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Process Reliability: Do You Have It?—What's It Worth To Your Plant To Get It

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Abstract

Process reliability combines new techniques from the field of reliability and six-sigma methodology to help identify areas for improvement and reduce variability in production output. Process reliability in this paper is addressed from a management perspective. Weibull probability plots are used to summarize issues and problems on one side of one sheet of paper to help prioritize corrective action for the organization. Some criteria are presented to show how to quantify issues. A contrast is made with world class operation to reduce the production problems to time and money using production output data.

Attributes of Good Processes

Every excellent process first needs availability. Availability, in the most simple form, is uptime/(uptime + downtime). Detractors from availability are downtime (unavailability).

Availability is a measure of the degree to which an item or process is in an operable and committable state at the start of the mission when the mission is called to perform at an unknown and random time. It is also known as operational readiness and % up-time. Availability + Unavailability = 1

Transients occur during the rise to availability or fall from availability as production output varies because of start-up/shut-down conditions. Transients are detractors from excellent processes. Transients also represent the loss of function when it is needed, which is a failure just as obvious downtimes which occur from failures.

Failures are events which render equipment or processes as non-useful for the intended or specified purpose during a designated time interval. Failures are the loss of function when needed. Failures can be sudden, partial, one-shot, intermittent, gradual, complete or catastrophic. Failures occur from weakness, imperfections, misuse, and so forth. In commercial environments failures represent the loss of money. Some failures are identified by broken components and other failures are observed by inferior process results.

Plants designed for excellence use detailed availability calculations based on reliability and maintainability (RAM) models to make availability calculations rather than simply state a hopeful number than cannot be demonstrated. RAM models use equipment life and equipment repair times to find central tendency for operational availability. RAM models also estimate the expected number of annual plant failures. Calculated availability values avoid the usually optimistic "best guesses" which often do not include detailed plans for excellent performance.

Excellent processes consistently have optimally large output quantities, small output variability, and the products produce conform to the contract specifications. Performance from excellent processes is both predicable and reliable. Seldom is reliability of the process deemed a variable for control in plant design (it's often take what you get). When owners/operators are questioned about process reliability, their response is often a blank look.

Reliability is the probability that a device, system, or process will perform its prescribed duty without failure for a given time when operated correctly in a specified environment. Reliability measures the capacity of both equipment and processes to operate without failure for a specified interval when put into service and operated correctly. Reliability + Unreliability = 1.

Everyone wants a process with highly predictable output. Few get predictability unless it is intentionally designed into the process capability. Predictability for owners/operators is a risk reduction effort.

Predictability knows in advance the outcome of production from the process with small variability in the results. Variability is undesirable and can be caused by bias which is a fixed error which is constant or systematic, and randomness from repeated measurements called precision error. From an owners viewpoint: by their investment, they paid for a given output from a process, and they want it to occur with small variations rather than with large variations. Most variations in process output occur in a direction which is undesirable, i.e., low side results which detract from their investment returns.

Excellent processes must be intentionally configured to perform with other critical plant and process elements. Key elements for an excellent process are not obvious at first glance. Good, productive, use of plant assets requires making products in optimally large quantities (quantity is a precursor for money received from shipping products) to achieve good financial returns on the monetary value of the investment. When output from the process occurs at a consistently high optimum value then owners and customers see the process as a reliable money maker particularly when the product quality conforms to the product specifications as occurs with a quality plant or process.

Quality is the totality of features and characteristics of a product or service that bear on its ability to satisfy a given need. This provides a fitness for purpose sense relating to the ability of goods or services to satisfy a given need. Quality for manufacturing is conformance of the product to engineering's drawings and specifications—and this includes quantity of production output. Quality is a static measure whereas reliability is a dynamic measure.

Excellent processes demonstrate excellent process reliability. Process reliability is a desirable attribute partially configured by piping, pumps, vessels, heat exchangers, towers, and control systems to achieve reliable results. Another portion of excellent process reliability is achieved by how the process is managed and operated—this also applies to people management.

Process reliability represents the percentage of product produced with small variability in output (a desirable attribute) and is identified on a Weibull probability plot as a failure point where a distinct cusp appears as variability in output increases (an undesirable attribute). Increases in output variability occur because of equipment failures, cutbacks and severe problems identified euphemistically as crash and burn issues. Reliability issues always require definition of a failure (the cusp on a Weibull process reliability probability plot) and the cusp tells the probability for the occurrence (percentage of product which meets or exceeds the failure criteria). If you do not measure process reliability, you cannot value it to paraphrase Dr. Deming's words.

Troubled processes have undesirably large variability in output. Usually, but not always, troubled processes are also unreliable. Undesirably large variations in process output along with unreliability of output results in products which cannot be delivered on time to meet shipment promises. Few troubled processes are large money makers. Troubled plants and processes cannot effectively use their assets because of "hidden factories". Hidden factories cause higher costs and lower outputs that cannot be easily broken out and traced to specific operations. Existence of hidden factories is often not known to management even though they suspect that process output is more expensive and the plant is not competitive and possibly a burden on the enterprise.

> **Hidden factories** represent inefficiency that function in stealth mode. Too many people, too many process steps, too much scrap, rework loops that have become vital to make the process function, and non-productive time wasters such as delays or obstructions are hidden factories. Hidden factories sap financial resources without adding value for the owners/operators or the customers of the processes. Hidden factories must logically be nipped in the bud at the source. The problem is identifying hidden factories operating in stealth mode and Weibull probability plots quantify hidden factories.

