Weibull NEWS™

The Latest in Life Data Analysis Technology℠
From: Dr. Bob Abernethy and Wes Fulton

Edition 17-2003 Editor: Paul Barringer

The world has suddenly found life data analysis! We've been busy with many Weibull workshops, and exciting new research.

Small Samples -We all want reliable products and systems. Items we purchase should work as expected. Things we sell should perform as intended. This requires good reliability built-in, as well as adequate quality and maintainability. Time and money allocations generally restrict test programs before bringing a product to market. The budget may allow fewer test articles than ideal. Large quantities of returns for inferior performing products can destroy the bottom line and produce negative publicity regarding excessive accidents or other side effects. Thus, practical reliability programs must focus on maximizing returns from small test samples. And here is where the problem lies.

Although mathematical statisticians have high regard for likelihood theory, life data techniques such as the maximum likelihood estimate (mle) do not work well for small and moderate sized samples (less than 100 failures). The mle approach gets accurate only when sample size is large. Concentrating on the real world of small samples provides a significant challenge in statistics. Based on continuing mle research, there is a way to more accurately measure product life and reliability for small samples [reference Fulton 1996 and Abernethy 2000]. This simple reduced bias adjustment (RBA) for mle is described in The New Weibull Handbook© and incorporated into SuperSMITH™ software, WinSMITH™ Weibull and WinSMITH™ Visual.

Accelerated Testing - The new kid on the block is Step-Stress Test Data Modeling…(SSDM). Just ask Dick Rudy of Daimler-Chrysler if you don't believe it. Although it is a more complex model, SSDM can help bring reliable product to market quicker by forcing failures at higher loads in the laboratory. However, there may be excessive uncertainty in the SSDM results due to model complexity. The best recommendation for SSDM is to get enough data to verify consistency.

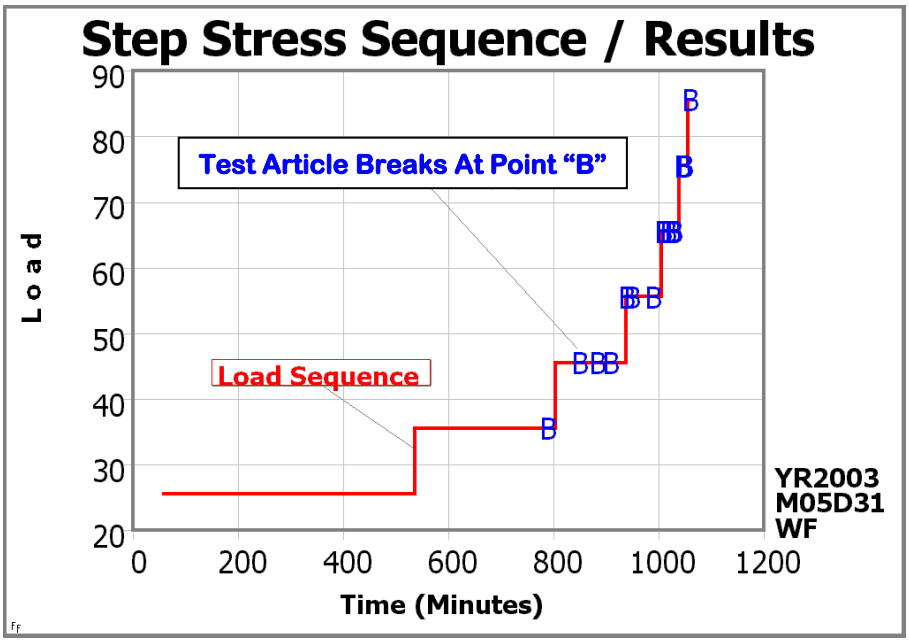


FIGURE 1. Step-Stress Sequence and Results

WinSMITH Weibull has added SSDM capability with clear output. Single load results are easily plotted for several individual levels simultaneously on the life data plot. This SSDM capability is completely compatible with the probabilistic S/N curve method and the Parameter as a Function of Engineering Variable (PFEV) analysis already in the SuperSMITH package software. Figure 1 shows a step-stress sequence for 15 test articles and their respective break points along the step-stress path.

