Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures

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Abstract

Reliability growth plots forecast when future system failures will occur. Trend line slopes, β, tell if failures are coming faster, slower, or without much change. Long term trend line slope β also tell if programs have a reliability-focus where $\beta<1$ or a repair-focus where $\beta\geq1$. Repair-focused organizations do not find failures intolerable, and they often reward faster repairs over avoiding repairs with acceptance of failure risks beyond prudent money limits. Reliability-focused organizations abhor failures, and they make improvements to extend time to the next failure by rejecting risk of failures. Examples are provided.

Is Your Organization Repair-focused Or Reliability-focused?

Components, equipment, systems, and people are not perfect and thus free from failures. In a naïve, simplistic and deterministic view we can have perfection. In the real world we fall short of perfection, as perfection exists only in a fantasy world. Everything fails—in the end the worms have us all and the same is true for our systems. A natural law of entropy expresses the lowest energy state is a failure—buildings always fall down, they never fall up, knives always grow dull and never grow sharp, batteries always run down and they never run to full charge. Thus we spend time and resources mitigating effects of failures. Nothing lasts forever without failure. Consider the status of the seven ancient wonders of the world, learned by every school child, and only one exists intact today (the pyramids, with no moving parts—and they're starting to look a little ragged!).

What's a failure? Failures must be defined. Failures have different degrees or grades.

- **Total failures** are the loss of function when needed.
- **Benign failures** are identified by experts that are undesired and will lead to severed failures up to and including loss of function. However non-experts will not identify a benign failure—for example, small cracks in concrete foundations are not desired although reinforcing rods installed in the concrete foundations will carry the load.
- **Functional failures** are degradation below a minimum performance level to those skilled in the art of engineering, maintenance, and operations.
- **Safety incidents**, recordable injuries, and deaths are all failures of different degrees or grades.
- **Non-preventive maintenance (PM) work orders**, in many organizations, are treated as failure—this is a more severe grading of failures but from a management position these non-PM maintenance orders result in undesirable expenditures of money.
- **"Failure** is an unaccepted difference between expected and observed performance": Petroski (2006), page 51.
- **"The event, or inoperable state**, in which any item or part of an item does not, or would not, perform as previously specified.": MIL-HDBK-338 (1998), page 3-6 and MIL-STD-721 (1991), page 3.

Only catastrophic failures are recorded accurately unless the organization has been trained and educated about failures. Risk adverse organizations and 1st quartile performance organizations carefully record failures and roots of failures. Risk accepting organizations and 4th quartile performance organizations are usually less diligent about recording failures and their roots.

Learning organizations benefit from failures. Petroski (2006), page 3, says "Though a focus on failure can lead to success, too great a reliance on successful precedents can lead to failures. Success is not simply the absence of failures; it also masks potential modes of failures. Emulating success may be efficacious in the short term, but such behavior invariable and surprisingly leads to failure itself…..Past success, no matter how numerous and universal, are no guarantee of future performance in a new context." On page 5 he comments: "Successful design, whether of solid or intangible things, rests on anticipating how failure can or might occur." On page 49 he says: "If the thing passes the test, we declare it a success—at least until the next test. Successful tests are unremarkable. If the thing does not pass a test, we say that it (and the hypothesis) has failed. Failures are remarkable. The failures always teach us more than the successes about the design of things. And thus the failures often lead to redesigns—to new, improved things." Finally, on page 114 is the idea: "Any failure, however, is incontrovertible evidence that weaknesses existed—in the design, the workmanship, the materials, the maintenance, or the defense against terrorists. Failure is the counterexample to the hypothesis of success. This again is the paradox of design: Things that succeed teach us little beyond the fact that they have been successful; things that fail provide incontrovertible evidence that the limits of design have been exceeded. Emulating success risk failure; studying failure increases our chances of success. The simple principle that is seldom explicitly stated is that the most successful designs are based on the best and most complete assumptions about failures." Learning organizations that are reliability-focused run scared. Reliability-focused organizations make improvements to avoid future failures by using reliability technology. Behind every successful product, device, system, or facility is the danger of a latent failure mode waiting to be exposed when you least suspected a failures.

