Weibull World from A to Z:

Benchmarks and Standards, Best Practice, Biographies, Classes/Seminars, Consulting, Good Software from Fulton Findings, Handbooks and References, Languages and International Use, Product Support, Skunky Software Alert, Software Tutorial . . . *OR CHOOSE FROM BELOW. . .*

SOFTWARE DESCRIPTIONS:

SuperSMITH(TM) Software Suite, SuperSMITH(TM) Weibull, SuperSMITH(TM) Visual, SuperSMITH(TM) YBath(TM)

PUBLICATION DESCRIPTIONS:

The New Weibull Handbook(c), PlayTIME(TM) with SuperSMITH(TM), New Weibull Methods + Video

Accelerated Test	Binomial	B-value
Censored Data	Confidence	Cost Reduction
Critical Correlation Coef.	Design Comparison	Distribution Analysis
Crow/AMSAA (Duane)	Exponential	Extreme Value Analysis
Forecast (Occurrences)	Goodness of Fit	Gumbel, E. J.
Gumbel Analysis	Grouped Data	Inspection
Interval Data	Kaplan-Meier	Likelihood Ratio
Lognormal Analysis	Maximum Likelihood	Mixed Distributions
Monte Carlo	Nelson Recurrent Events	Optimum Replacement
Poisson	Probabilistic Design	Probit
Regression Fitting	Reliability/Maintenance	Reliability Growth
Risk Analysis	Set Comparison	Suspension
Test Planning	T-zero (3 Parameter)	Variability

Warranty Data	WeiBayes	Weibull Analysis
Zoom (a closer look)		

Accelerated Test / Parameter as Function of Engineering Variable (PFEV) / Degradation / Covariate Data Analysis

There are lots of names for this kind of post-test results analysis. They all refer to a changing solution model parameter as test conditions change. The resulting model for lifetime is often termed an `S/N` relationship (Stress vs. N time units of life capability). Accelerated testing generally consists of increasing some or all the significant stresses that control the length of product life. This is done for the purpose of producing the same end-of-life results as normal operating level stresses, but with shorter overall test times and lower cost. It is often difficult to increase stresses without also changing the physics of failure invalidating this kind of test for the stated purpose, unless test levels are held within an acceptable range. Even after a successful accelerated test (no significant failure mechanism change) the life data from higher loading must be correlated to life at normal load. Dr. Wayne Nelson is the leading authority on accelerated testing, Refers to many such techniques in his "Accelerated Testing" book. One source for accelerated testing analysis is SuperSMITH Weibull software. S/N curves for the product can be easily estimated based upon such test results. Then the lifetime found at higher stress in the laboratory can be converted to estimate actual service lifetime using this model. SuperSMITH allows up to 16 sets of data each with possible different conditions.

There are two data analysis types in the Accelerated Test part of SuperSMITH:

A) Standard PFEV - This is where each data set represents a different stress (or a different group of stress factors) where stress factors are held constant for the length of the test.
B) Step-Load or Step-Utilization - This is where the stress level is changed according to a schedule as the item is being tested. As you might think, step-stress solution is a bit more challenging and a special case of the general methods in Dr. Nelson`s book used in the software considers Miner`s rule (incorporation of `equivalent damage`).

There are two data analysis types in the Accelerated Test part of SuperSMITH:

STANDARD PFEV: Variability models include Weibull, lognormal, normal, and Gumbel extreme value (lower and upper). Focus is on producing a 2-parameter solution which changes as a function of stress or as a function of some other covariate, the covariate being something changing in between sets of data. Maximum quantity of active data sets in the software is 16. SuperSMITH gives the user a choice whether to solve the relationship separately for each of the 2 model parameters, slope and life capability . . . OR . . . to solve for a common slope parameter (best choice for all data sets) and then solve for the life capability S/N curve by itself. Solution likelihood for all sets taken together is maximized to get the answer, also called maximum likelihood estimate (mle). The program does not select the PFEV equation form (Fit Type). That is the responsibility of the user. Equation forms for the PFEV Fit Type are:

1) Linear - not often used but available
2) Exponential - not often used but available
3) Power - very often used for mechanical stresses like tensile and torsion and bending (sometimes called Inverse Power)
4) Arrhenius - very often used for stresses related to temperature like voltage in electrical applications

After solution, the user can view the solution for a specific value of engineering variable by plotting a `Marker Line` result on the same plot as the data. Also, the user can view the resulting S/N curve with automatic use of the SuperSMITH Visual program.

