Reliability Data Analysis Using S-PLUS

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Overview

- History, other software
- Specific user needs and GUI development goals
- Data objects and outline of menu structure
- Examples
- Numerical Methods
- Concluding remarks and future work

History and Development of SLIDA

- Motivated by GE's STATPAC (Nelson et al. 1972,...)
- CENSOR Fortran program (Meeker and Duke 1978-1980 at ISU)
- STAR written in Old S (Meeker and others at Bell Labs QAC 1985-1986) then translated into C to be a commercial product (Others at Bell Labs QAC 1986-1989)
- GENMAX Fortran (Meeker 1986-1992)
- SLIDA S-PLUS functions for Meeker and Escobar (1998) examples (Meeker 1992-Present)
- SLIDA object-oriented S-PLUS commands (Meeker 1997-present)
- SLIDA S-PLUS GUI (Meeker 1998-present)

Other Reliability Data Analysis Software

- Terry Therneau's SURVIVAL package (in S-PLUS)
- SAS, JMP, MINITAB
- Special purpose packages:
  - ▶ WEIBULL++ and ALTA by Relisoft
  - ▶ WinSmith
- Various biomedical packages that handle censored data

General Needs for Reliability Data Analyses

- Complicated censoring and/or truncation; multiple failure modes.
- Wide range of standard and nonstandard models (e.g., non-normal distributions, nonlinear relationships)
- Estimates and statistical intervals for failure probabilities, distribution quantiles, failure rates, predictions for future number of failures, etc.
- Integration of analytical methods by graphically displaying data and fitted models together.
- Methods for planning reliability studies
- Use of simulation in inference and planning

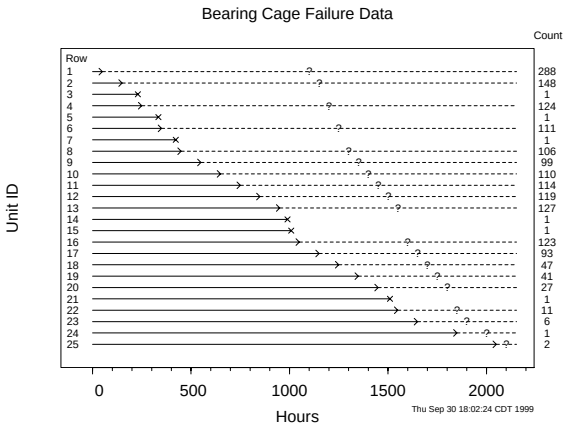
SLIDA User Interface

- Command User Interface: All functionality in Meeker and Escobar (1998) plus recent developments.
- Most outputs given in graphical form.
- With numerous options, command argument specification is complicated.
- GUI simplifies option choice. The most important functionality in Meeker and Escobar (1998) plus recent developments (driven by courses).

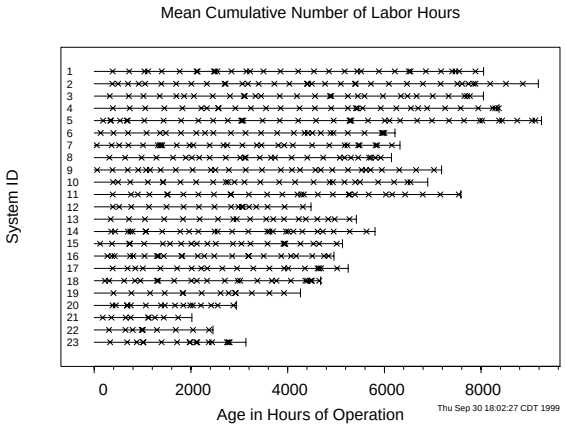
SLIDA Data Objects

- Data objects contain important and useful (optional) information about a data set (defines response, censoring, truncation, weights, explanatory variables, title, units, notes, etc.)
  - ▶ Life data objects
    - ∗ Single distribution
    - ∗ Multiple failure modes
    - ∗ Single explanatory variable with a few levels
    - ∗ Comparison explanatory variable
    - ∗ General explanatory variables
  - ▶ Recurrence data (point process) objects
  - ▶ Repeated measures (degradation) data objects
- Multiple methods (different types of analyses) can be performed on particular data objects

