WeibullNEWS

Eighth Edition | From: Dr. Bob Abernethy & Wes Fulton | Fall 1994

Kaplan-Meier Should be in Your Toolbox: There are data deficiencies that make Weibull analysis difficult, impossible, or questionable. The Kaplan-Meier (K-M) Survival function may be an excellent alternative for some of these cases. (See New Weibull Handbook Section 8.6) It is widely used in the medical industry. The method is simple and produces maximum likelihood estimates of survival. The compliment of the MLE survival function is the MLE cumulative probability of failure. The K-M estimates are distribution independent, i.e., there is no distributional assumption. (So if you ever get in an argument about the distribution, K-M may eliminate the argument.) Several authors including Wayne Nelson, suggest the K-M estimates may be plotted on probability paper. This is easily accomplished using Probit analysis (Inspection Option #3). Confidence intervals are available using Greenwood's estimate of the variance. The treatment of suspensions is different from Leonard Johnson's adjustment but provides similar results. The method may be used with individual failure times or with interval data.

Typical Kaplan-Meier Data Sets:

- Warranty data calendar month versus months since produced
- "Zillions" of failures (you don't need a histogram of failures option)
- "Zillions" of suspensions with a small or large number of failures
- "Snapshot" data, i.e., data for the last year or five years. An example follows.

The data are arranged in intervals, not necessarily equal, showing the number of survivors up to the beginning of the interval, N_i, and the number of failures within the interval, F_i. The survivors at the

$$N_{i+1}=N_i-(F_i+S_i)$$

beginning of the next interval is equal to the survivors beginning the previous interval minus the sum of the failures, F_i, and suspensions, S_i, within the interval $_i$.

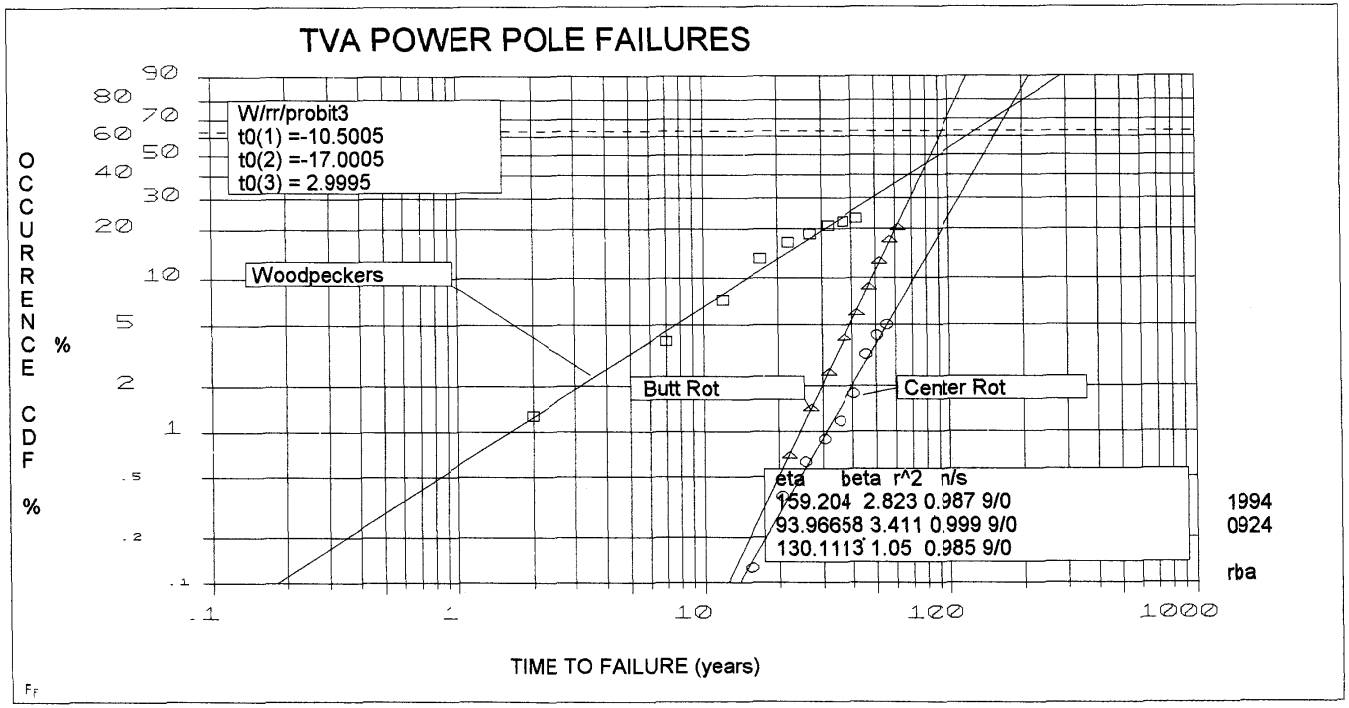
$$P(t\geq t_n) = \prod_{i=1}^{n} (1-F_i/N_i)$$

