Introduction And Evaluation Of Reliability

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Abstract

Reliability is the probability that a device, system, or processes will perform its prescribed duty, without failure, for a given time, when operated correctly, in a specified environment. Reliability numbers, by themselves, lack meaning for making improvements. For business, the financial issue of reliability is controlling the cost of unreliability from equipment and process failures which waste money. Reliability issues are understandable when converted into monetary values by using actual plant data. Several reliability engineering tools are discussed.

Keywords: Reliability tools, failure modes, data, reliability analysis, cost of unreliability

Reliability Definitions

Reliability has many definitions (Omdahl 1988). If repairs are not possible, reliability is the duration or probability of failure-free performance under stated conditions. If repairs are possible, reliability is the probability that an item can perform its intended function for a specified interval under stated conditions. Dependability is another single word definition for reliability.

Reliability definitions include probabilities with values between zero (absence of reliability) and one (perfect reliability—which only exists in your fantasy world). Reliability is difficult because probabilities change with time. Quantifying reliability sets the stage for quantifying risks when monetary values are included.

Measuring the reliability of plants and equipment by quantifying the annual cost of unreliability puts reliability into a business context. Measurement, planning, and improvement are things businesses do well, but only when efforts are focused on important problems which are highlighted by monetary values.

Reliability Improvement Motivation

Higher plant reliability reduces equipment failure costs. Failures decrease production and limit gross profits. Boosting reliability, by reducing the cost of unreliability, improves business performance. The clear reason for reducing unreliability is spelled: money. The motivation for improving reliability is straight forward for a business plan: Improve reliability, reduce unreliability costs, generate more profit, and get more business.

We talk about reliability (a good word), but we measure failures (a bad word). Failures demonstrate evidence of unreliability with unfavorable cost consequences for businesses. Failures in most continuous process industries are measured in process downtime. Cutbacks or slow-downs in output are also failures. Failures require a clear definition for organizations making reliability improvements. Failures are loss of function when the function is needed—particularly for meeting financial goals.

Everyone knows downtime stopping the production process measures unreliability and defines a failure. Fewer people know that cutbacks or slow-downs in output are demonstrated failures. Define your failures to understand the need for reliability improvements. Failure definitions (when measured by money) galvanize organizations into action for making improvements.

Make reliability improvements pay their way by reducing the flow of funds into costs of unreliability. Find affordable business solutions. Avoid searches for perfection as business reliability solutions must result in profit improvements.

Can your plant afford a reliability improvement program? Answer these questions for your plant:

- What is the annual cost of unreliability?
- Where are losses occurring inside the plant?
- Do you know the root cause for the losses?
- What are the alternatives for reducing costs?
- Are top ten Pareto items identified in terms of money? --What specific items need correction? --Who is responsible for corrective actions? --What is the budget (time and cost) for change? What are the rewards for improvement?

Answering these questions requires identifying the expected annual failures occurrences (both obvious failures and cutback or slow-down failures) and then calculating the losses. These money facts help motivate reliability improvement programs.

Reliability requirements for businesses change with competitive conditions and business risks—the playing field is always tilting. Unreliability values change with business conditions. You don't need the best reliability in the world for your business—you just need a cost advantage over your fiercest competitor. Even low cost industry providers need reliability improvement programs—reliability does not stand still. Unreliability costs usually increase.

Motivations for reliability improvements are driven by the cost of unreliability—this tells the magnitude of the pain. Where the pain occurs within the plant is important. Why the pain occurs gets to the root cause of the problem for corrective improvement programs. Don't rely on a magic bullet to fix reliability problems because seldom will correcting one item make a big change in overall reliability.

Reliability Policy

You need a reliability policy for decisive actions in preventing process failures. Management communicates with policies. What does your reliability policy say?

Most companies have a safety policy which says:

We will have an accident free work environment.

Just 40 years ago this was considered impossible.

Most companies have a quality policy which says:

We will ship defect free products.

