Process and Equipment Reliability

Paul Barringer, P.E.
Barringer & Associates, Inc.
P.O. Box 3985
Humble, TX 77347-3985 USA

Phone: 1-281-852-6810 Website: www.barringer1.com
FAX: 1-281-852-3749 E-mail: hpaul@barringer1.com

Definitions

- **Reliability—**
  The probability that a component, device, system, or process will perform its intended function without failure for a given time when operated correctly under specified environmental conditions.
- **Life Cycle Costs—**
  All costs associated with the acquisition and ownership of a system over its full life. The usual figure of merit is net present value.
- **Reliability and Life Cycle Cost—**
  Business issues come together as a rational task.

Reliability Is A Business Issue

- **System failures halt cash inflows plus incur repair costs**
- **Equipment failures cost money for repairs/claims**
- **Business needs equipment and processes that are**
  - **Available ← ready for duty when needed**
  - **Reliable ← free from system failures and high cost**
  - **Affordable ← a life cycle cost issue of tradeoffs**
- **We speak of technology, safety, and reliability but the main issue is money which addresses life cycle costs!**
- **Reliability issues involve details about time and money for the entire organization to make business decisions**

Reliability Starts With Management

- Management must communicate reliability issues and the $ need for a failure free environment
  - Most reliability issues are driven by money
  - Some reliability issues are regulatory
  - Most things are not perfect and not free of failures
  - Everything fails—some by aging—some by events
  - Perfection exists only in our fantasy world
- Management must say what they want and want what they say in policy statements to guide the staff

Management Double Speak

- Management says they want reliability then they describe **availability—with emphasis on fast repairs**
  - **Availability** describes the % of time the system is alive and ready for use when called upon
- Management verbalizes they want **reliability—with emphasis on uptime** (availability)
  - **Reliability** addresses the probability of the failure free interval under specific conditions
- Management seldom accurately defines costs of unreliability to focus the staff on $Risk tradeoffs for reliability issues

What's Your Reliability Policy?

- Your safety policy says: **We will have an accident free work place.** (Considered impossible 40 years ago)
- Your quality policy says: **We will ship products free from defects.** (Considered impossible 20 years ago)
- Your environmental policy says: **We will have no environmental spills/releases.** (Considered impossible 2 years ago)
- Does your reliability policy say: **We will build an economical and failure free process which will operate for 5 years between planned outage.** (Considered impossible today!)

Management Do You Know The Cost Of Unreliability?

- Are you managing to **control the cost of unreliability** including failure of the process?
- Have you defined a **strategy for the system** or do you simply have a collection of tactics that you think represent a strategy?
- Have you **communicated your cost of unreliability** with a plan for attacking high costs money issues—do your engineers know the cost details to implement the tactics?

The Most Important Tool

- Make **Pareto lists based on money.** Focusing on $issues is the most important reliability tool.
- Get engineers to **work the $Pareto money list** rather than on **love affairs with equipment**?
- If your Pareto list is based on **nose counts of problems**, you're on the **wrong track**!
- Ensure engineering/maintenance **tactics** support the plant reliability **strategy** for $issues?

Reliability vs Maintenance Engineering

- Renaming your maintenance organization to include the name reliability gives you style—but what about substance of actually using reliability tools?
- Reliability engineering tools work to avoid failures
- Maintenance engineering tools strive for fast repairs
- It's simple—

  Reliability engineers : Fire marshal ::
  Maintenance engineers : Fire fighters
- You'll need ~1 Reliability Engineer for every ~10 Maintenance Engineers (no increase in staff size)

Reliability Tools: Are You Using?

