Life Cycle Costs and Weibull Go Together Like PB&J

Abstract: Weibull details are needed to predict end of life for components and systems. When the failures/replacements occur will drive costs during specific project intervals. The cost details from Weibull analysis drive life cycle cost decisions for calculating a key performance indicator represented by a single number for net present value (NPV).

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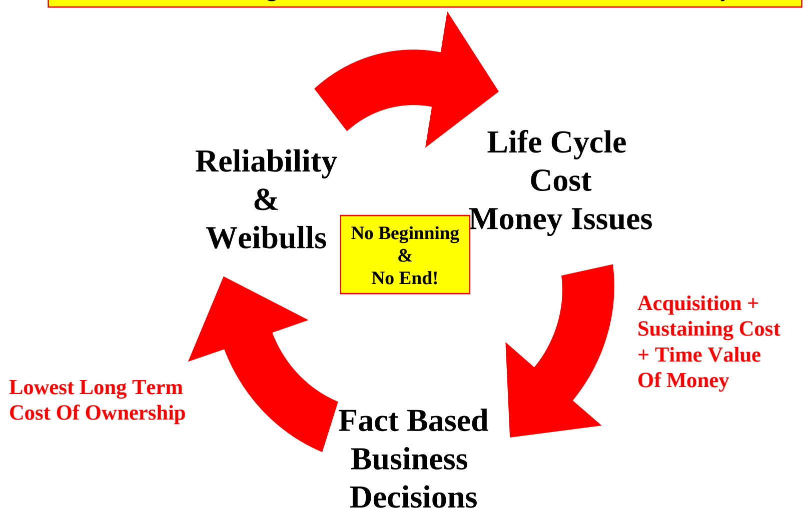
Why Do Life Cycle Cost Together and Weibull Distributions Go Together?

Facts About How Things Live and Die → Weibull Distributions → Money Issues



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Life Cycle Cost Definitions

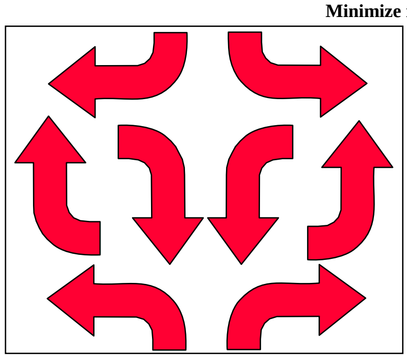
- **Life Cycle Costs--All costs associated with the acquisition and ownership of a system over its full life. The usual figure of merit is net present value.**
- **Net Present Value-- NPV is a financial tool for evaluating economic value added. The** present value of an investment's future net cash flows **(a measure of a company's financial health)** minus the initial investment for a given hurdle discount rate **(the interest rate used in discounting future cash flows) are** summed for the net

Need a life cycle cost Excel work sheet to calculate NPV?
See: http://www.barringer1.com/Anonymous/lcc.xls

Conflicting Issues--What To Do?

Project Engineers:
Minimize capital expenditures

Maintenance Engineers:
Minimize repair hours



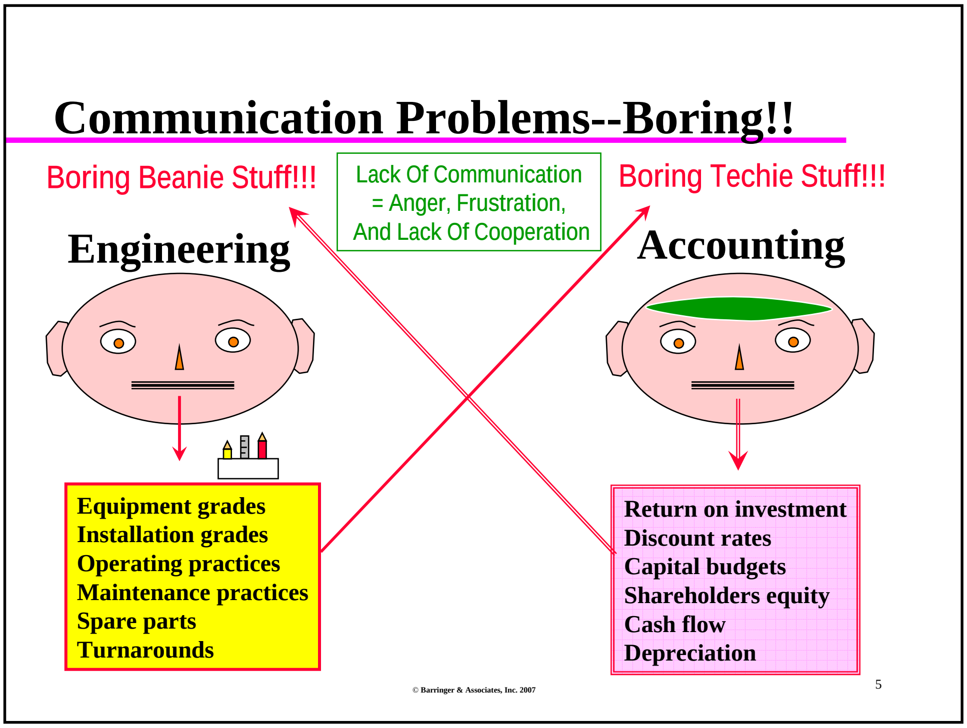
Shareholders
Maximize dividends and/or share price