STEP-LOAD OR STEP-UTILIZATION: We are again looking for the result of an S/N curve but with test conditions, e.g. stresses, changing during the running of the test. Each data set can have a different `step-stress` schedule. The resulting simple function is a 3-parameter model:
For Weibull, the 3-parameter model (Beta, v, p) is:
Beta (slope) = taken as same value for all stresses within useful range
Eta = (v/X) ^ p ... where v is stress reference value, X is equivalent applied single stress value for entire life, p is exponent.
For lognormal, the 3-parameter model (SigF, v, p) is:
SigF (antilog of std. dev. of log data, inversely related to slope) = taken as same value for all stresses within useful range
Med (median) = (v/X) ^ p ... where v is stress reference value, X is equivalent applied single stress value for entire life, p is exponent.
Maximum likelihood is again used with the special case of Miner`s rule for the solution. After solution, the user can view the solution for a specific value of engineering variable by plotting a `Marker Line` result on the same plot as the data. Also, the user can view the resulting S/N curve with automatic use of the SuperSMITH Visual program.

Benchmarks and Standards

SuperSMITH (TM) is the leading Weibull analysis software. Ours is the accepted metric analysis standard for the automotive industry, the medical industry, the power generation industry, the hydrocarbon processing industry, the railroad industry, the aerospace industry, the computer industry, the communications industry and many other industries and organizations including the U.S. military and the Federal Aviation Administration. Classic case studies out of standard textbooks provide ideal benchmarks for our software calibration. Our thousands of customers demand this high standard. Such case studies might typically include analysis of aircraft components after in-flight shutdowns, comparison of new and old medical remedies, and performance of electrical insulation in power transmission. SuperSMITH Weibull software includes several benchmarks ready to use for comparison and validation. The supplied data values are easily copied for use in other software. Full instructions are given for interpretation. Find out if you are using the best software. Can the software you use measure up? Try the benchmark data and see.

The latest edition of The New Weibull Handbook by Dr. Robert Abernethy contains standard procedures for performing Weibull analyses. Best-practice methods are specified for different data analysis situations. Does your reliability effort produce the most cost-efficient results and the most accurate results? Maybe you should be using standard procedures to minimize the work required for the maximum output. Join the thousands of companies that have chosen The New Weibull Handbook as the standard metric analysis method for their reliability programs.

Best Practice

Does your software give you the most for your time and effort? Is it performing at the highest industry expectations? A conscientious analyst can be selective with all of the analytical methods available for the computer. There are many complex equations thrown into software (copied directly from a textbook) that are practically unusable, or worse, misleading. This technical clutter can be confusing or maybe even misleading. We recommend picking out a few good tools to keep handy that have proven worthwhile in The New Weibull Handbook written by Dr. Bob. It is the world standard reference for Weibull analysis and provides the select few best-practice methods. This handbook cuts through the clutter with a handful of solid techniques. SuperSMITH (TM) is the only software that is 100% capable of these best-practice techniques. It is the only Weibull software widely recognized as the world standard.

Binomial and Poisson

Yes/no, on/off, good/bad, pass/fail all can be binomial situations. The simple classic formula for the binomial distribution was discovered in 1663 by John Newton (Is he any relation to Sir Isaac?). If you know the proportion of the time that each of the two outcomes are expected *and* you know how many samplings are to be made, you are home free. This most basic of all distributions is used extensively in quality control applications and in gambling. Another basic distribution is the Poisson distribution for rare events in a continuum. The Poisson is often used as an approximation for binomial when the values are within appropriate limits. Read more about these related methods in The New Weibull Handbook by Dr. Bob.

B-value/B-life/L-life

B-value is the shorthand for *percentile* in the world of Weibull. The bearing industry uses it as a barometer for rated length of service. For example, B-10 life represents the length of service time allowable with approximately 10 percent expected to fail. B-5 life for the same part would be some reduced service time with only 5 percent expected to fail. These values are provided in SuperSMITH Weibull, by entering the data and looking at the graph. It's easy to get precise readings with the *predict* button in the software.

Biographies

Dr. Abernethy was known worldwide for his Weibull workshops presented in Australia, China, Japan, Sweden, Israel, Great Britain, Canada and the USA. Retired from Pratt & Whitney Aircraft, he has numerous awards from SAE, ASME, AIAA, and ISA for his development of advanced Weibull technology during the last thirty years including the Weibayes method, failure forecasting and the Weibull substantiation test designs. He is a fellow of ASQ, SAE and the Royal Statistical Society, and an associate fellow of AIAA. He received the ASME 1988 Gold Medal the SAE 2001 McFarland award for contributions to Weibull education. He founded and chaired SAE's G11 Committee on Reliability and Maintainability. The patent on the J58 engine that powers the world's fastest airplane, the SR-71 Blackbird, is in his name, as well as the patent on the afterburner control on the F100 engine in the F15 and F16 fighters. He was a Navy Scholar as well as a Fulbright Scholar to Great Britain. He is the principal author of the original *USAF Weibull Analysis Handbook* and the sole author of The New Weibull Handbook. He has presented his course, the Weibull/Lognormal Analysis Workshop, all

over the world and continues to teach and provide consultation on Weibull related methods.

