The Role of Reliability in Quality

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Objectives

- Relationship between **Quality**, **Reliability** and **Statistics**.
- **Recognizing, controlling,** and **decreasing** variability to improve reliability of products and processes.
- Role of good **engineering** and **statistical** practices in reliability improvement.
- Give examples of some reliability studies.
- Outline some **current** and **future** research areas in reliability.

Industrial Environment (Manufacturing & Services)

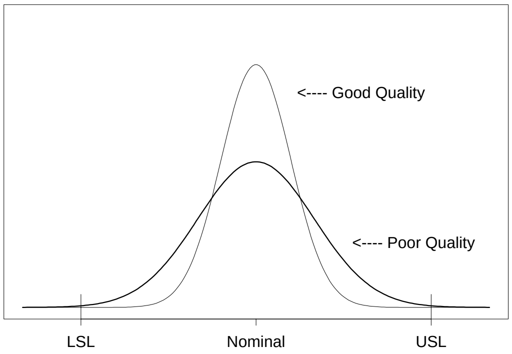
Today's industry faces:

- Intense global competition.
- Pressure for shorter product-cycle times.
- Stringent cost constraints.
- Higher customer expectations for **quality** and **reliability**.
- Complex, global, and heterogeneous markets.

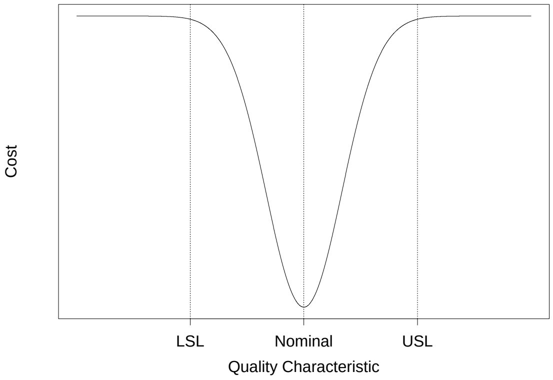
What is Good Quality?

- **Current View:** Quality is customer satisfaction.
- Good quality implies delivering products/services/processes within specifications, on time, at the lowest possible cost.
- If product specifications include customer requirements, the **quality level** can be measured by the fraction of units/services delivered that meet the specification.
- A high quality level is necessary for good quality. But it is also necessary that the quality characteristic is close to the nominal or target value.

Good and Bad Quality



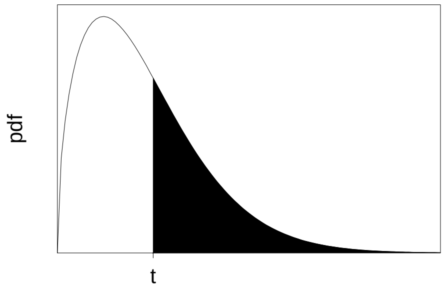
Quality, Variability, and Cost



Statistical Definition of Reliability

Reliability is the probability that a system, vehicle, machine, device, and so on, will perform its intended function under **encountered** operating conditions, for a specified period of time

$$R(t) = \Pr(T > t)$$



Reliability Scope

- In general, reliability relates to the proper functioning of equipment, systems, and processes.
- The reliability function $R(t) = \Pr(T > t)$ depends on many factors including: environmental factors, human factors, software, and hardware.
- Reliability is closely related to risk and safety factors where failure can have catastrophic consequences.
- An important aspect are the economical consequences of poor reliability.
- See also Lawless (2000).

Reliability as a Quality Concept

- Condra (1993): **“Reliability is quality over time.”**
- Condra (2001): **“A reliable product is one that does what the user wants it to do, when the user wants it to do so.”**
- Reliability has to do with the number of units that still meet specifications after a given period of time (weeks, years, miles, cycles, etc).
- Good quality is necessary but not sufficient for good reliability.
- To assess, predict, and build in reliability, reliability scientists use: engineering and/or historic knowledge, experimentation, statistical models, data analysis, simulation, optimization, etc.

