Life Cycle Cost Analysis—Who Does What?

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ABSTRACT
Life cycle cost (LCC) analysis works toward finding the lowest long term cost of ownership (usually the view point of the investor) rather than simply cheapest first cost (usually the view point of project management). Roles and responsibilities for preparing the LCC details are described for petrochemical and refining applications. Practical tips for effective analysis and presentation are given.

KEYWORDS
Life cycle cost, net present value, roles and responsibilities, project cost, first cost, reliability, availability.

INTRODUCTION

Life cycle costs are all costs expected during the life of an item over some finite study period. This means costs associated with acquisition and ownership of a system over its full life must be estimated and timed for the year of the expenditure. The summation of all costs from project inception to disposal of assets must be described in terms of the time value of money, which is the driver, for knowing how much money will be spent in each time slot.

Net present value (NPV), a financial term, is the most important single criteria for LCC. NPV takes into account financial impacts considering that money has other alternatives rather than being tied-up in a fixed asset or project. Engineering drives the cost study of alternatives for producing the lowest long term cost of ownership which must include consideration for alternatives/trade-offs for completing tasks to achieve the most favorable NPV.

Life cycle costs are affected by three important issues in addition to the obvious capital costs:

1. Installation and use practices are influenced by engineering and operations. Practices define loads, equipment defines strengths, and usage determines life of the components. Equipment life/death must be converted into money decisions (Barringer 1998).
2. Component life and death are influenced by the grade of equipment carrying the loads. Equipment grades have finite load carrying capability which defines when/how components live and die. Death of equipment defines maintenance demands and equipment outages which denies use of the equipment for productive use.
3. Load profiles during various segments of the use cycle are very important considerations. The simple use of "average" loads and "average" strengths are perilous decisions which generate inaccurate cost profiles and significantly influence life cycle costs. Be care of the "average" generalizations—they are traps!

Engineering thinks Accounting should produce the LCC analysis because Accounting is involved with money. Accounting thinks Engineering should prepare the LCC analysis since the three items mentioned above (installation/use practices, equipment grade driving equipment life/death, and load/strength profiles) determine equipment life/maintenance which converts to money. Accounting lacks the expertise to make the engineering calculations, but Engineering can produce most of the numbers needed for Accounting's oversight review.

This means Engineering must be responsible for preparing the life cycle cost analysis. Accounting is responsible for validating/auditing authenticity of the calculations. This defines the first set of roles and responsibilities for "who does what?" in LCC. Since Engineering has many disciplines, the life cycle cost problem must be broken into components for each discipline to solve, and then aggregated into the final LCC model.

All systems are born and all systems die following the precepts of entropy. Entropy is the scientific principle explaining why batteries run down with time, why buildings in time will fall down, and why components naturally progress from functioning to failed. System deterioration is inevitable and deterioration drives costs. Deterioration is slowed by preventive maintenance actions to prolong equipment life. When all life has been consumed and entropy has moved from order to disorder then maintenance replacements are required. Each step involves costs.

Propaganda from universities says engineers build systems to never fail using safe engineering principles (unfortunately many people believe this propaganda). Universities also teach the principle of entropy that systems move from order to disorder unless interventions occur to prevent the disorder. Unfortunately engineers often lack ways to calculate the life and maintenance efforts for handling entropy changes because it's too hard to quantify both life issues and maintenance issues--thus we ignore the effort and the costs. Since engineers "believe" their designs never fail, most engineers lack reliability/maintainability tools for calculating equipment life/death/maintenance. The inability to compute equipment failures driving replacement/repair costs means we're trapped by our own propaganda--this makes life cycle cost decisions both faulty and difficult.

Reliability problems are entropy driven failures. Failures cost money. Failures occur when a product or process cannot perform its intended function. Downtime is one measurement of equipment and process failures. The cost/price paid for failures is highly dependent upon the ground rules used for calculations. For example, a sold out manufacturing process has a high penalty cost for failures when product cannot be deliverd. However, if the process is not sold out, then failure cost may be much smaller. Life cycle cost techniques require a method for analyzing the failure data using appropriate cost profiles to reflect alternatives for converting failure problems into money decisions. The failure costs need to also reflect reality that failures have different prices at different time in the economic cycle. Forecasting future failures is explained in The New Weibull Handbook (Abernethy 2002).