Learning organizations abhor failures and become reliability-focused organizations for preventing future failures. Reliability-focused organizations have a strategic viewpoint for making more money by avoiding failures. Reliability-focused organizations are proactive where failure costs are to be reduced by active programs and they use more stringent performance standards for people, procedures, and processes than repair-focused organizations. Reliability-focused organizations start with standards set by industry, national standards, and international standards; and they impose extra requirements for achieving higher performance. Reliability-focused organizations work for the lowest long term cost of ownership rather than cheap first costs for equipment, maintenance, and operation of equipment and facilities.

Repair-focused organizations do not strongly benefit from their failures. Failures are not intolerable in repair-focused organizations, and faster repairs are the criteria for excellence rather than avoiding failures. Repair-focused organizations operate at a relatively constant failure rate or in many cases an increasing failure rate. Repair-focused organizations will verbally state they are doing a good job. They talk a great game—why were #1 (because we can fix things faster than anyone else) as the important standard of great value to repair-focused organizations is restoring failed equipment to operation quickly. Standards for people, processes, and procedures in repair-focused organizations represent minimum acceptable standards as described in national, international, and trade documents. Minimum standards do not address extra requirements for business issues and potential for community outrage problems from failures. Minimum requirements may not be affordable for protecting your business interests. It is unwise to have too few reliability requirements, and it is foolish to require too many burdensome requirements.

What type of organization are you: repair-focused or reliability-focused? How can you prove your statements with facts? The answer lies in the use of Crow-AMSAA (C-A) plots where cumulative failures and cumulative time are plotted on log-log paper. These plots are know by various names: reliability growth plots, Duane plots, and most recently as Crow-AMSAA plots in honor of the mathematical proof developed by Dr. Larry Crow which occurred when he worked for the US Army at the Army Materials Systems Analysis Activity (AMSAA) as described in MIL-HDBK-189 (1981).

Stable processes produce straight lines of cumulative failures versus cumulative time on log-log paper used for C-A plots. The straight lines make the forecast of future failures easy to predict. Cusps (doglegs or discontinuities) on the C-A plots indicate improvements or deteriorations and the line slope β provides useful objective evidence. In reliability-focused organizations it is the task of reliability engineers to develop successful cusps on the C-A trend lines to show improvements have been achieved.

An important statistic for C-A plots is the line slope beta, β. When $\beta \sim 1$, failures are coming at a ~constant rate where system failures are neither improving nor deteriorating. Failures come more slowly when $\beta < 1$. Failures come more quickly when $\beta > 1$.

Reliability-focused organizations have C-A plots when $\beta < 1$ and reliability is improving. Repair focused organizations have C-A plots when $\beta \geq 1$ and reliability is deteriorating (or not improving). Which do you prefer for your children, home, business?—increasing failures rates with more repairs or decreasing failure rates with less repairs? You can make improvements to improve reliability thus increasing the financial happiness of your business but you cannot repair yourself to happiness.

What Is Reliability?

Reliability is the probability that a component, system, or process will function without failure for a specified length of time when operated correctly under specified conditions. Reliability engineering is concerned with predicting and avoiding failures—this is a strategic task. To quantify reliability issues it is important to know ***why***, ***how***, ***how often, when,***, and ***costs*** of failures. Reliability issues are bound to the physics of failure mechanisms so the failure mechanisms can be mitigated. In the real world all potential failures are seldom well known or well understood, and prediction of failures is inherently a probabilistic problem where reliability analysis is a probabilistic process. Furthermore the inherent reliability of systems is seldom obtained because of induced failures from processes, procedures, and people who kill the system.

Reliability is not the same as availability (even though both are described as a value between 0 and 1). Availability tells the percent of time the system is alive and ready for use [uptime] when called upon. Stream factors define the actual online times as a percentage of uptime. Reliability addresses the probability for a failure free interval under specific conditions. The complement to the sweet portion of reliability (absence of failures) is the probability of failure which is the sour part of unreliability.

Risk assessment models connect money with failures in a simple equation: \$Risk = (probability of failure during a specified time interval and under specific conditions)*(\$Consequence of the failure event). \$Risks always exist, and they are never zero. How much \$Risk is affordable becomes a business issue. If the business organization is risk averse, then perhaps \$Risk values must be less than say \$10,000, or if risk accepting, then less than say \$100,000. Set the actual \$Risk value as a business decision rather than "backing into it" by failure to make a decision. Society expects planning for success and rejects abnormal $Risks. In the end, all reliability issues are connected to time and money as it costs money to incur failures and it cost money to avoid failures. Many organizations use a qualitative risk matrix to simplify decisions while other organizations use a quantitative risk matrix—both are based on the probability of failure and the monetized consequence of failure. For more details on risk matrix see http://www.barringer1.com/nov04prb.htm .