Production:
Maximize uptime hours

Reliability Engineers:
Maximize equipment reliability to avoid failures

Buy right? Or Buy Cheap?

Accounting:
Maximize project net present value


Communication Problems--Boring!!
Boring Beanie Stuff!!!
Lack Of Communication = Anger, Frustration, And Lack Of Cooperation
Boring Techie Stuff!!!
Engineering
Accounting
Equipment grades
Installation grades
Operating practices
Maintenance practices
Spare parts
Turnarounds
Return on investment
Discount rates
Capital budgets
Shareholders equity
Cash flow
Depreciation
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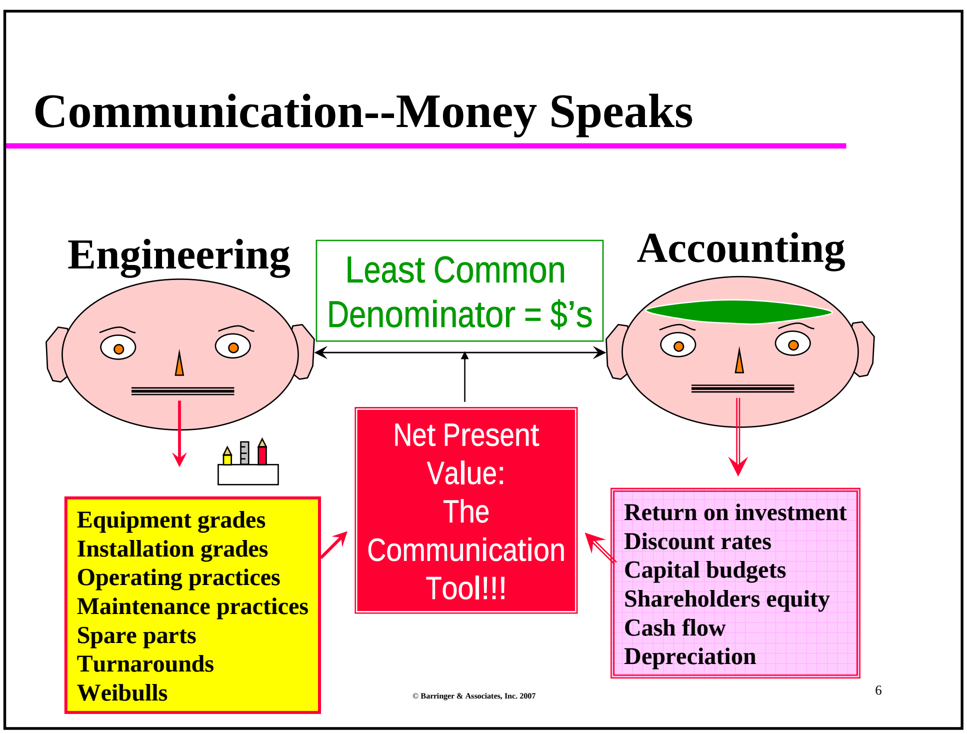
Communication--Money Speaks
Engineering
Least Common Denominator = $'s
Accounting
Net Present Value: The Communication Tool!!!
Equipment grades
Installation grades
Operating practices
Maintenance practices
Spare parts
Turnarounds
Weibulls
Return on investment
Discount rates
Capital budgets
Shareholders equity
Cash flow
Depreciation
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The Time Value Of Money

Two views of money
1. Present value
2. Future Value

Time Aspects Of Money											
Discount Rate = 12%											
Years hence	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
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
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
Present value of US$1.00 = 1/(1+ i)^n and Future value of US$1.00 = (1+ i)^n											
Years hence		**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Present value of US$1.00		$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		$3.48	$3.90	$4.36	$4.89	$5.47	$6.13	$6.87	$7.69	$8.61	$9.65
where i = discount rate and n = number of years into the future											

What is the present value (PV) of US$1.00 today over time?
What is the future value (FV) of US$1.00 received over time?

"A bird in the hand is worth two in the bush."
"Money is time and time is money."