This was considered impossible only 20 years ago.

Most companies have an environmental policy which says:

We will have no environmental spills or releases.

This was considered impossible 2 years ago.

Most companies have a reliability policy which says:

____________________?____________________

The slate is blank on the issue of reliability! Establishing a formal reliability policy is leading edge material for forward thinking organization. Consider this for your reliability policy:

We will build an economical and failure free production process which will operate for 5 years between planned outages.

The motivator for a reliability policy is to reduce the high cost of unreliability (Barringer 2003a). If you don't have a reliability policy, go get one to help reduce your costs.

Reliability Tools

Reliability tools showed their real value in the 1930s, '40s, and '50s when used on exotic military programs. Fortunately many reliability tools do not need a rocket scientist to use them cost effectively. Some simple reliability tools provide big gains quickly and defer the use of higher powered tools for squeezing out the remaining improvements. In all cases, score cards for reliability improvements in business need measurements in money.

Use of reliability tools is evolutionary:

- Start reliability programs with arithmetic and simple spreadsheets.
- Understand how to use age to failure data and make the data talk.
- Understand good practices and how practices affect life to gain momentum for improvements.
- Improve teamwork between maintenance and operations to reduce failures by use

of total productive maintenance programs.

- Solve the roots of failure problems by use of a formal program and build on a work process for continuously, effectively, and systemically eliminate failures to reduce the cost of unreliability.
- Convert failures into money considering both maintenance costs and gross margin losses for production items not produced
- Build models of reliability issues and consider alternatives for reducing costs.
- Spur improvements by using statistics to quantify and understand scatter in the data.
- Build Monte Carlo computer models to simulate plant availability, reliability, maintainability issues, production capability, and life cycle costs for deciding reliability strategies
- Use simple qualitative tools of failure mode and effects analysis (FMEA) and fault tree analysis (FTA) and as major problems are eliminated move the techniques to quantitative methods.
- Educate and train maintenance, engineering, and production in the fundamentals of mechanical failures, electronic failures, people failures, and software failures with the goal of controlling and eliminating failures.
- Keep reliability score cards (KPI's) measured in money terms.

The reliability improvement hierarchy shown in Figure 1 depends on having lower level programs operational as precedents to accomplish higher level objectives.

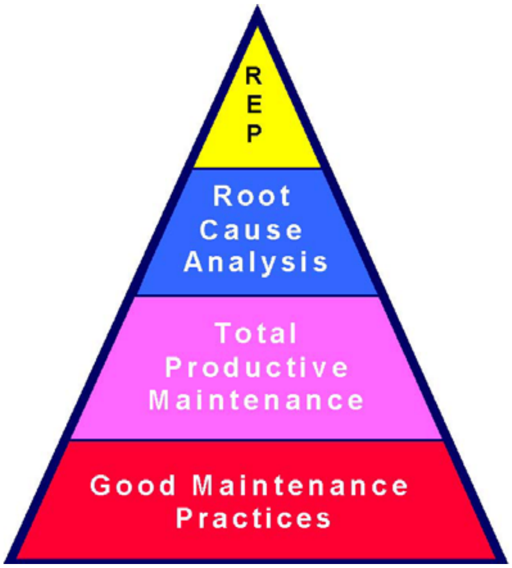


Figure 1: Reliability Hierarchy

The reliability improvement hierarchy uses a host of new tools to reduce both failures and the effects of failures. This work-process initiative is to gain a beachhead and expand territory by improvements. Few lasting improvements are maintained without improving reliability as a work-process using four important programs:

- **Good maintenance practices** (GMP) uses the best-of-class practices for "doing" activities. This requires having trained people at various levels with a commitment to on-going training. Use good procedures and practices to avoid calamities. Teach new techniques and verify the workforce has accepted them as requirements for correct performance—such as precision alignment of rotating equipment along with precision alignment of all piping and equipment. Start teamwork between maintenance and production departments. Teach each group the difference between right and wrong for installation, use, and maintenance of equipment.