Reliability engineers are strategic assets for preventing failures from occurring. Maintenance engineers are tactical assets for correcting failures which have occurred. You need about 10 maintenance engineers for every reliability engineer, and both need to know about the other's jobs/tasks to function as an effective team. Job descriptions for both jobs are available at http://www.barringer1.com/jobdescriptions.htm .

For reliability issues we talk about the sweet part—the absence of failures. We quantify reliability issues from the sour part—the measured failures. It is easy to kill equipment and processes. It is difficult to make equipment survive.

Many mangers and engineers believe most failures have a root cause in the equipment. Data from nuclear power plants (which maintain a culture of confessing failures and the roots of failures—this is in opposition to most industries were the culture is to hide the roots of failures) show the following roots for failures:

Early in the life of nuclear power plants-

Design error	35%	[people induced problems-not calculation errors]
Random component failures	18%	[process/procedure problems]
Operator error	12%	[people/procedure problems]
Maintenance error	12%	[people/procedure problems]
Unknown	12%	
Procedure error & unknowns	10%	
Fabrication error	1%	[people/procedure problems]
	100%	

Mature nuclear power plants-

People	38%
Procedures & Processes	34%
Equipment	28%
	100%

ASME (2002) shows a similar root for failures. For 10 years, from 1992-2001, 127 people died from boiler and pressure vessel accidents and 720 people were injured. In the 23,338 accident reports, 83% were a direct result of human oversight or lack of knowledge. The same reasons were listed for 69% of the injuries and 60% of recorded deaths.

Data shows that if you concentrate only on the equipment you miss the best opportunities for making improvements. Another point to seriously consider is little or no capital expenditures are required for improving people, procedures, and processes which can reduce failures.

In case you believe that equipment is the biggest root of problems it will be instructive to download (http://www.bpresponse.com) the **Final Report** of BP's Texas City Refinery explosion and tick off the reasons behind the explosion which took the lives of 15 people and maimed more than 200 addition people—you will see objective evidence for people, procedures, and processes as the major roots for failures. The #1 problem was not equipment!

Henry Petroski (1992) on page 205-207 list reasons for failures of buildings and bridges from McKaig's book as:

Ignorance [of people]
Economy in first cost and in maintenance [decisions made by people]
Lapses or carelessness [of people]
Unusual occurrence [Mother Nature's extremes exceeded design loads]

From Blockley's book Petroski shows:

Limit states [overloads, under strength, movement of foundations, and deterioration]
Random hazards [fires, floods, earth quakes, etc.—Mother Nature's extremes]
Human based errors [design errors and construction errors]

Petroski is a professor of structural engineering and history [yes, structural engineering and history] at Duke University. Petroski often uses bridges and dam failures as graphical and public evidence of failures that cannot be hidden. On page 215 Petroski has this quote concerning failures from Herbert Hoover when he was a builder of dams:

> "The great liability of the engineer compared to other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the architects, cover his failures with trees and vines. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope that the people will forget. The engineer simply cannot deny that he did it. If his works do not work, he is damned."

Petroski (1994) on pages 7 and 8 remarks about the role of humans in failures:

> "…the major challenge to reliability theory was recognized when the theoretical probabilities of failure were compared with actual rates of failure [and the] actual rates exceed the theoretical values by a factor of 10 or 100 or even more. They identified the main reason for the discrepancy to be that the theory of reliability employed did not consider the effect of human error……Human error in anticipating failure continues to be the single most important factor in keeping the reliability of engineering designs from achieving the theoretically high levels made possible by modern methods of analysis and materials…..nine out of ten recent failures [in dams] occurred not because of inadequacies in the state of the art, but because of over sights that could and should have been avoided…..the problems are essentially non-quantitative and the solutions are essentially non-numerical."

Good maintenance engineering techniques mitigate some failures. However, maintenance cannot restore strengths which never existing in original designs unless the design is changed. Thus direct replacement maintenance efforts cannot improve the inherent reliability of the equipment, but only restore to the original values following deterioration/destruction—however, upgrade replacements can provide greater capacity for resisting failures.