The Society of Automotive Engineers (SAE) has been addressing the issue of life cycle costs (SAE 1999) which is driven by the automotive industries ~US$4-billion/yr capital expenditures. The SAE model is directly applicable to NPRA activities. SAE's guide embraces the concept of up-front engineering plus continuous improvement in the design/operation of equipment and machinery to work toward the lowest long term cost of ownership through the use of reliability and maintainability (R&M) principles.

SAE's approach requires up-front engineering efforts to include the use of reliability and maintainability calculations leading toward lower life cycle costs. SAE's advocacy for reliability improvement is to increase productivity and throughput by designing-out failures. Increased reliability implies fewer machinery and equipment failures to provide less downtime consequences and reduce production costs. SAE's advocacy for maintainability improvement is to insure that reliable equipment is more failure free and repaired quickly and safely to reduce downtime. Both reliability and maintainability issues work toward reducing life cycle costs particularly when an organized engineering effort is driven by up front engineering calculation and not by engineering proclamation (this means making engineering decisions for plants and equipment based on the numbers—not opinions).

In petrochemical and refining businesses, reliability and maintainability capabilities are growing. Sadly, most R&M effort comes after completion of the engineering design. Late arrival of R&M tools denies significant gains. Bigger gains in influencing LCC occurs from doing more and better engineering up-front as shown in Figure 1.

Figure 1's dashed line shows great opportunity for influencing LCC with up-front decisions. Little LCC opportunity exists for meaningful changes after the bricks and mortar are in place as you can't significantly influence the LCC outcome by making decisions after selection and installation of equipment. Figure 1 is similar to a guided missile where up-front decisions significantly influence the impact point.

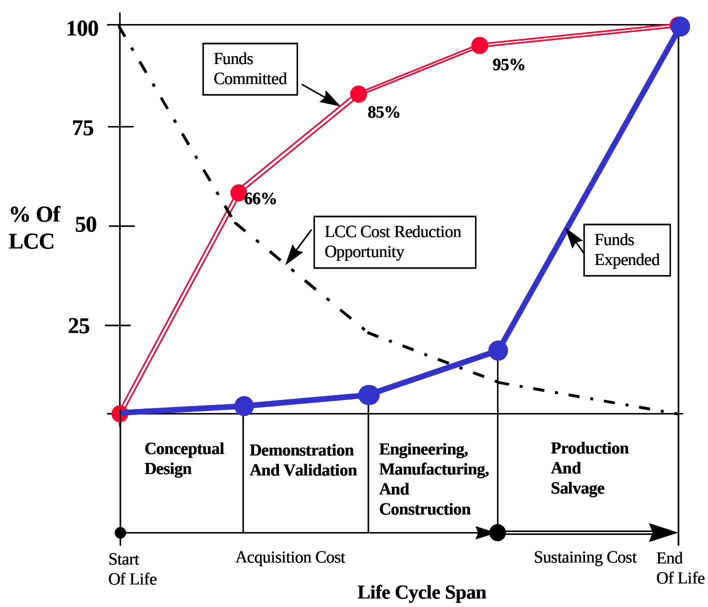

Figure 1: Commitment And Expenditure Trends

Life cycle costs of equipment or a facility begin with setting the design objective and then producing engineered numbers to design-in availability, reliability, and maintainability, which in turn, drive other decisions. First a few definitions:

- **Operational availability** is uptime expressed as a percentage of uptime plus downtime. Uptime is time for useful production activity where as downtime is not productive time as the system cannot be used for production activities (the denominator for availability in continuous process plants is 8760 hrs/year). The issue is to set the availability value and to design the process/equipment to achieve the results.
- **Reliability** is the probability that a device, system, or process will perform its prescribed duty without failure for a given time when operated correctly in a specified environment. Reliability is paced by the failure rate, mean time between failures, or the number of failures in a given time period. Failures define unreliability and absence of failures defines reliability. Restoration of failures contributes to downtime in the availability equation.
- **Maintainability** is the probability that a machine/process can be retained in or restored to specified operable condition within a specified interval of time, when maintenance is performed in accordance with prescribed procedures. Maintainability is a characteristic of design, installation and operation of equipment. Maintainability is influenced by the time allowed to perform the task and how frequently the task can be completed within the allotted time.
- **Maintenance** is an activity carried out to retain an item in, or restore it to, an acceptable condition for use or to meet its functional standard. Maintenance includes scheduled and unscheduled activities but does not include minor construction or change work.

