Chapter 1

Reliability Concepts and Reliability Data

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Chapter 1
Reliability Concepts and Reliability Data

Topics discussed in this chapter are:

- Basic reliability concepts.
- Examples of studies that resulted in different kinds of failure-time data and a general strategy and issues in failure-time data analysis.
- Failure-time data based on inspections.
- Failure-time data with explanatory variables, degradation reliability data, and recurrent-events reliability data.

Chapter 1

Segment 1

Basic Reliability Concepts

Quality and Reliability

Pressures on manufacturers to produce high quality, low-cost products. Pressures due to:

- Rapid advances in technology.
- Development of highly sophisticated products.
- Intense global competition.
- Increasing customer expectations.

Definitions of Reliability

- **Technical:** 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.
- **Succinct:**
  - Quality over time Condra (1993).
  - Failure avoidance.
- Reliability is a quantitative engineering discipline, often requiring complicated statistical and probabilistic analyses.

Reasons for Collecting Reliability Data

- Assess characteristics of materials.
- Predict product reliability in design stage.
- Assess the effect of a proposed design change.
- Compare two or more different materials, designs, or manufacturers.
- Assess product reliability in field.
- Check the veracity of an advertising claim.
- Predict product warranty costs.

Chapter 1

Segment 2

Introduction to Failure-Time Data

Types of Reliability Data

- Failure-time data (Chapters 2–19), also known as
  - Life data.
  - Survival data.
  - Event-time data.
- Degradation data.
  - Destructive degradation data (Chapter 20).
  - Repeated-measures degradation data (Chapter 21).
- Recurrent events data (Chapter 22).

Ball Bearing Data

Data from fatigue endurance tests for deep–groove ball bearings from four major bearing companies (Lieblein and Zelen 1956 and Lawless 2003)

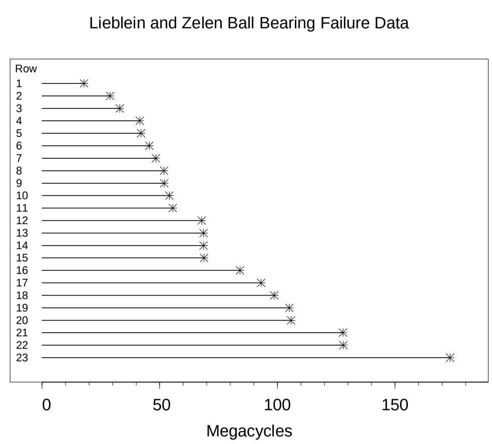
The data: Millions of revolutions to failure for each of $n = 23$ bearings before fatigue failure.

Main objectives of the study: Determine **best** values of the parameters in equation relating fatigue to load.

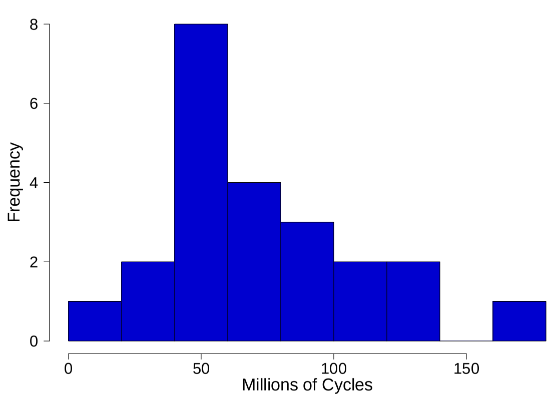
Motivation:

- Fatigue affects service life of ball bearings.
- Disagreement in manufacturing industries on the appropriate model parameter values to use to characterize the failure-time distribution.

Ball Bearing Failure Data Event Plot (Lawless 2003)



Ball Bearing Failure Data (Lieblein and Zelen 1956. Data from Lawless 2003)



Distinguishing Features of Failure-Time Data and Reliability Data Analysis

- Data are typically censored (bounds on observations).
- Positive responses (e.g., time or cycles to failure) need to be modeled. Commonly used distributions include the exponential, lognormal, and Weibull distributions. The normal distribution is not common.
- Model parameters **not** of primary interest (instead, failure rates, quantiles, and failure or survival probabilities).
- Extrapolation often required (e.g., want proportion failing at three years for a product in the field only six months).

Issues in Failure-Time Data Analysis

- Causes of failure and degradation leading to failure.
- Environmental effects on reliability.
- Definition of time scale.
- Definitions of time origin and time of failure.