The more successful reliability engineering becomes at avoiding failures to make systems more reliable, the more engineering becomes invisible and seemingly humdrum. But you let a system failure occur, then fingers point to engineering as almost everyone can see the failure but few can see the successes that make reliability possible. We learn little from successes. Failures are a great teacher of fallibilities with specific roots for the failures. We talk about reliability but we measure the term reliability based on failures and time. One method of making reliability visible and for predicting the next failure is the use of a C-A plot.

Where Did Crow-AMSSA Plots Originate?

The genesis begins with T. P. Wright's 1936 paper on learning curves for manufacturing of airframes which showed straight lines on log-log paper for cum man-hours consumed versus cum airframes produced. This method made it possible to predict future man power needs in manufacturing. Learning curves were one of the computer tools available on General Electric's time share computers in the 1960's and were known to a GE reliability engineer, James Duane. Duane noted that when cum mean time between failures was plotted against cum run time the results produced a straight line when plotted on log-log paper and produced a trend line $\beta \sim 0.5$.

Duane was a pragmatist. He didn't know why his test results produced the straight lines and thus his concept was a postulate. Later, Dr. Larry Crow used Weibull statistics to generate a mathematical proof of why the C-A plots generate straight lines for both cum failures vs cum time and cum mean time between failures vs cum time on log-log plots. More C-A details are available at http://www.barringer1.com/nov02prb.htm.

From the log-log plots of cum failures vs cum time you can predict/forecast when the next failure will occur given the process continues in its current state. Failure prediction for reliability focused organizations usually gives time to set up defenses against occurrence of the next failure.

The C-A slope of the line, β, is the most important statistic for the regression line and visual appearance of the trends lets the eye pick up cusps which are very important indicators of performance changes. C-A plots with their cusps gives graphical evidence of improvements [or deterioration]. Favorable cusps provide objective evidence of failure avoided when you have made positive improvements. Likewise when the gap between trend lines and their cusps can also show the deterioration in results when the cusps are unfavorable and bad things are happening. Note, the cum failure vs. cum time plot always increases in both the X-axis and the Y-axis. The simple regression trend line for C-A plots is $N(t) = \lambda * t^{\beta}$. The value of λ is the failure rate at time = 1 and illustrates the initial failure rate of the system. β tells you if failures are coming slower/faster/no-change.

From the log-log plots of cum mean times between failure vs cum time you have a Y-axis transform of the data. In this transformed plot, the line slope is α, where $\alpha = 1-\beta$, gives a clear signal of reliability or lack of reliability. When the trend line points upward, reliability is improving. When the trend line points downward, reliability is deteriorating. Often you can pick up information with the transform which is not clearly presented in the raw data.

Other C-A equations are shown at http://www.barringer1.com/nov02prb.htm which is needed for explaining other parts of the C-A technology.

Some Examples of Crow-AMSAA Plots

The following plots will illustrate cases of reliability growth and reliability deterioration using C-A plots. Businesses can be smart in some areas and not so smart in other areas. Businesses need graphical plots to persuade people to make improvements. The graphs of failure data from the records are a look backward view, and they make history visible. They are "show me don't tell me" plots. The trend line beta values tell factually if the organization is reliability-focused or repair-focused. The facts shown on one graph avoid the many opinions that exist in every organization.

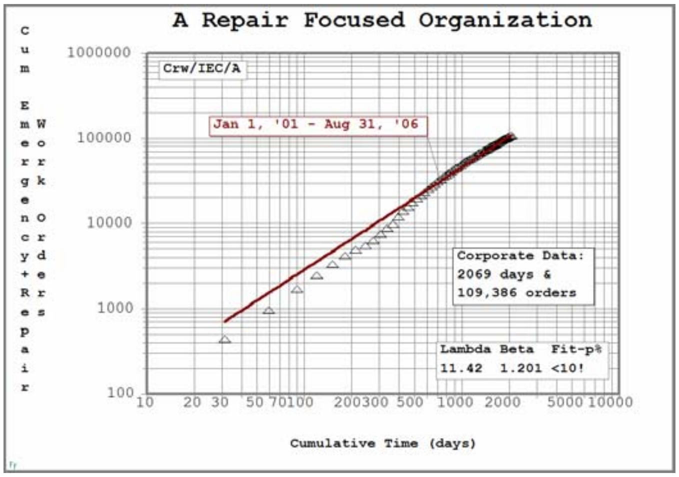
Example 1: A large international chemical plant uses SAP for administrating their maintenance records. SAP makes it easy to acquire repair orders plus emergency orders for all plants. The sum of repair orders are treated as failures recorded each month for all plants. If the company is repair focused then β>1, however, if the company is reliability focused β<1. The company believes they are reliability focused—you decide if their conclusions are correct.