Engineers Must Quantify All Costs

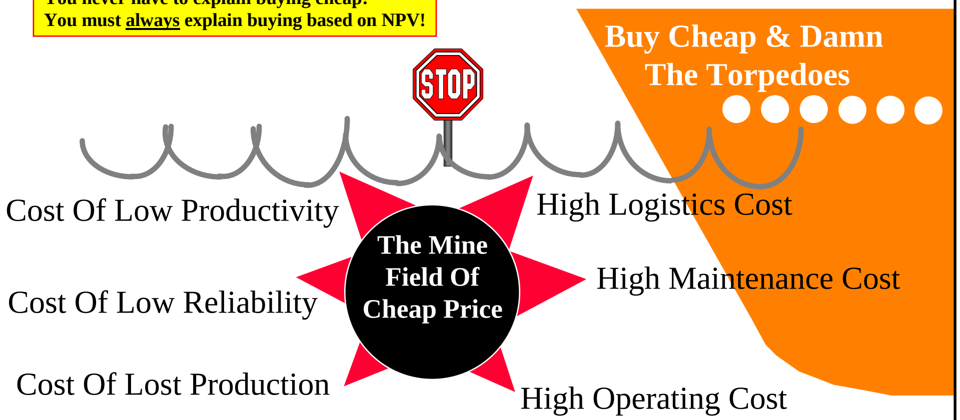
Can you calculate NPV?

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

First Cost Is Not The Last Cost

- Watch out for the lure of cheap first cost!!!!

You never have to explain buying cheap!
You must <u>always</u> explain buying based on NPV!



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Why Use LCC

- Affordability studies
- Source selection studies
- Design trade-off studies
- Repair level analysis studies
- Warranty and repair cost studies
- Supplier sales strategies
- Configure for lowest long term cost of ownership

Most business are in for the long haul so the lowest cost of ownership (NPV) is best for the business.

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LCC Helps Change Perspectives

- Engineering**--show non-redundancy costs**
- Purchasing**--buy right rather than buy cheap**
- Process engineering**--show operating costs**
- Maintenance**--calculate maintenance costs**
- Reliability engineering**--define improvements**
- Management**--operate for lowest long term cost of ownership rather than cheapest first cost**

Everyone has tradeoffs to make.
Don't operate like ENRON.
Think about the lowest long term cost of ownership for the stockholders!

LCC: A Management Decision Tool

- **Provides a costing discipline**
- **Useful for procurement strategies**
- **Balances acquisition costs and operating costs**
- **Useful for trade-off studies based on facts**
- **Requires engineers to:**
  - **Think like MBAs for cost considerations**
  - **Act like engineers by using numbers for decisions**
- **Requires use of teamwork to generate numbers**

Think smart. Act smart. Be responsible. No one has all the answers. Think and act with a conscience!

Engineers And Spreadsheets

- Most financial spreadsheets are generalities because engineers do not give accountants specific equipment details for making accurate financial calculations
- Engineers must add many equipment details to help accountants arrive at the correct economic impact--"I don't have the information" is a void in decision process which drives poor decisions toward bad economic results

If you don't have the information do what they taught you at the university:
1. Make a hypothesis
2. Test the hypothesis
3. Use your head! "Common sense is an uncommon virtue." Don't wait!

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What Goes Into Life Cycle Costs?

- Everything goes into LCC and each case is tailored for individual circumstances
- LCC follows a process that fits a simple tree for acquiring data

Management appreciates you following a process more than you as an engineer may appreciate it.

Step	Task
1	Define the problem requiring LCC
2	Alternatives and acquisition/sustaining costs
3	Prepare cost breakdown structure/tree
4	Choose analytical cost model
5	Gather cost estimates and cost models
6	Make cost profiles for each year of study
7	Make break-even charts for alternatives
8	Pareto charts of vital few cost contributors
9	Sensitivity analysis of high costs and reasons
10	Study risks of high cost items and occurrences
11	Select preferred course of action using LCC

Feedback

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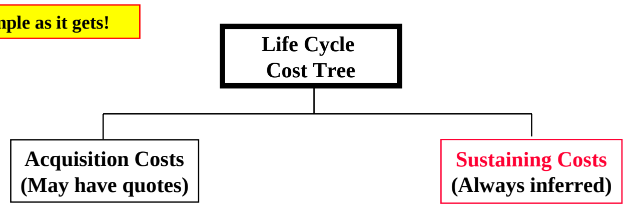
Top Levels Of The LCC Tree

- **LCC = Acquisition Costs + Sustaining Costs**

This is as simple as it gets!

