



Unit I: Reliability Concepts and Reliability Data

Notes largely based on
“Statistical Methods for Reliability Data” by W.Q.
Meeker and L.A. Escobar, Wiley, 1998 and on their
class notes.

Objectives

- Explain basic concerns relating to product reliability
- List some reasons for collecting reliability data
- Describe the distinguishing features of reliability data
- Provide examples of reliability data and describe the motivation for the collection of these data
- Outline a general strategy that can be used for data analysis, modeling, and inference from reliability data.

Quality and Reliability

New pressures on manufacturers to produce high quality products. Pressure due to:

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

Definition 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
 - Reliability is quality over time (Condra, 1993)



Reasons for Collecting Reliability Data

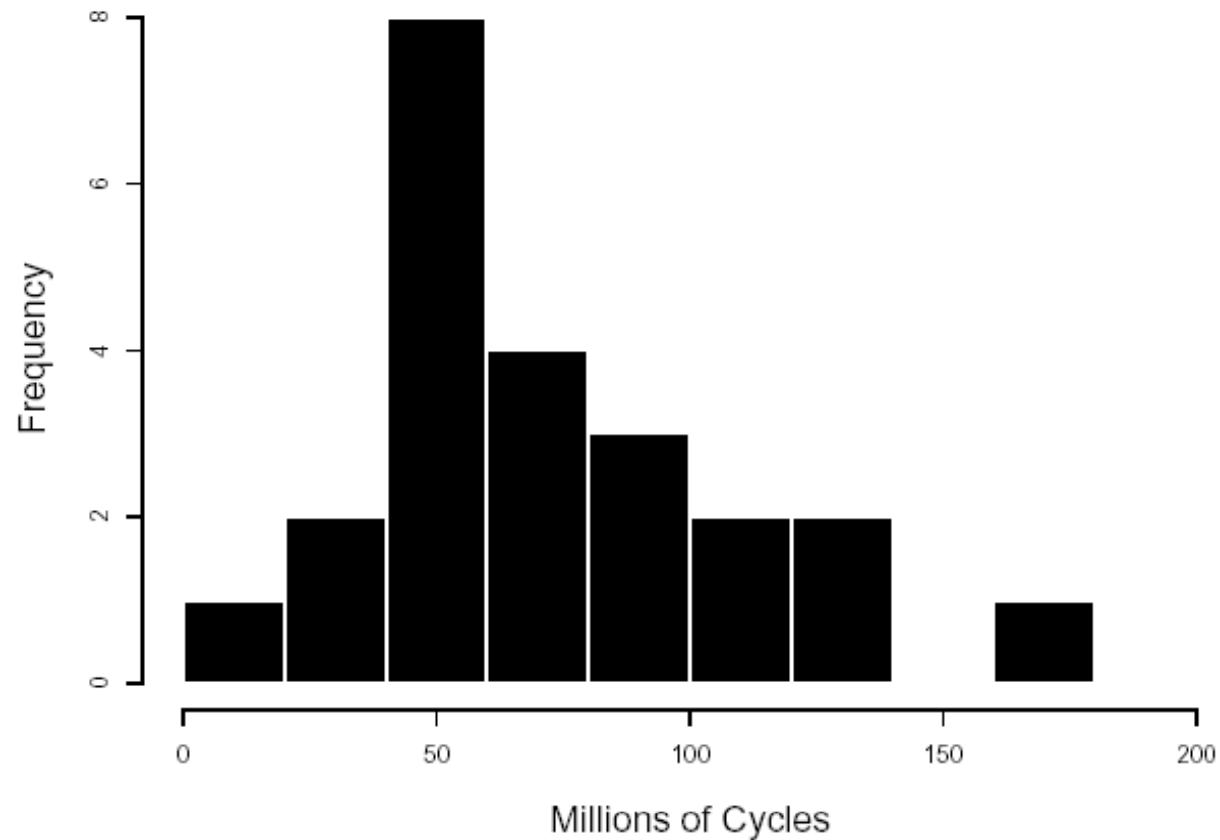
- Assessing characteristics of materials
- Predict product reliability during the design stage
- Assessing the effect of a proposed design change
- Comparing two or more manufacturers
- Assess product reliability in the field
- Checking the veracity of an advertising claim
- Predict product warranty costs

Other Common Names for Reliability Data

- Life data
- Lifetime data
- Failure-time data
- Survival data
- Time-to-event data
- Duration data

Degradation data is another type of reliability data that is being increasingly used.