- **Total productive maintenance** (TPM) is a way of life for involvement of production personnel into appropriate maintenance tasks for tender loving care of both equipment and processes. (Suzuki 1994) Aim TPM for effective use of equipment and loss prevention by a preventive maintenance effort with involvement of all people from top to bottom in the organization. Promote preventive maintenance through the TPM program by use of self-directed small work groups. The thrust of this effort is to find problems early for making corrections at the least cost. TPM is inexpensive to install, results are see quickly, and it forms a solid based for growing other, more complex, programs such as reliability centered maintenance (RCM).
- **Root cause analysis** (RCA) works on defining problems into categories such as people, procedures, or hardware. Demonstrate RCA solutions will prevent recurrence, meet the organizations goal, and be within an individuals control for preventing recurrence. The RCA program will generally show 505-70% of the problems have a root with people so you must allow the finding without destroying the people and without the people hiding their problems.
- **Reliability engineering principles** (REP) uses new tools to solve old nagging problems. The program is interested in solving the vital few problems that save/make the most money to reduce overall cost of unreliability. Many tools use bathtub concepts to match correct tools to cost effective strategies by applying science and engineering to RCM efforts. The thrust of this effort is to solve problems using new science and new technology on a fact driven basis to solve problems by engineering out the failures.

Work-processes for reliability improvements start at ground level with a firm foundation and builds toward greater successes. Successful, on-going, reliability improvement programs don't just happen overnight— they are the results of well thought out programs, carefully implemented. Generally, reliability work-process programs are driven by the need for improved profitability. They begin by determining the cost of unreliability. This exercise requires plant failure data and cost data.

Age-to-failure data-Acquiring good data for equipment life sounds easy. In many ways, it is a difficult task. The data acquisition task is as difficult as taking beautiful and saleable photos with a camera. Photos are advertised as easy to acquire. However, few candid photos are sold and used in professional literature. Taking a beautiful photo requires:

- Good data logging equipment i.e., camera,
- Knowledge of art and science of photography,
- Careful illumination of the subject,
- Clear understanding of the photo's purpose, and
- Photo appreciation for either art or commerce.

Failure of just one element results in a useless photo. Not all photos made by the experts are saleable—most are junk and professional photographers play the odds and take many photos to get the prize winning shot. Trying to take a beautiful photo by simply walking down the street taking snapshots won't produce good results. Similarly, acquiring photos rapidly is equally unproductive. In short, taking a good photo requires a carefully constructed plan—it doesn't just happen!

Abernethy (2002) says acquiring equipment failure data has three basic requirements (items 1-3); and for commercial businesses, add two other elements (items 4-5):

1. Define an unambiguous time origin,
2. Define a scale measuring the passage of time,
3. The meaning of failure must be entirely clear,
4. Measure cost consequences for failure, and
5. Gain data analysis expertise for using data.

A thoughtful plan to acquire a few pieces of carefully logged age-to-failure data for equipment is better than vast quantities of poorly planned data. Notice the parallels between photography and failure data.

People in many plants say they lack any data (Barringer 1995) when in fact; data is all around them, in various degrees of usefulness. Most industrial plants have been acquiring equipment failure data for many years and seldom is the data analyzed in a scientific manner. Rarely do people acquiring the data observe the data being used to solve their problems. The net result is vast data banks of nearly useless information acquired haphazardly and annotated poorly. Today's task is to "mine" through piles of existing data while acquiring new age-to-failure data in a carefully thought-out manner so it can be used for an economic advantage. The key phrase to remember is "age-to-failure" and of course that requires a consistent definition of failure.

The field of reliability offers many technical guidelines for how data should be acquired, annotated, and used for analysis. In many cases, failures need a "death certificate" just as occurs with human failures. Death certificates for humans have been so productive in producing analyzable results, that it now illegal in the civilized world for a person to be buried without a death certificate listing age and cause of death.