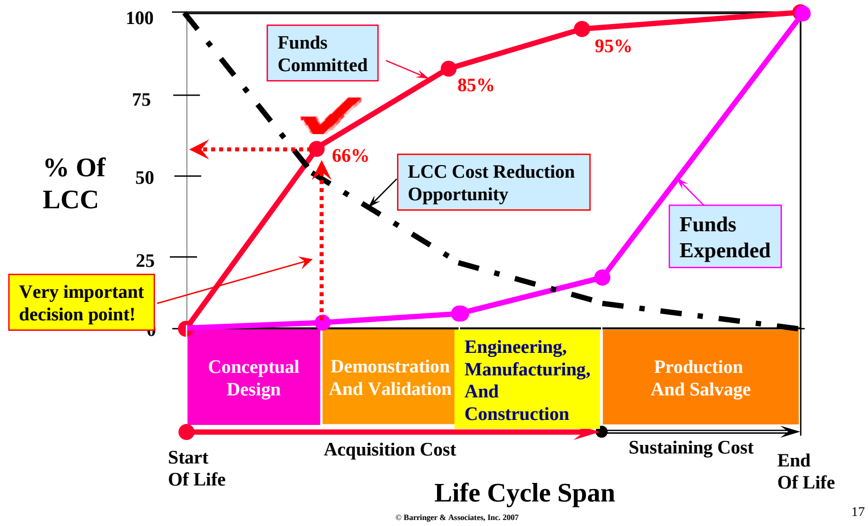


- Acquisition costs and sustaining costs are not mutually exclusive—find both by gathering correct inputs and identifying cost drivers

Hidden Costs Found By LCC

- **Often sustaining costs (including hidden costs) are 2-20 times acquisition costs (obvious costs)** — **Worry more about sustaining costs!!!**
- **About 65%+ of total LCC are fixed by the time equipment is specified (but only a few percent of funds have been expended at this point in time)** — **Wham! A key issue!**
- **Minimizing LCC pushes up NPV and builds stockholder wealth** — **Think long term!**
- **Finding the lowest long term LCC requires details for both acquisition costs and sustaining costs requires choices between alternativeS** — **Say it in NPV**

Commitments And Expenditures



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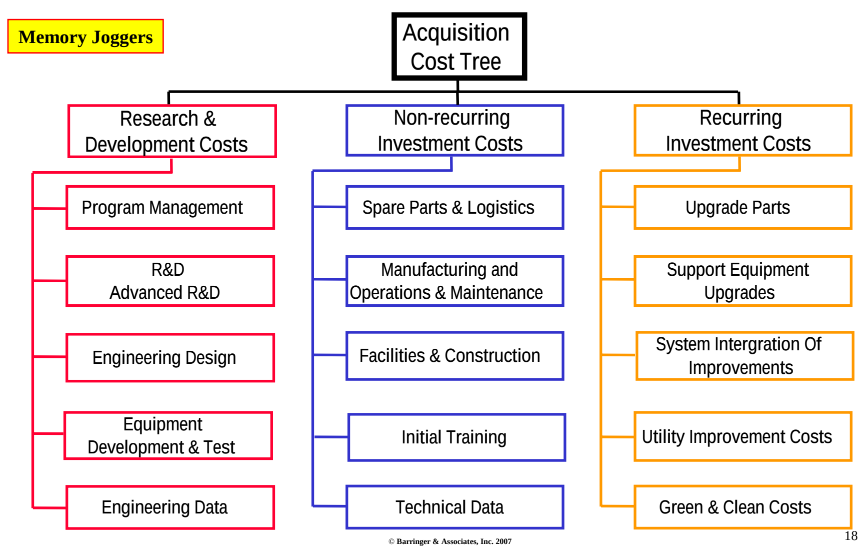
Branches For The Acquisition Tree



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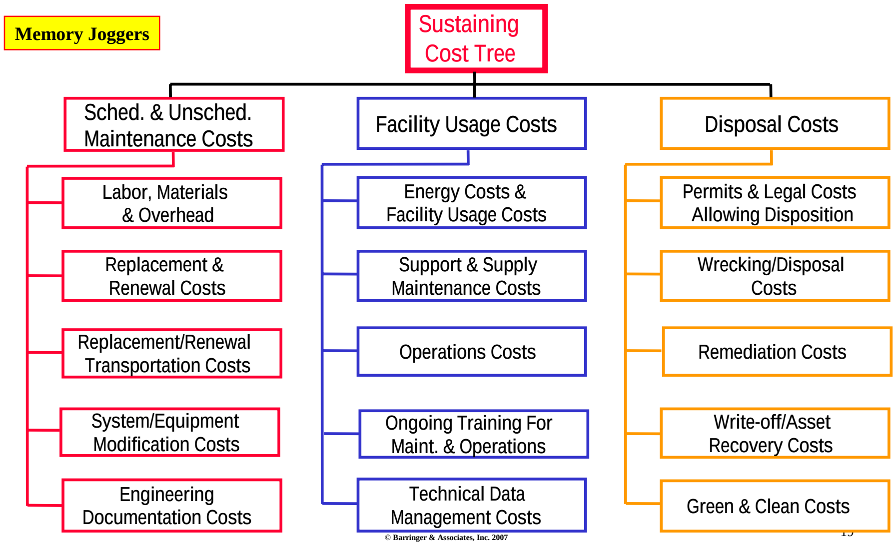
Branches For The Sustaining Tree

Memory Joggers



What Costs Goes Where?