Wes Fulton is founder/CEO of Fulton Findings(TM) and the creator of all of the Fulton Findings 'SMITH software including WeibullSMITH, Visual*SMITH, MonteCarloSMITH, BiWeibullSMITH, SuperSMITH(TM) Weibull, SuperSMITH Visual and the SuperSMITH package. He has 16 years of experience as program engineer for Garrett AiResearch (product line ownership changed several times, first to AlliedSignal and then later to Moog). He supervised development and production engineering of aircraft flight control projects, especially maneuvering fly-by-wire actuation systems. He supervised the successful Indigenous Defensive Fighter (IDF) wing leading edge flap actuation system from development through completion of production and also developed the IDF turbine engine flow-compensated fuel bypass. He was program engineer for the F-16 leading edge flap production program and the X-31A leading edge flap program. He co-patented the multi-fuseable shaft (a high-performance drive train device) and is a member of ASME, IEEE, and SAE. He originated the Fulton Factor used in set comparison, invented the concept of equivalent probability and confidence known as *assurance*, and developed probabilistic S/N curve analysis. He teaches seminars in Weibull analysis for organizations such as SAE and ASME.

E. J. Gumbel in the 1920's was the first to seriously investigate extreme values, such as the 100-year flood level. He found that there were only six separate extreme value distributions (proven by Gnedenko) and went on to complete a book, Statistics of Extremes, published in 1958. It is now the standard reference. The Type-III-smallest extreme value distribution is the Weibull distribution. Waloddi Weibull independently invented and used this distribution, and later acknowledged E. J. Gumbel's contributions to extreme value research by using his plotting paper.

Waloddi Weibull was a Swedish engineer and mathematician. He invented the distribution that now carries his name in 1937 and delivered his first American paper on the subject in 1951. He also wrote a treatise on fatigue testing, Fatigue Testing and Analysis of Results, which centered on the uses of this distribution. History has shown that his techniques are extremely useful. They have become the leading methods in the world for analyzing lifetime data.

Classes/Seminars

Dr. Robert B. Abernethy (Dr. Bob) developed the *Weibull/LogNormal Analysis* course in the early 1980`s, teaching the applications and techniques of Weibull analysis. Dr. Bob has taught this course hundreds of times for

engineering/trade society conventions and on-site for business and government with continuous improvements for new research. Wes Fulton has been presenting Dr. Bob`s Weibull Workshop since 1990 and has also presented Dr. Bob's class hundreds of times now. Carl Tarum joined in as co-presenter with Wes in 2005. Now Carl presents on his own. The workshops can be the best introduction to Weibull for the novice as well as a solid refresher course for the experienced. It comes in 2-day, 3-day and 4-day formats. Sample topics are:

Day 1: Overview, 23-minute Video, First Weibull, Good Weibulls, Bad Weibulls, Predicting Failures with/without Renewals, Case Studies, Customer Usage, Maintenance Planning, Goodness of Fit with Critical Correlation Coefficients, Weibull Experiments, Classwork Problems and Solutions.

Day 2: WeiBayes, Improving Accuracy, Smaller Samples, Substantiation Tests, Problem Resolution, Zero-failure Testing, Zero-one-failure Testing, Sudden Death Testing, Warranty Analysis, Maximum Likelihood, Rank Regression vs. Maximum Likelihood, Extremely Small Samples, Inspection Data, Suspensions/Sample-size Effects on Uncertainty, Experiment Analysis, Least-cost Replacement, Hands-on Computer Use, Analysis of Student-supplied Data.

Day 3: Confidence Intervals, Design Comparison, Monte Carlo Solutions, Binomial, Poisson, Exponential, Duane-AMSAA Reliability Growth, Kaplan-Meier Survivability, System Analysis, More Hands-on Computer Use.

Day 4: History of Monte Carlo, Examples, Random Numbers, System Simulation with Renewal, Case Studies, Hands-on Computer Simulation, Reliability and Maintainability with Raptor and Monten, Free Copies of Simulation Software.

Note: A separate *two day refresher* course includes review of risk analysis through to the latest Weibull technology recently implemented in software.

Lecturers: Either Dr. Bob Abernethy or Wes Fulton will lead the seminar. On occasion, both will participate.

Confidence - Useful confidence methods include:

Johnson's Beta-Binomial
Nelson's Fisher Matrix
Lawless's Likelihood Ratio
Greenwood's Variance for Kaplan-Meier
Binomial for Probit
Abernethy/Fulton Likelihood Ratio Contours

Monte Carlo Simulation

Before putting your faith in published analysis results, be sure to find out how confidence is calculated. According to The New Weibull Handbook by Dr. Bob Abernethy the best practice for small samples (around 10 or less) is MONTE CARLO SIMULATION based upon a pivotal statistic (pv method) as it is automated in SuperSMITH Weibull. The best practice for larger samples using the maximum likelihood fit method especially with a quantity of suspensions is LIKELHOOD RATIO confidence. Likelihood ratio was first made available for PC's in SuperSMITH Weibull. Best practice for larger samples using the least squares fit method and few suspensions is Fisher matrix. Fisher matrix was first made available for PC's in SuperSMITH. Binomial bounds are best for probit analysis. Greenwood's bounds are best for Kaplan-Meier (also available first in SuperSMITH. Many of these techniques are *not available elsewhere* as of this writing.