- Mean time between failures — Use arithmetic for figures of merit
- Decision trees — Use reliability values to get quick decisions
- Bathtub curves — Understand modes of failure from human experiences
- Availability/reliability — % of time available and % chance for no failures
- Preparing reliability data for analysis — Make data talk
- Normal probability plots — Bell shaped curve made into a straight line
- Log-normal probability plots — Tailed data made into a straight line
- Weibull probability plots — Organize chaos of data into a straight line
- Corrective action for Weibull failure modes — What to do and when
- Reliability block diagram models — Organize failures into RAM facts
- Monte Carlo simulations — Use for complex models to get facts on failures

Reliability Tools: -- Cont'd

- **Critical items list** — Reduce complexity to the vital few issues for management
- **Pareto distributions** — Separate the vital few issues from the trivial many
- **Failure mode effect analysis** — Bottom up search for problems to eliminate
- **Fault tree analysis** — Top down search for problems driven by experience
- **Quality function deployment** — Put the voice of the user into reliability
- **Design reviews** — Perform engineering review for reliability issues
- **Configuration control** — Document to avoid reliability problems
- **Mechanical components interaction tests** — Find problems early
- **Load/strength interactions** — Failures: strengths too low or loads too high

Reliability Tools: -- Cont'd

- **Electronic device screening and derating** — Eliminate failures
- **Software reliability tools** — Test/use/correct, test/use/correct, test/use/correct
- **Reliability testing strategies** — Find the limits to find weaknesses & correct
- **Simultaneous testing** — Testing/use strategy for inexpensive items
- **Sudden death testing** — Testing/use strategy for expensive items
- **Accelerated testing** — How to get test results in your life time!—add loads
- **Reliability growth models** — Show failures & forecast future failures
- **Failure recording, analysis, & corrective action systems** — Data!
- **Reliability policies and systems** — Say what you want & get what you say
- **Contracting for reliability** — Specify and communicate with your vendors
- **Reliability audits** — Find out how you're really doing by examination

Reliability Tools — Start Your Numbers With Arithmetic

- Start with MTTF or MTBF = (Σ life)/(Σ fail.)
- What are you mean times between failure for: Pumps? Heat exchangers? Valves? etc. — or are you clueless? If you're clueless on the numbers, <u>you just don't get the idea</u> about reliability issues!
- Understand MTTF or MTBF which begins with arithmetic and grows to statistics
- A key long term issue: mean time between maintenance actions—this is a durability issue!

MTTF/MTBF—Simple Arithmetic

This MTTF data from production, maintenance, and purchasing records

Remember: MTTF is a meterstick—not a micrometer!!

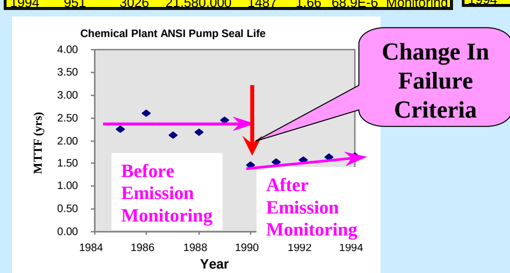
The Data

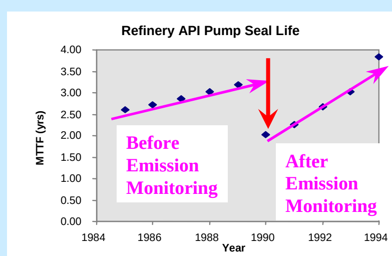
Chemical Plant ANSI Pump Life

Year	Number Of Unspared Pumps	Number Of Spared Pumps	Total Hours Of Pump Operation	Number Of Seal Failures	Seal MTTF (yrs)	Seal Failure Rate (fail/hr)	Conditions
1985	937	2996	21,330,000	1083	2.25	50.8E-6	No
1986	943	2996	21,380,000	937	2.60	43.8E-6	Emission
1987	950	2998	21,450,000	1156	2.12	53.9E-6	Monitoring
1988	950	3008	21,500,000	1127	2.18	52.4E-6	
1989	953	3012	21,540,000	1003	2.45	46.6E-6	
1990	955	3028	21,630,000	1689	1.46	78.1E-6	
1991	957	3036	21,680,000	1628	1.52	75.1E-6	
1992	963	3048	21,790,000	1581	1.57	72.6E-6	
1993	955	3038	21,670,000	1517	1.63	70.0E-6	Emission
1994	951	3026	21,580,000	1487	1.66	68.9E-6	Monitoring

