Reliability: The Other Dimension of Quality

William Q. Meeker
Department of Statistics
Center for Nondestructive Evaluation
Iowa State University
wqmeeker@iastate.edu

Manufacturing Environment

Today's manufacturers face:

- Intense global competition
- Pressure for shorter product-cycle times
- Stringent cost constraints
- Higher customer expectations for quality and reliability

Reliability

- Condra (1993): "Reliability is quality over time"

  Good quality is necessary but not sufficient!

- **Difficulty:** Reliability assessed directly only after a product has been in the field for some time; reliability prediction is difficult.
- Reliability is an engineering discipline. Statistical methods are important tools for reliability engineering.
- Most statistical effort has been on methods for assessing reliability. Much engineering effort is (correctly) focused on reliability improvement.

Engineering Functions that Affect Reliability

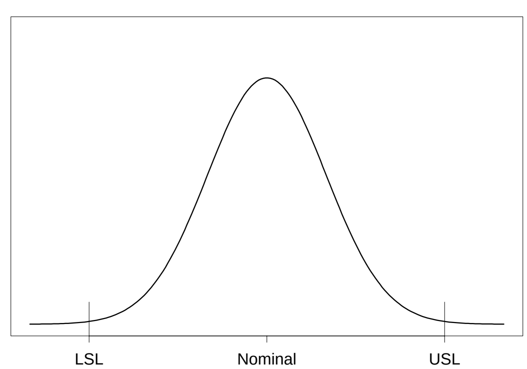
- Define product requirements
- Product design
- Verify product design
- Design for product robustness
  - Similar, parallel steps for manufacturing process design
- Maintain quality in production

Robustness: Ability (for a product or a process) to perform its intended function under a variety of operating and environmental conditions

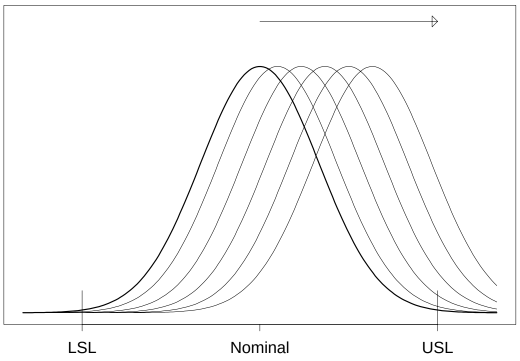
Overview

- Quality, variability, and reliability
- Failure modes (anticipated and unanticipated)
- Contrast between traditional **reliability demonstration** and today's need for **reliability assurance**
- The role of statisticians on the reliability team
- Reliability data and statistical methods
- Warranty and reliability
- A current example
- Future trends in reliability
- Comments on industrial/academic cooperation
- Concluding remarks

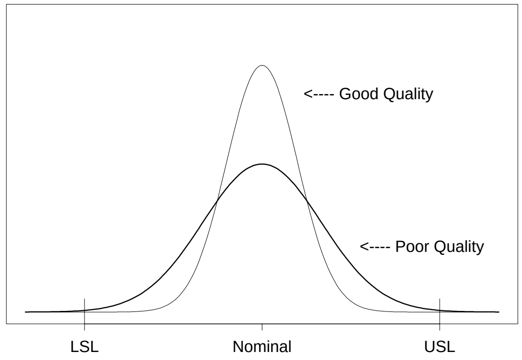
Three-Sigma Quality



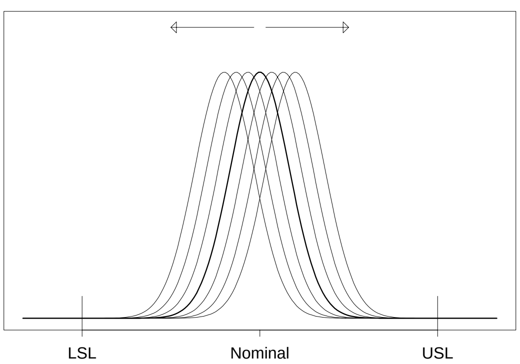
Drifting Three-Sigma Quality
(Effect on Reliability)



Good and Bad Quality



Six-Sigma Quality
(Target: 3.4 Defects per Million Opportunities)



Sources of Variability (Noise)
Affecting Product Reliability

- Manufacturing (including raw materials)
- Environmental conditions
- Customer use rates
- Wear/degradation

Anticipated Failure Modes

- Information on component reliability
  - Handbook values
  - Previous experience
  - Physical models (e.g. FEM) with some empirical model verification.
  - Test data and accelerated test data
- System reliability model

Unanticipated Failure Modes

Goal: To discover and eliminate failure modes as early as possible

- FMEA analysis in up-front design
- Robust design ideas (make product robust to external noises)
- HALT testing
- Early feedback from the field

Downstream discoveries are more expensive!