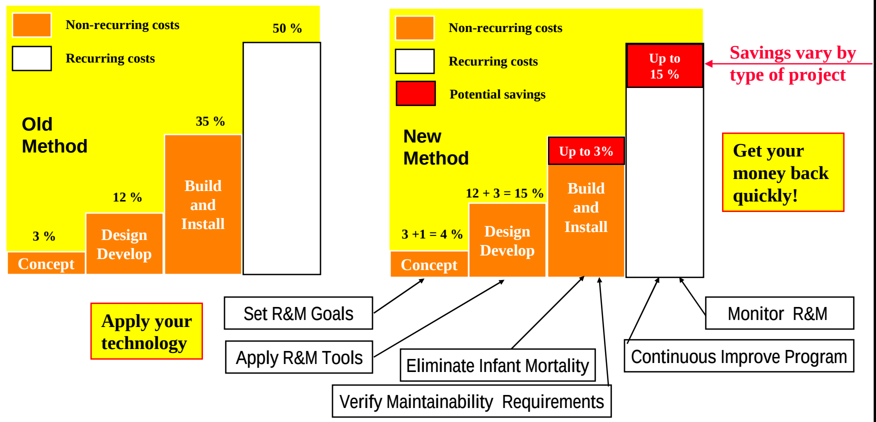
- Use common sense
- Each case is special
- Consider the details for BOTH acquisition and sustaining costs to develop the cost schedules
- When in doubt, include the costs
- Don't ignore obvious costs or include trivial costs
- Include the appropriate cost elements and discard the trivial elements--use standard models

Don't make this a career to complete the tasks!

A New View Of R&M Influence On LCC

Save up front and defer costs until later by holding down engineering costs

Use strong R&M engineering tools to reduce the largest cost components and reduce LCC



Source: SAE Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment, 2nd edition, M-110.2

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The Big Picture For Each Phase

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

Tailor the matrix to avoid too little or too much emphasis on R&M but meet the needs of the business to make the effort cost effective

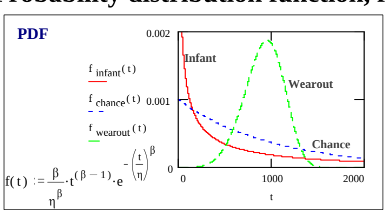
LCC Requires Facts

- Based on “typical” equipment justifications, equipment “rarely fails”—as maintenance cost is not detailed and not preplanned
- Real equipment needs constant and expensive maintenance activities--CM, PM, and PdM
- Most engineers don’t acknowledge failure data exists and lack training in how to use the data
- LCC calculations depend on equipment facts--not opinions—and reliability/maintainability details can decrease life cycle cost per SAE

Get as many facts as you can gather and supplement them with your assumptions. Don’t get bogged down in the trivia—keep some altitude!

Weibull Statistics: Important LCC Tools

Probability distribution function, f(t)

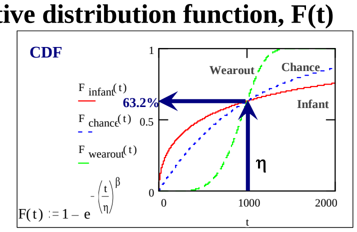


η = 1000 <—Characteristic life
β = 5 <—Shape factor
(β has literal interpretations for individual component failures)

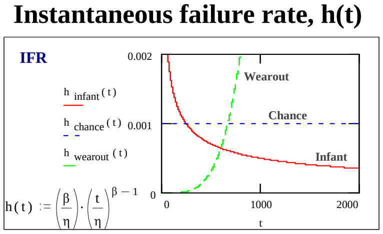
MTBF or MTTF = η∗Γ(1/β + 1) and when β = 1 then η = Θ

Values used for plots:
β = 0.5 for infant mortality,
1.0 for chance failures
5.0 for wear-out failures
η = 1000 for the characteristic life

Cumulative distribution function, F(t)

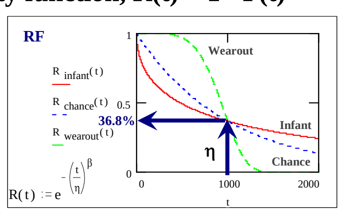


Instantaneous failure rate, h(t)



<—Weibull failure rates can represent: infant failure modes, chance failure modes, or wearout failure modes.

