternatives for LCC (other alternatives exist for solving this problem, however, the list is pared for brevity):

1. Base case-do nothing. Continue solo ANSI pump operations with a 100 horsepower, 1750 RPM, 250 psi, 500 gpm, 70% hydraulic efficiency, pumping fluid with a specific gravity of 1.

2. Add a new, second ANSI pump in parallel (literally in redundant standby) which can be started immediately without the loss of production upon failure of the running pump. Alternate running of the parallel unit every other week to avoid typical failures incurred by non-operating equipment. The capital costs for the second pump is $8,000 plus $3,000 for check/isolation valves, plus $2,500 for installation.

3. Remove the existing solo ANSI pump and replace it with a new solo API pump with the same performance as for the ANSI model. The API pump cost $18,000 plus $3,500 for installation and the installation will incur a four hour loss of production for connecting the new pump.

Step 3: Prepare cost breakdown structure/tree. Refer to Figures 3 and 4 for memory joggers of the cost buckets to consider for three cases.

Alternative 1: In the do nothing case, the cost breakdown structure will incur cost is these categories: 1) For the solo pump, the acquisition costs are sunk and acquisition costs need not be considered, 2) Sustaining costs must be accumulated for labor, materials & overhead, replacement/renewal costs + transportation, energy costs + facilities costs, support + supply maintenance costs, operations costs, ongoing training costs, and for the end of life conditions disposal permits + wrecking/disposal + remediation + asset write-off/recovery costs + miscellaneous green/clean costs will be incurred. This case is Accounting's default condition and the case Engineering usually wants to ignore.

Alternate 2: For the addition of a dual ANSI pump the cost breakdown structure will incur acquisition costs for program management, engineering design, engineering data, facilities and construction costs. All of the sustaining costs for the solo case will be incurred plus system/equipment modification costs and engineering documentation costs.

Alternate 3: For the replacement of the ANSI solo pump with an API solo pump we will incur both acquisition and sustaining costs which will be different (but similar) to the dual ANSI case.

Step 4: Choose analytical cost model. The model used for this case is explained in an engineering spreadsheet. The spreadsheet merges cost details and failure details to prepare the NPV calculations. Failure costs are prorated into each year since the specific time for failure, because of chance events, is not known. The same spreadsheet will be used with more details when statistical uncertainty is added in a section which follows. LCC spreadsheets are available on the Internet (Barringer 2002).

Step 5: Gather cost estimates and cost models. This is the complicated section where all the details are assembled. Of course the more thorough the collection process, the better the LCC model. For this summary, the details have been shortened with enough just information described to show the trends. Use of MTBFs and expected failures are based on the exponential distribution which is an acceptable first-cut for costs, but this technique is not an accurate predictor of failures for wear-out phenomena expected for many of these components. An improved accuracy method uses Weibull distributions for failures (Abernethy 2000). Assume all of the equipment follows the exponential distribution for reliability with constant failure rates. Note the reciprocal of failure rate is the mean time to failure. Since failure rates are constant, use one year time buckets to collect the cost of failures per year as the literal failure date is unknown. Use the following assumptions based on an accounting principle that costs will follow activity—in this case it will follow failure activity.

Alternative #1-Do nothing case--the datum: Use the following details from plant experience—See (Barringer 1996) for detailed cost at http://www.barringer1.com/Papers.htm: select paper #7. Cost details are not provided here because of space limitations.

Alternative #2-Add redundant ANSI pump: Use the following details from plant experience—This case results in pumps installed in parallel but operated as a standby redundant system as the redundant components are not energized but are literally standing by waiting to be used when failure of the operating system is detected—of course the detection/switching device is very important for calculating overall system reliability and for this case the reliability is assumed to be 100%. Also for simplicity, the reliability of the system is calculated as if the redundant pumps are operating in parallel. Again, cost details are listed in (Barringer 1996).