Table 1: Work Orders vs Time

All Sites: January 2001 through August 2006			
days in the month	**cum days**	emergency + repair orders	**Cum emergency + repair orders**
31	31	444	444
28	59	517	961
31	90	749	1710
30	120	786	2496
31	151	829	3325
30	181	897	4222
31	212	707	4929
31	243	600	5529
30	273	815	6344
31	304	1229	7573
30	334	1302	8875
31	365	1073	9948
31	396	2160	12108
28	424	1897	14005
31	455	1760	15765
30	485	1911	17676
31	516	1966	19642
30	546	1802	21444
31	577	1993	23437
31	608	1930	25367
30	638	1916	27283
31	669	2233	29516
30	699	2010	31526
31	730	1752	33278
31	761	1998	35276
28	789	1791	37067
31	820	1853	38920
30	850	1931	40851
31	881	2078	42929
30	911	1913	44842
31	942	1980	46822
31	973	1700	48522
30	1003	1986	50508
31	1034	2015	52523
30	1064	1799	54322
31	1095	1745	56067
31	1126	1836	57903
29	1155	1689	59592
31	1186	1910	61502
30	1216	1743	63245
31	1247	1734	64979
30	1277	2009	66988
31	1308	1725	68713
31	1339	1647	70360
30	1369	1633	71993
31	1400	1638	73631
30	1430	1651	75282
31	1461	1620	76902
31	1492	1721	78623
28	1520	1565	80188
31	1551	1710	81898
30	1581	1660	83558
31	1612	1614	85172
30	1642	1722	86894
31	1673	1630	88524
31	1704	1895	90419
30	1734	2047	92466
31	1765	1892	94358
30	1795	1624	95982
31	1826	1542	97524
31	1857	1631	99155
28	1885	1421	100576
31	1916	1638	102214
30	1946	1328	103542
31	1977	1443	104985
30	2007	1490	106475
31	2038	1408	107883
31	2069	1503	109386

Make a Crow-AMSAA plot using cumulative days on the X-axis and cumulative (emergency + repair) orders plotted on the Y-axis. Find the line slope β which is shown in Figure 1. Clearly the line slope beta at 1.2 shows the organization has a bias toward a repair oriented culture rather than a reliability centered culture.

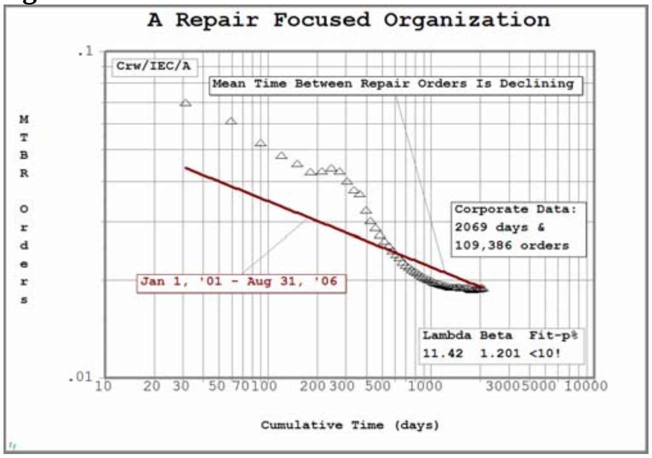
Figure 1: Crow-AMSAA Plot Of Table 1



The curve fit for Figure 1 has a P-value estimate less than the minimum desired value of 10% which indicates line segments may exist within the data that are not readily obvious in the plot. Figure 1 is also useful for predicting how many maintenance orders are expected during the next 365 days: extrapolating the trend line to 2069 + 365 = 2,434 days where the cumulative work orders is forecasted to be 132,948 so to get the actual work orders expected in the next 365 days it is (132,948 – 109,385) = 33,562 orders or 64.55 orders/day. The IEC1164 modified MLE method for the trend line goes through the last data point which makes it easy to forecast the next failure using the equation $N(t) = \lambda^{*}t^{\beta}$ or by using commercially available software (Fulton 2006) to predict future failures.