Substantial amounts of failure data exist in the literature awaiting knowledgeable use of the facts for improving the reliability of plants and equipment (IEEE 1984) (RAC 1994) (Barringer 2003b). New data acquisition initiatives by the Center For Chemical Process Safety (CCPS 1989) using proven skills of data analysis experts, are underway for acquiring data from chemical plants and refineries. Don't wait! Start with common sense data from your plants. Make your failure data work for solving your personal and company needs.

Many plants now know their mean time between failure (MTBF) for pumps from special emphasis on reducing failures on rotating equipment. Pumps and other rotating equipment is often installed in redundant arrays. The redundancy seldom shuts down plants. However, non-rotating equipment often causes plant shutdowns! Few plants know MTBF for heat exchanges, columns, reactors, and so forth. It is important to use failure data to prevent failures and concentrate solutions on the vital few problems. For many plants the beachhead is secure in the rotating equipment area. It is now time to reassign resources into non-rotating equipment areas (while holding gains in rotating equipment areas) to reduce and prevent failures which cause plant outages.

Plant data for calculating failure rates is accumulated in a simple form for evaluating the big picture in blocks as illustrated in Figure 2. Use a reasonable length of time for the study period. Count the number of failures occurring during the time interval to calculate MTBF. The failure rate is the reciprocal of MTBF. This effort for using plant failure data involves arithmetic. Figure 2 shows a reliability problem (high failure rates) in block B.

Block Diagram Of Plant

	A	→	B	→	C		Summary	
Study Interval-hrs	43800		26280		35040		8760	hrs/yr
Number Failures	1		3		2		1.7	fail./yr
MTBF	43800		8760		17520		5153	hrs/fail.
Failure Rate	22.8E-06	+	114.2E-06	+	57.1E-06	=	194.1E-06	fail./hr

Figure 2: Plant MTBF And Failure Rate

From the failure rate details, another spreadsheet is prepared to determine the lost time from the failures which leads to pricing the cost of unreliability. Figure 3 shows a maintainability problem (long repair times) in Block C.

Block Diagram Of Plant

	A	→	B	→	C		Summary	
Failure Rate	22.8E-06		114.2E-06		57.1E-06		194.1E-06	fail./hr
Failures Per Year	0.2	+	1	+	0.5	=	1.7	fail./yr
Corrective Time/Fail.	18		24		83		40.6	hrs/fail
Lost Time Hrs/Yr	3.6	+	24	+	41.5	=	69.1	hrs/year

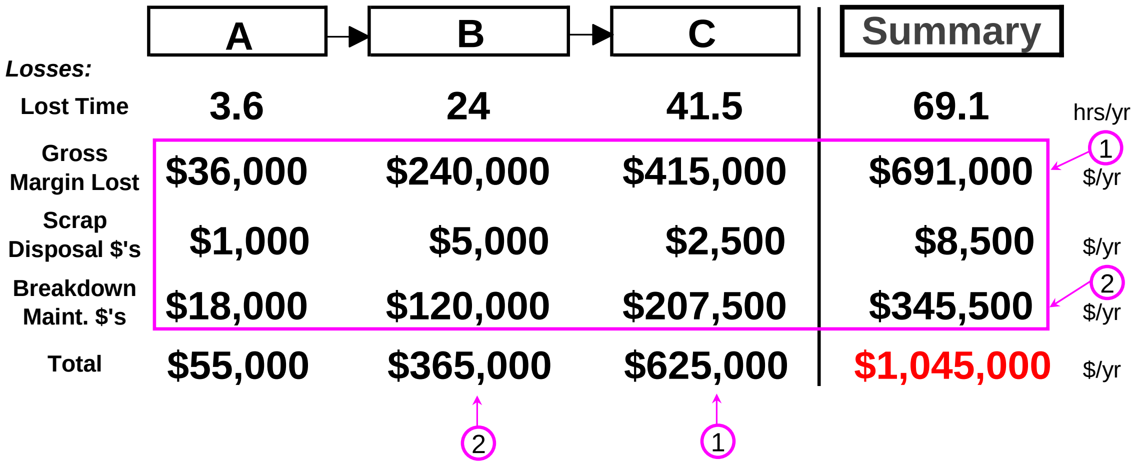
Figure 3: Time Lost From Unreliability

Figure 3 shows all failures are not equal. Setting work priorities only on the basis of failure "body counts" can be misleading. It's important to determine corrective times for failures to make good estimates for total downtimes—lost production time for the plant is also lost money. Average times for corrective efforts can be calculated in the same manner as shown in Figure 2.