Refinery API Pump Life

ar	Unspared Pumps	ber Of Spared Pumps	Total Hours Of Pump Operation	Number Of Seal Failures	Seal MTTF (yrs)	Seal Failure Rate (fail/hr)	Conditions
1985	313	1542	9,500,000	415	2.61	43.7E-6	No
1986	313	1542	9,500,000	398	2.72	41.9E-6	Emission
1987	313	1548	9,520,000	380	2.86	39.9E-6	Monitoring
1988	310	1560	9,550,000	361	3.02	37.8E-6	
1989	305	1580	9,590,000	343	3.19	35.8E-6	
1990	295	1580	9,500,000	535	2.03	56.3E-6	
1991	290	1590	9,500,000	481	2.25	50.6E-6	
1992	280	1598	9,450,000	403	2.68	42.6E-6	
1993	270	1602	9,380,000	354	3.02	37.7E-6	Emission
1994	265	1610	9,370,000	278	3.85	29.7E-6	Monitoring





Knowing MTBF or MTTF Tells About Maintenance Demands

- Suppose you have **400** pumps. Half of the pumps are running at any one time (which means we accumulate 200 years of life annually).
- Suppose your MTBF = **2** years/failure.
- How many pump repairs should you expect?

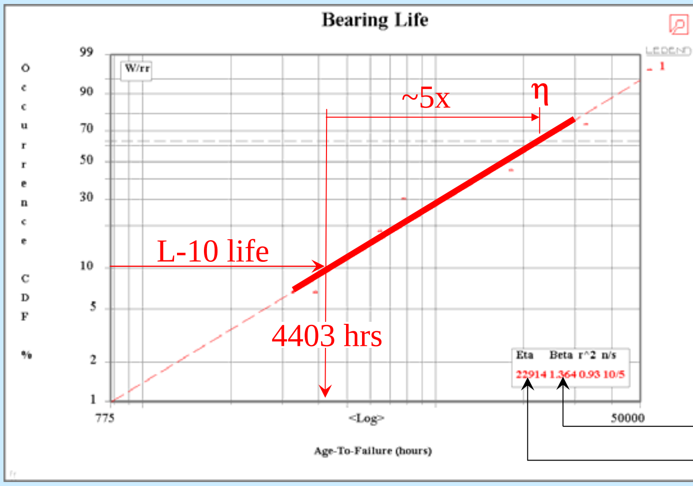
$$MTBF = \frac{\Sigma Life}{\Sigma Failures} = 2\,\frac{years}{failure} = \frac{200\ years}{X\ failure}, \quad \therefore X = \mathbf{100}\ \frac{failures}{year}$$

- If your competitor has MTBF = **4** years — who has the advantage and by how much?

Can We Do Better Than Arithmetic?

- **Weibull analysis** provides specific details about failure modes and allows us to forecast future failures
- We have 5 **ages-to-failure** data from bearings on a specific machine at (in rank order): 3900, 6500, 7800, 18100, 32600 hours. We also have 5 bearings in operation that have not failed (**suspensions**) at: 4000, 6000, 15000, 25000, and 30000 hours will be replaced with similar bearings when failure occurs.
- **What's the failure mode, when are future failures predicted for the bearings in continuous service?**

Weibull Plot



Forecasted Future Failures:
1 by month 6
1 by month 12
1 by month 18
1 by month 24
1 by month 31
1 by month 37

Wear-out failure mode
β > 1

Characteristic Life η = 22,914 hours

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PM Bearing Replacements?