Alternative #3-Replace Solo ANSI pump With Solo API Pump: Use the following details from plant experience—Again, the cost details are listed in (Barringer 1996).

Step 6: Make cost profiles for each year of study. This step will take into account the annualized charges plus the lumped charges at the front and rear end of the project as shown in Table 2.

Table 2

	Year 0	1	2	3	4	5	6	7	8	9	10
Alternative #1-Existing Solo ANSI Pump											
Capital	0										
Cost		57827	57827	57827	57827	57827	57827	57827	57827	57827	60827
Savings		0	0	0	0	0	0	0	0	0	0
Depreciation	0	0	0	0	0	0	0	0	0	0	0
Profit b/4 taxes		-57827	-57827	-57827	-57827	-57827	-57827	-57827	-57827	-57827	-60827
Tax Provision		21974	21974	21974	21974	21974	21974	21974	21974	21974	23114
Net Income		-35853	-35853	-35853	-35853	-35853	-35853	-35853	-35853	-35853	-37713
Add Back Depreciation		0	0	0	0	0	0	0	0	0	0
Cash Flow	0	-35853	-35853	-35853	-35853	-35853	-35853	-35853	-35853	-35853	-37713
Discount Factors	1.00	1.12	1.25	1.40	1.57	1.76	1.97	2.21	2.48	2.77	3.11
Present Value	0	-32011	-28582	-25519	-22785	-20344	-18164	-16218	-14480	-12929	-12142
Net Present Value	$ (203,175)	using a 12% discount rate									
Alternative #2-Add Parallel/Redundant ANSI Pump											
Capital	13500										
Cost	3500	21493	21493	21493	21493	21493	21493	21493	21493	21493	24493
Savings		0	0	0	0	0	0	0	0	0	0
Depreciation		1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Profit b/4 taxes		-22843	-22843	-22843	-22843	-22843	-22843	-22843	-22843	-22843	-25843
Tax Provision		8680	8680	8680	8680	8680	8680	8680	8680	8680	9820
Net Income		-14163	-14163	-14163	-14163	-14163	-14163	-14163	-14163	-14163	-16023
Add Back Depreciation		1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Cash Flow	-17000	-12813	-12813	-12813	-12813	-12813	-12813	-12813	-12813	-12813	-14673
Discount Factors	1.00	1.12	1.25	1.40	1.57	1.76	1.97	2.21	2.48	2.77	3.11
Present Value	-17000	-11440	-10214	-9120	-8143	-7270	-6491	-5796	-5175	-4620	-4724
Net Present Value	$ (89,993)	using a 12% discount rate									
Alternative #3-Replace ANSI Pump With Solo API Pump											
Capital	18000										
Cost	12900	44444	44444	44444	44444	44444	44444	44444	44444	44444	47444
Savings		0	0	0	0	0	0	0	0	0	0
Depreciation		1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Profit b/4 taxes		-46244	-46244	-46244	-46244	-46244	-46244	-46244	-46244	-46244	-49244
Tax Provision		17573	17573	17573	17573	17573	17573	17573	17573	17573	18713
Net Income		-28671	-28671	-28671	-28671	-28671	-28671	-28671	-28671	-28671	-30531
Add Back Depreciation		1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Cash Flow	-30900	-26871	-26871	-26871	-26871	-26871	-26871	-26871	-26871	-26871	-28731
Discount Factors	1.00	1.12	1.25	1.40	1.57	1.76	1.97	2.21	2.48	2.77	3.11
Present Value	-30900	-23992	-21422	-19126	-17077	-15247	-13614	-12155	-10853	-9690	-9251
Net Present Value	$ (183,328)	using a 12% discount rate									