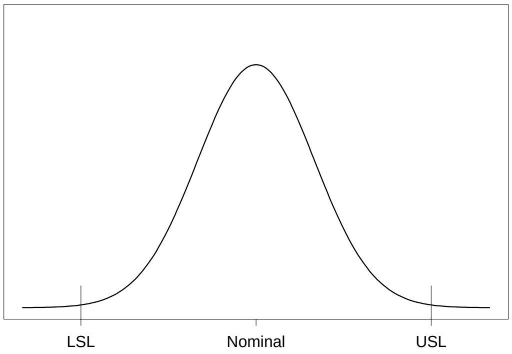
The Reliability Challenge

- **Difficulty:** Reliability assessed **directly** only after a product has been in the field for some time; reliability prediction is difficult.
- Reliability relies heavily on **engineering.** Statistics provides important tools for understanding, improving, and maintaining reliability.
- Most statistical effort has been on methods for **assessing** reliability.
- Much engineering effort is (correctly) focused on **reliability improvement.**
- Modern quality practices (i.e., **Six Sigma**) institutionalize interdisciplinary reliability teams.

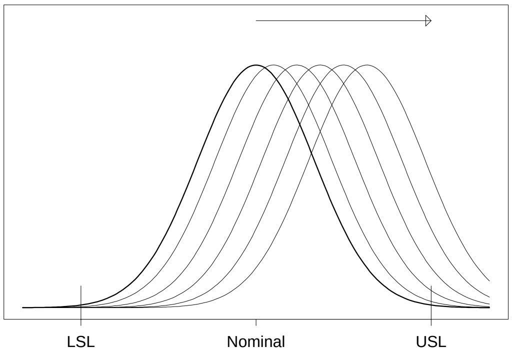
What Is the Source of Quality & Reliability Problems?

- Variability is everywhere.
- There will always be variability in a process.
  This is well said by Nelson in his statement: **Failure to understand variation is a top problem in USA industry.**
- We can tolerate variability if
  - The process in on target.
  - The process variability is small when compared with the process specification (**capability**).
  - The process is stable.

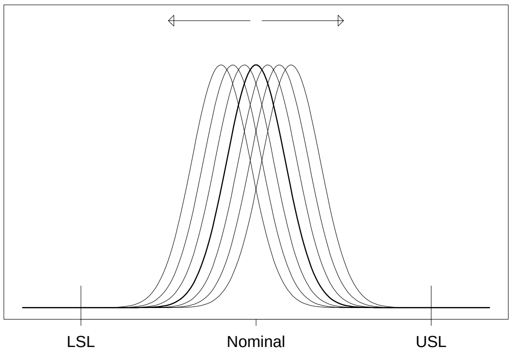
Three-Sigma Quality



Drifting Three-Sigma Quality (Effect on Reliability)



Drifting Six-Sigma Quality (Effect on Reliability)

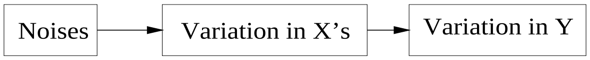


Some Sources of Variability Affecting Product Reliability

- Raw materials and parts.
- Manufacturing.
- Environmental.
- Wear/degradation.
- Customer usage rate.

Key Questions

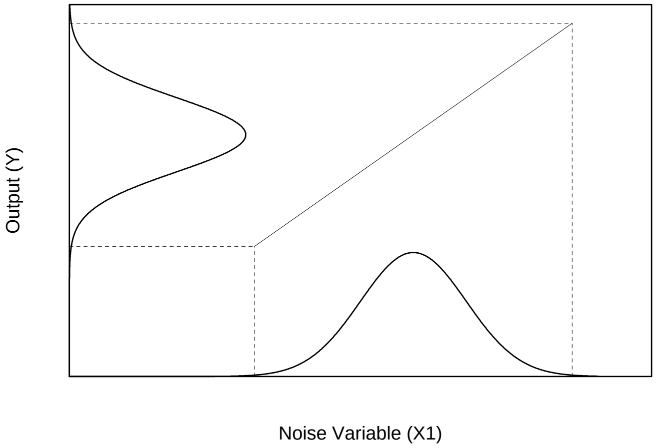
- What causes X and thus Y to vary?
- How much variability can we expect in X and Y?
- To what extent can we reduce the variability in X?
- To what extent can we reduce the transmission of variability in X?