Ball Bearing Failure Data (Lieblein and Zelen, 1956)



Ball Bearing Failure Data

- Data from fatigue endurance tests for deep-groove ball bearings from four major bearing companies (Lawless 1982)
 - **The data:** Millions of revolutions to failure for each of $n = 23$ bearings before fatigue failure
 - **Main objective of the study:** Determine best values of the parameters in equation relating fatigue to load

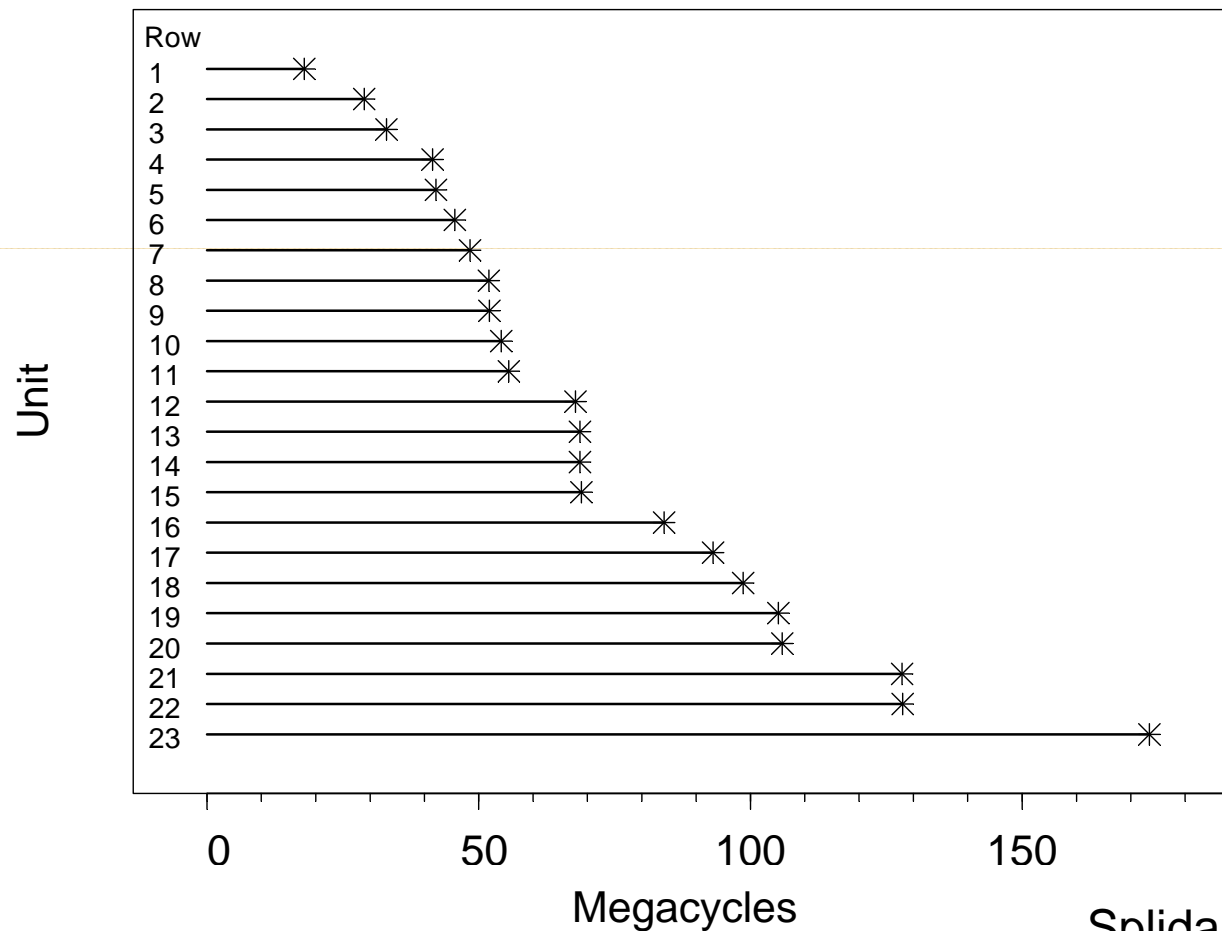


Ball Bearing Failure Data: Motivation of the Study

- Fatigue affects service life of ball bearings
- Disagreement in the industry on the appropriate values of the parameters in equation relating fatigue to load.