Generally several questions arise in using failure data for calculating the cost of unreliability:

- Will the number of future failures follow past failure histories? The answer is generally yes unless heroic efforts have resulted in substantial improvements in decreasing failure rates.
- Will future times for corrective actions to repair and restart the plant follow past histories? Yes, in general, and times for corrective actions are usually skewed data with tails to the right.
- Should planned turnarounds for renewal of equipment be counted as failures? Yes—for investors, the plant is in a failure mode.
- Should turnaround costs be included in the cost of unreliability? Yes—investors incur a double hit for financial losses because the plant is not generating gross margin dollars and it is spending money rapidly for the renewal process.
- What's the advantage of starting at the "top level" of the plant to examine failures and make cost of unreliability predictions? The purpose for the plant is to manufacture products and generate gross margins for the corporation even when individual equipment fails. Think of the plant as an army, the army must move forward in conquest knowing that individual soldiers will die and the battle plan must consider the price to be paid for its efforts—including concern about casualties. Unreliability cost quantifies losses expected from failures and promotes concentration on the vital few items to minimize losses for failures.

Put the failure data to work calculating the cost of unreliability as shown in Figure 4 based on lost gross margin at $10,000 per hour, scrap disposal at $5,000 per incident, and maintenance cost at $5,000 per hour of down time for breakdowns.



Losses:	A	B	C	Summary	
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	$625,000	$1,045,000	$/yr
		②	①		

Figure 4: Cost Of Unreliability

The plant expects 1.7 failures per year which causes a cost of unreliability of $1,045,000 per year. Cell C generates the greatest problem (60.2% of total losses) and should rank at the top of the Pareto distribution for corrections by production-engineering-maintenance. Root cause reasons for these projected losses must be determined as described in the above. The number one priority problem for the site manger is to keep the plant running (66.7% of total losses).

From the failure data, two other important values can be determined: annual availability and reliability as shown in Figure 5. High availability provides the opportunity to make money because the plant is ready to respond. Low reliability provides the opportunity to incur outages which cost money.

In Figure 4, the cost of unreliability is a million dollar problem! In the petrochemical industry, it is very common to find high availability numbers and poor reliability as shown in Figure 5 which entitles the plants to have a large cost of unreliability.

$$Plant\ Availability = \frac{Uptime}{Total\ Time} = \frac{8760 - 69.1}{8760} = 99.2\%$$

$$Plant\ \mathrm{Re}liability = e^{-N} = e^{-1.7} = 18.3\%\ chance\ of\ running\ one\ year\ without\ a\ failure$$

$$Plant\ Unreliability = 1 - 18.3\% = 81.7\%\ chance\ of\ failing\ once\ a\ year$$

Figure 5: Annual Availability And Reliability

Figure 5 also explains how plants benchmarked in Solomon Reports can have superior quartile availability and inferior quartile maintenance costs caused by numerous breakdowns. Examination of the reliability equation for Figure 5 shows chances of meeting a five year turnaround interval without failures is only 0.02% chance for success—this plant will pay a high price for outages requiring corrective maintenance! Furthermore, inclusion of loss time from turnaround outages (whenever they occur) will pull down availability. Likewise inclusion of costly turnarounds also increases the cost of unreliability.

How much can we afford to spend to fix the problems causing unreliability? Using a rule of thumb for one year payback, Figure 4 tells the expenditure limits: Don’t spend more than $625,000 to correct problems in Cell C or more than $365,000 in Cell B.