Consulting

Carl Tarum and Wes Fulton are available as schedule allows for consulting on life data, reliability and maintenance concerns. Dr. Abernethy, the principle author of the original U.S. Air Force Weibull Handbook, has over 40 years of experience as one of the leading Weibull experts in the world. Wes Fulton, who released the first useful PC Weibull plotting software over 35 years ago, is a pioneer in the development of user-friendly technical software and he is the CEO of Fulton Findings ™. Both are degreed engineers with many years of experience in actual application of these techniques, and both now teach Dr. Abernethy's three-day course on Weibull.

Cost Reduction

Are you talking only the language of engineers and statisticians? Or can you speak the universal language of business, so the people holding the checkbook understand? When it comes time to renew the annual budget or buy capital equipment for manufacture, then it helps to speak as clearly as possible. You can benefit by thinking and communicating in terms of money. If you do, you will be noticed and your priorities might go directly to the top of the agenda. How? Paul Barringer of Barringer and Associates knows how. From what we have seen, he communicates pretty well for an engineer. One of the techniques promoted by Dr. Bob Abernethy and Mr. Barringer is determination of the lowest-cost planned replacement interval. The optimum replacement interval, or best allowed time of service before equipment is retired and new equipment is substituted, is the one with the smallest cost

per unit time. Another way to reduce cost is by using sudden death Weibayes testing as described in The New Weibull Handbook. These techniques are automated in SuperSMITH Weibull software and provide an excellent icebreaker for an executive boardroom discussion. But whatever you do in a boardroom, do not confess any technical ability. We do not want anybody getting hurt.

Critical Correlation Coefficient (CCC) and Distribution Analysis

Dr. Bob Abernethy has developed critical values of the correlation coefficient for the Weibull distribution based upon simulations performed by Carl Tarum using Monte Carlo simulation. Goodness of fit tests have been greatly simplified and have become easier to understand. Use of the CCC is best practice for determining the most appropriate distribution for a set of data from statistics. Certainly CCC must also be used in conjunction with results from investigation into root cause of failure to complete the analysis. These values are automatically included in SuperSMITH Weibull distribution analysis and in the reporting.

Design (Data Set) Comparison

Comparing designs is easy with SuperSMITH Weibull. It automates the use of likelihood ratio and provides the amount of difference between different sets of data. Comparison is not limited to two sets. This technique is useful for comparing new design to old design, supplier A against supplier B, and application C vs. application D vs. application E, etc. You can also use techniques such as likelihood contour comparison and graphical comparison as requirements dictate. Let The New Weibull Handbook be your guide to selecting the appropriate design comparison method.

Handbooks and References

* Abernethy, Robert B., *The New Weibull Handbook* (NWH), self-published, 1997. This is the world standard reference for Weibull analysis techniques. The NWH replaces the original Air Force Weibull Handbook also written by Dr. Bob Abernethy, one of the leading authorities on Weibull analysis. It contains step by step instructions for performing a Weibull analysis and related techniques such as forecasting failure quantity expected, WeiBayes comparison, substantiation test planning, least cost replacement interval, and

related techniques, with several case studies for each method included. You can order this from as indicated in Products and Services.

* Abernethy, Robert B., New Weibull Methods + Video, self-published, 2003. Seven case studies in a Powerpoint presentation, explained in detail with an included Word document, plus a 22 minute video showing 3 more case studies.

* Fulton, Wes, *PlayTIME(TM) with SuperSMITH(TM)*, self-published, 2003. This is the computer tutorial for the Fulton Findings(TM) software. This is available for download free in Products and Services.

* Gumbel, E. J., *Statistics of Extremes*, Columbia University Press, New York, 1958.

* Liu, Chi-Chao, *A Comparison Between the Weibull and Lognormal Models Used to Analyse Reliability Data*, University of Nottingham Doctoral Thesis, 1997.

* Nelson, Wayne, *Accelerated Testing*, John Wiley & Sons, New York, 1990. The world standard reference on accelerated testing. This is an excellent sourcebook for life data analysis. There are many new techniques in this volume to complement his other standard references on life data analysis. Contact Dr. Wayne Nelson as indicated in the Links page if you are interested.

* Weibull, Waloddi, *Fatigue Testing and Analysis of Results*, Pergammon, New York, 1961.

Languages and International Use

Version 2.0 and above of all Fulton Findings™ Windows software includes simple language translation capability. Please contact Wes Fulton in Links if you want to have the program translated into another language. New language capabilities will be added to the distributed software, as they become available. A character or a brief character combination can be selected to specify currency. Also, Version 2.0 and above recognizes the selection of decimal symbol (either period or comma) made in the Control Panel setup in Windows. These new features were added by request from our customers overseas. Languages have been added and now include . . .