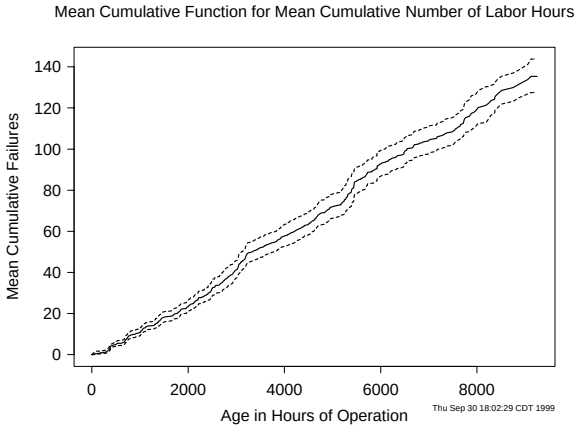
Bearing Cage Failure-Time Data



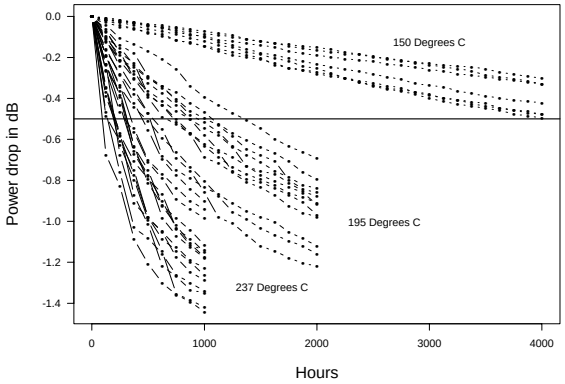
Earth-Moving Machine Maintenance Actions Event Plot



Earth-Moving Machine Maintenance Action Mean Cumulative Labor Hours.



Accelerated Degradation Test Results Giving Power Drop in Device-B Output for a Sample of Units Tested a Three of Levels Temperature.



Goals for the SLIDA GUI Design

- Easy for occasional new/users.
- Organize according to how users want to do their work.
- Hide complexity for common users and every-day tasks; allow access for experts/experienced users.
- Develop structure to guide unfamiliar users through their work (without restricting the experts).
- Minimize required inputs; use defaults whenever possible.
- Minimize the need for typing/remembering. Present some or all choices whenever possible; eliminate inappropriate choices. Recall previous inputs for defaults, when appropriate.
- Signal bad (or questionable) input as soon as possible.

Result: Some complicated analyses much easier to do through the GUI than through commands; engineers like it.

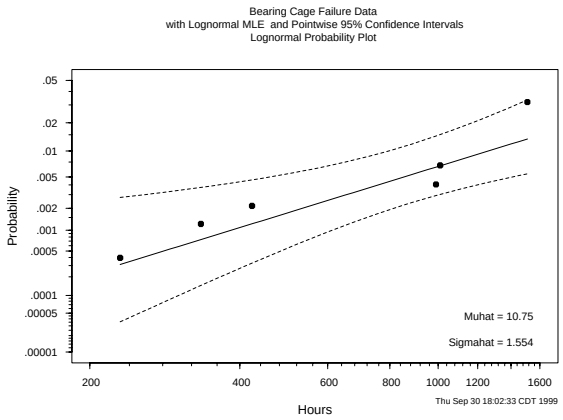
SLIDA Top-Level Menu

- Make/summary/view/modify data object →
- Plan single a distribution study →
- Single distribution life data analyses →
- Multiple failure mode life data analysis →
- Comparison of distributions life data analysis →
- Plan an accelerated life test (ALT) →
- Simple regression (ALT) data analysis →
- Multiple regression (ALT) life data analysis →
- Regression residual analysis →
- Recurrence (point process) data analysis →
- Degradation (repeated measures) data analysis →
- Preferences (change SLIDA default options) →

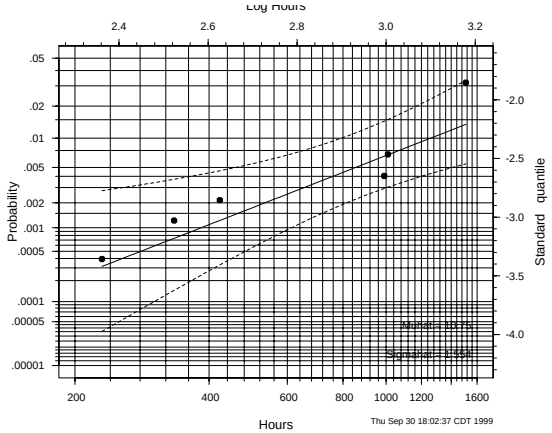
SLIDA → Single distribution life data analyses →

- Plot nonparametric estimate of cdf and confidence bands
- Probability plot with nonparametric confidence bands
- Probability plot with parametric ML fit
- Likelihood contour plot
- Compare distribution ML fits on probability plot
- Threshold parameter probability plot with parametric ML fit