Weibull probability plots of daily process output data provide a single page view of process performance. Weibull plots use daily plant output of prime product from the process. Weibull plots disconnect process output from the time line to show unique patterns of performance. Weibull plots show data plotted in rank order rather than in time order. Daily production data is always available because it is a precursor of money and Weibull probability plots show process performance with a quick, visual, assessment. Weibull plots are tedious to produce if done by hand but are easy to produce with commercial Weibull Analysis software written to perform process reliability analysis (Fulton 2001).

Steep slopes on Weibull plots are desirable and display small variability in process output from small common cause variation which is built into the process. Flat slopes on Weibull plots display large variability from larger common cause variation which is built into the process or from special causes.

When cusps appear on Weibull plots they mark the change from small variability (to the right of the cusp) to large variability (to the left of the cusp and the cusps often result from special causes. Cusps signal that changes have occurred as if the production mode (failure) has changed.

Weibull plot line slopes refer to the grade of the process. Steep slopes tell of high grade processes (small variability) and flat slopes represent low grade processes (large variability).

> **Process Grade:** A rank indication of the degree of refinement, features, or capabilities for processes, materials, services, and products.
>
> High grade processes produce products which conform to specifications for quality and quantity while demonstrating low variability in output (i.e., steep slopes on Weibull plots).
>
> Low grade processes cannot simultaneously demonstrate high quality, high quantity, and low variability in output.
>
> When grade is applied to a service, it represents the diversity of functions or facilities provided (high grade provides many service whereas low grade provides few service).
>
> When grade is applied to products, high grade products with many features have low quality if they do not meet specifications and low-grade products with few features have high quality if they meet or exceed the specifications.

If production output variation were extremely small, each variation would be detectable for immediate correction. When natural output variation is large, small changes are undetected and thus uncorrected which allows undetected hidden factories to exist.

Introduction to Weibull Plots

Most reliability issues have too much information and too little knowledge. Process plants have vast quantities of data concerning equipment and operating conditions. The problem is making the data "speak" about reliability in terms that are understandable to the ordinary person. One simple method is to use the daily production output from the process and let the production data "speak" based on patterns of output.

Every production process has daily output data usually organized and studied in time sequence with a major effort for relating cause and effect to daily production values. Few organizations view the data as output from a "black box" to study the results in statistical format to see patterns in the data which are disconnected from time sequences so the signal and the noise can be separated for clarity.

Weibull analysis is one way to organize plant data as described by Abernethy (1998). Weibull plots, the tool of choice for most reliability issues, will be used in this paper in a non-traditional manner. The Weibull probability plots will define process reliability and calculate losses from failure of the process to perform. Production losses, output units, are a precursor for money. When problems are explained in money and time, everyone understands them.

The cost of process failures usually exceeds the cost of individual equipment failures by many multiples. We anguish over failure of pumps and heat exchangers—these are the low cost pawns, and we should worry about are expensive process failures—this is the high priced king. The problem is to decide if you have a reliability problem with equipment or a problem with the production process. Weibull plots help explain and categorize problems in a visual format understandable by engineers, process owners, and management. Weibull plots tell you the health of your process in a manner similar to a physical medical examination—it's important to know your health but it's more important to take immediate and permanent corrective action.

The X-axis of the Weibull probability plot uses daily production data plotted in rank order. The Y-axis uses information from Bernard's median rank equation, which is a statistical tool to remove bias from the plotting positions of the ranked data (Benard 1953).

Often production output datasets contain zero daily outputs. Zero values cannot be plotted on a log scale for a Weibull plot, thus zero values are replaced by a "small output value" which is often chosen as two logs smaller in output so that no-output stands out like a sore thumb on a measurable scale without unduly influencing calculations of losses.

Why Use A Weibull Plot?

Weibull probability plots organize many different types of data into straight line X-Y plots. Engineers need data plots, with straight lines, for comprehension at a practical level. For engineers and processes owners the relationship is simple—no cartoon, no comprehension.

Weibull distributions are chosen pragmatically. When data produces a straight line on a Weibull probability plot, the data is considered to be from a Weibull distribution. Weibull distributions are complicated as they are non-linear and usually non-symmetrical distributions; however the resulting straight line plots simplify the non-linear complexities.

Weibull plots: Non-linear data from production processes, when plotted on a Weibull probability plot, usually produce straight lines in an X-Y format. Patterns are easy to see and provide a one page assessment of how the process is functioning.

Cusps on the Weibull plot where data scatter increases are evidence of process failures and define reliability of the production process. If the process produces steep straight lines without cusps it provides evidence of a high grade production process. If the process produces flat slopes without cusps it provides evidence of a low grade production process. Low grade processes offer great opportunities for cost and output improvement.

Weibull plots help identify problems and quantify losses by categories, and other traditional tools can ferret out events/conditions leading to substandard performance. Evidence provided by Weibull plots is often used by reliability engineers and six-sigma experts to search for a variety of problems to be resolved so the goal of reducing variations and increasing profits is obtained.