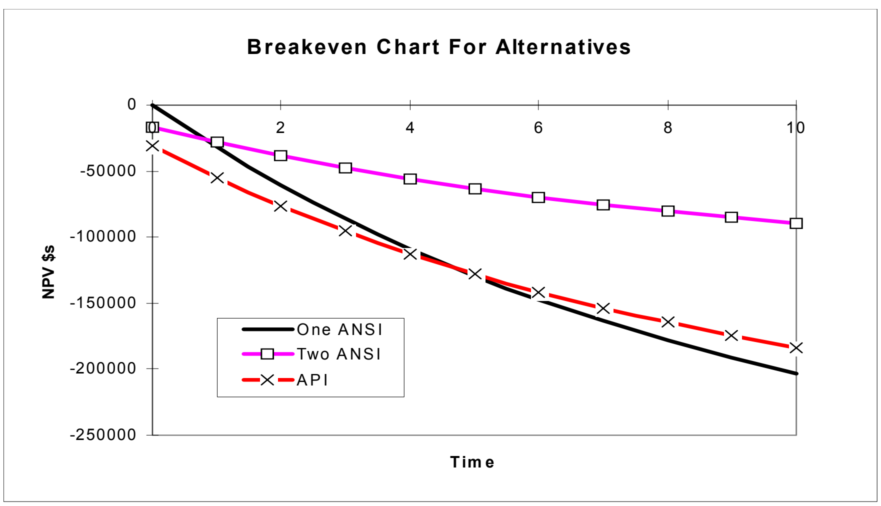

Figure 5: Breakeven Chart

Based on these alternatives in Table 2, adding the ANSI pump in parallel looks more attractive based on the NPV at the 12% discount rate using straight line depreciation and planning for a 38% tax rate. No revenue stream is included in these calculations so the case with **the least negative NPV will be the most attractive case**. Remember each company will have it's favorite discount rate, depreciation schedule, and method for making capital decisions. That means local conditions may prevail in making decisions.

Step 7: Make break-even charts for alternatives. Breakeven charts are useful tools for showing effects of fixed and variable costs. Results for the three alternatives are shown in Figure 5 for a quick grasp of how the breakeven points compare to the base case.

In Figure 5, net present values are shown on the Y-axis to combine cost of money with time and show how the effects of expenditures and cost reductions play together. Of course the issue is to choose alternatives which payback quickly and payback big returns with favorable NPVs which for this case favors the dual ANSI pumps.

Step 8: Pareto charts of vital few cost contributors.

The purpose of Pareto charts is to identify the vital few cost contributors so the details can be itemized for sensitivity analysis and ignore the trivial many issues. Pareto rules say that 10 to 20% of the elements of a cost analysis will identify 60% to 80% of the total cost—these high cost items are the vital few items of concern and need to be carefully considered.