Test stress values are increased according to the step-stress sequence until breakage occurs. This process almost always produces failures unless test articles have to be removed before the end of the test or are caused to fail by a mechanism not under study. Articles caused to fail by a different mechanism are considered as suspensions for the mechanism being evaluated. The simplest SSDM solution involves maximizing likelihood for a 3-parameter model. Then a new Weibull (or lognormal) fit line can be projected for untested load levels closer to the nominal load. This option for step stress analysis is under the Accelerated Testing / Degradation icon on the main screen of the WinSMITH Weibull software.

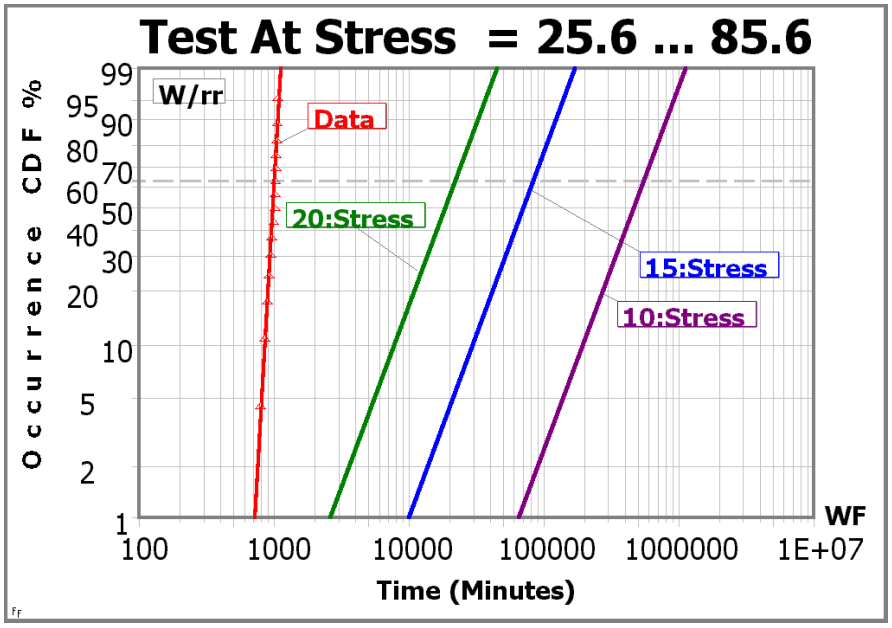


Figure 2 - Step Stress Testing Data Model Results

In the WinSMITH Weibull software, the procedure for step stress analysis starts with entry of the total test time values. After selection of the Accelerated Testing icon and then the Step Stress analysis, you will be asked to enter the step stress sequence. Different sets of data may have different step stress sequences. Figure 2 shows SSDM analysis of the test results data with a higher slope fit line through the data. The plot also displays other fit lines at lower slope for expected performance at individual untested load levels. The slope of the fit line through the original data is excessively high, because the load is being increased and this forces the data values closer together. The true slope at a single load should be lower.

In Wayne Nelson's book on the subject, Accelerated Testing©, he cautions that we should be careful with these new analysis methods. Hopefully, SSDM results agree with common sense.

Weibull Library - An important addition to the WinSMITH Weibull software is automatic Weibull Library generation and library item addition. Activate the new library capability under the Setup icon (showing a computer) on the main screen. After activation, a fresh library item is generated each time Weibull engineering analysis results are saved. You will be asked to provide additional information, but you do not have to enter existing information (such as calculated slope values, plot labels, etc.). Additional information such as type of equipment, type of mechanism, type of environment, and so on may be added to the library item. Then, you can save the library item to a file or put the library item into the Windows Clipboard for later pasting into database software. Establishment and maintenance of a Weibull Library is MOST IMPORTANT.

Extended Forecast Range Especially for Extended Warranty - SuperSMITH software forecast capability in the WinSMITH Weibull program has been upgraded allowing several forecast period selections from 60 days to 60 years. Model options include real usage schedule, actual production schedule input, pre-emptive replacement, new replacement unit design, scheduled retirement, warranty limits, and adjustment of appropriate fleet size for what-if analysis. These new tools in the Abernethy risk option provide a way to evaluate future product liability exposure and to estimate projected cost. Thanks goes to Joe Wauben of Honda Transmissions for several key suggestions.

Barringer Process Reliability (BPR) - Jose Wilkins of Dupont Corporation requested upgrades to the BPR mixture analysis section in WinSMITH Weibull. Now multiple data sets can be evaluated at the same time. Also, colors for the individual lines and data can be assigned in several ways. The current software shows indications of the fit line slope while production lines or nameplate lines are being added on the plot.