The K-M estimate, $P(t_i)$, [above] estimates the cumulative probability of surviving to time t. (F_i/N_i) estimates the probability of failure within the interval i. Greenwood's estimate, used for confidence intervals, (inadvertently omitted from the Weibull Handbook) is :

$$\sigma_{P(t)} = [P(t_i)] * \sqrt{(\sum_{1}^{t} (F_i / N_i(N_i-F_i)))}$$

Example: Table 1 shows data on wooden power poles in the Tennessee Valley Authority system, a snapshot of the last five year period. (Thanks to TVA for their permission). Weibull is impossible as the failures and suspensions from the earlier periods are unknown but K-M provides an excellent substitute. There are three different failures modes, butt rot, woodpecker attacks, and center rot. The plot shows the K-M estimates on Weibull paper. The woodpecker mode appears to be random (as expected) after a t zero correction of about 3 years. This might be interpreted as the time needed by the woodpecker to create the damage. The two rot modes need a negative t zero correction. The negative t zero implies that some of the life was used up before the power poles were "planted". TVA engineers said the poles were often stored for long periods before installation and therefore may already have some rot from storage. The data is given in columns A-E. Total Suspensions (column F) is the sum of suspensions (col B) and failures (col B, D & E). The interval failure estimates are in column G = (1- col C/col F). These are converted into K-M survival estimates (col H) using the second equation above. One minus column H is the K-M failure cumulative probabilities in column I. Figure 1 is based on column I and Inspection Option #3. The three part input to Option #3 for the first point would be x-value = 5.0, Sample size = 5547, and cumulative percent failed = 0.703%. Greenwoods variance estimate, (columns J-M) provides two standard deviation (95% confidence).(col N & O).

PAGE 2. TVA POWER POLE DATA...					KAPLAN-MEIER....					...GREENWOODS CONFIDENCE BOUND					
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Butt Rot	Analysis				TOT S	INT P(F)	KM	1-KM			σ	2σ	KM + 2σ	KM - 2σ
Interval	Suspend	Butt Rot	Woodpeck	Center Ro	B+C+D+E	1-(C/F)	G5XG6X..	(1-H)	C/F(F-C)	SUM J	H*SQRT	2 L	I + M	I-M
0y-5	5469	39	71	7	5586	0.993018	0.993018	0.006982	1.26E-06	1.28E-06	0.001123	0.002247	0.009229	0.004735
6-10y	5450	42	152	14	5658	0.992577	0.985647	0.014353	1.32E-06	2.60E-06	0.00159	0.00318	0.017533	0.011174
11-15y	6382	70	232	17	6701	0.989554	0.97535	0.02465	1.58E-06	4.18E-06	0.001993	0.003987	0.028636	0.020663
16-20	6383	122	448	18	6971	0.982499	0.958281	0.041719	2.56E-06	6.73E-06	0.002486	0.004973	0.046692	0.036746
21-25	8637	179	356	27	9199	0.980541	0.939634	0.060366	2.16E-06	8.89E-06	0.002802	0.005603	0.065969	0.054763
26-30	8637	270	219	55	9181	0.970591	0.912001	0.087999	3.3E-06	1.22E-05	0.003184	0.006368	0.094368	0.081631
31-35	7096	343	214	112	7765	0.955827	0.871715	0.128285	5.95E-06	1.81E-05	0.003713	0.007426	0.135711	0.120859
36-40	7097	402	123	84	7706	0.947833	0.82624	0.17376	7.14E-06	2.53E-05	0.004155	0.008309	0.182069	0.16545
>40	37779	1573	513	303	40168	0.960839	0.793884	0.206116	1.01E-06	2.63E-05	0.004071	0.008142	0.214258	0.197973
Woodpecker	Analysis					INT P(F)	KM	1-KM			σ	2σ	KM + 2σ	KM - 2σ
Interval	Suspend	Butt Rot	Woodpeck	Center Ro	B+C+E	1-(D/F)	17*G18*.	(1-H)	C/F(F-C)	SUM J	H*SQRT	2L	I + M	I-M
0y-5	5469	39	71	7	5586	0.98729	0.98729	0.01271	1.26E-06	1.29E-06	0.001121	0.002243	0.014953	0.010467
6-10y	5450	42	152	14	5658	0.973135	0.960767	0.039233	1.32E-06	2.61E-06	0.001553	0.003105	0.042339	0.036128
11-15y	6382	70	232	17	6701	0.965378	0.927503	0.072497	1.58E-06	4.19E-06	0.001898	0.003796	0.076292	0.068701
16-20	6383	122	448	18	6971	0.935734	0.867896	0.132104	2.56E-06	6.74E-06	0.002254	0.004507	0.136611	0.127597
21-25	8637	179	356	27	9199	0.9613	0.834309	0.165691	2.16E-06	8.90E-06	0.002489	0.004978	0.170669	0.160713
26-30	8637	270	219	55	9181	0.976146	0.814408	0.185592	3.3E-06	1.22E-05	0.002845	0.005689	0.191282	0.179903
31-35	7096	343	214	112	7765	0.97244	0.791963	0.208037	5.95E-06	1.82E-05	0.003374	0.006748	0.214785	0.201289
36-40	7097	402	123	84	7706	0.984038	0.779322	0.220678	7.14E-06	2.53E-05	0.003919	0.007839	0.228517	0.212839
>40	37779	1573	513	303	40168	0.987229	0.769369	0.230631	1.01E-06	2.63E-05	0.003946	0.007892	0.238524	0.222739