Traditional Weibull plots in the field of reliability utilize age-to-failure data obtained from component failures to make straight-line plots. For components, the slope of the Weibull line tells the failure mode for the component. This is an important feature for letting the data "talk" about what portion of the bathtub curve is best represented, i.e., infant mortality, chance failures, or old age wear out. Unfortunately, process data contains mixtures of information without clear details about failure modes.

Traditional Weibull analysis carefully separates different failure modes to get clean data with suspensions (i.e., the data is censored) so only single modes of failure are represented in each straight line Weibull plot. When mixed failure modes are plotted on a Weibull plot, cusps often appear that give clues to changes and provide evidence for mixed failure modes. Process reliability techniques will take advantage of the cusps to provide information about process reliability.

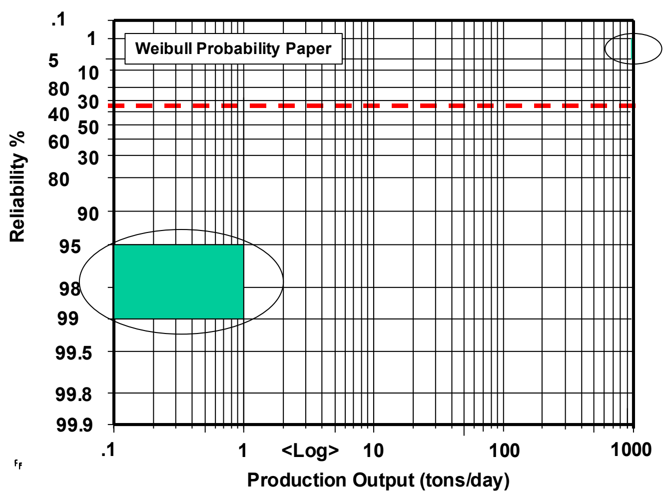

Figure 1: Weibull Probability Paper

Figure 1 shows Weibull probability graph paper. The X-axis is a log scale, used to plot the daily production from a production unit. The Y-axis is an irregularly divided scale resulting from taking the log of another log.

The Y-axis of Figure 1 is plotted in a reliability scale (it counts downward) as you move upward on the Y-axis rather than the traditional cumulative distribution function (CDF) scale reflecting unreliability (which counts upward) as you move upward on the Y-axis. This is possible because of the complementary equation between reliability and unreliability.

Notice Weibull plot scales magnify problems in the lower left hand corner so they can easily be observed as shown by the darkened rectangular areas highlighted by the ellipses in Figure 1. Both ellipses surround a rectangular area which is 4% (on the Y-axis) by 0.9 units of production (on the X-axis). Notice that you can barely see the highlighted zone in the upper right hand corner but the zone in the lower left hand corner is clearly obvious. Weibull plots magnify the zones of low production which cause all the headaches and the loss of money!

How Does Scalar Production Data Get Into An X-Y Format?

Production data from a process is usually acquired as daily output. If daily averages, weekly results, or monthly data summaries are used, the smoothing of the data hides reliability problems of the process. The daily output reflects conditions upstream and downstream from the pay-point under measurement. Daily output is a scalar value.

Statisticians have worked out a scheme for handling the conversion of scalar results into a X-Y coordinate system. Data is ranked from low to high to form N pieces of information. The rank of each value is identified with its "i" position using Bernard's median rank equation which gives the reliability Y-position as $1 - [(i - 0.3)/(N + 0.4)]$. Details are explained in Abernethy.

> **Benard's median rank:** A tool for allowing scalar data to be plotted on probability paper as an X-Y coordinate to avoid bias in the Y-axis elevation of ranked data as probability paper has no 0% or 100% locations. Please note that 10 data points would have vertical positions on the CDF scale of 6.7%, 16.3%, ….83.7%, and 93.3%; or in the Reliability scale the plot positions for the same 10 data points would be 93.3%, 83.7%,…16.3% and 6.7%. This is a different location than you would expect intuitively as you might want to place the first point on the Y-axis at 10% for the CDF scale or 90% on the R scale—of course you would still face the problem of plotting the last point at 100% which does not exist on probability paper because the probability scale has not beginning and no end.

For a rank column of production data with N = 365 days of production, suppose the 10^{th} data point (i = 10) was 703 of production. The X-value is 703, and the reliability Y-value by Benard's median rank is 1- [(10 - 0.3)/(365 + 0.4)] = 1 – [9.7/365.4] = 100% - [2.65753%] = 97.34247%. This information gives a Cartesian position (703, 97.34247%) on Weibull probability paper.

Notice this plotting scheme abandons the typical time position of the data. Instead, data is treated as randomly occurring information generated by a "black box" which is the process. Please note, the well-known Weibull modes of failure do not apply to the "black box" data. Thus the trend line slope β does not have physical relationships to infant mortality, chance failures, and wear out failures associated with individual failure modes in typical reliability analysis. However the values do have physical relationships, of a different type, for process reliability plots.

Production data, from a high altitude perspective, displays Weibull plot details with trend lines of β (line slope) and η (characteristic values for a single point estimate of output).

Physical relationships of β and η on process reliability Weibull plots: Weibull shape factor β measures rise over run for a line slope indicating grade of the process. Small values of β describe low grade processes with great variability in output. Large values of β describe high grade process with small variability in output.

Often a top (first) quartile producer, with carefully designed processes, may demonstrate a world class β = 100 for their high grade processes. A bottom (fourth) quartile producer with a take what you get processes may demonstrate a β = 27 (or lower) for their lower grade processes. Thus line slope β allows a benchmark evaluation. Processes with large β's are desirable and small β's are undesirable.