The Crow-AMSAA trend line is transformed to produce a cum MTBF line by simply taking the cumulative failures divided by the cum time to produce a new Y-axis value. This trend line will have a line slope which is the complement of the line slope β and of course the Y-axis intercept will be a different value than found in Figure 1. Often you can discover different phenomena at work when you look at the cum MTBF vs cum time curves.

Figure 2: Cum MTBF For Work Orders



From Figure 2 you can see changes in the rates at which work orders are occurring. At about day 1000, the work orders have slowed considerably and are producing a flat section to the trend of data points. However, the metric Cum MTBF has not turned the corner toward a reliability-focused environment.

Figure 1 can only increase in altitude on the Y-axis. Whereas in Figure 2, because of the transform, the Y-axis of data points can both climb and descend. It is good that data points have slowed their descent, however it is bad that that the transformed data points have not yet started to climb

Example 2: A 72" pipe line transporting cooling water from the sea contains some large elbows which are cement lined. Failures have occurred at roughly 35 years too early! Most likely the failures are due because thermal expansion loads exceed the strength of the elbows which may be acting as expansion compensators.

Table 2: Failure Data For 72" Cooling Water Pipeline

72" Sea Water Cooling Line Failure Data

		Data For WinSMITH Visual		Days Between Failures
		Cum Days	**Cum Failures**	
Start Date-->	**11/1/1997**	Datum	Datum	
Last Data Report On June 27, 2006 No more failures have occurred as of September 1, 2006	**11-Sep-99**	679	1	679
	23-May-00	934	2	255
	3-Jul-02	1705	3	771
	23-Jul-02	1725	4	20
	12-Oct-02	1806	5	81
	10-Apr-03	1986	6	180
	25-May-03	2031	7	45
	23-Sep-03	2152	8	121
	14-Oct-03	2173	9	21
	8-Dec-03	2228	10	55
	13-Jan-04	2264	11	36
	4-Apr-04	2346	12	82
	27-Sep-04	2522	13	176
	31-Oct-04	2556	14	34
	30-Jan-05	2666	15	110
Forecast-->	29-Apr-05	2736	16	70
Forecast-->	6-Jul-05	2804	17	68
Forecast-->	9-Sep-05	2870	18	65
Forecast-->	12-Nov-05	2933	19	63
Forecast-->	12-Jan-06	2994	20	61
Forecast-->	13-Mar-06	3054	21	60
Forecast-->	9-May-06	3112	22	58
Forecast-->	5-Jul-06	3168	23	56
Forecast-->	29-Aug-06	3223	24	55
Forecast-->	21-Oct-06	3277	25	54

Table 2 shows the failure data for the 72" pipe line. Note the last failure occurred on January 5, 2005. No other failures have been recorded by the report time of September 1, 2006.

Had failures continued as had occurred for the previous 15 failures then the forecasted events would have been expected based on the statistics shown in Figure 3 for the Crow-AMSAA plot with it's beta = 2.477. The beta indicates a severely deteriorating system.

The time interval from the last failure on January 30, 2005 represents censored data. It appears that repairs completed in January 30, 2005 have removed the failure mode from the system.

We can make use of the suspended data two ways: 1) Draw the trend line thru the cum time and the last suspension (which gives a poor curve fit), or 2) Use the suspended time with a hypothesis--assume a failure will occurs tomorrow for construction of a new trend line based on engineering judgment. The hypothesis trend line will have two data points: a) cum failure 15 at cum time 2666