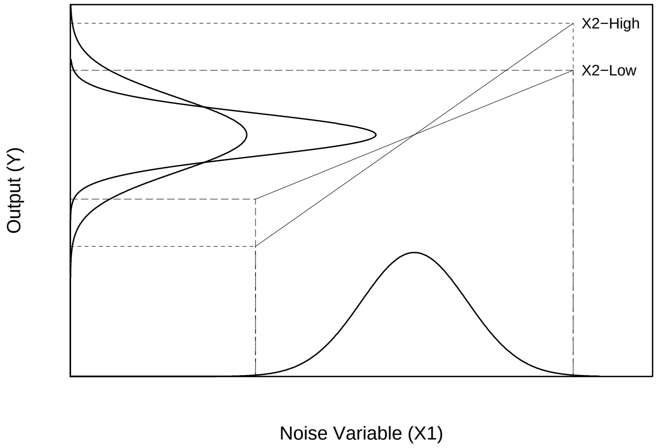
In summary,

- Find the important X's that impact the important Y's.
- Use engineering, DOE, Robust design, and other engineering/statistical techniques to reduce variability in X and the transmission of variability to Y.

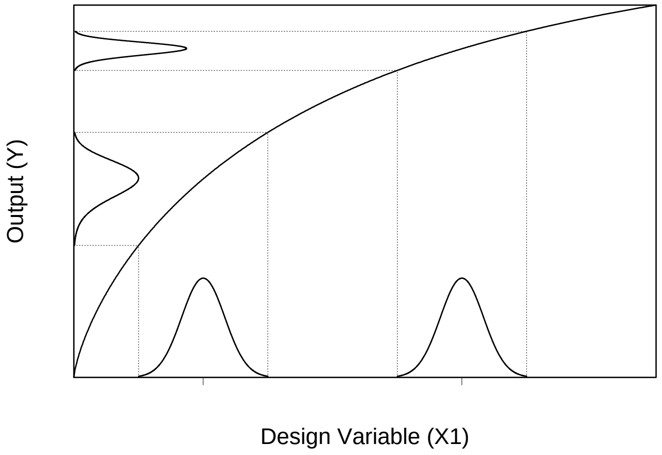
Transmission of Variability



Reducing Transmission of Variability Using a Design Variable (X_2) by Noise (X_1) Interaction



Reducing Variability Using Nonlinearity



Reliability Issues

- Causes of failure and degradation leading to failure.
- Environmental effects on reliability.
- Quality problems leading to early failure.

Failure Modes

	Anticipated	Unanticipated
Wear related	ALT/ADT	HALT
Defect related	QC/SPC	HALT

- **Robust engineering and Robust product design** can help in all cases.

Robustness: Ability to perform intended function under a variety of operating and environmental conditions.

The Interface Between Quality and Reliability

- Good quality is a prerequisite for high reliability.
- Like quality, reliability should be customer-focused.
- How can we assure **reliability?**
  - Robust product design from component to subsystem to system level.
  - Robust process design from operation to machine to plant level.
  - Process monitoring, where necessary.
  - **DFR:** Design for Reliability.
  - Objective use of engineering knowledge and historic information.

Variability Reduction and Reliability Improvement

The idea is to improve reliability to decrease the cost attributable to poor reliability.

The general approach is:

- Reducing variation during the creation of products and services:
  - Reduce variation of factors that can be controlled.
  - Reduce product variation due to noise.
- Fixing processes so that they are nearly perfect. Controlling these processes so that they stay fixed.

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 has the **DMADV** steps: **D**efine, **M**easure, **A**nalyze, **D**esign, **V**erify.
- Compare with the Shewhart/Deming **PDSA** steps: **P**lan, **D**o, **S**tudy, **A**ct.
- Other company-specific reliability improvement programs.

Contrast with the traditional Build, Test, Fix, Test, Fix, . . . approach used in **reliability growth modeling.**

Role of Experimentation, Testing, and Measurement in Design for Reliability

- The Measure, Analyze, and Verify steps in **DMADV** and the Do step in **PDSA** imply the use of experimentation.
- When possible, experiments should be done with computer models of a product.
- Verification generally requires some amount of physical testing.
- Good measurement capability is extremely important.
- Related, a challenge is to relate laboratory data to field data, see Meeker, Escobar, and Wu (2003).