Best Practices and Recommendations Flow Chart - Bob Rock of PACCAR took the recommendations from The New Weibull Handbook and made a comprehensive flow chart for easy use. This flow chart is available in Chapter 10 of the handbook. It can be also be accessed electronically from the SuperSMITH software thanks to the programming efforts of Carl Tarum. To access in the software, just select the Help drop down menu on the main screen and choose Analysis Wizard.

New Methods for Life Data Analysis – A Management Overview – A new CD introduces Weibull analysis to engineers and managers. The new CD shows newer, more advanced techniques to the same audiences that view the Weibull Analysis Video/CD. We have produced a PowerPoint presentation of seven case studies illustrating new methods for warranty analysis, failure forecasting, Crow-AMSAA modeling, cost analysis, R&D testing, accelerated testing and more. The presentation emphasizes the benefits of the analysis but avoids the detailed how-to-do-it during the PowerPoint presentation. Step-by-step how-to-do-it details are included in a Word document for engineers that want to reproduce the case studies. The new CD packages all three items, the video, the PowerPoint presentation and the Word document on one CD.

Dr. Bob Replies to E-mail Questions at weibull@worldnet.att.net

1. The *average and the standard deviation* estimates in the SuperSMITH software are different from the simple average and standard deviation (as calculated by Excel, for example). Please explain why there are differences. *Dr. Bob's reply: You cannot use the usual equations for the mean and standard deviation because they do not account for suspensions . Instead we first solve for eta and beta (you choose the method), then use the Weibull equations in Appendix G to estimate the mean,μ, and standard deviationσ as occurs with use of the calculator icon in WinSMITH Weibull.*

2. **With *interval and inspection data* I use the data shortcut to input points at the same value. For example, 88x9 means there nine failures occurred at time eighty-eight. This data quantity appears as the number 9 on the plot. If I change from median rank regression (MRR) to the Inspection Option the plot position of the 9 changes. Why?** *If you input the 9 failures individually they would appear as a vertical column of points on the Weibull plot. With MRR the 9 is located in the middle of this column which is approximately where we expect the standard Weibull line to appear. With the Inspection Option the 9 is located at the topmost point of the column, where we expect the Inspection Option line to appear.*

***3.* In the New Weibull Handbook you use *median bias* for most of the comparison of methods and yet you write about *unbiased estimates*. I thought an unbiased estimate is one whose expected value equals the true value. I am confused as the expected value is the mean value. Correct?** *You are correct that an unbiased estimate is one whose expected value equals the true value an that the mean value is the expected value. However, the mean value is not a good measure, or a typical measure, for skewed distributions and most life distributions are skewed. We recommend the median value instead of the mean value for skewed distributions. Statistical estimates will split 50/50 around the median. For example, we recommend the median rank plotting instead of the mean rank positions for life data analysis. In the case you selected, five failures, B1 and beta are highly skewed. See the simulation results below. For comparing the accuracy of alternative methods like MRR versus MLE, I use the median bias rather than the mean bias. With MLE-RBA Weibull we employ the median bias correction as the standard or default, but we also offer a mean bias correction in our software. These are quite different corrections; the median bias correction is C4^3.5 versus C4^6 for mean bias. The mean bias correction is much larger.*

4. When I use a *three parameter Weibull* the slope, beta, is less than the two parameter beta. Which beta is correct? *The 3-parameter Weibull is a much more complex distribution than the two parameter. We have **four** fixed requirements to meet before we adopt the 3P solution. If you meet all these criteria above the 3p distribution is the best distribution and the 3P beta is the correct beta. The 2p beta is irrelevant. For example, when we have some data sets with missing data and use the 3p and compare it to data sets without missing data from the same source the 2p with all the data fall on top of the 3p with missing data, same beta.*

5. For *warranty claims forecasting by age* you recommend both the Inspection Option and the Kaplan-Meier model. Which should I use? *We have research underway comparing all the interval methods, Inspection Option, Probit, K-M, and Interval MLE but it is not completed. Industry seems to prefer the Inspection Option for warranty claims by age but many use K-M. There is a problem with K-M. When we use the K-M with the actuarial correction, some of your suspensions are eliminated from the data set. This prohibits using the Abernethy Risk forecast as the suspension histogram is wrong. However, this does not effect the estimate of per cent claims at the end of the warranty period which is the usual objective. The Inspection Option does not have this problem. If the probability of repeat warranty claims for the same problem is significant you may want to consider Wayne Nelson's Graphical Repair method described in Appendix M of the Handbook.*