Reliability Demonstration versus Reliability Assurance

- **Example:** Using minimal assumptions, to demonstrate that reliability at time t_0 hours is .99, with 90% confidence, requires testing at least 230 units for t_0 hours with zero failures. To have a 80% chance of passing the test, requires that the true reliability be approximately .999
- For complicated, expensive systems, traditional reliability demonstration is usually not practicable
- Reliability assurance is the alternative

Reliability Assurance

Based on Reliability Modeling and Combining Information

Inputs:

- Engineering knowledge
- Physical models
- Previous experience (e.g., field data)
- Physical experimentation
- Factors of safety

Challenge: Quantify uncertainty

Approach: Responsible use of Bayesian methods (e.g. LANL PREDICT)

Structured Programs for Design for Reliability

Design for Reliability implies the use of product and process design to eliminate problems before they occur

- Design for Six Sigma (DFSS developed at GE) has the DMADV steps: Define, Measure, Analyze, Design, Verify
- Other company-specific reliability improvement programs.

Contrast with the traditional Build,Test,Fix,Test,Fix,... approach that uses "reliability growth modeling."

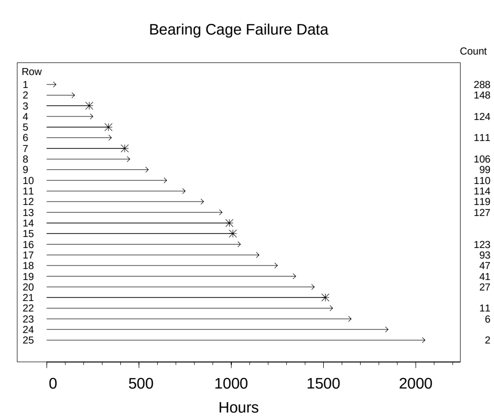
The Role of Statisticians on the Reliability Team

- Contribute to the understanding and modeling of variation
- Help fill in the gaps in engineering knowledge by designing experiments and interpreting results
- Use appropriate statistical method to make the most effective use of field and warranty data
- Develop appropriate methods for combining information
- Develop methods for quantifying uncertainty (statistical and model)
- Develop methods (especially graphical methods) for the effective presentation of results.

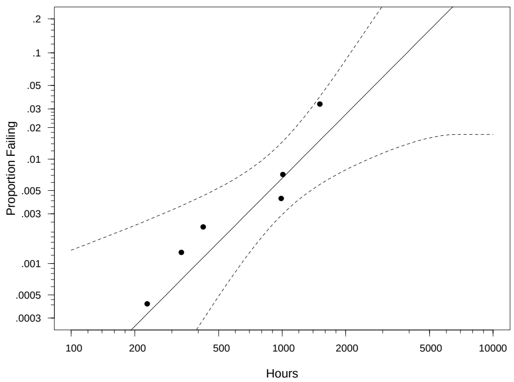
Distinguishing Features of Reliability Data

- Data are typically censored (bounds on observations).
- Models for positive random variables (e.g., exponential, lognormal, Weibull, gamma). Normal distribution not common.
- Model parameters **not** of primary interest (instead, failure rates, quantiles, probabilities).
- Extrapolation often required (e.g., have one year of data, but want proportion failing after three years).