Reliability Demonstration Versus Reliability Assurance

- Traditional reliability demonstration is essentially a statistical hypothesis test:

  $$H_0 : \text{Reliability is smaller than the target.}$$

  Rejecting the null hypothesis provides a demonstration that the reliability target has been met.
- To demonstrate that reliability at time $20{,}000$ hours is 0.99, with 90% confidence, requires testing at least $n = 230$ units tested for $20{,}000$ hours with zero failures, where

  $$n = \log(0.10)/\log(0.99) \approx 230.$$

- To have a 80% chance of passing the test, requires that the true reliability be approximately 0.999, i.e.,

  $$\Pr(\text{passing test}) = (0.999)^{238} = 0.794 \approx 0.80.$$

A Feasible Reliability Demonstration

- Under certain circumstances, it is feasible to demonstrate reliability for a component with respect to a particular failure mode.
- Suppose that life has a Weibull distribution with a shape parameter of β, a zero-failure test that runs for $k \times$ 20,000 cycles requires a sample size of (see Meeker and Escobar 1998),

  $$n \geq \frac{1}{k^{\beta}} \times \frac{\log(\alpha)}{\log(1-p)}.$$

- When $\beta = 2$, a zero-failure test that runs for $6.77 \times$ 20,000 cycles will provide the required demonstration with a sample size of only $n = 5$ units.
- Interesting $\Pr(\text{pass test}) \approx 0.80$ and it **does not** depend on β or n.
- For complicated 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.

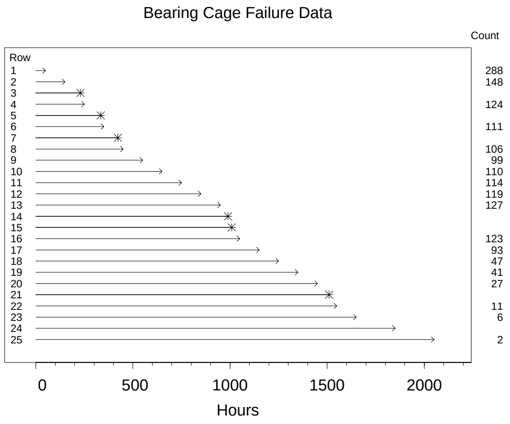
Challenge: Quantify uncertainty.

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

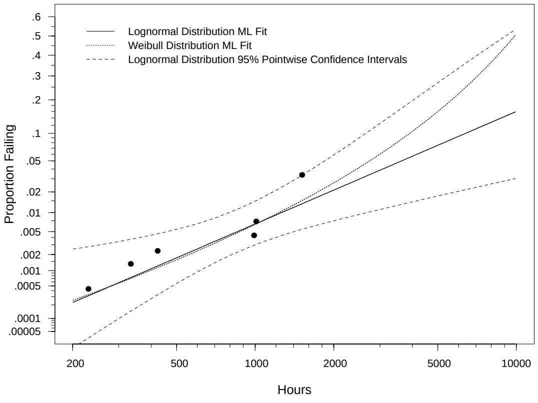
Distinguishing Features of Reliability Data

- 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., want proportion failing by 900 hours but test runs 400 hours).

Bearing Cage Fracture Data
(Abernethy, Breneman, Medlin, and Reinman 1983)