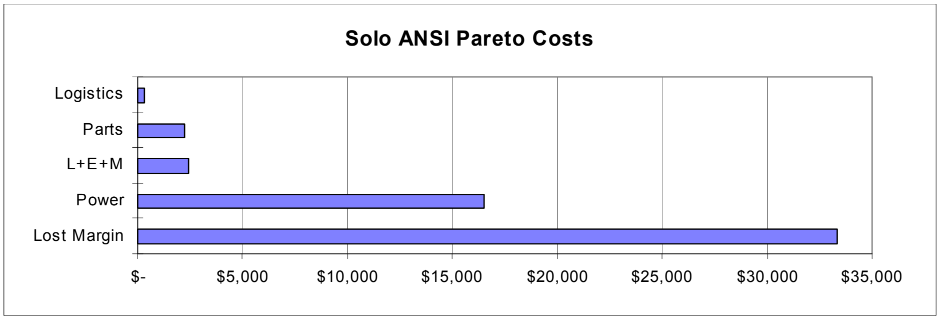

Figure 6: Pareto Cost Chart For Solo ANSI Pump

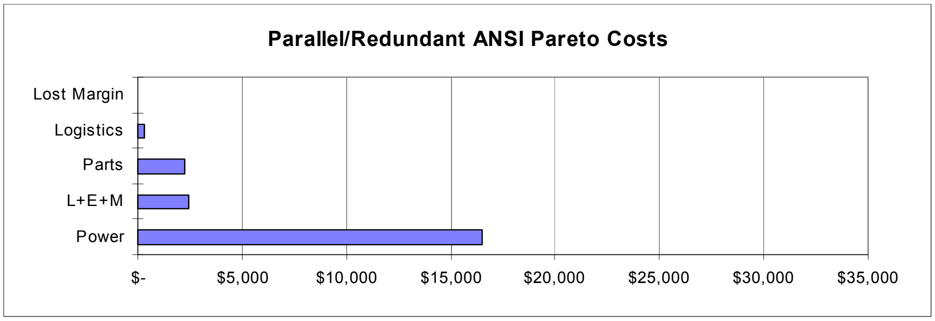

Figure 7: Pareto Cost Chart For Parallel/Redundant Pumps

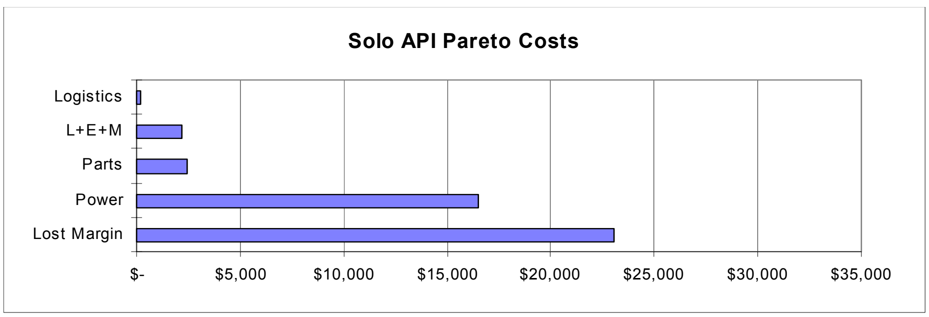

Figure 8: Pareto Cost Chart For Solo API Pump

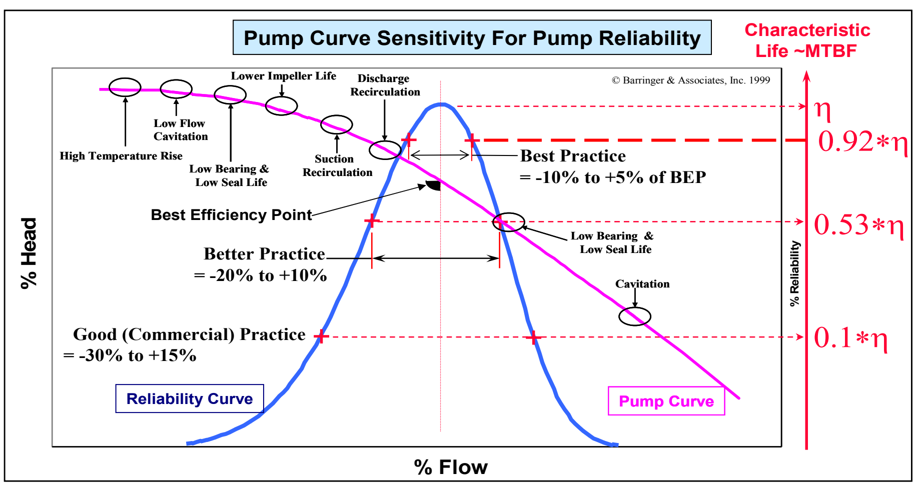

Figure 9: Pump Reliability vs Pump Curve

The cost elements for the solo ANSI pump are shown in Figure 6 with the high cost of lost gross margins more than twice the cost of the next item. Compare the absolute magnitude of the costs with the cost elements for Figures 6, 7, and 8.

When redundant ANSI Pumps are installed, the Pareto chart looks substantially different as shown in Figure 7 where electrical power becomes the most significant cost item.