The cost of unreliability index is a simple and practical reliability tool for converting failure data into costs. When the entire organization can understand the problem on one side of a sheet of paper, effort focuses on solving important problems.

Of course other reliability data can be converted into uncomplicated, figure-of-merit, performance indices useful for “getting a grip” on reliability by using mean times between failure. Reliability is observed when MTBF is large compared to the mission time. Likewise, small values of MTBF, compared to the mission time, reflect unreliability.

Accuracy of these simple indices are improved when many data points are screened using well known statistical tools described in IEEE, and RAC publications referenced above. When only a small volume of data is available it is best analyzed using Weibull analysis techniques for component failures to arrive at better estimates of MTBF.

Probability plots-Failure data is chaotic because of scatter in the data. Data scatter can be studied arithmetically for first, quick look results, or refined into statistical details providing richer descriptions when converted into straight line plots of time-to-failure against cumulative chances for the failure.

Most engineers need graphical representation of data to fully understand problems. Without graphs, engineers are often overwhelmed by scatter as age-to-failure data provides no traditional X-Y facts for making conventional plots.

Probability tools are growing in importance with the use of personal computers which generate the curves with ease (Fulton 2004). Weibull probability charts are the tool of choice for reliability problems. For components Weibull plots tell failure modes (how components die):

- infant mortality—use a run to failure strategy,
- chance failures—use a run to failure strategy, or
- wear out failure modes—consider a timed replacement strategy based on costs.

Data from Weibull plots support RCM decisions based on highly idealized bathtub curves. (Moubray 1992) Weibull plots tell component failure modes.

Weibull charts are particularly valuable for pointing correct direction for finding root causes of problems using a few data points. Larger quantities of data add confidence to the decision making process, but at considerable greater expense for acquiring both failures and data. The motivation for using probability charts is to understand failure data and reduce costly failures by appropriate corrective actions.

Consider Figure 6: The slope of the line tells the failure mode is wear out and the chances for failure can be read directly from the Y-axis. In Figure 6, Pump B's seal life is short. By standing and waiting for duty it experiences a service which is 38.1/10.4 = 3.7 times more severe than Pump A based on characteristic life values shown in the figure. Figure 6 was made with commercially available software. (Fulton 2004)

Perhaps a better strategy for the pumps in Figure 6 is to swing the pumps into service every other week (or so) rather than continue the current strategy of operation of standing and waiting. This requires a written operational practice for how to switch pumps without killing the system. Often the frequency of switching equipment is driven by the need to keep humans current on the practice. Humans need practice or else they become rusty and stale which in turn precipitates failures.