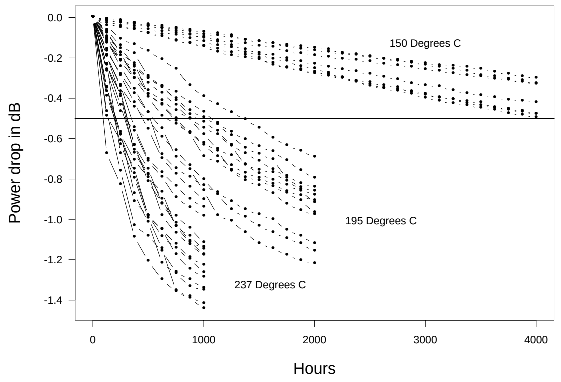


Lognormal Probability Plot for the Bearing Cage Fracture Data

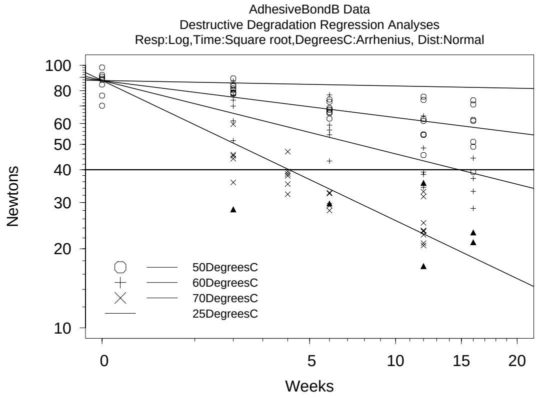


Device-B Power Drop Accelerated Degradation Test Results at $150°\mathrm{C}$, $195°\mathrm{C}$, and $237°\mathrm{C}$

(Use conditions 80$°\mathrm{C}$)

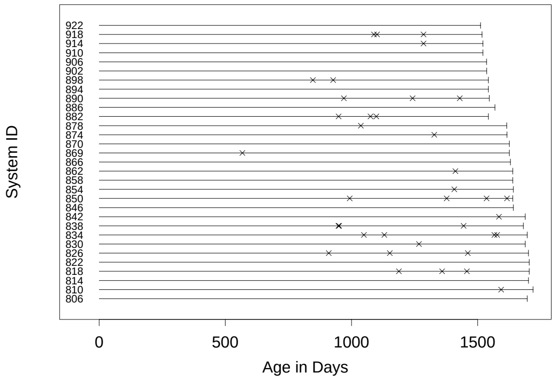


Adhesive Bond Accelerated Degradation Test

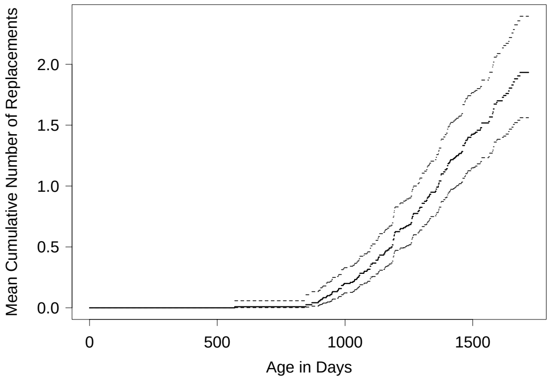


Cylinder Replacement Time Event Plot Subset of Systems

(Nelson and Doganaksoy 1989)



Estimate of Mean Cumulative Replacement Function for the Diesel Cylinders



A Unifying Approach: Reliability Data as a Counting Process (See Lawless 2000)

Consider a a system with:

- J types of events operating on a time scale $t > 0$.
- $T(t)$ describes the condition of the system including degradation.
- $X(t)$ fixed and time dependent explanatory variables.
- $N_j(s,t)$ the number of events of type j in the interval $[s,t]$.
- $H(t)$ relevant “history” of events prior to t.
- The events intensity functions λ_j are defined by

$$\lambda_j = \lim_{\Delta \to 0} \frac{\Pr\left\{N_j(t, t+\Delta) = 1 \mid H(t)\right\}}{\Delta t}.$$

- Most problems described earlier can be described by modeling the intensity functions. For simple problems there is not need of the complexity, but for new emerging problems the approach is very powerful.

Trends in the Use of Statistics in Reliability

- More use of degradation data and models.
- Increased use of statistical methods for producing robust products and robust processes.
- More use of computer models to reduce reliance on expensive physical experimentation.
- Reliability on dynamic and heterogeneous environments. Including 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 **meaningful Bayes** methods).
- A better understanding of the counting process methodology and its applicability to problems of interest.

Concluding Remarks

- Reliability is an interdisciplinary field in which experimentation (perhaps using physical/computer models), engineering, statistics, and computational methods play an important role in improving quality.
- Some form of up-front **Design for Reliability** is probably necessary in today's competitive environment.
- The concept of robustness in product/process design is very important.
- Some general principles and tools are available, but many specifics of a Design for Reliability program will be product specific.
- There many opportunities for improving the current methodology and developing new methodology for relevant problems.
- Good and friendly software for reliability is (will be) in great demand.

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