Weibull characteristic value η, which occurs at the CDF = 63.2% or the R = 36.8% reduces the non-linear data from production processes into a single point estimate of daily production. The significance of the Y-axis position at CDF = 63.2% or the R = 36.8% has mathematical properties explained in Abernethy. Processes with large η's are desirable and small η's are undesirable. The magnitude of the η value is determined by the size of the physical facility and how it is managed.

When data from the actual process is compared with Monte Carlo results of the black box details, they have a similar appearance. Thus modeling adds credibility that the actual data can be represented by a Weibull probability model (Barringer 1999a).

Production Data from 365 Days—Two Data Sets With Two Points Of View

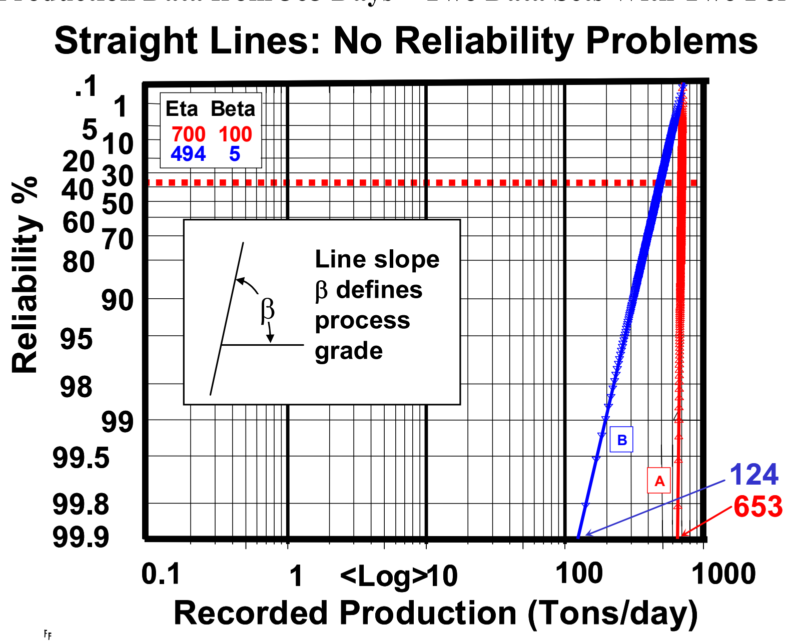

Figure 2: Weibull Plot

Consider the Weibull plot in Figure 2. Neither curve has reliability problems, i.e. a cusp. Trend line A is a best of class process, with small variation in output, is preferred over trend line B, with its larger variation. Both curves have the same maximum daily output, which is usually fixed by physical restraints in the system.

On an exception basis with a 0.1% risk for error, production output less than 653 tons/day for process A or 124 tons/day for process B would be considered out of control. Note that if process B used process A's criteria then 98.2% of process B's output would be out of control!!!

A mergers and acquisition team studying both processes would prefer trend line A with its consistent, higher grade, production over trend line B with its wider range in output indicating a lower grade process with its higher losses which indicates many hidden factory problems to be solved which will take time and money to correct. Doubling β values cuts losses by roughly ½.

The lost production gap between process A and process B is the summation of the horizontal values between data points. The lost production gap is 88,490 tons/year!!! So the owner of process B has a significant disadvantage in the marketplace compared to process A!

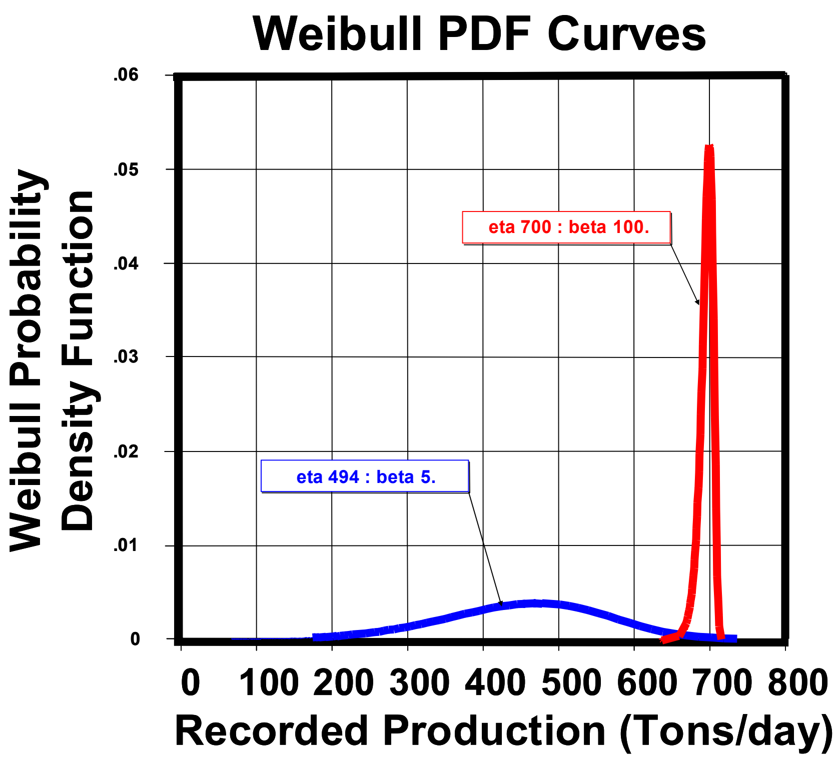

Figure 3: Weibull CDF Plots

Shapes of the probability density functions are shown in Figure 3—these are the shapes you would see if a tally sheet was constructed of daily production quantities. Figure 2 (b) curves have been normalized so area under the curve is unity and thus the Y-axis represents relative frequency of occurrences. Notice that both curves pass through the same maximum value for the 365th data point indicating the practical limit from the plant facility.