IC Data

Integrated circuit failure times in hours. When the test ended at 1,370 hours, 4,128 units were still running (Meeker 1987)

0.10	0.10	0.15	0.60	0.80	0.80
1.20	2.50	3.00	4.00	4.00	6.00
10.00	10.00	12.50	20.00	20.00	43.00
43.00	48.00	48.00	54.00	74.00	84.00
94.00	168.00	263.00	593.00		

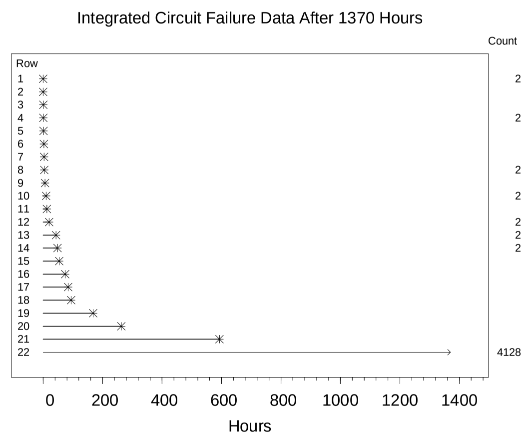
IC Data

$n = 4156$ IC's tested for 1370 hours at 80°C and 80% relative humidity, there were 28 failures (Meeker 1987).

Quantity of interest:

- Proportion of defective units.

Event Plot of the Integrated Circuit Life Test Data Where 28 Out of 4156 Units Failed in the 1370 Hour Test at 80°C and 80% RH (Meeker 1987)

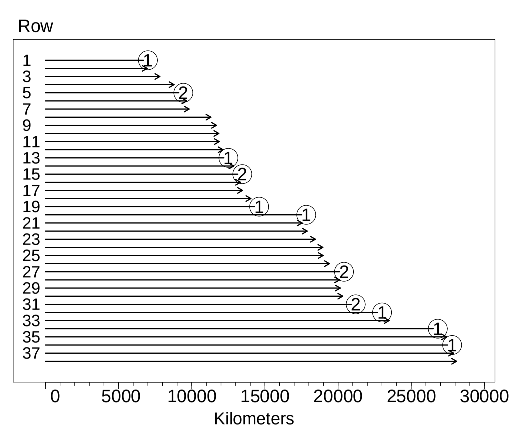


Shock Absorber Failure Data

First reported in O'Connor (1985).

- Failure times, in number of kilometers of use, of vehicle shock absorbers.
- Two failure modes, denoted by Mode 1 and Mode 2.
- One might be interested in the distribution of time to failure for
  - ▶ Mode 1 (e.g., after Mode 2 has been eliminated).
  - ▶ Mode 2 (e.g., after Mode 1 has been eliminated).
  - ▶ A shock absorber with both Mode 1 and Mode 2 active.

Failure Pattern in the Shock Absorber Data (O'Connor 1985)



Strategy for Data Analysis, Modeling, and Inference

- Model-free graphical data analysis.
- Model fitting (parametric, including possible use of prior information).
- Inference: estimation or prediction (including statistical intervals to reflect statistical uncertainty).
- Graphical display of model-fitting results.
- Graphical and analytical diagnostics and assessment of assumptions.
- Sensitivity analysis.
- Conclusions.

Computer Software

Capabilities for reliability data analysis can be found in:

- R/RSplida
- JMP
- MINITAB
- SAS
- WinSMITH
- Weibull++/ALTA

With JMP, one can accomplish most of the data analyses needed for this course.

Chapter 1

Segment 3

Failure-time Data Based on Inspections

Heat Exchanger Tube Crack Data

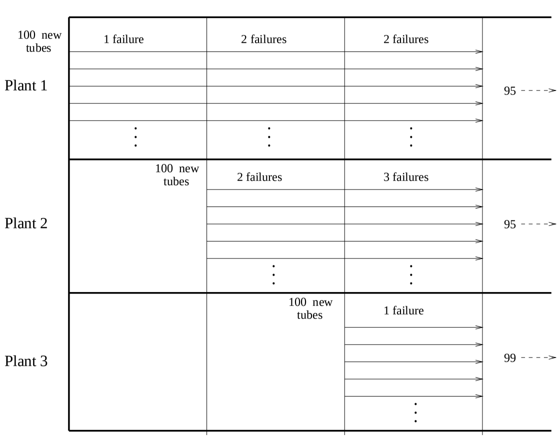
Data from heat exchangers from three power plants.

- 100 tubes in each exchanger.
- Each tube **inspected** at the end of each year for cracks. Cracked tubes are plugged, reducing efficiency.
- Data from 3 plants with same design. Each plant entered into service at different dates.