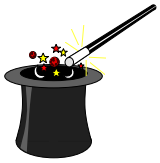
6. The failures were produced by two competitive, "dueling," failure modes. We cannot separate the data into two failure modes. How can we do a failure forecast? *The cumulative probability of failure considering both modes is* **[***1-(F(t1))x(F(t2))]. The first step is do a mixture analysis with WSW. If the "p" value supports two Weibulls rather than one Weibull, it is now possible to do an Abernethy risk analysis with the WSW, version 4.0V and later. Alternatively, you could use Monte Carlo Simulation. "RAPTOR" would be a good choice for the simulation software.*

7. Is there more information about how the *adjusted rank algorithm* (that adjusts the plotting positions for suspensions) was calculated. Leonard G. Johnson's book, "The Statistical Treatment of Fatigue Experimentation," has been out of print for some time. Any help would be most appreciated. *The derivation in Johnson's book is not too clear; however Charles Mischke's ASME paper listed in the References is excellent, very clear. You may download it from http://www.barringer1.com/wa_files/Mische-Plot-Position-1979.pdf.*

8. Hi Dr.Bob, I'm lost. I have a Beta of 0.80 and the BetaU is 1.03 and BetaL is 0.70. Does that tell me if the data is close enough to be *exponential*? *If your double sided confidence bounds are at 90% confidence, your data is not significantly different from an exponential at 90% confidence as the value one is in the interval.*

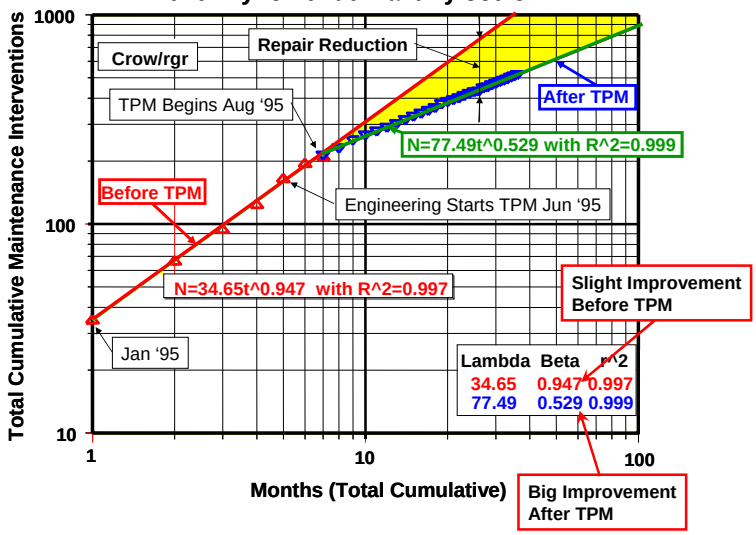
9. My statisticians recommend Cramer-Mise and Kolmogorov-Smirnoff as measures of *goodness of fit* but you do not. Why? *Comparing all the known goodness of fit tests the two best goodness of fit tests are the likelihood ratio test and our "p" value for the correlation coefficient squared (Coefficient of Determination), [as shown in Chi Chao Liu's thesis]. The likelihood ratio test described in Chapter 5, is used with MLE or better with MLE Reduced Bias Adjustment. The p value for r squared presented in Chapter 3, goes with median rank regression, X on Y. Of course, either technique may be used with either method. For testing goodness of fit, both are excellent and we recommend using both. For distribution analysis, both work well, but you need at least 21 failures to have enough information to make a credible choice with any method. Less than 21 failures always use the Weibull 2p even if you know the data are log normal. If you do not have Chi Chao Liu's thesis you may download it from http://www.barringer1.com/wa_files/C-CL.pdf.*

"Predict Future Failures From Your Maintenance Records" - Paul Barringer presented a paper with this title in Australia. The paper includes some good background on using Crow-AMSAA modeling for maintainability plus several case studies. The following is one of the most interesting case studies (http://www.barringer1.com/pdf/PredictFutureFailures.pdf).