Straight Weibull probability trend lines in Figure 2 have curves with tails in Figure 3 for the probability density plots (PDF) (the same shape curve you would get if you made a tally sheet of production data). The flat slope (small β's), lower grade process, for trend line B, with large variations in output and shows a long tail to the right. The steep slope (large β's), higher grade process, for trend line A shows a long tail to the left.

The PDF curve shows the real opportunities for exceeding the maximum output are very small, however opportunities for having downside production quantities is very large. Both of these conditions are easily recognized by seasoned production personnel and the curves are substantially different than you would get using symmetrical Gaussian statistics.

The interest of six-sigma concepts and Weibull concepts are complementary ideas directed toward reducing variation in the data (Barringer 1999b). The Weibull concept works with non-symmetrical shapes to the curves and the idea of reducing variation in output is considered desirable to change low grade production process to higher grade processes to save money.

Where Weibull trend lines of production data cut the dashed line in Figure 2, the resulting X-value represents a single characteristic value for demonstrated production output. This value is represented by eta (η) to show 36.8% of the production will exceed the η value and 63.2% (the complement) will be less than the single point estimate of daily-demonstrated production, η. η is the single point estimates of the demonstrated production value.

The Weibull characteristic value, η, represents a stretch goal for production. The η value is used to best describe the single point estimate of production from non-linear distributions. It is the bull's-eye for aiming the process output.

> **Bull's-eye:** The small central circle on a target which is the aim point objective for process output. The precise accomplishment of a goal or purpose—associated with well aimed shots which hit the mark. Aiming for η as the center of production's bull's-eye neither over extends the process nor under achieves the objective as some natural scatter about η will occur.
>
> Scatter about the bull's-eye needs to be tightly controlled before attempting to change the location of the bull's-eye.
>
> Clear communication about location of the production bull's-eye is essential to bringing the process under control for repeatability as closeness of agreement between successive results using the same method, same operator, same materials, and etc., characterizes repeatability.

Problem Production Data From 365 Days—Two Data Sets With Two Points Of View

In Figure 4 shows processes with reliability failures. The first cusp in the upper right hand corner of the plot on the Weibull trend line defines a failure point (i.e., the trend line switches to greater variability). The highest cusp in the upper right hand corner generally identifies the reliability of the process.

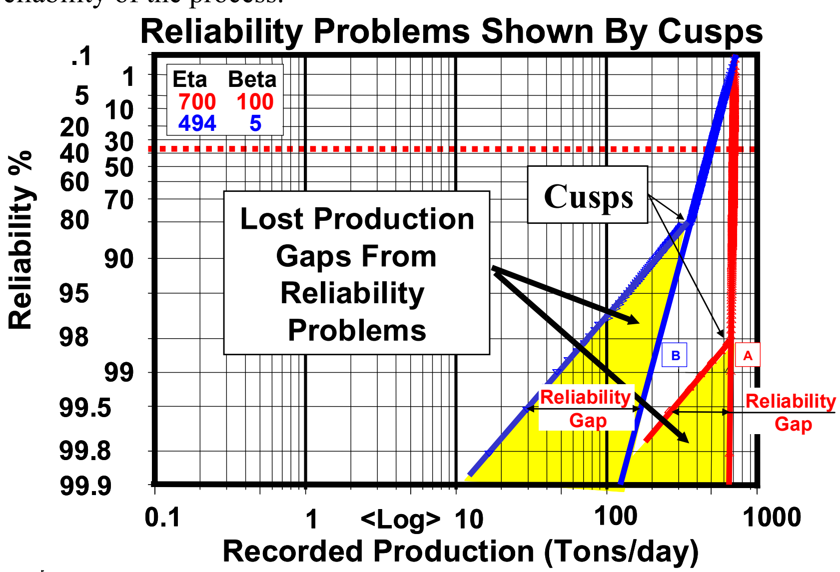

Figure 4: Weibull Plot With Failure Cusps

Cusps on Figure 4 show reliability problems. The line A cusp at 98% reliability is better than the line B cusp at 80% reliability. Cusps define process reliability where larger scatter begins in the output.

Cusps on Figure 4 are undesirable and contrary to concepts of six-sigma efforts because they show a horizontal gap between the expected trend line and the actual trend line. The gaps are often characterized as hidden factories—a hidden factory has the cost of the real factory but the hidden factory generates waste and thus lowers production output.

Reliability losses occur in the gaps between the demonstrated production line (devoid of cusps) and the actual production values which lie to the left of the demonstrated line. Some minor reliability losses are associated with cutbacks. Other reliability losses are associated with significant disasters related to "crash and burn" problems.

