

Practical Reliability Tools For Refineries And Chemical Plants

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Abstract

Reliability is the probability of equipment or processes to function without failure, when operated correctly, for a given interval of time, under stated conditions. 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.

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. A single word definition for reliability is: dependability.

Reliability definitions include probabilities with values between zero (absence of reliability) and one (perfect reliability). 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 incurred by the facility puts reliability into a business context. Measurement, planning, and improvement are things businesses do well, but only when efforts are focused on important problems.

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/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/slow-downs in output are demonstrated failures. Define your failures to understand the need for reliability improvements. Failure definitions (when attached to dollars) 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?
--What are the specific items for correction?
--Who is responsible for corrective actions?
--What is the budget (time and cost) for change?

Answering these questions requires identifying the expected annual failures occurrences (both obvious failures and cutback/slow-down failures) and then calculating the losses. These 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 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 dollars.

Use of reliability tools is evolutionary:

- Start reliability improvement programs with simple arithmetic and spreadsheets. Quantify important cost and failure numbers.
- Gain momentum with good maintenance practices. Improve teamwork using total

productive maintenance programs. Use root cause analysis to efficiently solve problems. Learn and use a host of straight forward reliability engineering tools to solve problems.

- Spur improvement programs by using statistics to quantify and understand scatter in the results.
- Build Monte Carlo computer models to simulate plant availability, reliability, maintainability, capability, and life cycle costs for deciding reliability strategies.

Keep all reliability scores measured in dollars.

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

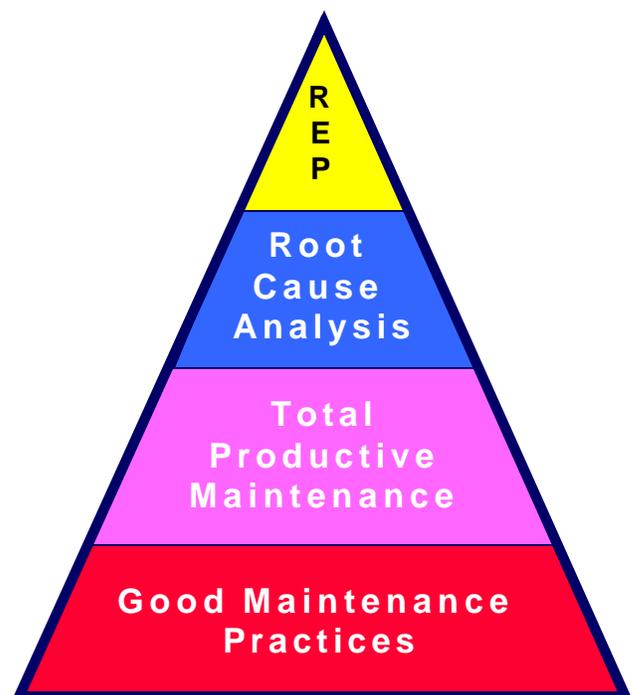


Figure 1: Reliability Hierarchy

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.
- **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. 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.
- **Root cause analysis (RCA)** works on defining problems into categories such as people, procedures, or hardware. Demonstrate RCA solutions to problems will prevent recurrence, meet the organizations goal, and be within an individuals control for preventing recurrence.
- **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 reliability-centered maintenance (RCM) efforts.

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 which are 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 sounds easy. In many ways, it is a difficult task. The data acquisition task is as difficult as taking beautiful and salable 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:

1. Good data logging equipment i.e., camera,
2. Knowledge of art and science of photography,
3. Careful illumination of the subject,
4. Clear understanding of the photo’s purpose, and
5. 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 salable—most are junk. 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 (1996) 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 see the data 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 1993-reading list). New data acquisition initiatives by the Center For Chemical Process Safety (CCPS 1989) using proven skills of data analysis experts at Det Norsk Veratas (OREDA 1992), are underway for acquiring data from chemical plants and refineries. Don't wait. Start with common sense data from your plants. Make 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. Because of redundancy, pumps (and other rotating equipment) today seldom shutdown 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 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—for example: $MTBF_C = (35,040 \text{ hours}) / (2 \text{ failures}) = 17,520 \text{ hours/failure}$.