Figure 3: Forecasted Time For Future Failures

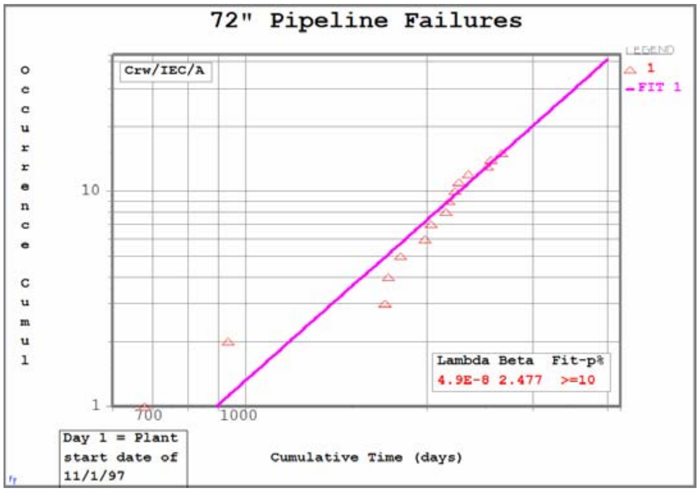
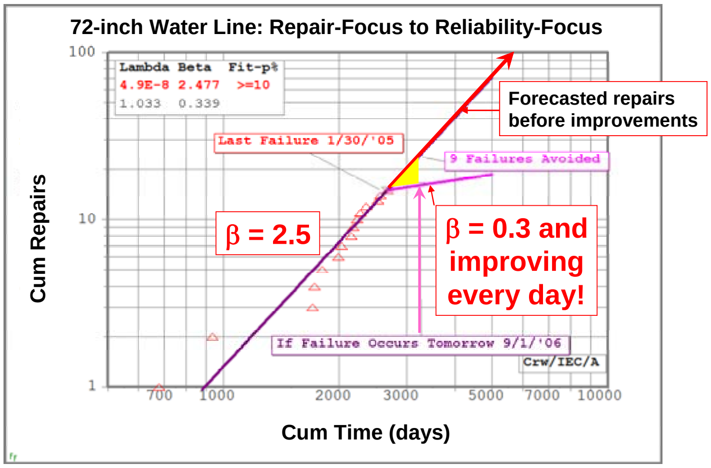


Figure 4: Forecasted Time For The Improved Curve



days which was the last actual failure and the hypothesis failure time of tomorrow (September 2, 2006) which will be cumulative time 3226 with hypothesized failure 16. Use the hypothesized failure 16 to form a new "fearless forecast".

Making the hypothesized new trend line will show the gap between failures expected at cum time 3226 and the forecasted line from the data trend passing through actual cum failure 15 at actual cum time 2666. The new trend line (based on the hypothesis) is shown in Figure 4. The new trend line shows that 9 failures have been avoided (15 recorded – 24 forecasted from the old line). The system has changed from a repair-focus to a reliability-focus.

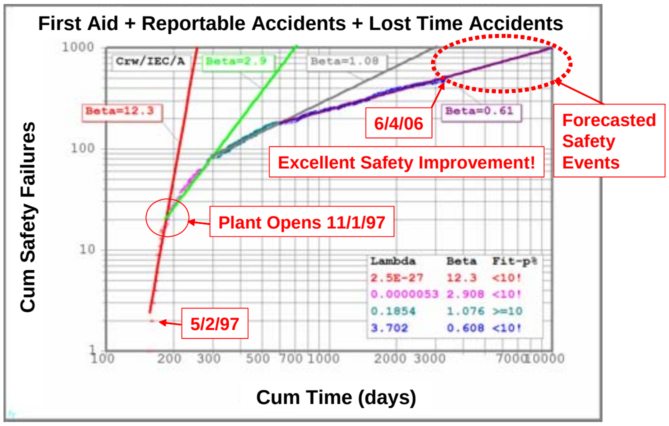
Expect your audience will react to the "fearless failure forecast" with disbelieve. They usually will not believe that future failures can be predicted from the actual trend lines nor will they believe the hypothesized failure that you predict will occur tomorrow on the new trend line shown in figure 4. I frequently respond to the disbelieve this way: "Here is my technology of modeling mixed failure modes for a system using your data. Show me your forecast, and tell me your technology for your future forecast." You should anticipate silence from your audience with this challenge.

While the Crow-AMSAA plots allow reasonable forecast of future failures, it is also helpful for clearly showing failures avoided. Most of your critics believe you only talk about improvements rather than show improvements. Crow-AMSAA plots are clearly show me don't tell me about improvements!

Expect wide scatter in the Crow-AMSAA plots on the left hand lower corner. In the upper right hand corner, the data points have less scatter as the cumulative effects dampen the scatter. The key statistic for a Crow-AMSAA plot is the line slope beta, and a secondary statistic needed for the regression is the Y-intercept at time = 1 which gives a general indication of the failure rate at time = 1 and only has a general meaning of a hypothetical failure rate.