Setting the availability, reliability, and maintainability goals is an up-front business decision that drives design of the plant, equipment and process. The business team is responsible for setting the goals for availability, reliability, and maintainability with primary leadership from engineering plus support from manufacturing. Engineering is responsible for implementing design, by the numbers, with verification of the numbers by calculation to achieve the goals set by the business team. The lowest long term cost of ownership is LCC resulting from the design with consideration for the trade offs. Implementing RAM tools into the design effort requires commitment, strategy, and action with planned activities during each phase of the plant, machinery, equipment, and process life cycle.

Here are some examples of availability, reliability, and maintainability: Airliners are designed to achieve operational availability of greater than 97%. Airliner gas turbine engines are designed for not less than 25,000 hours per in-flight shutdown. Removal and reinstallation of commercial gas turbine aircraft engines is planned for 2.5 hours per maintenance event. None of these business oriented statements were easy to accomplish. The criteria were driven by economics and the design effort. Up-front reliability and maintainability improvements lead to lower life cycle costs. Wise men will tell you buying cheap is usually no bargain. The problem with a mentality of "cheap first cost" is simple; the first small cost is not the last big cost. Often the mentality of plant and equipment is to spend a small amount up front and pay through the nose later because "it's not on my watch" gamesmanship.

One easy way to get the lowest long term cost of ownership is to require the design team, project management, and signers of the authorization for expenditures to remain at the new or improved facility for a period of not less than seven years as a responsible member of the organization. This simple "ownership" requirement will avoid the usual buy cheap and pay later for many problems using a Pilate Pontus justification for lack of responsibility

The new approach espoused by SAE in Figure 2 is for reducing life cycle costs by spending more effort up front for both the conceptual design (+1%) and detailed design (+3%) with emphasis on applying reliability and maintainability tools to reduce build and install costs (-3%) with greater cost reduction achieved (up to -15%) during operation of the facility. The way to save life cycle cost money is by using R&M tools to reduce the long term cost of ownership.

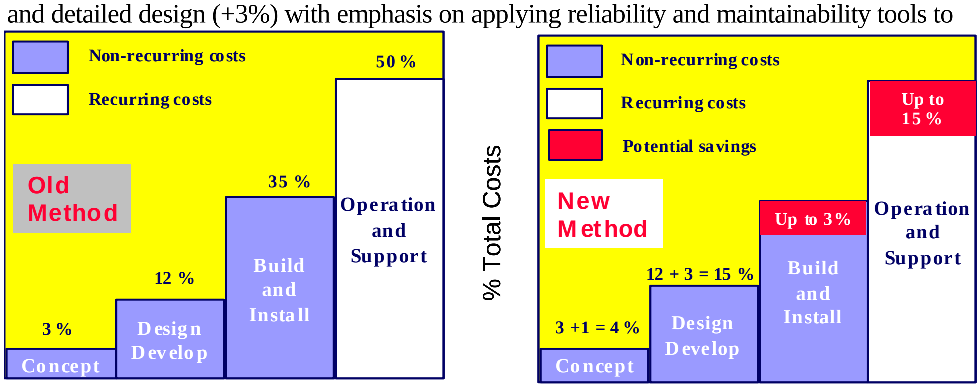

Figure 2: Old/New Approaches To Lower Life Cycle Costs

The structured up front effort in the concept and proposal phase emphasizes setting reliability requirements, maintainability requirements, defining what a failure is, and establishing the environment/usage issues as shown in Figure 3. The details for the RAM issues drive the way the equipment and process will look so the preliminary bills of material are set with many thoughtful decisions rather than based on only a few sketchy details.