American / English - `English`

Dutch - `Nederlands`

Filipino - `The Phillipines`

French - `Francais`

German - `Deutsch`

Hungarian - `Magyar`

Italian - `Italiano`

Java (Indonesian) - `Basa Jawa`

Polish - `Polsku`

Portuguese (Brazilian) - `Portugues`

Romanian - `Romaneste`

Spanish - `Espanol`

Swahili - `Kiswahili`

Swedish - `Svenska`

Turkish - `Turk`

From the `Setup` section, select the Language / Currency / Decimal / Time / Date icon (showing two people talking) and then select L (for Language) from that menu to get the language menu.

Likelihood Ratio Techniques

The likelihood ratio method for confidence was made accessible by Fulton Findings ™ in 1990 and is still *not available elsewhere* for easy use on a PC as of this writing. Since that time, the likelihood ratio technique has been expanded in Fulton Findings software to compare designs for significant difference based upon exclusive research conducted by Wes Fulton and Dr. Bob Abernethy. At this writing, SuperSMITH Weibull appears to be the only easily accessible and widely used personal computer software using it for confidence. Many other uses of this technique are projected. With proper compensation for small sample bias, it is the best practice available for comparison of groups of data.

Method of Analysis

Several data formats and associated methods of analysis are available. They include rank regression, maximum likelihood, probit, Kaplan-Meier, etc. Each technique has benefits for certain data formats. For example, inspections produce data different than tests where precise failure times are known. This is similar to coarse readout data from imprecise instrumentation. Grouped data can be handled effectively with either probit or Kaplan-Meier. Rank regression has benefits for smaller sample size and maximum likelihood is suggested for data with many suspended values. There are other issues associated with plotting methods and interval data.The New Weibull Handbook is the best source of information regarding these different methods and their application. SuperSMITH Weibull provides all of these techniques that are best practice based upon the particular data format.

Mixed Distributions

Sometimes the data collection is less than perfect. Different failure mechanisms can be mixed together. The mixed distribution model is covered in The New Weibull Handbook ™ (NWH). One technique is to analyze for competing risk. SuperSMITH Weibull (SSW) searches for a competing risk solution from two possible mechanisms (two Weibulls or two Normals or two Lognormals, etc.) by evaluating ordered combinations. P-value technology is found to indicate the power of the mixed distribution model. If the power is very low, SSW indicates a small probability of mixture. Otherwise the p-value is given along with the four parameter solution. This level of competing risk mixture analysis is not available elsewhere.YBath ™ software programmed by Carl Tarum and now part of SuperSMITH provides additional analysis of more complex situations including partial populations and competing risk.

Beware of amateur software from other sources with unsubstantiated mixture analysis methods. Bad software provides solutions even without reasonable supporting evidence. You must always take care with mixture analysis, since false indication of mixture for non-mixed data is common. This can be easily tested. Feed the suspect software several random samples from a single distribution and determine the frequency you obtain mixture solutions. If a high proportion of mixture solutions (high p-values if given) are provided for the single distribution samples, then the software is not very good. The best procedure is to perform careful analysis of mechanism root cause to avoid mixing altogether. Refer to NWH for more details.

Monte Carlo Simulation and Confidence

Monte Carlo (mc) is a special technique for simulation made possible with fast computers. It is used as a prediction tool and can provide a reference for analytical techniques. The pivotal (pv) confidence method is based upon generating and processing large quantities of random variates. SuperSMITH Weibull software uses the power of Monte Carlo to generate correlation P-Value and confidence limits for B-lives and parameters such as Beta and Eta. Distribution of the correlation coefficient and t0 (third parameter in Weibull) for research purposes can be investigated with MonteCarloSMITH™. SuperSMITH(TM) Weibull pv confidence should be used for small samples (around 10 or less) instead of analytical techniques. The 4th day in Dr. Abernethy's 4-day Weibull Engineering Workshop is devoted to mc simulation.

Probabilistic Design

Probabilistic analysis is just what the doctor ordered for new designs. The previous method of using safety margins and safety factors is not good enough any more. Reducing the chance of failure is the real challenge. That means you need to measure the probability of the applied stress being larger than the strength for each load application. If you can estimate the distribution of stress and the distribution of load, then SuperSMITH Weibull can estimate the probability of failure within your needed accuracy. This very flexible and powerful technique can also be applied to life distribution vs. usage distribution with similar results.

Product Support

For software questions contact Wes Fulton at Fulton Findings and for Weibull analysis questions contact Carl Tarum as indicated in Links. All software and handbooks are guaranteed for customer satisfaction. Most questions are resolved with one call. Any suggestions for software or handbook enhancement are welcome.