β = 1.364
η = 22,914

- It depends on β, η, planned & unplanned costs.
- Supposed the planned cost is $5000.
  - Case 1: Suppose the unplanned cost is $15,000
  - Case 2: Suppose the unplanned cost is $25,000
- Case 1: No optimum replacement. **Run bearings to failure**
- Case 2 says the optimum replacement interval is **19,465** hours for a **PM replacement but cost savings is so small—∴run to failure**

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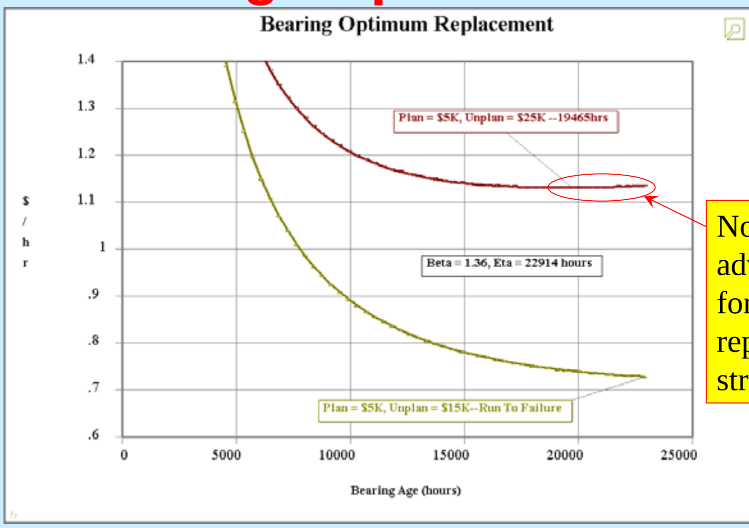
Bearing Replacement Curve