SPLIDA “Life Data Event Plot”

Lieblein and Zelen Ball Bearing Failure Data



Splida: Lzbearing.ld



Distinguishing Features of Reliability Data. I

- Data are typically censored (bounds on observations)
- Models for positive random variables
 - Exponential
 - Lognormal
 - Weibull
 - Gamma
 - Normal distribution is not commonly used



Distinguishing Features of Reliability Data

- Model parameters are not of primary interest. Instead:
 - Failure rates
 - Quantiles
 - Probabilities of failure
- Extrapolation often required
 - For example, one may want to estimate the proportion failing by 900 hours based on a test run for 400 hours

Issues in Life Data Analysis

- Causes of failure and degradation leading to failure
- Environmental effects on reliability
- Choice of time scale
 - Operating time?
 - Revolutions to failure?
- Choice of time origin
- Definition of failure and failure time

IC Data (Meeker, 1987)

Integrated circuit failure times in hours

- $n = 4156$ ICs tested for 1,370 hours at 80°C and 80% relative humidity
- There were 28 failures
- When the test ended at 1,370 hours, 4128 units were still running

.10	.10	.15	.60	.80	.80
1.20	2.5	3.0	4.0	4.0	6.0
10.0	10.0	12.5	20.	20.	43.
43.	48.	48.	54.	74.	84.
94.	168.	263.	593.		

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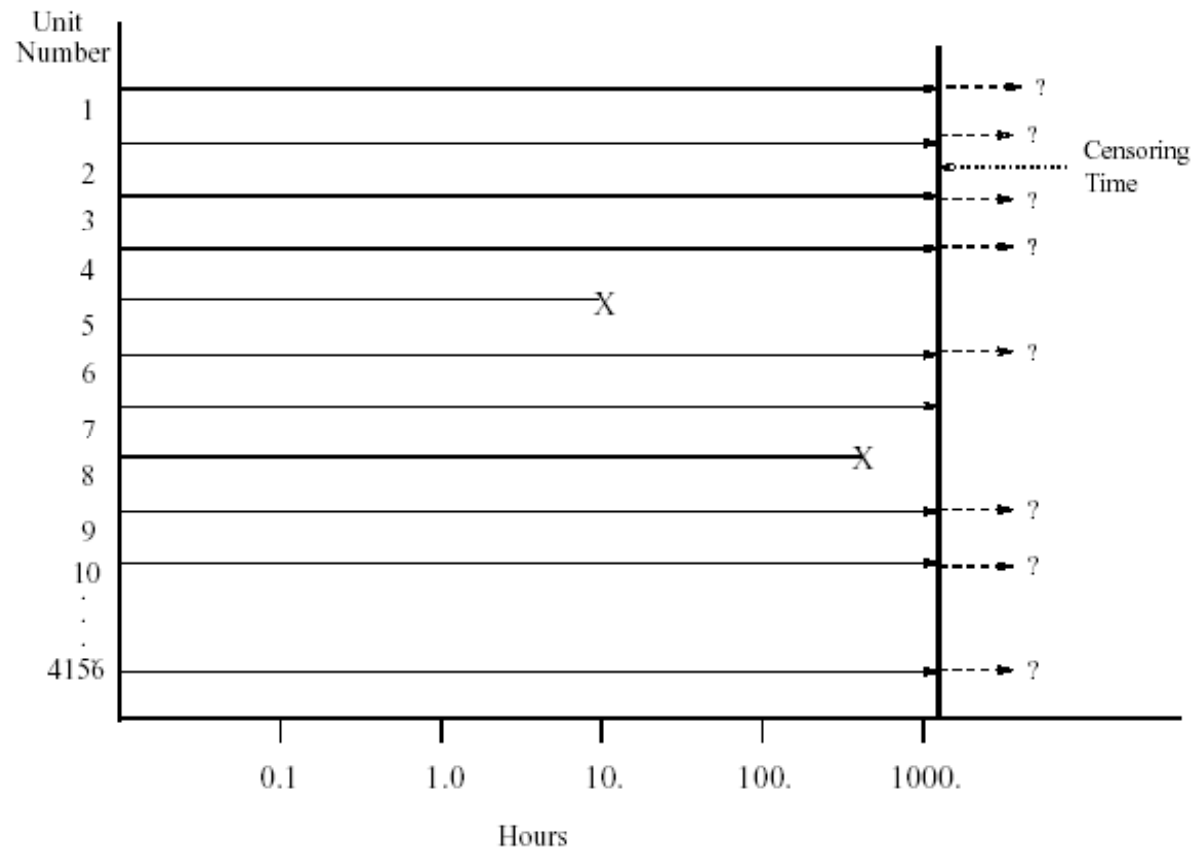
Issues with IC Data

- Simple random sampling?
- Inspection or recording times?
- Explanatory variables (fixed or random)?
- Other sources of variability?