Reliability function, R(t) = 1 - F(t)



See Weibull database at: http://www.barringer1.com/wdbase.htm

Weibull Failure Databases

Typical Weibull Failure Data						
	Beta Values (Weibull Shape Factors)			Eta Values (Weibull Characteristic Life--hrs)		
Item	Low	Typical	High	Low	Typical	High
Ball Bearings	0.7	1.3	3.5	14000	40000	250000
Couplings	0.8	2	6	25000	75000	333000
Housing						
Impeller	0.5	2.5	6	125000	150000	1400000
Motors	0.5	1.2	3	1000	100000	200000
Seals	0.8	1.4	4	3000	25000	50000
Shafts	0.8	1.2	3	50000	50000	300000

- **Use Weibull data and equations to find random times to failure using Monte Carlo methods**

Age-to-failure = $t = \eta^*\{\ln(1/(1-CDF))\}^\wedge(1/\beta)$

$= \eta^*\{-\ln(1-CDF)\}^\wedge(1/\beta)$ ←Less computer intensive

substitute the Excel function RAND() for CDF

Download this Excel model from http://www.barringer1.com/MC_files/LCC-Simple-Monte-Carlo-Model.zip

Monte Carlo Failures Find Costs

Individual Failure Iteration--->

Cumulative Iterations--->

Annualized Failures--->

Costs Of Failures--->

NPV ✔

Solo ANSI Pump Fix When Broken Life Cycle Cost Simulation In An Excel Spreadsheet													
a) Individual Iteration			1st Age	Project Year Of Replacement And Number Of Replacements Required									
Cost Element	η	β	To	1	2	3	4	5	6	7	8	9	10
Electricity			Failure										
Seal	3	1.4	1.28	0	1	2	0	0	0	0	1	0	0
Shaft	18	1.2	9.26	0	0	0	0	0	0	0	0	0	1
Impeller	12	2.5	13.28	0	0	0	0	0	0	0	0	0	0
Housing	18	1.3	49.44	0	0	0	0	0	0	0	0	0	0
Pump Bearings	4	1.3	9.03	0	0	0	0	0	0	0	0	0	1
Motors	12	1.2	17.31	0	0	0	0	0	0	0	0	0	0
Coupling	8	2.0	5.53	0	0	0	0	0	1	0	0	0	0
Hours Down Time For This Iteration =				0.00	8.00	16.00	0.00	0.00	8.00	0.00	8.00	0.00	18.00
Number Of Failures For This Iteration=				0	1	2	0	0	1	0	1	0	2
Cumulative Number Of Suspensions=				0	0	0	0	0	0	0	0	0	0
b) Cum. Iterations-->	**10000**			Project Year Of Replacement And Cumulative Number Of Replacements Required									
Cost Element	η	β		1	2	3	4	5	6	7	8	9	10
Electricity													
Seal	3	1.4		1997	3051	3469	3573	3617	3647	3581	3664	3639	3636
Shaft	18	1.2		296	383	432	516	463	500	519	508	538	578
Impeller	12	2.5		19	82	207	301	460	575	700	780	891	995
Housing	18	1.3		220	323	396	458	417	462	485	528	543	512
Pump Bearings	4	1.3		1563	2284	2529	2632	2659	2591	2730	2711	2688	2673
Motors	12	1.2		500	630	747	704	759	798	793	790	809	791
Coupling	8	2.0		153	451	779	955	1159	1266	1351	1416	1421	1451
Cumulative Hours Down Time =				39896	60336	71712	76884	79700	82468	85228	87360	88566	89308
Cumulative Number of Failures=				4748	7204	8559	9138	9534	9837	10160	10397	10529	10635
c) Annual Failures Expected				Project Year And Average Number Of Failures Required Each Year									
Cost Element	η	β		1	2	3	4	5	6	7	8	9	10
Electricity													
Seal	3	1.4		0.200	0.305	0.347	0.357	0.362	0.365	0.358	0.366	0.364	0.364
Shaft	18	1.2		0.030	0.038	0.043	0.052	0.046	0.050	0.052	0.051	0.054	0.058
Impeller	12	2.5		0.002	0.008	0.021	0.030	0.046	0.058	0.070	0.078	0.089	0.100
Housing	18	1.3		0.022	0.032	0.040	0.046	0.042	0.046	0.049	0.053	0.054	0.051
Pump Bearings	4	1.3		0.156	0.228	0.253	0.263	0.266	0.259	0.273	0.271	0.269	0.267
Motors	12	1.2		0.050	0.063	0.075	0.070	0.076	0.080	0.079	0.079	0.081	0.079
Coupling	8	2.0		0.015	0.045	0.078	0.096	0.116	0.127	0.135	0.142	0.142	0.145
Average Down Time Hours For All Iterations=				3.99	6.03	7.17	7.69	7.97	8.25	8.52	8.74	8.86	8.93
Average Number Of Failures/year For All Iterations=				0.47	0.72	0.86	0.91	0.95	0.98	1.02	1.04	1.05	1.06
d) Annual Cost Expected For Each Time Interval				**Project Year And Annual Costs Expected From Simulation**									
Cost Element	η	β		1	2	3	4	5	6	7	8	9	10
Electricity	--	--		16500	16500	16500	16500	16500	16500	16500	16500	16500	16500
Seal	3	1.4		6865	10488	11925	12282	12433	12537	12310	12595	12509	12499
Shaft	18	1.2		1296	1678	1892	2260	2028	2190	2273	2225	2356	2532
Impeller	12	2.5		69	296	747	1087	1661	2076	2527	2816	3217	3592
Housing	18	1.3		1351	1983	2431	2812	2560	2837	2978	3242	3334	3144
Pump Bearings	4	1.3		5185	7577	8390	8732	8821	8596	9057	8994	8917	8868
Motors	12	1.2		1815	2287	2712	2556	2755	2897	2879	2868	2937	2871
Coupling	8	2.0		513	557	606	633	663	680	692	702	703	707
Maintenance PM visits				$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600
Operations PM visits				$ 364	$ 364	$ 364	$ 364	$ 364	$ 364	$ 364	$ 364	$ 364	$ 364
Vibration Dept				$ 520	$ 520	$ 520	$ 520	$ 520	$ 520	$ 520	$ 520	$ 520	$ 520
Training costs				$ 128	$ 128	$ 128	$ 128	$ 128	$ 128	$ 128	$ 128	$ 128	$ 128
Total				**$35,205**	**$42,977**	**$46,815**	**$48,473**	**$49,034**	**$49,922**	**$50,827**	**$51,553**	**$52,084**	**$52,324**
Approximate suspensions per failure=				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Approximate system failure rate (failures/yr)=				0.47	0.72	0.86	0.91	0.95	0.98	1.02	1.04	1.05	1.06
Approximate system MTBF(years/failure) =				2.11	1.39	1.17	1.09	1.05	1.02	0.98	0.96	0.95	0.94
Theoretical 1 yr Reliability =				60.5%									
# of iterations->	**10000**	1 yr reliability, R=		62.2%	48.7%	42.5%	40.1%	38.5%	37.4%	36.2%	35.4%	34.9%	34.5%
Fix When Broken Strategy		1 yr Availability, A=		99.95%	99.93%	99.92%	99.91%	99.91%	99.91%	99.90%	99.90%	99.90%	99.90%