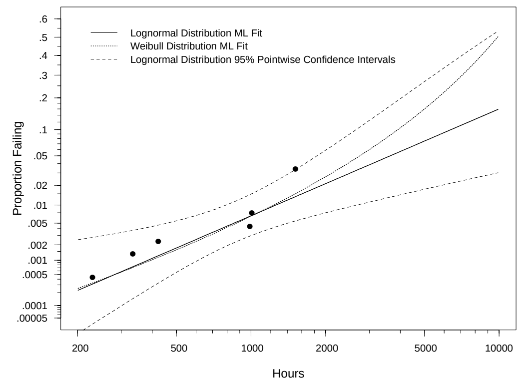
Failure Pattern in the Bearing Cage Data



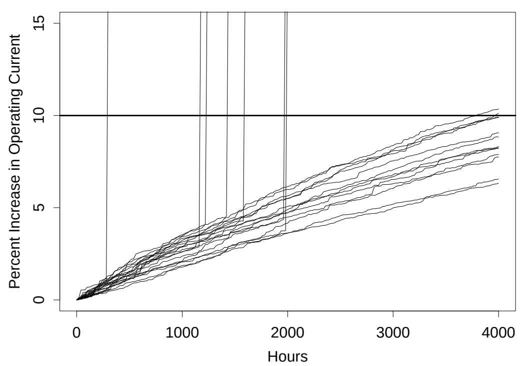
Weibull Probability Plot for Bearing Cage Data



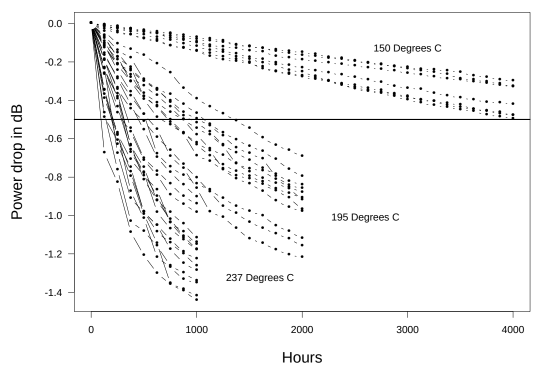
Lognormal Probability Plot for Bearing Cage Data



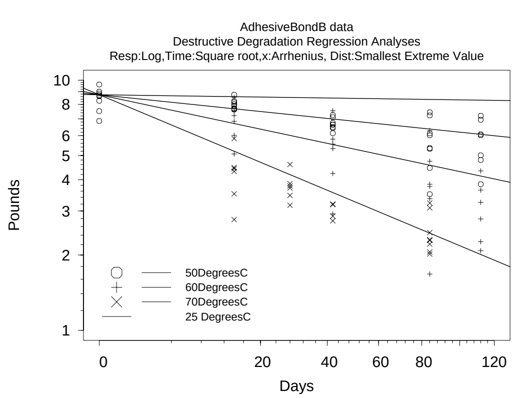
Percent Increase in Operating Current for GaAs Lasers Tested at 80°C (Use conditions 10°C)



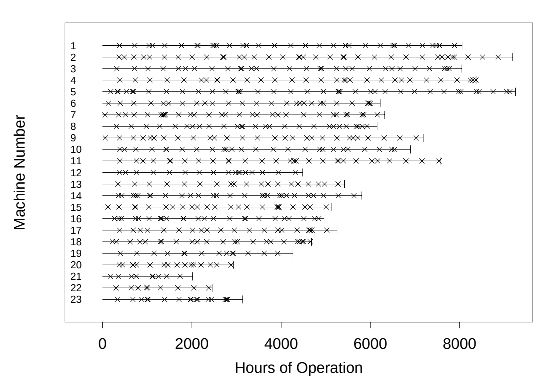
Device-B Power Drop Accelerated Degradation Test Results at 150°C, 195°C, and 237°C (Use conditions 80°C)



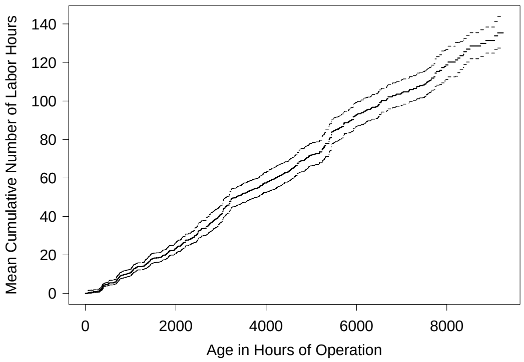
Adhesive Bond Accelerated Degradation Test



Maintenance Events for a Fleet of Earth-Moving Machines



Mean Cumulative Cost for a Fleet of Earth-Moving Machines



Warranty and Reliability

- Warranties are more related to marketing than reliability!
- In many industries, warranty costs are substantial.
- Warranty data are messy
- Useful information in warranty data for:
  - Financial reporting
  - Feedback for the next product generation
  - Early warning of unanticipated problems
  - Connection with laboratory testing and environmental characterization.