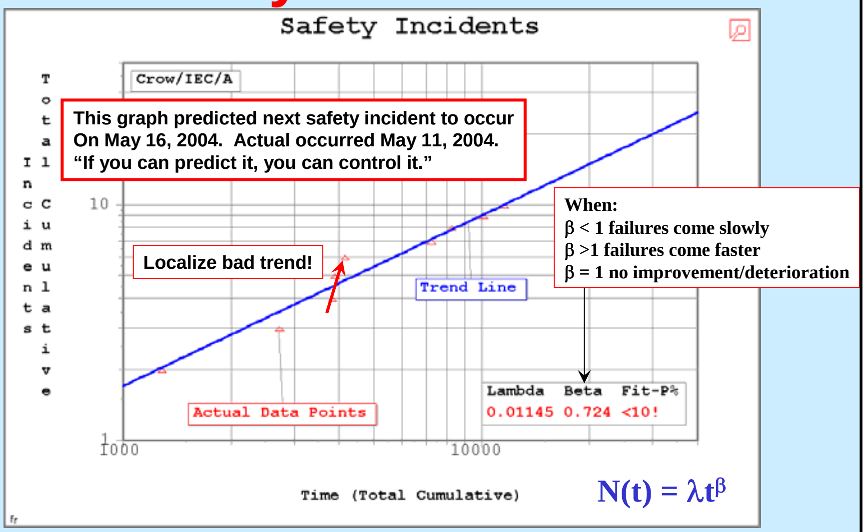


No <u>real</u> $/hr advantage for using a PM replacement strategy

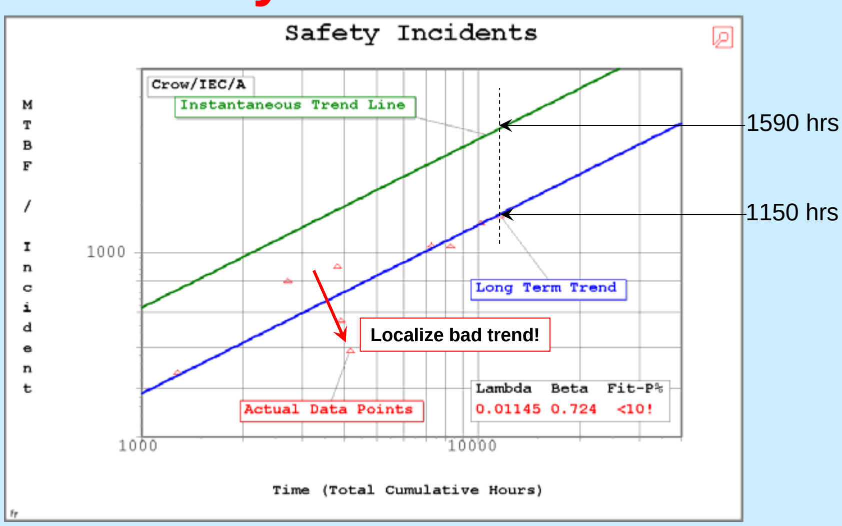
Models Organize Thinking

- Gather facts, build models, get the math right.
- **Weibull** models are “smart” models with heavy data demands by **individual failure modes**.
- **Crow-AMSAA** models are not so smart, have lesser data demands, and **allow use of mixed failure modes**.
- C-A plots allow **“fearless forecasts”** of future failures.

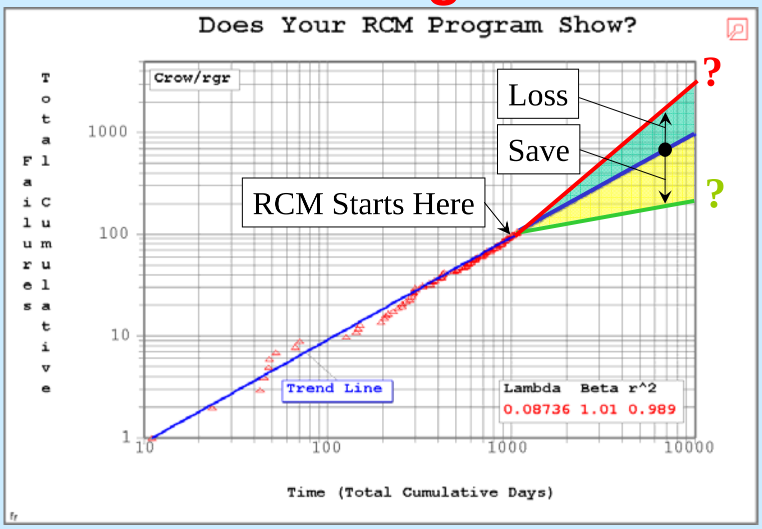
Reliability Growth Models



Reliability Growth Models



Did Your RCM Program Do This?



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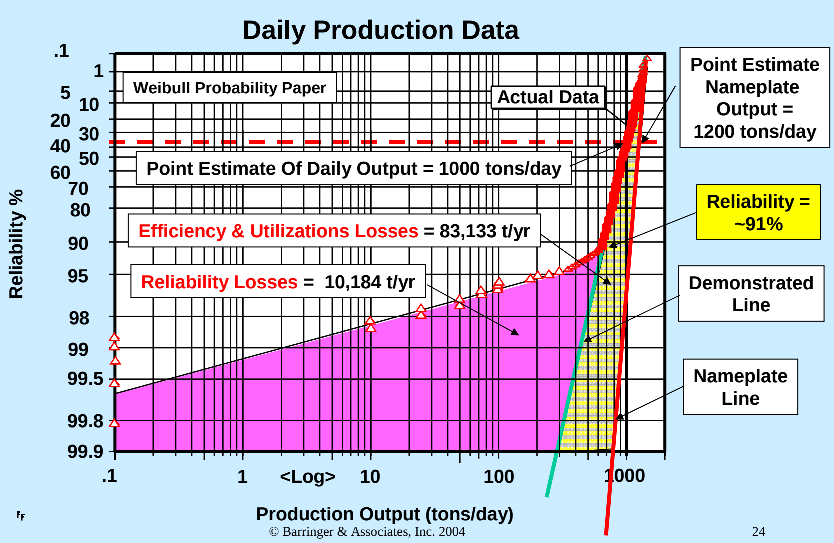
What's Your Process Reliability ?