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

The Big PictureTasks	Concept & Proposal Phase	Design & Development Phase	Build & Install Phase	Operation & Support Phase	Conversion Or Decomm. Phase
Set Availability Requirements	X				`
Set Reliability Requirements	X				
Set Maintainability Requirements	X				
Define Functional Failures	X				
Define Environment/Usage	X				
Define Capital Budgets and Make TradeOff Decisions	X	X			
Set Design Margins		X			
Design For Maintainability		X			
Make Reliability Predictions		X			
Do FMEA & Fault Tree Analysis		X			
Do Preliminary Cost Of Unreliability		X			
Conduct Design Reviews		X			
Make Machinery Parts Selections		X			
Do Tolerance/Process Studies		X			
Do Critical Parts Stress Analysis		X			
Do Reliability Qualification Testing			X		
Do Reliability Acceptance Testing			X		
Do Reliability/Maintainability Growth Improvement		X	X	X	
Collect Failure Reports & Analize			X	X	
Provide Data Feedback	X	X	X	X	X

Figure 3: When R&M Tools Are Introduced Into Project Phases

Development of the design follows conceptual design by defining loads to be carried with strengths established to fix the design margins to prevent the overlap of loads/strengths that drive many failures. Likewise maintainability designs are planned and goals set for the length of allowed downtimes and achievement of the goals is designed into the equipment and facilities. Reliability predictions are made to quantify the decisions with Monte Carlo models based on factual details of life/death experienced in existing facilities. Lessons learned are formally converted to hard copies and meticulously introduced into the detailed designs. Failure modes and effects analysis (FMEA) are performed during the designs as a bottoms up effort to find weakness while top down experience is introduced during the design with fault tree analysis (FTA) to include operating experience into the design to attack roots of the problems for resolution on paper rather than in the operating plants. This effort is driven by both engineering and suppliers to make issues fact driven to price out the consequences for the important upfront decisions in Figure 3.

Details in Figure 3 are tailored for each project. More detail for some projects; less for others. Convert long term consequences into time when expenditures are expected and money to cover the expected costs into the future. This will balance the usual case of emphasizing the acquisition costs and going blind to the sustaining costs which give the top level cost details as explained in Figure 4 as described in Barringer and Weber (1996) which discusses the nuts and bolts of LCC. Furthermore LCC will also encourage truthful realization that contrary to good salesmanship, equipment and processes do fail and they require expensive nurturing for survival (you do recall the usual drill: “My equipment and processes never fail but you should buy this list of spare parts and plan for turnarounds every X-years”).

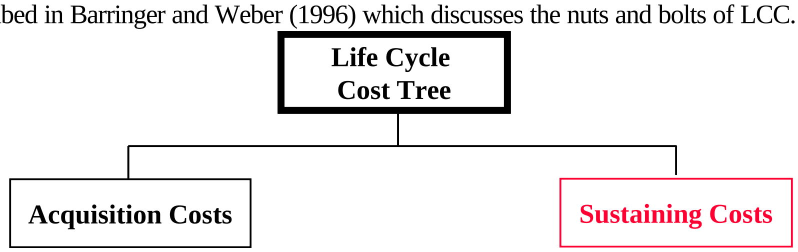

Figure 4: Life Cycle Cost = Acquisition + Sustaining Costs With Time Considerations

Defining the costs into the annual periods into which they occur, i.e., time buckets for accumulating costs to implement Figure 4 often results in a knee jerk reaction: “If we lay down all the costs, we can’t afford to implement the project”. Such head in the sand mentality leads to “Enron Stories” to show “profits” on known losers. It is better to kill loosing project than build a sink hole for cash at a later date with too little equipment of too low a grade that cannot function failure free for a highly productive process.

Figure 5 shows how to convert the concepts into implementation tasks.

From the implementation tasks of Figure 5, flow the roles and responsibilities shown in Figure 6. Notice the leadership roles and the supporting roles along with the numerous details rarely studied in depth for most installations.

First reactions at the detailed list in Figure 6 is one of alarm at the numerous up-front requirements—this is a typical engineering reaction. However, if you're the investor, what do you want to know before you're spending big money for bricks, mortar, and piping?

The list of issues and details in Figures 5 & 6 provides ideas about where the extra up-front money goes for the additional conceptual engineering costs. The extra work lays the ground work for better designed plants and facilities with consideration for the lowest long term cost of ownership to benefit the investors. Yes, the pain is greater for Engineering to do a more thorough job using new technology to enhance the plant and process for the purpose of making more money in the end. Also note that multiple areas of responsibility carry leadership efforts for LCC.