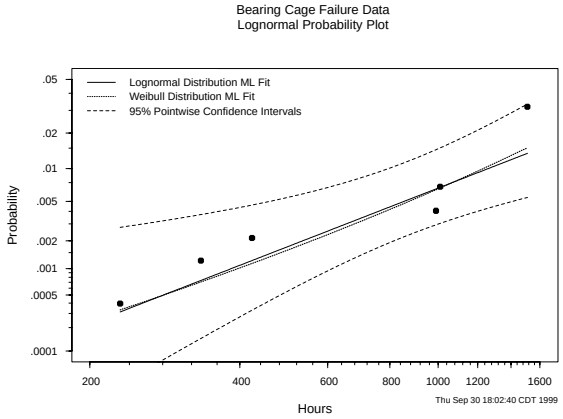
Bearing Cage Failure-Time Data Lognormal Probability Plot and MLE



Bearing Cage Failure-Time Data Lognormal Probability Plot and MLE



Bearing Cage Failure-Time Data Weibull-Lognormal Comparison



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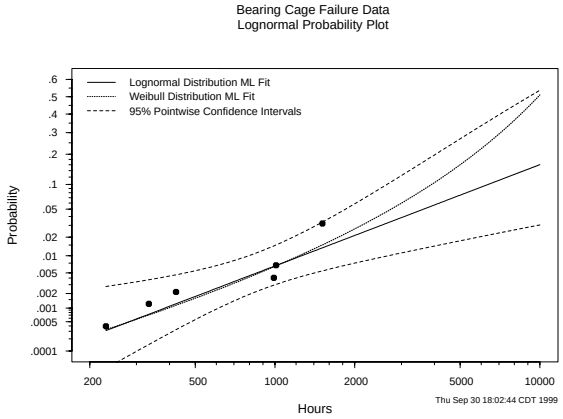
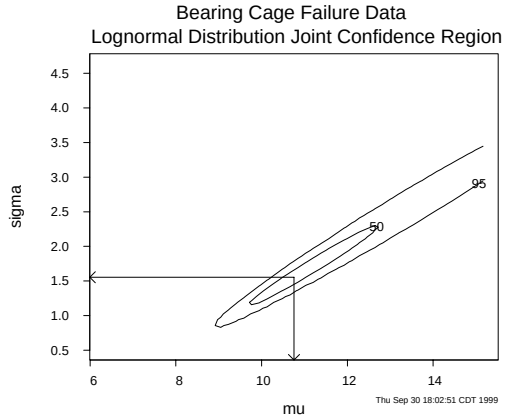
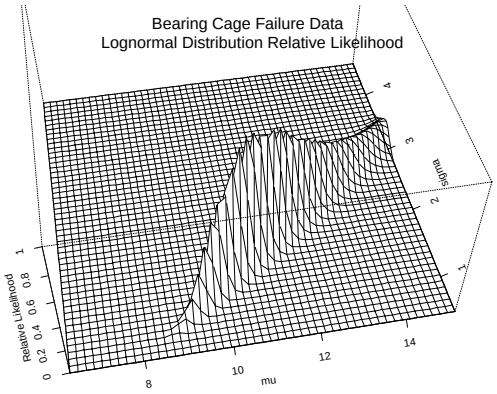


Bearing Cage Failure-Time Data
Lognormal Joint Confidence Region



Bearing Cage Failure-Time Data
Lognormal Relative Likelihood



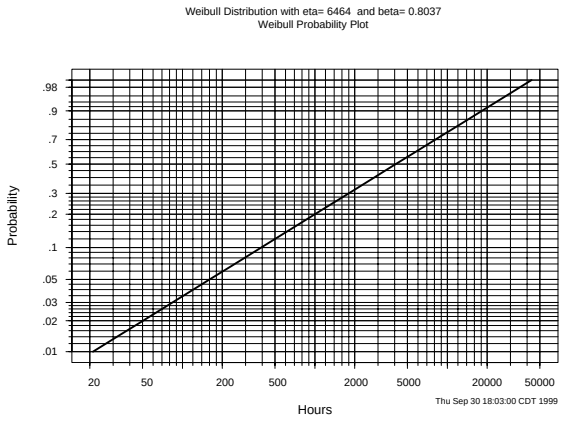
Numerical Methods

- Algorithms
  - Stable optimization
  - Accurate mathematical/statistical functions
  - Analytical and numerical derivatives
- Maximum likelihood estimation
  - Stable parameterization
  - Good starting values
  - Dealing with unbounded or flat likelihood functions.