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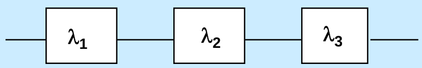
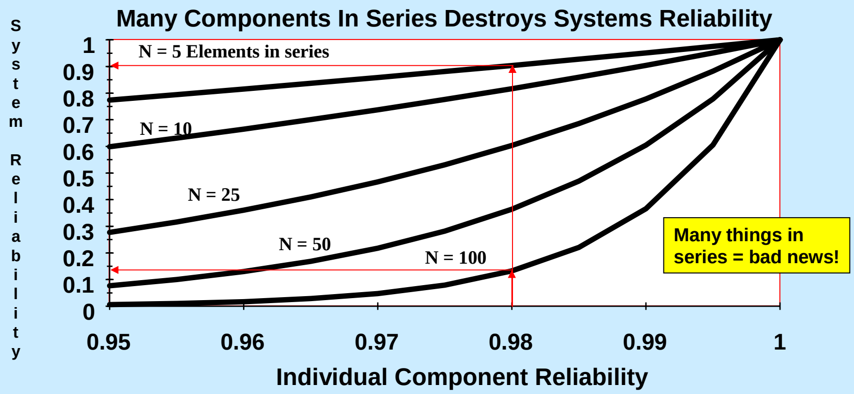
Series Reliability Models



$R_1 = e^{(-\lambda_1 t)}$ $R_2 = e^{(-\lambda_2 t)}$ $R_3 = e^{(-\lambda_3 t)}$

$\lambda_T = \Sigma\lambda_i = \lambda_1 + \lambda_2 + \lambda_3 \cdots$

$R_S = \prod_{i=1}^{i=n} R_i = R_1 * R_2 * R_3 = e^{(-\lambda_T t)}$



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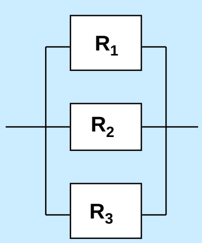
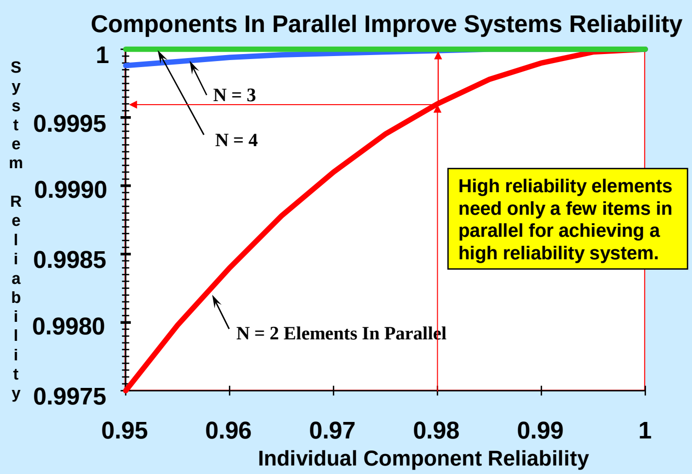
Parallel Reliability Models



Each element in parallel must be able to carry the full load

$R_{overall} = 1 - (1 - R_1)*(1 - R_2)*(1 - R_3)*(\cdots)$



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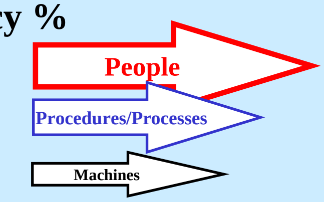
Roots Of Reliability Failures

	Mature Plants	Frequency %
#1	• People	38
#2	• Procedures + Processes	34
	• Equipment	<u>28</u>
		100



- **Human reliability problems are opportunities for improvement by error proofing operations**
- **Some human failures are also tied to procedures and processes problems**

Human Models

Table 2 Time Available For Diagnosis Of An Abnormal Event After Control Room Annuciation	
Time (minutes)	**Probability Of Failure (%)**
1	~100
10	50
20	10
30	1
60	0.1
1500	0.01

Fast action required by humans = failure! → 1

If they don't forget! → 0.01

Reliability = (1 - pof)

Top Down Cost Of Unreliabilty Model

For each block and the plant summary: What is the cost of unreliability if gross margin is $10,000/hr, scrap is $5,000/incident, and maintenance cost is $5,000 per hour of down time?