Reliability and Maintenance

Probability of success is the definition of reliability. A reliable product intelligently maintained will provide adequate service life and garner high marks for customer satisfaction. An unreliable product without proper maintenance is a disaster. Scheduled maintenance can be costly and should only be considered for *wearout* failure mechanisms when older parts are more likely to fail (increasing instantaneous failure rate). Weibull analysis can

indicate whether older parts or newer parts are more likely to fail. For electronics, generally newer parts are more likely to fail at least during normal usage (decreasing instantaneous failure rate). This type of failure mechanism common in electronics is called *infant mortality* due to the higher probability of failure at the start of service life. Constant failure rate indicates the *exponential* distribution. Maintenance for infant mortality and exponential failure mechanisms is wasteful. A better approach is to apply some sort of screening just before actual usage. Certainly, this is why we feel better after the computer store has burned-in our new computer for a few hours before we take delivery. SuperSMITH Weibull software provides useful estimates of failure mechanism type, the predicted number of failures to expect, the lowest-cost replacement strategy, spares requirements, and assessments of corrective action effectiveness.

Reliability Growth (Crow-AMSAA based upon J.T. Duane's postulate)

A technique related to Weibull analysis for evaluating failure occurrence is called reliability growth modeling. It requires less information than Weibull requires, but it still can indicate instantaneous failure rate changes. Of 27 different competing reliability growth models, Crow/AMSAA has been found to be best practice. Dr. Larry Crow took J. T. Duane's postulate for learning curve modeling and extended the analysis with powerful statistical capabilities while working with AMSAA. It is included as a part of SuperSMITH Visual software. There is no need for a separate program, since this technique simply consists of plotting a straight line on a log-log plot. Predicting the quantity of failures to expect for spares ordering and maintainability planning is very easy. The New Weibull has a complete section devoted to Crow/AMSAA.

Risk Analysis (Expected Quantity Forecast)

Estimating the expected quantity of occurrences or failures in the coming months is called *risk analysis*. Chapter 4 in The New Weibull Handbook covers this type of estimating. It is extremely useful for identifying a batch problem or for determining spares purchase policy. It was developed and used effectively by Dr. Abernethy years ago in response to customer information requirements. Risk analysis is automated in SuperSMITH Weibull software and is *not available elsewhere* as of this writing for easy use on a PC.

Skunky Software Alert!

Be careful. We recommend checking all potential software out with a set of benchmarks from standard textbooks. Our software meets the benchmarks and often betters them. We have copied the benchmarks for you and they are easily accessible from our Windows software. Please contact us if you want to use the benchmarks for comparison. If possible, try the benchmarks on software you might buy before actual purchase to see if the software measures up. You may be surprised to find out how disappointing some software can be. You will not be disappointed with our software. It is the world standard for performing Weibull analysis.

Software from Fulton Findings

General descriptions follow.

SuperSMITH(TM) `SS` is a bundled package of programs from Fulton Findings™ for reliability and variability solutions on a personal computer at a discount price. It is a complete self-study package with SuperSMITH Weibull and SuperSMITH Visual and SuperSMITH YBath™ from Fulton Findings.. The `PlayTIME With SuperSMITH (TM)` tutorial is now available free online as a `.PDF` file. AMAZON sells Dr. Bob`s standard Weibull handbook, and it is easy to order there. SuperSMITH performs all the techniques in Dr. Bob`s handbook. SuperSMITH is the standard for performing Weibull Engineering analysis, and is used by thousands of companies worldwide. Recently published benchmarks indicate SuperSMITH as the only trustworthy source for best practice solutions to these kind of problems.

You can order SS software as indicated Products and Services.

SuperSMITH Weibull `SSW` software for Windows performs all of the Weibull techniques in Dr. Abernethy's New Weibull Handbook. SSW contains results of independent research with several methods developed by Dr. Abernethy in cooperation with Fulton Findings. Many of these techniques are *not available elsewhere*, such as likelihood ratio confidence, simplified design (set) comparison, Kaplan-Meier simulation and solution, critical correlation coefficient, sudden-death WeiBayes, parameter as a function of engineering variable, etc. SuperSMITH Weibull for Windows uses Weibull, Normal or LogNormal equations. It replaces the DOS program WeibullSMITH™ and the Windows program SuperSMITH(TM) Weibull (SSW), previously the leading Weibull analysis software programs.

SuperSMITH Visual `SSV` software for Windows provides general scientific plotting. It includes Crow-AMSAA modeling for reliability growth analysis and it plots probability density functions, cumulative distribution functions (regular scaling), likelihood contours, least-cost replacement intervals, failure

forecasts, and histograms all from SuperSMITH™ Weibull files. The modified lower-bias likelihood contour comparison capability in SSW & SSV is *not available elsewhere*. The program also includes function plots, data transforms (global edit), and curve fitting as well as XY plots, bar charts and pie graphs.