←Metrics

Recommended replacement item?

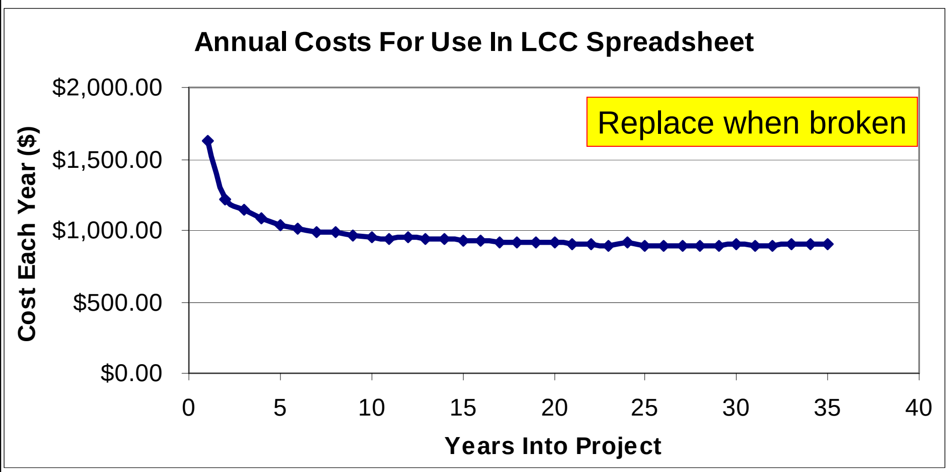
- We have three replacement components that we can use for a 10 year project life:

	Weibull's	Expense
Item 1:	β = 0.8, η = 10 years,	cost = $10,000
Item 2:	β = 1.0, η = 10 years,	cost = $10,000
Item 3:	β = 3.5, η = 10 years,	cost = $10,000