Reliability Problem

Block Diagram Of Plant

Maintainability Problem

	A	B	C	Summary	
Failure Rate	22.8E-06	114.2E-06	57.1E-06	194.1E-06	fail./hr
Corrective Time/Fail.	18	24	83	40.6	hrs/fail
Lost Time	3.6	24	41.5	69.1	hrs/yr
Gross Margin Lost	$36,000	$240,000	$415,000	$691,000	(1) $/yr
Scrap Disposal $'s	$1,000	$5,000	$2,500	$8,500	$/yr
Breakdown Maint. $'s	$18,000	$120,000	$207,500	$345,500	(2) $/yr
Total	$55,000	$365,000 (2)	$625,000 (1)	$1,045,000	$/yr

Cost of Unreliability

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Don't Forget Simple Tools: FMEA

FMEA Work Sheet

Occurrence Ranking Index:	
Rank	Criteria
1	Remote chance for failure
2	Low failure rate based on
3	previous designs with low failures
4	Moderate failure rates based on similar
5	designs which have some occasional
6	failures but not in major proportions
7	High failure rates based on similar
8	designs which have been troublesome.
9	Very high failure rates and the failures
10	will be major occurrences.

Severity Ranking Index	
Rank	Criteria
1	Undetectable effect on system
2	Low severity impact because failure
3	will cause slight customer annoyance
4	Moderate severity with some customer
5	dissatisfaction and with performance
6	loss which is noticable by customer
7	High severity with high degree of
8	customer dissatisfaction
9	Very severe problem involving potential
10	safety problem or major non-conformity

Customer's Detection Ranking Index	
Rank	Criteria
1	Almost certain detection of failure mode
2	Very high likelihood of detecting failure
3	High likelihood of detecting failure mode
4	Mod. high likelihood of detecting failure
5	Mod. likelihood of detecting failure
6	Low likelihood of detecting failure mode
7	Very low likelihood of detecting failure
8	Remote likelihood of detecting failure
9	Very remote likelihood of detecting failure
10	Can not detect failure mode

Component:
Supplier:
Engineer:

FMEA Date/Rev Level:
Customer:
Assembly :

Component Name	Component Function	Cause(s) Of Failure	Effect(s) Of Failure	Occurrence Index (O)	Severity Index (S)	Detection Index (D)	Risk Priority Number (O)*(S)*(D)	Recommended Corrective Action

SAE: J1739
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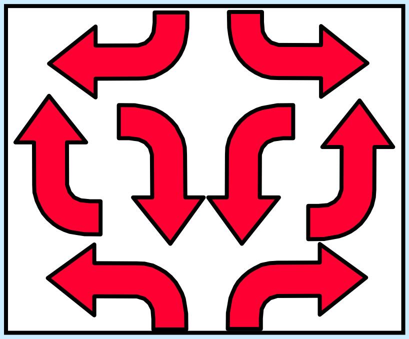
Conflicting LCC Issues-- What To Do?

Project Engineers:
Minimize capital expenditures

Maintenance Engineers:
Minimize repair hours



Shareholders:
Maximize dividends
and/or share price

Production:
Maximize uptime hours

Reliability Engineers And Regulators:
Maximize equipment reliability
to avoid failures

Buy right? Or
Buy Cheap?