R&M Practices For Concept & Proposal Phase

Tasks For Phase 1: Concepts And Proposal	User	Supplier
Preliminary Availabilitly, Reliability, and Maintainability Planning	X	X
Define The Availability, Reliability, and Maintainability Plan	X	X
Implement Lessons Learned	X	X
Specify Availability, Reliability, and Maintainability Requirements	X	
Define How Machinery Will Be Used	X	
Specify Duty Cycles For Equipment	X	
Define Environment For Machinery	X	
Define Continuous Improvement Monitoring	X	X
Define Equipment Life In Throughput Terms	X	
Establish Data Collection Details For R&M	X	X
Develop Application Specific R&M Program Matrix	X	
Develop R&M Program Planning Worksheet Details	X	
Establish Criteria For R&M In Design Reviews	X	X

Tailor the details to avoid too little or too much emphasis on R&M. Meet needs of the business. Make the effort cost effective! Keep profitability in mind.

Design Review Objectives

Concept Review: Focuses on feasibility of the proposed design approach with budget restrictions

Preliminary Design Review: Verifies adaptability of evolving design to meet technical requirements

Final Design Review: Validates the design and analysis are complete and accurate

Build: Addresses issues from equipment build and runoff testing

Installation: Do failure investigation of problems--Do continuous improvement

Figure 5: Big Picture Of Tasks For Concept & Proposal Phase

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

Legend: L = Lead Responsibility, S = Support The Process, I = Input To the Process, A = Approval Responsibility

		Users		
Tasks For Phase 1: Concept And Proposal	Supplier	Engineering	Operations	Purchasing
Set Availability and Reliability Requirements		L	S	S
Set Maintainability Requirements		L	S	S
Define Functional Failures		S	L	
Define Environment/Usage		S	L	
Set Design Margins	I	L	S	
Design For Maintainability	I	S	L	
Make Reliability Predictions and Validate Availability Targets	I	L	I	
Do FMEA & Fault Tree Analysis		L		
Do Preliminary Cost Of Unreliability	I	S	L	
Conduct Design Reviews	L	A	S	S
Make Machinery Parts Selections	L	S		
Do Tolerance/Process Studies	L	S		
Do Critical Parts Stress Analysis	L	S		
Do Reliability Qualification Testing	S	L	I	
Do Reliability Acceptance Testing	S	L	I	
Do Reliability/Maintainability Growth Improvement	I	S	L	
Collect Failure Reports & Analize For Lessons Learned	S	L	S	
Provide Data Feedback	L	I	S	
Assess Lessons Learned	S	L	S	
Define Machinery Use	S	L	S	S
Define Machinery Duty Cycle		L	S	S
Define Machinery Environment		L	S	S
Share Continuous Improvement Information With Suppliers		L	S	
Define Life In Terms Of Throughput		L	S	S
Specify Data Collection System	S	L	S	S
Prepare Procurement Documents		S	S	L
Prepare LCC Objectives	I	S	L	
Prepare And Submit Reliability & Maintainability Plan	L	A	S	S
Prepare Life Cycle Cost Projections	I	L	S	

Figure 6: Roles and Responsibilities For Concepts and Proposal Phase

Moving forward to the design phase where RAM details impose greater effort and expenditures for quantification. This is shown in Figure 7 with each case requiring more/less depending upon the specific situation. A few of these issues are now being addressed by forward looking companies with interesting results. Seldom are these studies completed without learning something about existing facilities—usually the finding is the facility does not live up to the promised productivity and maintenance expectations. Usually improvements flow from the studies to make the new plants better and more productive.

Figure 7 shows concepts which drive design details in Figure 8 with roles and responsibilities. Note the suggested leadership role for suppliers in driving the design efforts which, of course, will cost more money during the upfront effort with the expectation that doing the job right upfront eliminates costs during the construction and operation phase of plant and equipment.