When a API pump is substituted for the ANSI pump, the Pareto cost look similar to Figure 6 but the magnitude is different as shown in Figure 8.

Step 9: Prepare sensitivity analysis of high costs and reasons for high cost. Sensitivity analysis allows study of key parameters on LCC. In Table 2 the analysis begins with mean time between failures which drives the failure rate. Since all of the components are in series, the failure rates for the exponential distribution can be added to obtain an overall failure rate for the system. Figure 6 shows the key for controlling cost is to avoid the downtime which results in lost gross margin caused by unreliability.

If an inferior operating philosophy that "…all pumps cavitate…" then reliability within the plant will be low as equipment will be killed before it reaches its inherent life span. Figure 9 (Barringer 2003) illustrates the sensitivity of pump reliability to pump curves and other well known problems. The shape of the reliability curve is dependent upon many pump features and operating conditions.

Step 10: Study risks of high cost items and occurrences. Failure data is available from many sources (Bloch 1994) or (Bloch 1995) to test if the assumptions made in the analysis are valid or if unusual risks have been taken with numbers used in the study. Consider the following failure rate values in Table 4 as failure rate or the reciprocal MTBF which shows the failure data used for the analysis is within the expected range

Table 3: Failure Data				
	Failure rate (failures/10^6 hours)		MTBF (years)	
Item	Low	High	Low	High
Ball Brgs	4	70	1.6	28.5
Couplings	3	40	2.9	38
Housing				
Impeller	0.7	8	14.3	163
Motors	5	900	0.1	22.8
Seals	20	30	3.8	5.7
Shafts	3	20	5.7	38.1

Step 11: Select preferred course of action using LCC. The selection of a parallel/redundant strategy using ANSI pumps is the most attractive alternative out of the three proposed because it avoids process failure and thus reduces the high cost of unreliability. Buy equipment which is electrical power efficient and correctly sized with high hydraulic efficiency to make substantial reductions in electrical power consumption which is usually a hidden cost item but clearly identified by LCC as a vital element.

7. SUMMARY

Life-cycle costs include cradle to grave costs converted to NPV economic models. When failure costs are included, the quantity of maintenance manpower required can be engineered which avoids the use of antique rules of thumb about how maintenance budgets are established. LCC is a method to correctly consider long term business decisions which have advantages for profitability. LCC is not easy, but it is effective for building a sound business case for action.

LCC techniques provide methods to consider trade-off ideas with visualization techniques as described above which are helpful for engineers. Likewise LCC analysis provides NPV techniques of importance for financial organizations, and LCC details give both groups common ground for communication to aid in insuring sound business decisions and actions. LCC is the "laser guided missile" attack on important business problems for projects and processes—of course it requires greater sophistication than attacking problems with proverbial "hammers, tongs, and brute force".

Good alternatives for LCC require creative ideas. This is the role of the engineer to suggest and recommend cost effective alternatives. Much lower LCC are obtained when creative efforts are employed in the design area--making changes downstream in the operating plants has smaller chances for improvements because it's employed too late in the improvement cycle. Design engineers are the most important link in devising cost effective plants and naturally the burden of LCC falls on their shoulders—but design engineers can't perform an effective analysis unless they have reasonable failure data from operations. Thus the need for plant and industry databases of failure characteristics—remember, to obtain good failure data, both failure and success data must be identified.

LCC is simply a way-stop on the never ending journey for reducing costs. LCC is clearly not a destination. LCC provides the tools to engineer maintenance budgets, ownership costs, and present decision making scenarios in a financial perspective to achieve the lowest long term cost of ownership.