Actual pump maintenance interventions were reported from a Brazilian chemical plant. The Crow/AMSAA plot is shown in Figure 3. The cumulative failures versus cumulative time produce two straight lines. The trend line before starting a TPM program shows slight improvement (β = 0.947). After introducing the total productive maintenance program taught operators fundamental things they could do to reduce failures, the TPM failure trend line shows a distinct cusp. The improvement curve shows a slope β = 0.529.

Figure 3 Reduction Of Pump Failures In A Brazilian Monovinyl-Chloride Plant By Use Of TPM



Using Figure 3 the savings from the TPM program at time t=36 months is an avoidance of 516 interventions in 29 months. Assume each intervention has an average cost of US$1000, the savings from the TPM program is $516,000. The net savings for the TPM program will be amount saved less amount spent for introducing the TPM effort. Every maintenance program requires factual justification of costs and benefits and Crow/AMSAA plots quantify the savings and provide forecast of future failures.

Table 1 The Fearless Monthly Forecast

Maintenance Interventions					
Month	**1995**	**1996**	**1997**	**'98 Fcst**	**'99 Fcst**
January	35	12	8	8	7
February	32	13	3	7	7
March	28	12	15	7	6
April	30	11	5	7	6
May	41	11	10	7	6
June	30	11	9	7	6
July	16	15	8	7	6
August	18	9	7	7	6
September	21	8	7	7	6
October	14	8	9	7	6
November	12	10	7	7	6
December	11	10	8	7	6
Total =	**288**	**130**	**96**	**85**	**74**
TPM Began August 1995					

Major improvements for this example were achieved by putting pumps on the best efficiency point (BEP) and introducing a pump maintenance training program. This required cooperative efforts between operations and maintenance. A Pareto distribution established prior to the kick-off of the TPM program to identify bad actors and build a priority action team—in most cases, the pumps required trimming of the impellers using the laws of affinity along with correction of net positive suction pressures. Pumps operate on their BEP by decisive action whereas pumps operate off their BEP by benign neglect. Insufficient net positive suction head and off-BEP causes vibration, cavitation, and other harmful actions which drive-up the need for maintenance interventions.

Table 1 is a forecast of failures for the next 12 months using the trend line after implementation of the TPM program. This monthly forecast of failures will be for months 37 through 60 to cover a two-year forecast interval.

2003 ORDER FORM

Weibull / Lognormal Workshop - Please contact either Dr. Bob Abernethy or Wes Fulton as listed below for participation.

NWH: The New Weibull Handbook©, 4th Edition - The worldwide standard Weibull reference and the reference text for Weibull software. It describes the latest methodology for life data analysis, and includes many case studies. Figures and equations are large print for easy reading. This is the standard reference adopted by the U.S. military, the FAA, NASA, and hundreds of business organizations.

WSW: WinSMITH™ Weibull Software, Version 4.0 - The leading Weibull (lognormal, Gumbel, …) plotting and analysis software for Windows with techniques such as warranty data conversion, design comparison, failure forecasting, Monte Carlo confidence bounds, Barringer process reliability, probabilistic S/N curve, and other methods that are not available elsewhere.

WSV: WinSMITH™ Visual Software, Version 4.0 - General scientific plotting for Windows with curve fitting, functions, transforms, and Crow/AMSAA (Duane) reliability growth modeling. It generates auxiliary plots from WSW data such as risk plots, optimal replacement plots, likelihood contours, ACH, hazard, PDF and CDF plots. The logical partner to WSW.

PT: PlayTIME™ with SuperSMITH Tutorial Booklet - Computer exercises and coaching notes with case study data examples.

SS: SuperSMITH™ Package - All above (NWH, WSW, WSV, and PT) bundled and discounted. Included with workshops.

Weibull Training Videotape – Three real in-depth case studies show how Weibull guides the way to practical solutions. Available on video tape for $40 or CD for $50.

New Methods for Life Data Analysis-A Management Overview Seven case studies showing the latest methods and applications in a PowerPoint presentation emphasizing the benefits of this analysis, designed for group presentations to managers and engineers, plus how-to-do-the-case-studies, step-by-step, in a "Word" document. This material compliments the video above so they are packaged together on one CD for $98.00. ***New May 2003.***

Ordering Handbooks and Software: Orders may be E-mailed, faxed, or mailed to either Dr. Bob Abernethy, Wes Fulton or Paul Barringer. Payment for handbooks must be by check or money order. Purchase orders from overseas companies must be prepaid before shipment. Shipments are usually sent priority (or global priority) mail. For overnight shipment, please FAX orders, and add $20.00 per item. Call us, E-mail, or FAX us for questions, quantity discounts and upgrade costs. DEMO software can be quickly downloaded from our website and unlocked to FULL capability by password. Prices are subject to change without notice.