Reliability & Maintainability Practices For Design & Development Phase

Tasks For Phase 2: Design And Development	User	Supplier
Verify Design Margins (Safety Factors) & Do Stress Analysis		X
Specify How Critical Machinery Components Will Be Selected		X
Do Failure Modes and Effects Analysis:		X
Process FMEA	X	
Machinery FMEA		X
Do Fault Tree Analysis & HAZOPS	X	
Do Design Reviews		X
Do Tolerance/Process Studies		X
Generate Reliability Block Diagrams For Reliability Analysis		X
Do Accelerated Testing To Validate Critical Equipment Details		X
Do Maintainability Design Details To Minimize Downtime/Meet Max Time Limits		X
Define Maintenance Manuals, PM Requirments & CM Details		X
Prepare Spare Parts List & Spare Parts Inventory Plans	X	X
Prepares Details of Built-In Diagnostic Equipment For Maintainabiltiy	X	X
Prepares Details of Captive Hardware For Rapid Maintainability	X	X
Identify Spare Parts To Be Managed Based On Criticality	X	X
Define Maintenance Procedures For Adjustments/Replacements/Repairs	X	X
Define Visual Management Techniques For Workplace Awareness	X	X
Define Modularity Of Physical and Functional Units For Removal/Replacement		X

Figure 7: Big Picture Of Tasks For The Design Concepts

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

Legend: L = Lead Responsibility, S = Support The Process, I = Input To the Process, A = Approval Responsibility

		Users		
Tasks For Phase 2: Design And Development	Supplier	Engineering	Operations	Purchasing
Verify Design Margins (Safety Factors) & Do Stress Analysis	L	S		
Specify How Critical Machinery Components Will Be Selected	L	S	S	
Do Failure Modes and Effects Analysis:				
Process FMEA	S	S	L	
Machinery FMEA	L	S	S	
Do Fault Tree Analysis & HAZOPS	L-FTA	S	L-HAZOPS	
Do Design Reviews	L	S	S	
Do Tolerance/Process Studies	L	S	S	
Generate Reliability Block Diagrams For Reliability Analysis	L	S	S	
Do Accelerated Testing To Validate Critical Equipment Details	L	S		
Do Maintainability Design Details To Minimize Downtime	L	S	S	
Defines Maintenance Manuals, PM Requirments & CM Details	L	S	S	
Prepare Spare Parts List & Spare Parts Inventory Plans	L	S	S	
Prepares Details of Built-In Diagnostic Equipment For Maintainabiltiy	L	S	S	
Prepares Details of Captive Hardware For Rapid Maintainability	L	S	S	
Identify Spare Parts To Be Managed Based On Criticality	S	S	L	
Define Maintenance Procedures For Adjustments/Replacements/Repairs	L	S	S	
Define Visual Management Techniques For Workplace Awareness	L	I	I	
Define Modularity Of Physical and Functional Units For Removal/Replacement	L	i	i	
Define Accessibility Parameters	L	S	S	
Consider Life Cycle Cost Impact In Machinery Design	L	I	I	

Figure 8: Roles and Responsibilities For Design and Development Phase

Figure 9 shows the decreasing list of special R&M conceptual requirements for the build and install phase of projects. Figure 9 in turn drives a smaller list of issues to be addressed in Figure 10 for roles and responsibilities.

Reliability & Maintainability Practices For Build & Install Phase

Tasks For Phase 3: Build And Install	User	Supplier
Verify Attainment Of Specific R&M Goals During Testing		X
Do Preliminary Evaluation Of Process Performance To Eliminate Infant Mortality		X
Do Dry Run Testing In Vendors Facilities For A Set Duration (e.g., 1-day no failures)		X
Collect Reliability Data During Supplier Acceptance Testing As Future Precursor	X	X
Collect Reliability Data During Acceptance Testing In User's Plant After Installation	X	X
Do Root Cause Failure Analysis To Permanently Eliminate Failures		X

Figure 9: Big Picture of Build And Install Concepts

Note SAE's suggestion for vendors to demonstrate compliance of equipment in their own facilities for a one day test run, under load, without failures. This occurs during the build and install phase where the effort is reasonably practical. This puts the onus on vendors to eliminate infant mortality problems with equipment prior to field delivery. Of course like chemical and petroleum operations, this is never easy for automotive manufacturing suppliers and of course alternatives for this requirement are allowed.