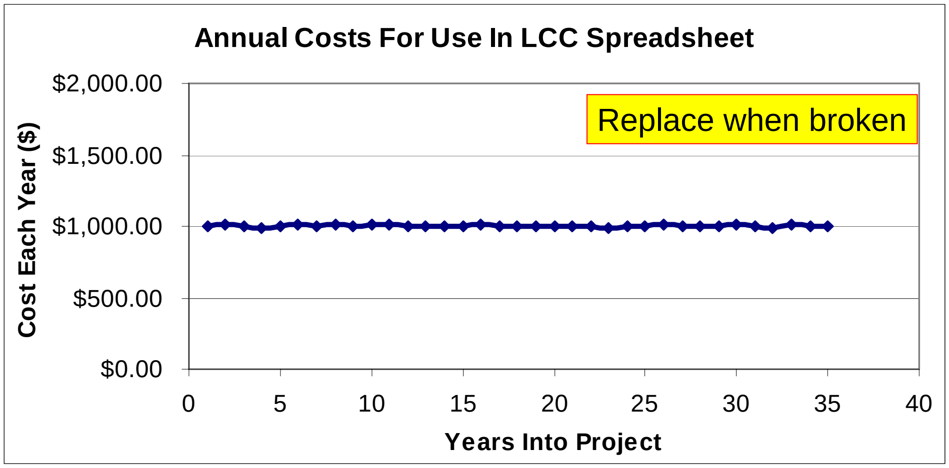
- Which component should we select and why?
- What typical costs should we expect each year for a fix when broken replacement strategy?

See: http://www.barringer1.com/dec04.htm ← fix when broken
http://www.barringer1.com/jan05.htm ←periodic replacement
for Weibull MC cost simulations

#1: Weibull: β = 0.8, η = 10, replacement expense costs = $10,000, Discount rate = 12%, tax rate = 38%, project = 10 years,
NPV = -$4,050 where simulated expense cost each year is:
$1624, $1216, $1146, $1088, $1039, $1011, $986, $989, $968, and $957



#2: Weibull: $\beta = 1.0$, $\eta = 10$, replacement expense costs = $10,000, Discount rate = 12%, tax rate = 38%, project = 10 years,
NPV = -$3,513 where simulated expense cost each year is:
$1003, $1009, $999, $994, $996, $1012, $997, $1012, $1001, and $1011



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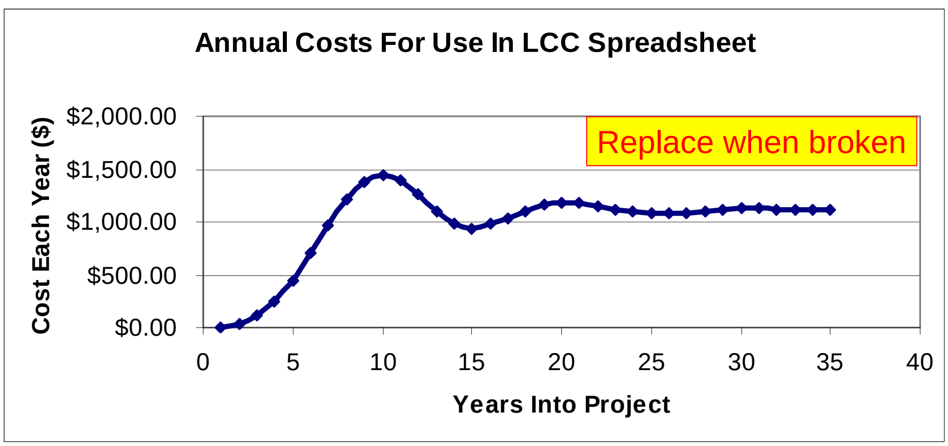
#3: Weibull: $\beta = 3.5$, $\eta = 10$, replacement expense costs = $10,000, Discount rate = 12%, tax rate = 38%, project = 10 years,
✔ **NPV = -$1,714** where the simulated expense cost each year is:
$3, $32, $110, $251, $450, $700, $967, $1211, $1379, and $1441



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Monte Carlo Summary

- **The Results:**

	Weibull's	Expense	NPV
Item 1:	β = 0.8, η = 10 years, cost =	$10,000	-$4,050
Item 2:	β = 1.0, η = 10 years, cost =	$10,000	-$3,513
Item 3:	β = 3.5, η = 10 years, cost =	$10,000	✓ -$1,714

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LCC Summary

Want more to read? See: http://www.barringer1.com/lcctrng.htm

- **Life cycle costs include cradle to grave costs**
- **Including Weibull failures into LCC decisions permits engineering quantities of resources**
- **LCC provides a visualization technique for trade-off studies and uses NPV for sound decisions**
- **Monte Carlo models add realism to numbers**
- **Good engineering produces LCC alternatives to search for the lowest long term cost of ownership**
- **In the end, the effort is all about the money and Weibull analysis is a key tool to get to the money!**
- **Weibull distributions and LCC go together like peanut and jelly sandwiches for great results!** ✓

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