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Paul Barringer, PO Box 3985, Humble, TX 773476
281-852-6810 (TEL), 281-852-3749 (FAX) … hpaul@barringer1.com

	List Price ($US) Each	Quantity	Total
NWH - The New Weibull Handbook	98.00	X _____	= $ _____
PT - PlayTIME Tutorial Booklet	48.00	X _____	= $ _____
WSW - WinSMITH Weibull Software	580.00	X _____	= $ _____
WSV - WinSMITH Visual Software	480.00	X _____	= $ _____
SS - SuperSMITH Package (ALL OF THE ABOVE)	960.00	X _____	= $ _____
Weibull Training Videotape or CD	50.00	X _____	= $ _____
New Methods Overview With Weibull Training CD	98.00	X _____	= $ _____
NOTE: Enter shipping and handling cost below and then add last column for grand total cost.			
Shipping and Handling	20.00 (40.00 overseas)	X _____	= $ _____
		GRAND TOTAL COST	= $ _____

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2003 On-Site Weibull/Log Normal Workshops

Three-Day Complete Workshop – Our standard seminar includes treatment of the Fourth edition of The New Weibull Handbook©, and the latest upgrade of the SuperSMITH™ software including two afternoons of hands-on computer tutorial (PlayTIME™) covering every type of problem and every option. The Workshop is designed to bring the novice to full expert capability. Topics include failure analysis, optimal parts replacement, cost analysis, failure prediction, warranty analysis, reliability system models, and substantiation test design.

Four-Day Workshop - Follow Up Consulting or Model Simulation - The complete Workshop plus a fourth day for student presentations of their own real problem analysis completed in the workshop. This allows Dr. Bob and the class to serve as a consulting forum reviewing each problem. The students should be strongly urged to bring one or more of their own problems to the workshop. Students get consulting on their real problems and show how they are applying the new techniques learned. Managers are invited. Alternatively, the fourth day may be devoted to system simulation tools for building models of any level of complexity regarding reliability, maintainability, safety, spare parts, logistics analysis and warranty-guarantee costs including a half day hands-on with computer simulation models.

Half-Day Management Overview - Following a 3 or 4-day Weibull Workshop, a morning presentation to senior managers may be scheduled to provide an overview of this new technology including application to their problems.

Fees: For Weibull Workshops in the USA, Canada and Mexico:

Workshop Days→	3-Day Workshop	½-Day Overview	4-Day Workshop	1-Day Refresher
8 or Less students	$7896	$1330	$9784	$2800
Extra Students > 8	$840	No charge	$976	$350

Examples:

Students	3-Day	3-Day/Student	4-Day	4-Day/Student
8	$7896	$987	$9784	$1223
10	$9576	$958	$11736	$1174
15	$13776	$918	$16616	$1108
20	$17976	$899	$21496	$1075
25	$22176	$887	$26376	$1055

The fees include the SuperSMITH Package: The New Weibull Handbook, 4th Edition, The Playtime with SuperSMITH computer tutorial, the WinSMITH Weibull and Visual software valued at $960 for each student, plus a graduation certificate for each student as well as our travel expenses.

On-Site Workshop Advantages: Workshop features include introduction, video, lectures using case studies, Weibull experiments in low cycle fatigue, classwork, hands-on computer tutorial, student analysis of their own data & problems, many question & answer periods, oral quiz, graduation. We tailor the workshops to your specific needs. We can use your data and problems in the special computer tutorial. We can add, or delete, or emphasize specific topics. The students are invited to bring their own problems to the workshop. The cost per student is about half of the fee for our public workshops and there are no travel costs for the students. The New Weibull Handbook is provided well in advance to allow study before the workshop. The latest life data technology will be presented including failure and warranty forecasting, new methods for minimizing testing costs and time, comparing the new design with the old design, confidence intervals and trending fleets of in-service units for reliability, safety and maintainability. E-mail or call Dr. Bob for more detailed information. See Paul Barringer's website, www.barringer1.com, for information on his workshops in life cycle cost and production process control.

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