Current Example Service Life of Organic Paints and Coatings

- **Goal:** Develop useful accelerated testing methods to allow the rapid screening and assessment of service life of potential new products.
- Previous efforts in this industry have not been satisfactory
- Useful discussions at two international conferences on the subject

NIST Cooperative Research and Development Agreement (CRADA)

- Multi-year project at National Institute of Standards and Technology, Materials and Construction Research Division, Building and Fire Research Laboratory (Jon Martin, Project Leader)
- **Approach:** Use careful experimentation and physical/chemical theory to understand degradation mechanisms and to build (and verify) the necessary predictive models.
- Focus on an important industrial problem.

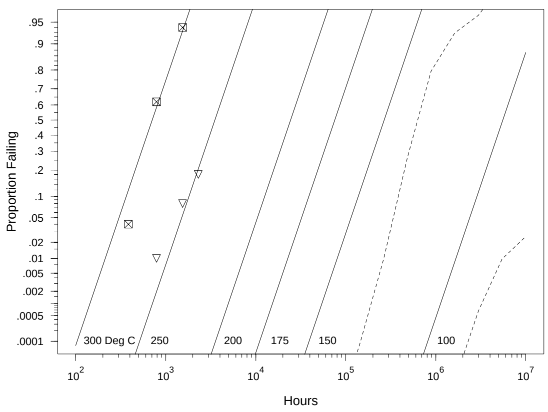
Scientific Plan

- Careful laboratory experiments controlling UV radiation intensity and spectrum, temperature, and humidity.
- Experimental setup based on the NIST SPHERE (Simulated Photodegradation by High Energy Radiant Exposure)
- Outdoor experimental sites in four different climates, with monitoring of UV radiation intensity and spectrum, temperature, and humidity.
- Environmental realization, when used to drive the physical/chemical model, should produce results similar to outdoor exposure.

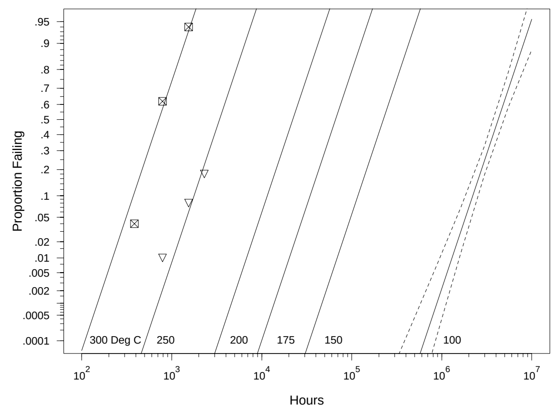
Trends in the Use of Statistics in Reliability

- More use of degradation data and models
- Increased use of statistical methods for producing robust product and process designs
- More use of computer models to reduce reliance on expensive physical experimentation
- Better understanding of the product environment (e.g. through the use of **"smart chips"**).
- More efforts to combine data from different sources and other information (through the use of **"Responsible Bayes" methods**).

Accelerated Test Results Using Standard Censored Data Regression



Accelerated Test Results Using Standard Censored Data Regression Assuming That Arrhenius Activation Energy is Known



Academic Involvement in Manufacturing Reliability Problems

- Manufacturing industries have interesting, challenging, technical problems in reliability.
- There should be more academic involvement in these projects
- Benefits:
  - ▶ The quality of academic research will improve with access to real problems
  - ▶ High probability of impact
  - ▶ Cost-effective for industry
  - ▶ Better industry/academic relationships

Facilitating Academic Involvement in Manufacturing Reliability Problems

- Student internships with opportunities for faculty visits (LANL model).
- NSF GOALI (Grant Opportunities for Academic Liaison with Industry) program
- Work for free
- Needs:
  - ▶ Academics willing to get their hands dirty (and learn the language and science used in real problems)
  - ▶ Industrial sponsors willing to invest the time needed to lead and conduct the project.

Concluding Remarks

- SPC and designed experiments have been useful for improving quality and reliability
- Statisticians have an important supporting role to play in the reliability area
- Further improvements in reliability possible by focusing on causes of failure
- Upstream reliability testing/analysis has important advantages
- Use downstream information (e.g. Warranty data) on current and previous product to make upstream improvements in future product
- **Problem:** Importantly large savings may be difficult to quantify to management.