SuperSMITH(TM) YBath(TM) `SSY` for Windows is the most advanced mixture analysis software available for bathtub curve modeling with multiple and mixed failure mechanisms in the same set of data. YBath has capability for solving up to three different mechanisms convolved in the data. With enough input data entered YBath will provide the correct mixture solution. Both rank regression and maximum likelihood techniques are available.

ARCHIVED PROGRAMS . , .

WeibullSMITH (WS) for DOS (no longer available) was the first commercial PC implementation of Weibull analysis including plotting and failure forecasting. It was replaced by SuperSMITH(TM) Weibull (SSW) for Windows and finally SuperSMITH(TM) Weibull (SSW). All previous capability plus a lot more is now in SSW.

VisualSMITH (VS) for DOS (no longer available) is the precursor to SuperSMITH(TM) Visual (SSV) and finally SuperSMITH(TM) Visual (SSV). All capability plus a lot more is now in SSV.

BiWeibullSMITH TM (BW) for DOS (available only from archives) solves two fit lines for one set of data without partitioning. This is useful for warranty analysis with both infant mortality and wearout failure mechanisms. The late Alan Townsend of Allison Engines pioneered this BiWeibull solution technique. This competing risk analysis capability is not available elsewhere and has now been moved to SuperSMITH(TM) Weibull. Other software available for mixed population analyis is YBath(TM) from Fulton Findings. Contact us as designated in E-mail Addresses, Sites and Telephone #'s section.

MonteCarloSMITH™ (MC) for DOS (no longer available) is a research tool available for general use. Regular Monte Carlo simulation and Monte Carlo confidence is available in SuperSMITH(TM) Weibull. What makes MC special is its ability to create, analyze and store the data from up to 1000 simulations (up to 1000000 for certain comparisons). This process provides Monte Carlo estimates of confidence for probability model parameters such as the mean, standard deviation and 95th percentile of a normal distribution for example. Weibull, Normal and LogNormal equations are provided. These techniques, absolutely necessary to remove bias for small samples, are *not available elsewhere*. The current MC software is already easy to run in Windows, since graphics are not involved.

Software from Other Sources

Reliability, Maintainability, Availability - Please contact Paul Barringer indicated in E-mail Addresses, Sites and Telephone #'s for information on reliability/maintainability/availability modeling tools. These tools are especially needed for complex facility or system management to minimize costs and maximize product integrity. MonteCarloSimulationS and Reliability/Maintainability Modeler are software packages summarized below:

1) MonteCarloSimulationS(TM) is a collection of Excel spreadsheets for use in simulations. Details are available at http://www.barringer1.com/simul.htm. MonteCarloSimulationS contains a series of simulation models written in Excel which combines the use of spreadsheets, Weibull statistical failure data, and random numbers to solve diffiult problems in reliability, availability, and cost..

2) Reliability/Availability Modeler TM is a software modeling package using process flow diagrams of unit operations, subassemblies of plants, or a complete plant for building a reliability/availability Monte Carlo simulation model. The simulation model joins equipment with logic, costs, and Monte Carlo calculations. Outputs from the simulation model give ages-to-failure for finding the overall reliability, availability, and costs for unreliability for a plant or process. The simulation model and its pallet of tools are under development with first applications expected beginning of second quarter '97. The software package will use Gensym's G2 knowledge-based intelligent modeling engine running simulations on a PC in a Windows NT environment.

Suspensions and Censored Data

Units that could fail but have not failed yet by the failure mechanism under investigation are called suspensions, or censored units. Suspension times represent values that are less than the actual life with respect to the failure mechanism of interest. In other words, the actual length of life is greater than the length of service recorded. One way to enter a suspension value into the SuperSMITH Weibull software is by putting a “>” (greater than) symbol in front of the value. Such data can make the study more accurate and should always be included to complete the analysis. Methods are available for treating suspended data as detailed in The New Weibull Handbook.

Test Planning

When is it better to make something more difficult? Answer: When planning a test, of course. Test design is based on setting up a tough obstacle course and then navigating through it. The harder the obstacle course, the better you feel when you walk (or crawl) across the finish line. Completing a difficult course gives you more confidence that you could do it again if needed. Using this impeccable logic and the binomial distribution you can plan your test, but be prepared for lots of testing! The binomial (pass or fail) distribution requires lots of test samples. You don't get much life information from pass/fail tests. However, combining this with the Weibull distribution to model useful life can drastically lower the amount of testing needed (and reduce the cost). Good software should include comprehensive test planning. You may have to make it difficult for your products when planning a test. So make it easy on yourself and use SuperSMITH(TM) Weibull, the most comprehensive software for test planning.