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

Legend: L = Lead Responsibility, S = Support The Process, I = Input To the Process, A = Approval Responsibility

		Users		
Tasks For Phase 3: Build And Install	**Supplier**	**Engineering**	**Operations**	**Purchasing**
Verify Attainment Of Specific R&M Goals During Testing	L	A	A	
Do Preliminary Evaluation Of Process Performance To Eliminate Infant Mortality	L	I	I	
Do Dry Run Testing In Vendors Facilities For A Specified Duration (e.g., 1-day no failure	L	A	A	
Perform Acceptance Tests	L	A	A	
Collect Reliability Data During Supplier Acceptance Testing As Future Precursor	L	S	S	
Collect Reliability Data During Acceptance Testing And In User's Plant After Installation	S	S	L	
Do Root Cause Failure Analysis To Permanently Eliminate Failures	L	S	S	
Collect Life Cycle Cost Data	I	L	S	

Figure 10: Roles and Responsibilities For The Build And Install Phase

Reliability & Maintainability Practices For Operation And Support Phase

Tasks For Phase 4: Operation And Support	User	Supplier
Implement R&M Data Collection, Analysis, & Feedback System From Start Up	X	X
Implement Proactive Planned Maintenance Program For PM and PdM	X	
Implement R&M Growth Program Using Data, RCA, & Visual Displays Of Data	X	X
Implement Closed Loop Failure Reporting & Corrective Action System	X	X
Implement User/Supplier Data Exchange Of R&M Data To Reduce Cost On Both Sides	X	X
Implement Feedback Model On R&M Issues For User/Supplier Benefit	X	

Figure 11: Big Picture of Operation And Support Concepts

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

Legend: L = Lead Responsibility, S = Support The Process, I = Input To the Process, A = Approval Responsibility

		Users		
Tasks For Phase 4: Operations And Support	**Supplier**	**Engineering**	**Operations**	**Purchasing**
Implement R&M Data Collection, Analysis, & Feedback System From Start Up	S	S	L	
Implement Proactive Planned Maintenance Program For PM and PdM	S	S	L	
Implement R&M Growth Program Using Data, RCA, & Visual Displays Of Data	S	S	L	
Implement Closed Loop Failure Reporting & Corrective Action System	S	S	L	
Implement User/Supplier Data Exchange Of R&M Data To Reduce Cost On Both Sides	L	S	S	
Implement Feedback Model On R&M Issues For User/Supplier Benefit	S	S	L	
Collect Life Cycle Cost Data	I	S	L	

Figure 12: Roles And Responsibilities For The Operations And Support Phase

In working for the lowest long term cost of ownership, SAE recommends a continuing effort of involving the operations departments into RAM activities as shown in Figure 11 with roles and responsibilities listed in Figure 12. This is similar to total productive maintenance (TPM) efforts which have demonstrated great cost reductions in the sustaining efforts as operations and maintenance departments function in a teamwork environment rather than the usual adversarial relationship. TPM is described by Suzuki (1994). One USA refinery has actually won a Japanese award for achieving a top notch rating for their TPM activities (ConocoPhillips Refinery in Sweeney, Texas) which demonstrates this cost reduction methodology can be mastered by an American company.

The final phase of the life cycle costing is planning for end of life. Figure 13 shows some decisions for consideration. No manufacturing facility lasts forever. Consideration must be given for the conversion or decommission phase of life. As remediation and decontamination efforts are looming for many facilities, this is now a major cost impact driven by the actions taken during design and operation of existing plants. It is unlikely that these costs will decline in the future and consideration should be given for future costs.

Reliability & Maintainability Practices For Conversion And Decommission Phase

Tasks For Phase 5: End Of Life Decisions For Conversion And/Or Decommission	User	Supplier
Implement Retool Decisions For Make/Buy/Modify/Sell	X	X
Implement Remanufacture Decisions For Make/Buy/Modify/Sell	X	X
Implement Rebuild Decisions For Make/Buy/Modify/Sell	X	X
Imprelemt Retrofit Decisions For Make/Buy/Modify/Sell	X	X
Implement Rework Decisions For Make/Buy/Modify/Sell	X	X
Implement Lessons Learned For Future Plant Improvements	X	X
Decontaminate/dispose Of Unneeded Assets With Permits As Required	X	

Figure 13: The Big Picture of Conversion and Decommission Concepts

Roles and responsebilities for end of life decisions are shown in Figure 14. The cost decisions for this phase are difficult to quantify with any high degree of accuracy. However, if you plan for conversion or decommission, it leads to more responsible decisions during life of the project for reducing contamination and waste products which are expensive to neutralize prior to disposal.