8. REFERENCES

Abernethy, Robert B., **The New Weibull Handbook**, 4th edition, 536 Oyster Road, North Palm Beach, FL 33408-4328 (2002)

Barringer, H. Paul and David P. Weber, *"Life Cycle Cost Tutorial"*, **Fifth International Conference on Process Plant Reliability**, Gulf Publishing Company, Houston, TX. (1996)

Barringer, H. Paul, *"Download free Life-Cycle Cost Spreadsheet"*, **http://www.barringer1.com (**2002)

Barringer, H. Paul, **Reliability Engineering Principles** (a training course), Barringer & Associates, Inc., P.O. Box 3985, Humble, TX 77347-3985 (2003)

Bloch, Heinz P. and Fred K. Geitner, **Practical Machinery Management for Process Plants, Volume 2: Machinery Failure Analysis and Troubleshooting**, 2nd Edition, Gulf Publishing Company, Houston, TX (1994)

Bloch, Heinz P. and Fred K. Geitner, *"Simplified Life-Cycle Cost Computations Applied in the Hydrocarbon Processing Industries"*, **Fourth International Conference on Process Plant Reliability**, Gulf Publishing Company, Houston, TX. (1995)

Fabrycky, Wolter J., Benjamin S. Blanchard, **Life-Cycle Cost and Economic Analysis**, Prentice-Hall, Englewood Cliffs, NJ (1991)

Landers, Richard R., **Product Assurance Dictionary**, Marlton Publishers, 169 Vista Drive, Marlton, NJ 08053. (1996)

MIL-HDBK-259, *Military Handbook, Life Cycle Cost in Navy Acquisitions*, available from Global Engineering Documents, phone 1-800-854-7179 (1 April 1983)

MIL-HDBK-276-1, *Military Handbook, Life Cycle Cost Model for Defense Material Systems*, Data Collection Workbook, Global Engineering Documents, phone 1-800-854-7179 (3 February 1984)

MIL-HDBK-276-2, *Military Handbook, Life Cycle cost Model for Defense Material Systems Operating Instructions*, Global Engineering Documents, phone 1-800-854-7179 (3 February 1984)

RAMS 2001: Proceedings Annual Reliability and Maintainability Symposium, *"Cumulative Indexes"*, page cx-29 for LCC references, available from Evans Associates, 804 Vickers Avenue, Durham, NC 27701 (2001)

Society of Automotive Engineers (SAE), **Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment, M-110.2**, Warrendale, PA (1999)

Society of Automotive Engineers (SAE), *"Life Cycle Cost"*, **Reliability, Maintainability, and Supportability Guidebook**, 3rd edition, Warrendale, PA (1995)

United States Government: Sieglinde K. Fuller and Stephen R. Petersen, **Life-Cycle Costing Manual for the Federal Energy Management Program, NIST Handbook 135**, available for download as a PDF file from http://www.bfrl.nist.gov/oae/publications/handbooks/135.pdf (1995)

United States Government: Sieglinde K. Fuller and Stephen R. Petersen, **Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – April 2002 [Annual Supplement to NST Handbook 135 and NBS Special Publication 709]**, available for download as a PDF file from http://fire.nist.gov/bfrlpubs/build02/PDF/b02017.pdf (2002)

BIOGRAPHIC INFORMATION-

H. Paul Barringer, P.E.
Manufacturing, engineering, and reliability consultant and author of the basic reliability training course **Reliability Engineering Principles,** a practical financial evaluation course **Life Cycle Costs**, and a high level method of assessing and understanding for a course in **Process Reliability**. More than forty years of engineering and manufacturing experience in design, production, quality, maintenance, and reliability of technical products. He is a contributor to **The New Weibull Handbook**, a reliability engineering text published by Dr. Robert B. Abernethy. Barringer is named as inventor in six U.S.A. Patents and numerous foreign patents. Registered Professional Engineer in Texas. Education includes a MS and BS in Mechanical Engineering from North Carolina State University, and participated in Harvard University's three week Manufacturing Strategy conference. Visit the World Wide Web site at **http://www.barringer1.com** for other background details or send e-mail to **hpaul@barringer1.com** concerning LCC or reliability issues.

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