Accounting:
Maximize project net present value

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Engineers Must Quantify All Life Cycle Costs

Engineers Must Think Like MBA's
And
Act Like Engineers
To Get
Lowest Long Term Cost Of Ownership
Over The Entire Life Cycle

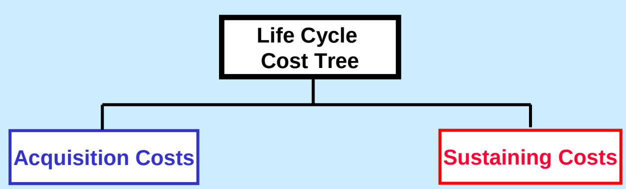
 Think NPV 32

Life Cycle Costs Are Fixed During Design

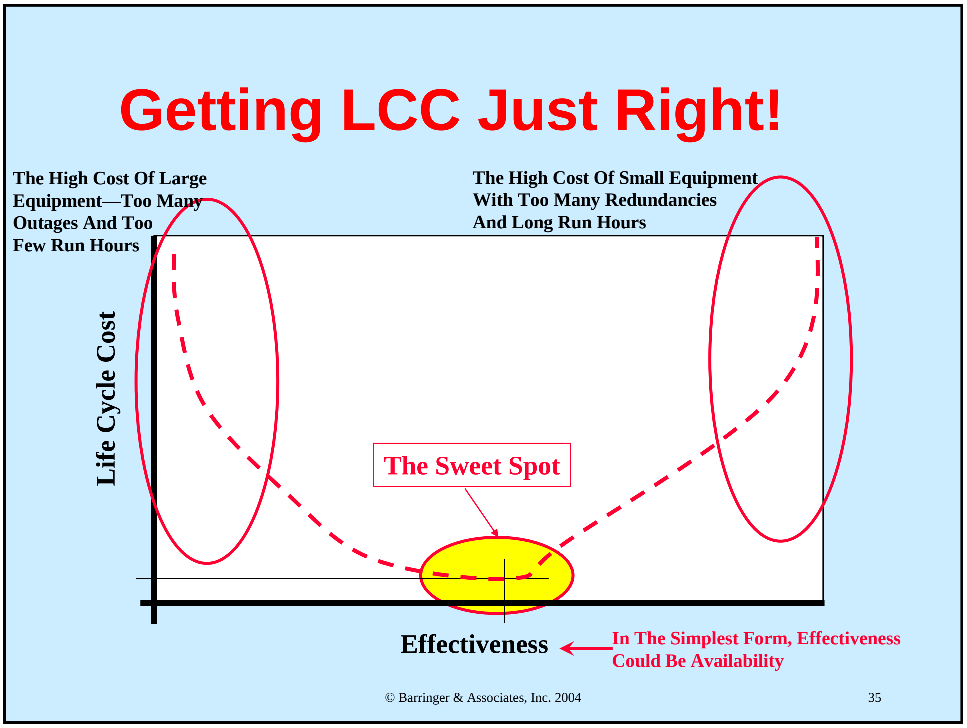
- Often sustaining costs (including hidden costs) are 2-20 times acquisition costs (obvious costs)
- About 65% of total LCC are fixed by the time equipment is specified (but only a few percent of funds have been expended)
- Minimizing LCC pushes up NPV
- Finding the minimum LCC required details for both acquisition costs and sustaining costs

Top Levels Of LCC CostTree

- LCC = Acquisition Costs + Sustaining Costs



- Acquisition costs and sustaining costs are not mutually exclusive—find both by gathering the correct inputs and identifying cost drivers



LCC Thumbnail

- Life cycle costs include cradle to grave costs
- Including failures into LCC decisions permits engineering quantities of manpower, spare parts, and alternatives on a rational basis rather than use of rules of thumb or emotion
- LCC provides numbers for trade-off studies and uses NPV for sound, unemotional decisions
- Monte Carlo models add realism to numbers and help find trade-off values

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Summary

- Set a policy for a failure free environment
- Use data to predict problems and fix them
- Think time, money, and alternativeS
- Quantify unreliability and unreliability costs
- Plan for organized improvements
- Learn new tools for solving old problems
- Prevent system failures

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Internet Downloads

- Copies of the technical paper Process and Equipment Reliability and slides are available as down loadable PDF files
- http://www.barringer1.com/Papers.htm
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Yes, that's a capital "P"

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