> **Why make Weibull plots for processes?** Weibull plots of daily production shows patterns of problems which may need characterization for selling corrective action. The plots serve the same functions as a health examination for humans—it's better to find problems early when they can be corrected with minor adjustments than to wait until major corrections are required. Too often problems recognized by outsiders (or internal critics) become the accepted norm and thus you cannot see the forest for the trees and bad habits become accepted operating practice.

Production data scatter along the steep slopes is usually the result of common cause variations built into the process and the reasons for the variation are difficult to detect and correct. Production data scatter to the left of cusps is caused by special causes. Special causes are identified by cause and effects conditions which are easier to identify and correct.

If production output variations were extremely small, each variation would be detectable for correction. When natural output variation is large, small changes are undetected and thus uncorrected which allows undetected hidden factories to exist

Nameplate Ratings for the Process

An important issue for judging how well a process performs is to define a nameplate rating. The nameplate rating is the maximum production capacity under ideal operation and control. The site contractor that designs and constructs the factory usually provides the nameplate rating and subsequent capital improvements/enhancements add to the value as it is adjusted to reflect investments. Nameplate is rarely measurable under a specific test which would require ideal conditions. Some organizations measure their best outputs over a contiguous period of time such as the best 5 days, best 10 days, etc. as judged on a single value to characterize the best nameplate rating and this establishes the demonstrated production output which lies to the left of the nameplate line. Comparisons between actual plant results and Weibull analysis show the nameplate line has a larger characteristic value and the nameplate line has a steeper slope than typically obtained by the demonstrated production characteristic values.

Nameplate capacity: For a single piece of equipment it is the maximum production capacity of the equipment under ideal operation and control as described by process planners or the supplier of the equipment. For a process comprised of many different components of equipment it is the maximum production capacity of the factory under ideal operation and control as provided by the site contractor that designs and constructs the factory.

The single point estimate for the nameplate capacity is found when the maximum production value in the upper right hand corner of the Weibull plot is extended with a specified slope to cross the 63.2% CDF or 36.8% reliability line to locate the characteristic value. The nameplate characteristic value (what you can do) always exceeds the demonstrated value (what you have done) and the beta slope of the line is always greater than the demonstrated production line. The slope of the nameplate line is set by benchmarking of representative plants, businesses, technologies, or based on coefficients of variation expected in other businesses.

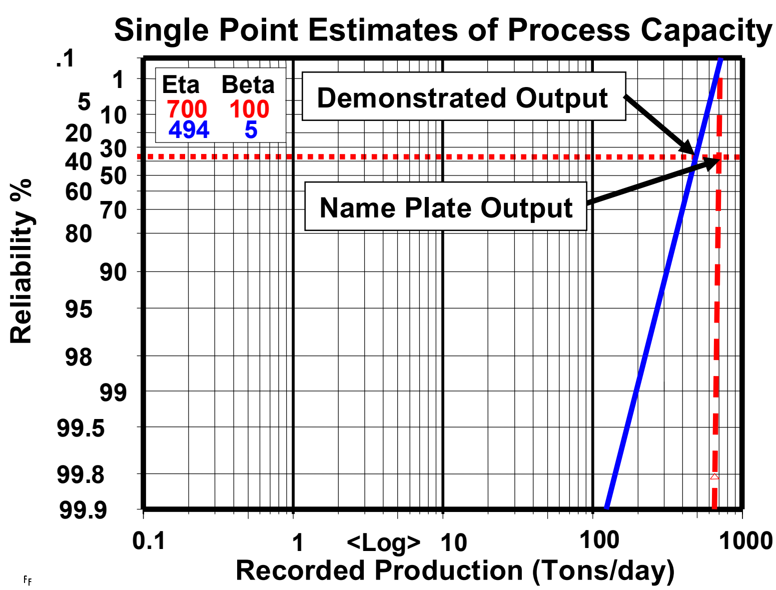

Figure 5: Weibull Plot Single Point Estimates

Figure 5 shows the actual plot of the production line from figure 4 cuts the 36.8% line to give a single point estimate of the demonstrated output (494 t/d), and in a similar fashion the trend line for the nameplate value (700 t/d) is found using coefficient of variation concepts from statistics or benchmarking.

World-class processes, have name-plate lines with a beta slopes equal to or greater than 100. Not all processes are capable of steep slopes. Here are some guidelines for nameplate β's:

Poor control-	β ≈ 5
Fair control-	β ≈ 10
Tight control-	β ≈ 25
Excellent control-	β ≈ 50
World class control-	β ≈ 100
Seldom achieved-	β ≈ 200

Doubling β values cuts efficiency and utilization losses in ≈ half.

The slope and location of the nameplate line is fixed by design of the process and how it is operated—both issues are under management control. The wedge shape zone between the name-plate line and the demonstrated production line refer to gaps in output best categorized as efficiency/utilization losses.

Efficiency and utilization losses: The difference between the Weibull nameplate capacity line and the Weibull line for demonstrated production.