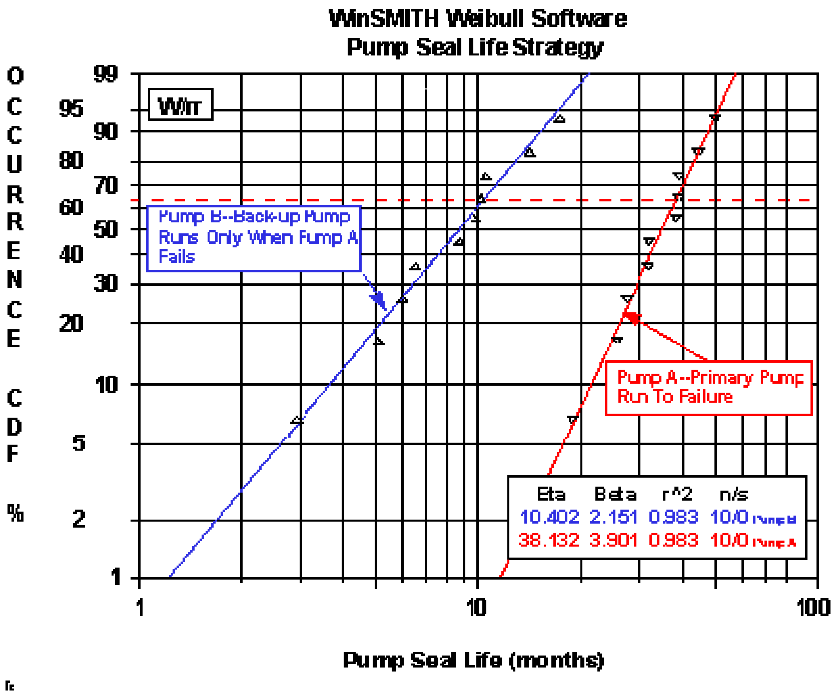


Figure 6: Weibull Probability Chart

Knowing the odds for success/failure is an important fact for assessing risks. Probability charts are easily interpreted, and simple plots of probabilities multiplied by costs can be plotted against time to quantify decisions and consider alternatives. In practice we seldom have too many data points for assessing risks. Weibull plots use few data and help the decision making process—some data is better than no data for making cost effective decisions. Notice the Y-axis scale in Figure 6 is unreliability which is the probability of failure.

***Crow-AMSAA reliability growth models*-**Crow-AMSAA plots are simple log-log plots of cumulative failures on the Y-axis against cumulative time on the X-axis and the plots often show straight lines which makes forecasts of future failures very easy. The line slope, beta, has kinship to Weibull plots and when beta<1 failures come more slowly. When beta>1, failures come more quickly. (Abernethy 2004, Fulton 2004)

When improvement changes have been implemented and failures come more slowly, a cusp forms on the plot of cumulative time versus cumulative failures. Thus by extrapolating the old method line and building the new method line, you can visibly see the savings achieved. The gap between old and new is illustrated in Figure 7 and thus provides the usual missing link to prove that improvements have been achieved. The methodology also works when the Y-axis is in money and the X-axis in time. (Barringer 2003c)

When the Y-axis is transformed by dividing the cumulative failures by the cumulative time you get Cum MTBF vs Cum time plots which makes reliability very visible. Thus improvements cause the curve to rise and deteriorations cause the curve to fall so that reliability is highly visible.