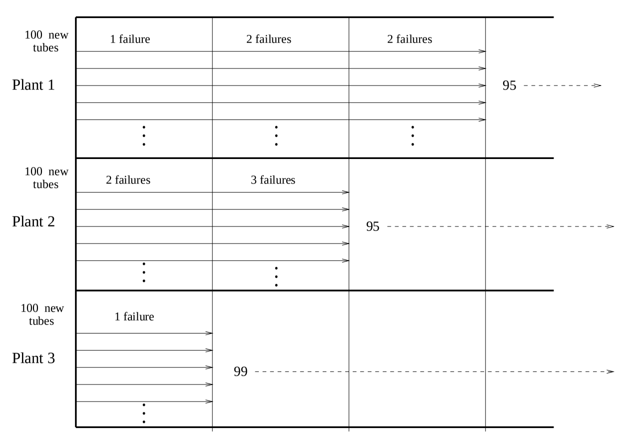
Cracked tubes at the end of each year,

Exchanger	Year 1	Year 2	Year 3
1	1	2	2
2	2	3	no inspection
3	1	no inspection	no inspection

Heat Exchanger Tube Crack Inspection Data in Calendar Time



Heat Exchanger Tube Crack Inspection Data in Operating Time



Current-Status Data

Current-status data arise when

- A population (or sample from a population) of units is inspected within a short period of time to learn the extent of a recently discovered unanticipated serious failure mode.
  - ▶ Excessive wear found in an aircraft jackscrew triggered inspection of similar aircraft.
  - ▶ A crack detected in an aircraft engine rotating component triggered inspection of all such components in service.
- Rockets in a weapons stockpile either operated correctly or not when fired.

Turbine Wheel Data (Nelson 1982)

Each of $n = 432$ wheels was inspected once to determine if it had started to crack or not. Wheels had different ages at inspection (Nelson 1982).

In this case, some **important** objectives are:

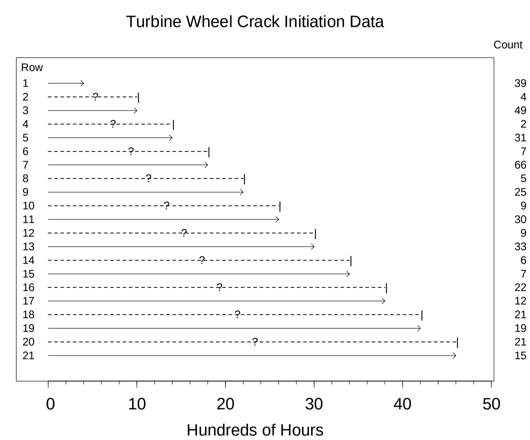
- Need to schedule regular inspections.
- Estimate the distribution of time to crack.
- Is the reliability of the wheels getting worse as the wheels age?

  An increasing hazard function would require replacement of the wheels by some age when the risk of cracking is too high.

Turbine Wheel Data
Summary at Time of Study

100-hours of Exposure	# Cracked Left Censored	# Not Cracked Right Censored
4	0	39
10	4	49
14	2	31
18	7	66
22	5	25
26	9	30
30	9	33
34	6	7
38	22	12
42	21	19
46	21	15

Event Plot
Turbine Wheel Inspection Data (Nelson 1982)

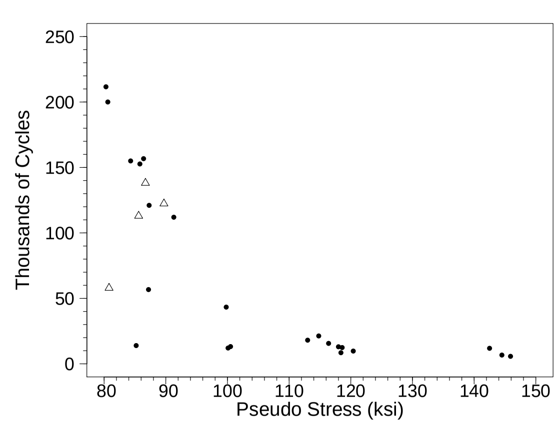


Chapter 1

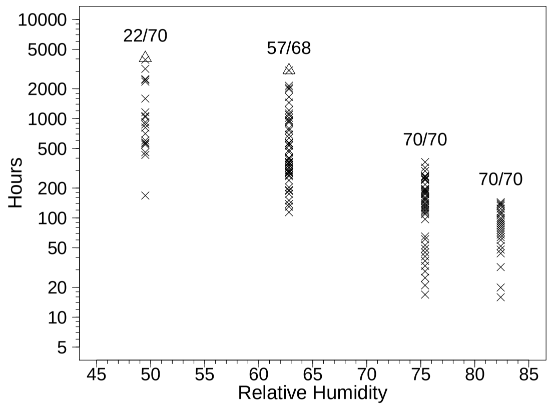
Segment 4

Failure-Time Data with Explanatory Variables
Degradation Reliability Data
Recurrent-Events Reliability Data

Scatter Plot of Low-Cycle Fatigue Life Versus Pseudo-Stress for Specimens of a Nickel-Base Superalloy (Nelson 2004)