Tutorial for Software and Solutions

PlayTIME (TM) with SuperSMITH is a tutorial for learning how to perform Weibull analysis, available now in `.PDF` form for download from this website. It is a complete self-study course when combined with SuperSMITH software and The New Weibull Handbook(c). This combination is called the SuperSMITH package. Over 50 case studies are presented in the tutorial representing 50 years of actual problem-solving in the product and service industries. It is written in an easy-to-follow style with actual computer exercises. This tutorial comes as part of Dr. Bob Abernethy`s Weibull Workshop presented by Wes Fulton and/or Carl Tarum, or it is available separately for self-study.

T-zero (3 Parameter)

The third parameter for Weibull analysis is called t-zero. It is a time shift causing curvature on the Weibull graph for time scaling as originally recorded. The t-zero can also be used for other distributions. The value of t-zero is subtracted from each data value before analyzing. A positive t-zero solution indicates a failure-free period where the probability of failure is negligible. A negative t-zero indicates loss of some reliability before service officially begins. The critical correlation coefficient (CCC) accounts for the bias in correlation associated with an additional parameter. SuperSMITH(TM) Weibull solves for the optimum t-zero for a given data set and distribution.

Warranty Data

Warranty data naturally forms a triangular matrix, also called `layer cake` format. The data is collected by batches produced on a regular basis. If production is by months, then reports for the last batch produced cannot have age greater than one month and reports for the batch a month earlier than that cannot have age greater than two months and so on. Underneath the production quantity number for the last month there is only one age interval (one month). The batch produced just before the last one can have ages of either one month or two months, so there are two age intervals underneath the production quantity number for that batch. This trend continues with each month further back into the past having additional age intervals possible. The first row in the table below represents production quantity by month, in this case 1000 each month. Underneath the production quantity are report quantity grouped by age in months after shipment.

WARRANTY DATA FORMAT

1000	1000	1000	1000	1000	1000
1	0	0	3	1	4
4	1	1	3	1	
2	0	1	1		
1	1	2			
1	4				
0					

SuperSMITH(TM) can convert warranty data into Weibull inspect option #1 (with or without renewal), or Weibull Kaplan-Meier option #4 (with or without renewal), or Duane/AMSAA reiliability growth (with or without renewal) . . . depending on which software is used. The analysis can be truncated before the last month of production or can be extended past the end of production by selection of less or additional columns respectively as described in the software. The data above is from The New Weibull Handbook.

WeiBayes

WeiBayes is a term coined by Dr. Bob Abernethy for Weibull analysis when the slope parameter is selected beforehand, relating to Bayesian assumption. Dr. Abernethy refers to this technique alternately as the one-parameter Weibull, since one of the two standard Weibull parameters is already selected. Other sources now also refer to this technique pioneered by Dr. Abernethy and independently by Lois Jackson (Gates Rubber Co.) using the same

terminology. This powerful method based upon maximum likelihood provides answers to difficult questions concerning product improvement and design comparison. Use is possible without the requirement of testing to failure, which can be long and costly. The no-failure situation produces a lower confidence bound for characteristic life. The presence of failures reduces the characteristic life value to a point estimate. Dr. Wayne Nelson has extended the technique producing confidence limits even when failures exist. Case studies and technique details can be found in The New Weibull Handbook, Chapter 5.

Weibull Analysis for Variability Control (including Normal, Lognormal, Exponential, Gumbel lower and Gumbel higher)

Graphical analysis using several probability distributions is now called Weibull analysis. The most commonly used is the Weibull 2-parameter distribution, but the Weibull 3-parameter, the normal distribution, the lognormal distribution, the exponential distribution, the Gumbel lower (or "Extreme Value") distribution and the Gumbel higher distribution can also be used effectively. The Normal and Gumbel distributions can predict negative life for high reliability requirements, an impossibility. Car must be used when modeling product life with these distributions. Weibull and Lognormal never predict negative life when used properly. In addition, Weibull has the special capability to diagnose failure types such as infant mortality (particulary for electronics), age-independent (accidents and natural occurrences), or wear-out type mechanisms (bearings, filters, etc.). Dr. Abernethy's course on Weibull and Lognormal Analysis has become the standard introduction to this method with hands-on use of related software. Engineers, technicians, quality assurance personnel, management and others responsible for variability control can begin to apply Weibull techniques in the workplace afterward. Many societies and professional organizations host these seminars during organizational meetings. Please contact Wes Fulton or Carl Tarum or one of the organizations, if you are interested in attending. Contact information is indicated at the main website page (WeibullNEWS.com).

Zoom (A Closer Look)

Get closer to reality by investigating the source of your data. There is no substitute for some old-fashioned detective work to find the root cause of reported difficulties or measured phenomena. Data analysis methods cannot improve bad data. When there is an indication of mixed root-cause mechanisms, the first thing you should do is to group the data according to mechanism. Weibull analysis is best when analyzing each mechanism

separately. You can also zoom into your statistical analysis by using the Zoom button (showing magnifying glass) in SuperSMITH(TM) Weibull. There are many features for graphical data editing, hiding or highlighting, changing X-axis and Y-axis ranges and so on in the Zoom portion of the software.