Short List Of Reliability & Maintainability Activities Over The Life Cycle Phases

Legend: L = Lead Responsibility, S = Support The Process, I = Input To the Process, A = Approval Responsibility

		Users		
Tasks For Phase 5: End Of Life Conversions And/Or Decomission	**Supplier**	**Engineering**	**Operations**	**Purchasing**
Implement Retool Decisions For Make/Buy/Modify/Sell	I	S	L	
Implement Remanufacture Decisions For Make/Buy/Modify/Sell	I	S	L	
Implement Rebuild Decisions For Make/Buy/Modify/Sell	I	S	L	
Imprelemt Retrofit Decisions For Make/Buy/Modify/Sell	I	S	L	
Implement Rework Decisions For Make/Buy/Modify/Sell	I	S	L	
Implement Lessons Learned For Future Plant Improvements	I	S	L	
Decontaminate/dispose Of Unneeded Assets With Permits As Required	I	I	L	
Characterize Equipment Reliability And Maintainability	I	L	S	
Collect All Data And Lessons Learned	I	S	L	
Total Life Cycle Costs And Compare To Original LCC Objectives	I	L	S	
Adjust Methodoloty If Required	I	L	S	

Figure 14: Roles And Responsibilities For Conversion And Decommission

How would this system work for forward looking organizations?

1. Start with an objective such as: "We will build an economical and failure-free process which will operate for 5 years between planned outages with an availability of 98% (including lost production time during turnarounds), and 80% of all component failures must be capable of being repaired in less than 24 hours". This requires pricing out alternatives for achieving the lowest long term cost of ownership using LCC techniques to achieve a highly available process which is free from failures and thus lacks instability of process changes so as to produce consistently large outputs as advocated by process reliability techniques described by Barringer and Roberts (2001).
2. The purpose of planning for a failure-free process is to increase manufacturing productivity and manufacturing throughput recognizing the process is the king while individual equipment are the pawns for the strategy. This requires planning for, calculating, and understanding reliability principles as improved reliability tends toward lower life cycle cost.
3. The purpose of maintainability improvement is to design machinery and equipment that can be quickly and safely repaired to reduce downtime of individual pieces of equipment so the risk of failing the process is low in both probability of failure and low in the $risk of exposure. This requires identifying planned maintenance actions and improving the reliability and longevity of equipment which is driven by economics. Planning for both quick and safe maintenance activities decreases the exposure for safety issues and exposure for financial damage from the required repairs.

So why would you want to pursue this difficult path of introducing RAM technology into life cycle costing? The one word answer is money. By the way, forward looking companies are already complaining the 5 year failure free interval for the process is not good enough as they are planning for a 6 year time frame!

Of course, pursing this path for cost reductions has a prerequisite of knowing, understanding, and using technology from the field of reliability and maintainability which as been summarized in previous NPRA documents, see Barringer (1995). Many other papers concerning reliability and the high cost of **un**reliability from failures are available for download at http://www.barringer1.com/Papers.htm .

SUMMARY

Many companies are quietly accumulating their failure data and building models of their operations. They are doing the fundamental efforts to build more reliable plants that deliver the lowest long term cost of ownership for their investors. These improved plants are showing cost reductions and more stable operations without fanfare as the leading edge of a new wave of improvements becomes based on technology.

An ancient Chinese warlord summarized the same type of issue succinctly 2000 years ago when he said "All men see the battles I win, but no man knows the strategy for my success." In other words, don't look for your competitors to advertise how they're making more money with improved plants. They will not volunteer to tell you the secrets of their hard work in making better and more effective life cycle cost decisions though the use of reliability and maintainability technology. You've got to make a technology change to get a change in your performance.

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BIOGRAPHIC INFORMATION-

H. Paul Barringer, P.E. is a reliability, engineering, and manufacturing consultant. He is author of the basic reliability training course **Reliability Engineering Principles,** a practical financial evaluation course **Life Cycle Costs**, and **Process Reliability** which is a high level method of assessing and understanding process reliability. He has 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. He is a licensed professional engineer in Texas. His education includes a MS and BS in Mechanical Engineering from North Carolina State University, and he has participated in Harvard University's three week Manufacturing Strategy conference. Other details and technical papers on a variety of reliability and life cycle cost issues are available at **http://www.barringer1.com.** For other background or details, send e-mail to **hpaul@barringer1.com**.

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