Example 3: Most industrial organizations view safety events as a failure. The failure can be due to people, processes, or equipment. Figure 5 shows the safety results from a chemical plant prior to it's official start up and through several phases. Because of the large number or recorded events, the data is not shown in tabular format.

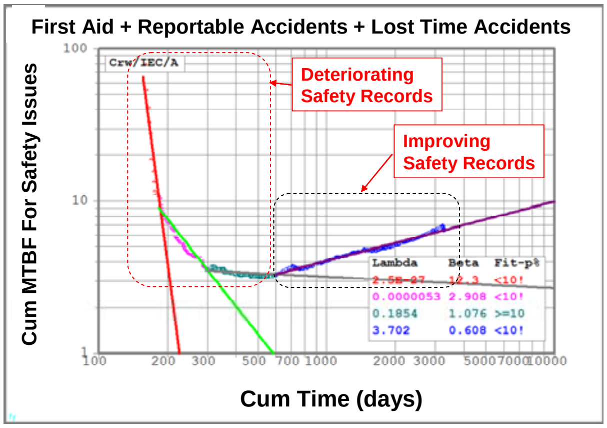
Figure 5: Safety Data In A Crow-AMSAA Plot



Note the four distinct trend lines with their associated cusps. Beginning with the steepest line we have the start up phase with beta line slope at the alarming value of 12. It is followed by the learning phase where beta is nearly 3. Then work the pattern phase occurs with beta = 1. Finally we have the reliability-focus with beta 0.6 where safety failures are undesirable and the failures are rejected as the new paradigms are accepted. The cusps highlight initiation of effective safety improvements. Notice the straight line segments.

Good safety records show betas in the range of 0.6 to 0.75. Betas of ~0.8 to ~1 show little desire for excellence. Of course plants with poor safety records consistently show betas greater than 1.

Figure 6: Cum MTBF For Safety Events



When the trend lines in Figure 5 are transformed, interesting details also appear as shown in Figure 6. The zones are marked off between increasing failure rates (to the left) and improving safety records on the right. Notice in recent time periods the plant has seen improvements followed by the most recent deterioration (most likely by over confidence whereby the bullet-proof mentality allows increased failures because the organization forgets to pay attention to the details.

Summary

Crow-AMSAA plots are simple and easy to make plots and frequently result in straight lines. They are cumulative format of failures and time. They show both good and bad trends with quantification of performance by use of the line slope beta. The straight line cumulative failures versus cumulative time provide a method of predicting future failures. The reason for making these plots is to provide motivation for preventing future failures. A transformation of the cumulative times to failure by dividing the cumulative times by the cumulative failures when plotted against the cumulative time gives a different viewpoint of the data which is often most helpful for visualizing what is happening. In short, you've got to see it to believe it!—this is a simple relationship for engineers because if you can't see it, you won't believe it. The methodology is easy to use and easy to predict future failure—"if I can predict your next failure, why can't you prevent the failure from occurring?"

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Biography

Paul Barringer, P.E. is a manufacturing, engineering, and reliability consultant with more than forty years of engineering and manufacturing experience in design, production, quality, maintenance, and reliability of technical products. Experienced in both the technical and bottom-line aspects of operating a business with management experience in manufacturing and engineering for an ISO 9001 facility. Industrial experience includes the oil and gas services business for high pressure and deep holes, super alloy manufacturing, and isotope separation using ultra high speed rotating devices.

He is author of training courses: **Reliability Engineering Principles** for calculating the life of equipment and predicting the failure free interval**, Process Reliability** for finding the reliability of processes and quantifying production losses, and **Life Cycle Cost** for finding the most cost effective alternative from many equipment scenarios using reliability concepts.

Barringer is a Registered Professional Engineer, Texas. Inventor named in six U.S.A. Patents and numerous foreign patents. He is a contributor to **The New Weibull Handbook**, a reliability handbook, published by Dr. Robert B. Abernethy.

His education includes a MS and BS in Mechanical Engineering from North Carolina State University. He participated in Harvard University's three-week Manufacturing Strategy conference.

Other reliability and life cycle costs details are available at **http://www.barringer1.com**

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