Block Diagram Of Plant				
	A	B	C	Summary
Study Interval	43,800	26,280	35,040	8,760 hrs/yr
Number Failures	1	3	2	1.7 failures/yr
MTBF	43,800	8,760	17,520	5,153 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.

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	0.5	1.7
Corrective Time Per Failure	18	24	83	40.6 hrs
Lost Time/yr	3.6	24	41.5	69.1 hrs

Figure 3: Time Lost From Unreliability

From Figure 3 it is clear all failures are not equal. Setting work priorities only on the basis of failure "body counts" can be misleading. It's important to determine average 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.

Block Diagram Of Plant				
Losses	A	B	C	Summary
Gross Margin	36,000	240,000	415,000	691,000 ← ①
Scrap Disposal	1,000	5,000	2,500	8,500
Br'kdown Maint.	18,000	120,000	207,500	345,500 ← ②
Total \$	55,000	365,000	625,000	\$1,045,000

②
①

Figure 4: Cost Of Unreliability

This 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.

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

$$\text{Plant Reliability} = e^{-(\lambda \cdot t)} = e^{-(194.1E-06 \cdot 8760)} = 18.3\%$$

$$\text{Plant Unreliability} = 1 - 18.3\% = 81.7\%$$

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 will also increase 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 mean time between failure (MTBF) is large compared to the mission time. Likewise, small values for mean time indices, 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, OREDA, 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 1996). Weibull probability charts are the tool of choice for reliability problems because they often tell failure modes (how components die):

- infant mortality—use a run to failure strategy,
- chance failures—use a run to failure strategy, or
- wearout 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 the curves in Figure 6.

The slope of the line tells the failure mode is wearout 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. Perhaps a better strategy may be to swing the pumps into service every other week rather than continue the current strategy of operation.

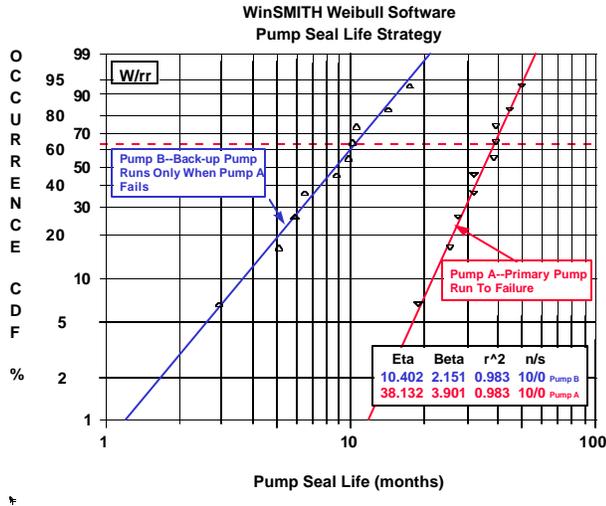


Figure 6: Weibull Probability Chart

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.

Monte Carlo models-Plant availability/reliability models are constructed starting with P&ID diagrams and predominate failure modes determined by Weibull analysis. Monte Carlo models use failure data statistics along with computer generated random numbers to gain insight into economic improvements.

Some simple, but practical, Monte Carlo demonstration 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 1996a).

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.

Now 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 and prevents 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 are never better than the 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 1996b) The real key to success is putting reliability tools, developed in the past 60 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 nor too much reliability—reliability must be harmonized with cost issues.

Know the cost of unreliability based on failure data. It is an important reliability index. The cost of unreliability must be engineered and controlled by solving top level items on the Pareto list.

As expertise in using failure data grows, use Weibull analysis to help with problem solving by putting statistics to work on practical problems. Weibull results give details for supporting RCM activities.

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

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