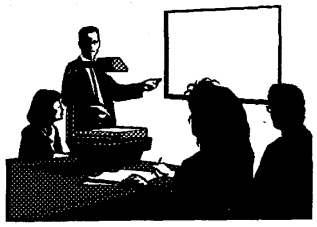


More Surprises from Research

■ Likelihood ratio (LR) confidence intervals are much more sensitive to suspensions than the Fisher Matrix (FM) bounds. The LR bounds with random suspensions are wider, more conservative, than the FM. LR are also more consistent with MonteCarloSMITH bounds. For complete samples, LR & FM give very similar results.

■ The problem of comparing two Weibull data sets to see if they are significantly different is common in all industries. There are at least three solutions: (1) Select a B life within the range of the data and compare the B lives for both data sets to see if they are significantly different. Jim Lempke's Ford example is in Section 7.6. Weibull recommended this approach for bearings, compared at B10 life. I like the simplicity and interpolating within the range of the data, instead of extrapolation. (2) The method in Section 7.5 is based on MonteCarloSMITH and works well for complete samples, but is complicated with suspensions. (3) The assumption of constant beta is built in to the null hypothesis. Therefore, the use of Weibayes confidence bounds as described in Wayne Nelsons's 1985 paper may be the most accurate. Research on this approach will be reported in the next WeibullNEWS.

Color Plots & Slides With my new Hewlett Packard 1200C inkjet we have **color!!** For those of you with color capability let me share my knowledge so far. There are at least three ways to output color plots and overhead slides. (1) If you operate WeibullSMITH™ or VisualSMITH™ as DOS programs under Windows, you may "paste' your VGA screen plot into the notebook with **Alt+Enter, Printscreen**. Go to Word or Powerpoint and retrieve the plot with **Paste Special.** Paintbrush & Pizzaz may also be employed for retrieval. One minor problem with this method is the Basic language red, the color of the first data set, is invisible in the Windows palette so Copy the first data set and labels to give them an alternative visible color.(2) To output directly from WeibullSMITH™: from the Additional Services on the main menu, select Output setting and change Laser Mode to =LJ III HPGL (Plotter simulation) and N, number of pens to 6. After you have the plot on the monitor, use **H** , the hot key to access the output menu. Select Laser and you will generate color on your inkjet. (3) A third method that produces excellent results is to save the WeibullSMITH™ plot screen using the **M** plotter file. Give the file a name with an .hgl or .plt extension and call it up in Word or Powerpoint. The number of pens selected changes the resulting colors. Six work well for me. VisualSMITH ™ output works the same way.



WeibullSMITH™ User Conferences Star National Weibull Experts: We had two excellent SuperSMITH User Conferences this year: The SAE Weibull User Conference was in Dearborn in the spring and ASME sponsored the second in Denver in August. Wes and I were joined by five national Weibull experts at each Conference and they deserve our sincere appreciation as they volunteered for this task at their own expense. The forum atmosphere was just fantastic! Wes and I provided an overview of the new methods and options in the New Handbook and SuperSMITH, but we were upstaged by the experts presentations. The attendees were so interested in the experts presentations and in each others comments that we had difficulty ending the two day seminars. Each was a wonderful experience! **Windows on the Way:** Wes gave us a short demonstration at the Denver User's Conference. It looks great! When?? Wes won't say.

The Dearborn experts included Jim Lempke, Ford; Dick Rudy, Chrylser; Carl Tarum, GM; Tom Albright, Caterpillar; and David Weber, General Electric. In Denver, Dave Weber was joined by Paul Barringer, Consultant; Steve Vogel, Gates Rubber; James McLinn, Consultant; and Lyle Bitker, Cessna.

Our ***Next Weibull User's Conference*** will be sponsored by SAE in Detroit, March 2-3, 1995. I am very pleased to announce that Dr. Wayne Nelson will be joining Wes and I as well as Julius Wang. The rest of the Expert Panel is tentative but we hope to have SAAB of Sweden as well as the Big Three . Wes and I will be pleased to see you there. Call Brenda Bargo at SAE [412] 776 4841.

Dr. Bob's Public Weibull Workshops:(1)University of Tenn, Palm Beach, October 17-20 (4-day) [615] 393 7276:(2) Gulf Publishing Reliability Conference, Houston, Texas, November 13-15, 1994. [713] 520 4430:(3) SAE Detroit Feb 27-Marl [412] 776 4841, (4) SAE User Conference (with Wes) Mar 2-3:(5) ASME Seattle April 24-27 (4 day) [212] 705 7398.

Wes's Weibull Workshops:(6) SAE California January 1995; (7&8) SAE June and September, Detroit.