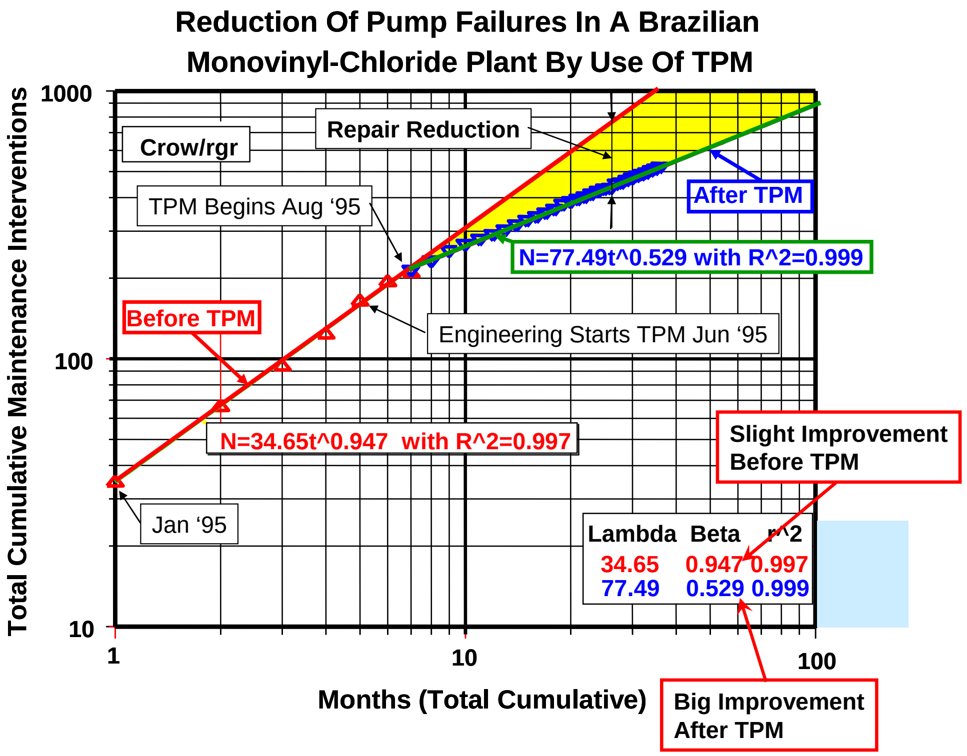


Figure 6: Crow-AMSAA Plot

Monte Carlo models-Plant availability/reliability models are constructed from predominate failure modes determined by Weibull analysis. Monte Carlo models use failure data statistics along with random numbers to gain insight into economic improvements.

Some simple, but practical, Monte Carlo models are available in Excel™ spreadsheets to provide ideas about how Monte Carlo models function. The demonstration models also show end results for availability, reliability, and cost of unreliability when changes are made to components of the model—these models can be downloaded from the Internet. (Barringer 2001). Now you can also download very practical Monte Carlo software known as RAPTOR at no charge which was produced for the US Air Force. (Barringer 2004)

Results from Monte Carlo models depend on good failure data (either actual or engineered data), good repair data, and accurate configuration by the modeler of how the plant physically operates. Of course models are only approximations of plants and making a model does not improve reliability— improvements must be converted into hardware.

Static spreadsheet model always produce the same results each time using arithmetic failure data. However equipment never fails at the same age-to-failure or repair times in real life. Thus Monte Carlo models give different answers for availability, reliability, and costs each time the model is solved.

With today's fast PCs and Monte Carlo models, thousands of solutions can be generated quickly at very low cost to model thousands of years of operation. From the multitude of answers produced by the model come trends, plant characteristics, and often alternatives for correcting deficiencies without incurring expense and delay of building hardware.

Monte Carlo reliability models can realistically assess plant conditions when combined with costs, repair times, and statistical events. Monte Carlo simulation models are very helpful for considering approximate operating conditions in a plant including cost effective sizing of tankage to provide protection for short duration equipment failures.

Good simulation models help determine maintenance strategies and turnaround timing for equipment renewal as simulation models are usually based on simple, heuristic rules. Heuristic rules are based on observed behavior of components or systems and heuristic rules are easy to construct using computer systems knowledge based software.

Reliability models stimulate creative ideas for solving costly problems. Good models help prevent replication of old problems. Reliability models offer a scientific method for studying actions, responses, and costs in the virtual laboratory of the computer using actual failure data from existing plants. Monte Carlo models rely on good data supplied.

Monte Carlo models provide a way to search for lowest cost operating alternatives and conditions by predicting the outcome of conditions, events, and equipment. Monte Carlo models aid in finding the lowest long term cost of ownership.

Other reliability tools-The list of reliability tools is great. (Barringer 2000) The real key to success is putting reliability tools, developed in the past 65 years, to work for cost reductions. Few engineers receive university level training in the use of reliability tools for solving practical problems. The new reliability engineering tools require educating management and training engineers in their use to reduce risk, reduce costs, and improve operations.

Summary

Use failure data from existing plants with new tools to solve reliability problems in practical ways. Businesses cannot afford too little or too much reliability—reliability must be harmonized with cost issues.

Find the cost of unreliability using failure data as an important reliability index. Engineer the cost of unreliability by solving top level items on the Pareto list based on money.

Develop expertise in use of Weibull analysis to solve problems by putting statistics to work on practical problems. Weibull results give details for supporting RCM activities.

Train staffs to use new reliability tools for a competitive business advantage by increasing skills to reduce costs. Cutting edge companies are using new tools such as Monte Carlo models to find cost effectively alternatives for reducing their cost of unreliability.

Develop a reliability policy to build unity of purpose for reliability issues to attack the high cost of unreliability.

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