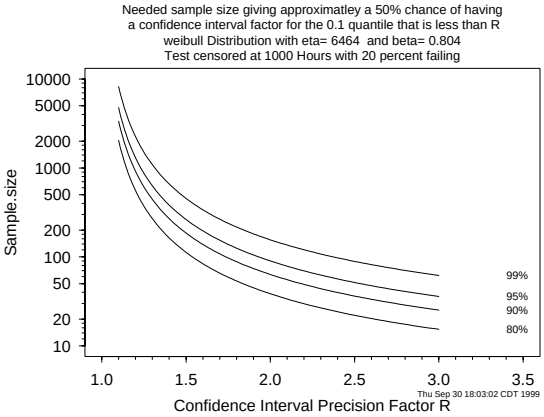
SLIDA → Plan single distribution study →

- Specify life test planning information (planning values)
- Plot life test planning information (planning values)
- Plot of approximate required sample size
- Simulate a life test
- Probability of successful demonstration

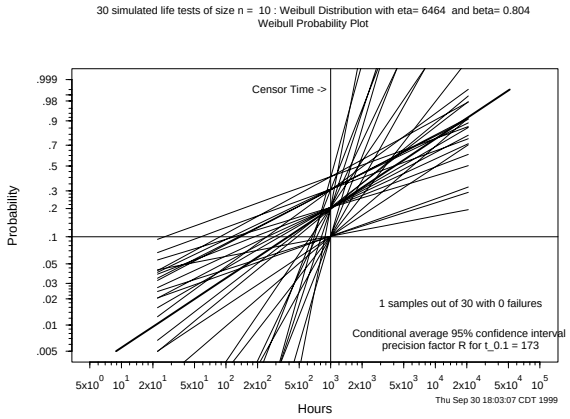
Life Test Planning Values



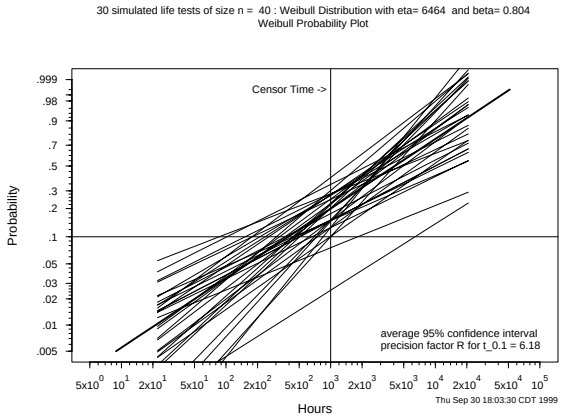
Needed Sample Size for a Life Test



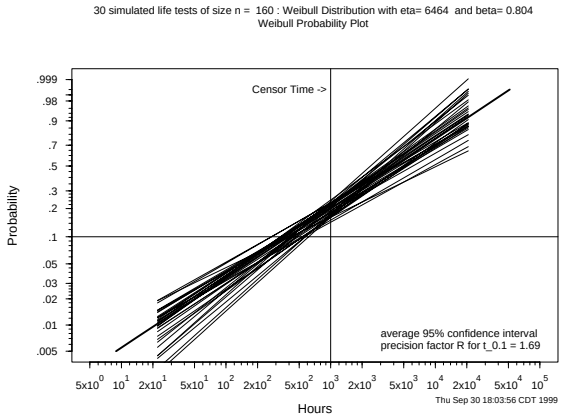
Simulated Life Test $n = 10$



Simulated Life Test $n = 40$



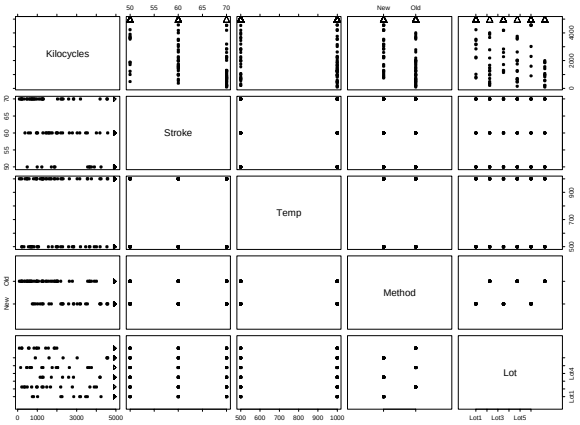
Simulated Life Test $n = 160$



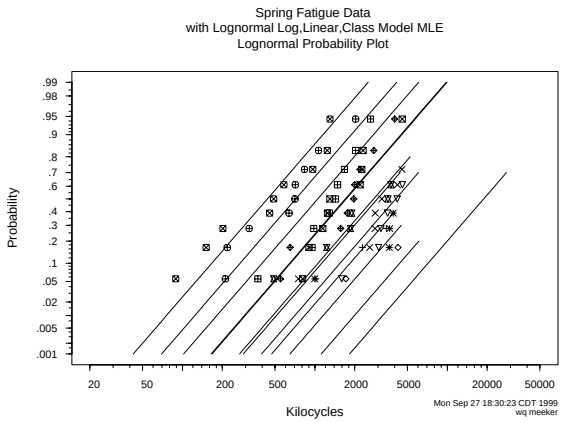
SLIDA → Multiple regression (ALT) life data analysis

- Censored data pairs plot
- Censored data scatter plot
- Probability plot and ML fit for individual conditions
- Prob plot and ML fit for indiv cond: common shapes (slopes)
- Probability plot and ML fit of a regression (acceleration) model
- Conditional stress plot
- Sensitivity analysis plot

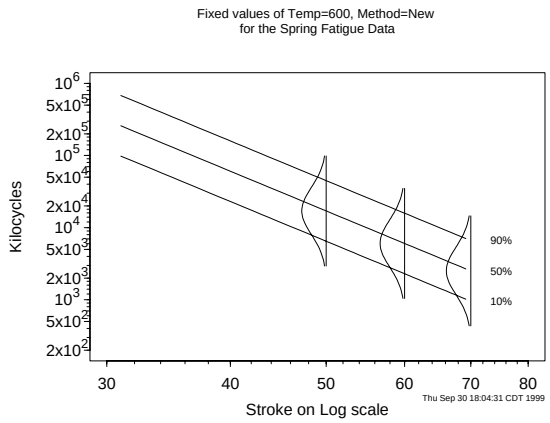