Efficiency losses relate to output/input issues. We only pay for making products right the first time where the manufacturing group earn production hours against a standard value. The standard value used for budgeting/pricing/etc. For example, suppose your process (with no screw-ups or waste) could make 1000 lbs/hr as the standard. What you get from the process is 750 lbs/hr because of the hidden factory, then your efficiency is 750/1000 = 75%. This is the input/output relationship as if you earned 0.75 hrs of work while you spent 1.0 hrs

Utilization losses relate to time waste issues. You generally have two big buckets for charging manufacturing time: 1) direct labor for making the product and 2) wasted labor not chargeable against the product or it's inventory value, and this is called labor loss. We spend time for direct labor AND labor loss for say an 8 hour shift. If the direct labor is productive 50% of the time then we literally have DL = 4 hrs and LL = 4 hrs. Our utilization is DL/(DL + LL) = 4/8 = 50%.

Productivity = Efficiency*Utilization. Productivity = Efficiency*Utilization or 0.75*0.50 = 37.5%

What Causes Efficiency and Utilization Losses?

Major stresses on the system have large effects such as temperatures, pressures, flow rates, and chemical concentrations. These conditions manifest themselves in displacement of the demonstrated production rates to smaller values in an unhappy direction from the installed capacities of the system.

Other items have large effects such as mixing efficiencies, late starts and early quits, running plants at continuously reduced outputs, which are failures to use the installed capacity paid for my the investors, inattention to long-term process optimization with inherent inefficient operations, lack of maintaining steady state conditions, use of analog controls rather than rapid response digital controls, use of sub-optimum raw materials, and continuously inefficient scheduling of production facilities. These are the deviations that determine the upper and lower control limits of the process and determine tightness of control.

Rework loops and side streams started by exception which become insidious asset wasting extra steps which in time become normal and accepted parts of the production process resulting in adding output variability as they feed the hidden plant. All of these items can be worked on to reduce variations for better and more productive control of output from the process.

Quantifying Losses for the Weibull Plots?

In Figure 6 the annual hidden plant from efficiency and utilization gaps contains 88,490 tons of unrealized production. The gap (a sum of the horizontal distance from the demonstrated line to the nameplate line) is equal to 88,490/494 = 179 days at the demonstrated rate or 88,490/700 = 126 days at the nameplate rate—this is a huge loss for investors!

Figure 6 shows the daily production with a straight trend line without reliability problems. Absence of cusps on the demonstrated line leaves an impression the process needs no work. However, when the nameplate line is added, a huge category of losses appear. Most real processes have both reliability losses plus efficiency and utilization losses. Solving reliability problems requires different tools than solving efficiency and utilization problems.

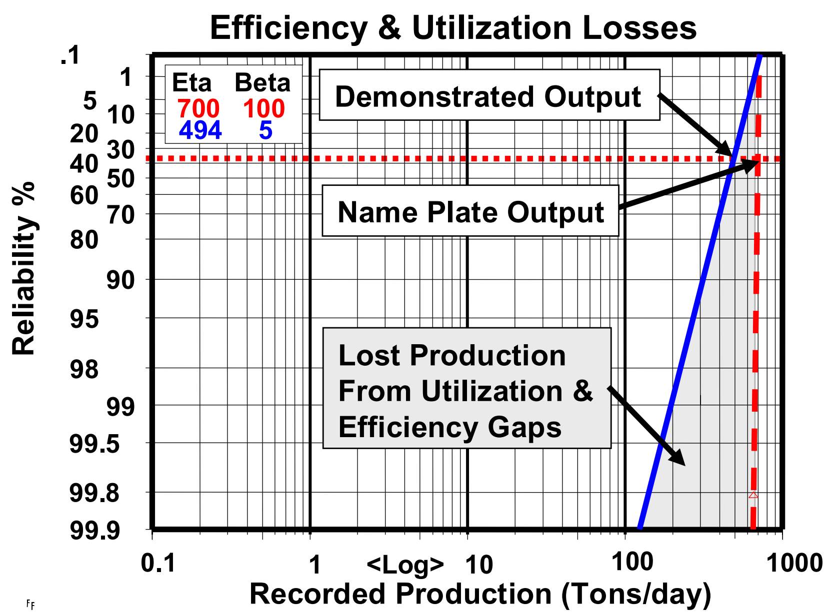

Figure 6: Weibull Plot Production Losses

Figure 7 shows the production data from a simple process with a problem. The process has demonstrated a reliability of 40% which answers a frequently unknown issue. Figure 7 shows great opportunities for improvement and solutions must start with avoiding 1 day out of every 5 as a down day graphically shown with the data points along the left hand axis.

Figure 7 is a one page summary of 79,148 tons of losses which is equivalent to between 102 to 106 days of losses or roughly 1 day lost out of every 4. A Pareto distribution for the order of solving problems is also shown in Figure 7.