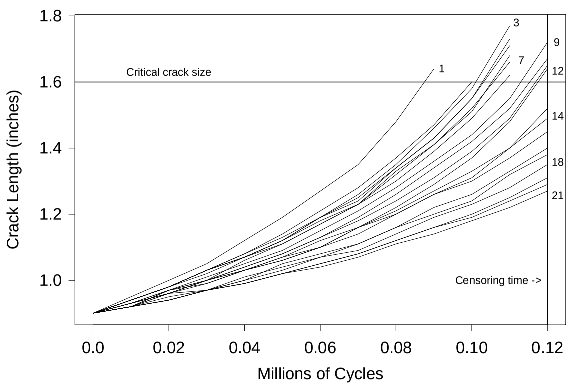
Scatter Plot of Printed Circuit Board Accelerated Life Test Data (Meeker and LuValle 1995)



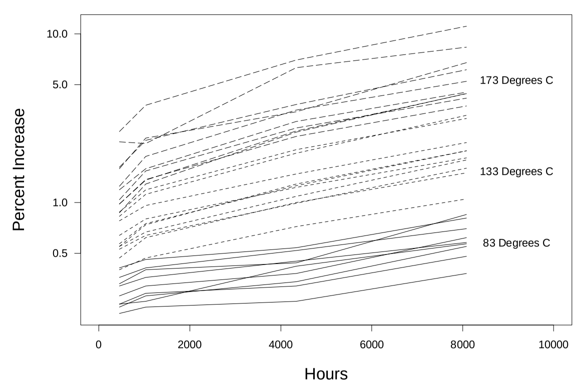
Degradation Data

- Provides information on progression toward failure.
- Becoming more common in certain areas of component reliability where few or no failures expected in life tests.
- Important connections with physical mechanisms of failure and failure-time reliability models.
  - ▶ Destructive degradation data (Chapter 2).
  - ▶ Repeated measures degradation data (Chapter 20).

Fatigue Crack Size as a Function of Number of Cycles (Bogdanoff and Kozin 1985)



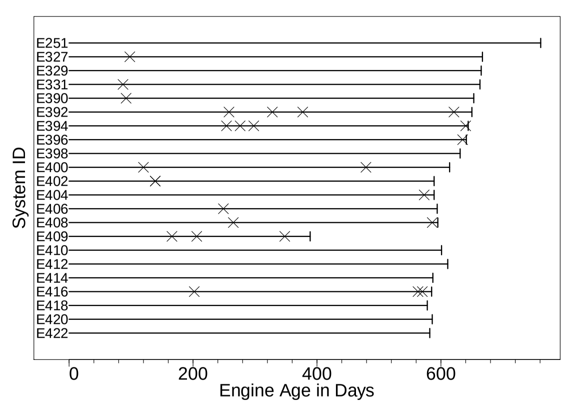
Change in Resistance Over Time of Carbon-Film Resistors (Shiomi and Yanagisawa 1979)



Repairable Systems and Nonrepairable Units

- Failure-time or degradation data on **components** or nonrepairable units.
  - ▶ Laboratory tests on materials or components.
  - ▶ Data on components or replaceable subsystems from system tests or monitoring.
  - ▶ Time to **first** failure of a system.
- **Repairable Systems** result in recurrent-events data that describe the failure trends and patterns of a system (Chapter 21).

Recurrent-Events Data Valve Seat Replacements



References

Bogdanoff, J. L. and F. Kozin (1985). *Probabilistic Models of Cumulative Damage*. Wiley. [33]

Condra, L. W. (1993). *Reliability Improvement with Design of Experiments*. Marcel Dekker. [5]

Lawless, J. F. (2003). *Statistical Models and Methods for Lifetime Data* (Second Edition). Wiley. [9, 10, 11]

Lieblein, J. and M. Zelen (1956). Statistical investigation of the fatigue life of deep-groove ball bearings. *Journal of Research, National Bureau of Standards 57*, 273–316. [9, 11]

Meeker, W. Q. (1987). Limited failure population life tests: Application to integrated circuit reliability. *Technometrics 29*, 51–65. [14, 15, 16]

Meeker, W. Q., L. A. Escobar, and F. G. Pascual (2021). *Statistical Methods for Reliability Data* (Second Edition). Wiley. [1]

Meeker, W. Q. and M. J. LuValle (1995). An accelerated life test model based on reliability kinetics. *Technometrics 37*, 133–146. [31]

Nelson, W. B. (1982). *Applied Life Data Analysis*. Wiley. [26, 28]

Nelson, W. B. (2004). *Accelerated Testing: Statistical Models, Test Plans, and Data Analyses* (Paperback Edition). Wiley. [30]

O'Connor, P. D. T. (1985). *Practical Reliability Engineering*. Wiley. [17, 18]

Shiomi, H. and T. Yanagisawa (1979). On distribution parameter during accelerated life test for a carbon film resistor. *Bulletin of the Electrotechnical Laboratory 43*, 330–345. [34]