New Spring Experiment Pairs Plot
Spring Life, Stroke, Temp, Method



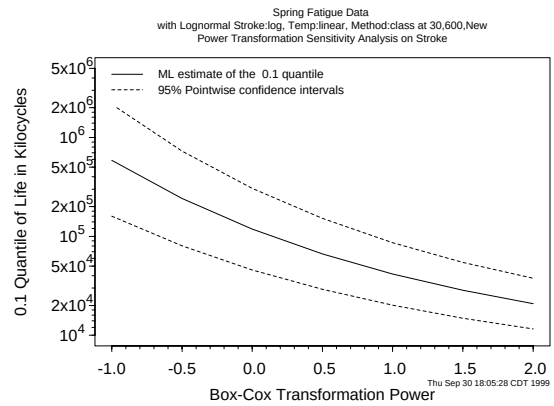
New Spring Multiple
Probability Plot Lognormal Regression Model
$t_{.1} = g(\textbf{Stroke}, \textbf{Temp}, \textbf{Method})$



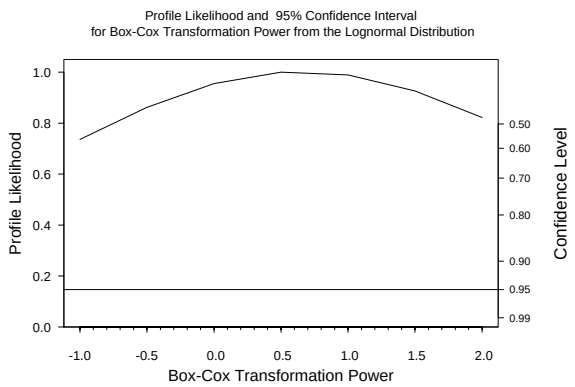
New Spring Experiment
Lognormal Regression Model Life vs Stress Plot



New Spring Experiment
Sensitivity Analysis Plot



New Spring Experiment
.1 Quantile Sensitivity Analysis Likelihood Profile



Reliability Data Analysis
Concluding Remarks and Future Work

Considerable progress has been made in this area in the past 10 years; much remains to be done.

- Improvements in the user interface. Make it easy to learn how to use.
- Better approximate methods for censored-data confidence intervals (e.g., likelihood ratio and/or bootstrap).
- Better and more methods for recurrence and degradation data.
- Methods for incorporating prior information (flexible, easy to use, Bayes methods).
- Better (i.e., easier to implement and more robust) methods for fitting user-specified models the system.