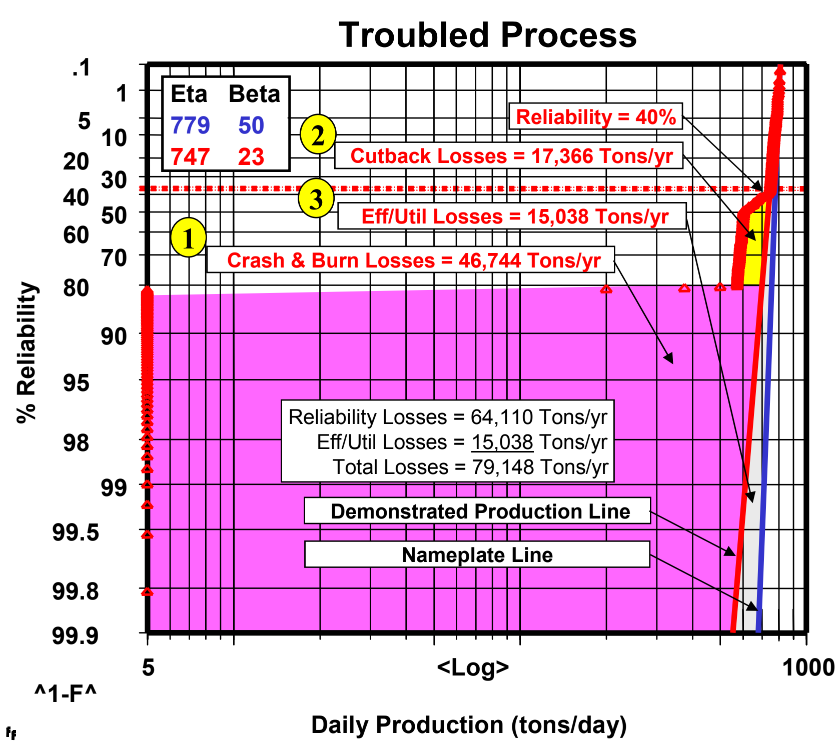

Figure 7: Weibull Plot Of Troubled Process

Convert the production losses into money figures by use of gross margin values (assuming the process is sold out)—assuming the gross margin is \$0.10/lb or \$200/ton this process has an opportunity cost of \$15.8 million/year. The next question is how much will it take to correct the problems? If you need a one year payback, the most you could spend to fix all problems is \$15.8 million. If you need a 1.5 year payback, the amount that could be spent is \$23.7 million, and so on. Thus the issues have been reduced to time and money so everyone clearly understands the situation. The next tough issue is finding what is required to solve the problem.

Figure 7 shows a process reliability problem as only 40% of the days show small scatter in output. The problem is worth $15.8 million/year to the plant. Now the roots of the problems are needed to fix problems in a timely manner. Reasons for reliability problems and efficiency/utilization problems have along with potential solutions have been described in other papers (Roberts 2001). The single sheet summary shows the value of making a Weibull plot for getting issues on one side of one sheet of paper. Clarity is needed to get the big picture in view so hidden factories are identified and corrected in a timely manner.

Crash and burn output losses: A euphemism for seriously deficient production quantities during periods of substantial process upsets, severe deteriorations, or down days due to outages.

Cutback losses: A production quantity recorded during a period when output is restricted by partial failures resulting in a slowdown from the intended/scheduled production rate. The zone is often characterized by a cusp at either end of the zone on a Weibull plot.

Demonstrated Weibull production line: A straight-line trend in upper reaches of the Weibull probability plot defining "normal" production when all is well—as quantities deviate from this segment, failures occur (by definition) because the process loses it's predictability.

Processes: Processes are collections of systems and actions following prescribed procedures for bringing about a result. Using a set of inter-related activities and resources to transform inputs into outputs often uses processes for manufacturing saleable items.

Summary

Weibull techniques provide a method, using daily production data, for assessing data to find process reliability, reliability losses, and efficiency/utilization losses. The losses provide enough details to define a Pareto distribution to rank the problem solving priority. The Weibull plots show reliability of the process and allow simple methods for pricing the value of correcting all the problems. Problems must be found by attacking the roots to get permanent correction for adding value to the effort.

These are tools to determine if you have a process reliability problem and what it's worth to correct the problems discovered.

References

1. Abernethy, Robert B., **The New Weibull Handbook**, fourth edition, Dr. Robert B. Abernethy author and published, 536 Oyster Road, North Palm Beach, FL 33408-4328, Phone/FAX: 561-842-4082, e-mail: Weibull@worldnet.att.net, ISBN 0-9653062-0-8, 1998.
2. Barringer, H. Paul, *"Process Reliability Concepts"*, **SAE 2000 Weibull Users Conference**, Detroit, MI, 1999, Free downloads of this paper in PDF format are available at http://www.barringer1.com/Papers.htm (note the URL is case sensitive).
3. Barringer, H. Paul, *"Process Reliability and Six-Sigma"*, **National Manufacturing Week Conference 2000**, 1999, Free downloads of this paper in PDF format are available at http://www.barringer1.com/Papers.htm (note the URL is case sensitive).
4. Benard, A. and E. C. Bos-Levenbach, *"Het uitzetten van waarnemingen op waarschijnlijkdeids-papier" (The Plotting of Observations on Probability Paper)*, **Statististica Neerlandica**, Volume 7, pages 163-173, 1953. An English translation of this paper is available as a downloadable PDF file at http://www.barringer1.com/wa_files/The-plotting-of-observations-on-probability-paper.pdf (note the URL is case sensitive).

5. Fulton, Wes, WinSMITH Weibull software, 2001, Fulton Findings, 1251 W. Sepulveda Blvd., PMB 800, Torrance, CA 90502, Phone: 310-548-6358.
6. Roberts, Woodrow T. and H. Paul Barringer, *"Consider using a new reliability tool: Weibull analysis for production data"*, Hydrocarbon Processing, Vol. 80, No. 10, October 2001, pages 73-82. Free downloads of this paper in PDF format are available at http://www.barringer1.com/Papers.htm (note the URL is case sensitive).

Biographies

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For other issues on process reliability refer to **Problems Of The Month** at **http://www.barringer1.com.**

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