Questions to Answer with IC Data

- Probability of failing before 100 hours?
- Hazard function at 100 hours?
- Proportion of units that will fail in 10^5 hours?

IC Data Failure Pattern



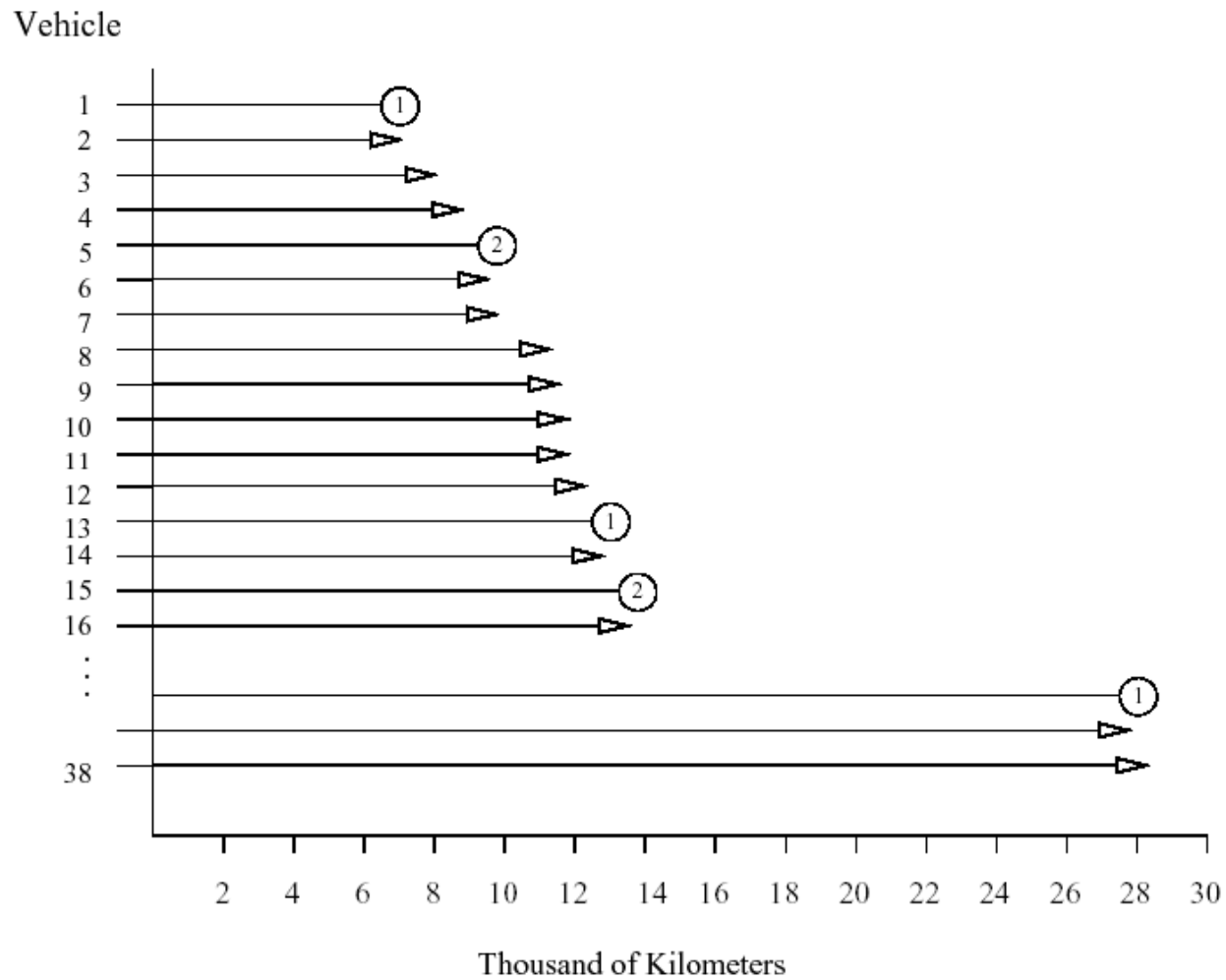
Repairable Systems and Nonrepairable Units

- Reliability data on components or non-repairable units
 - Laboratory tests on materials or components
 - Data on components or replaceable subsystems from system test or monitoring
 - Time to **first** failure of a system
- Data on **Repairable Systems** describe the failure trends and patterns of an overall system

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 M1 and M2
- Interest could be on the distribution of time to failure for
 - Mode 1
 - Mode 2
 - Overall part

Failure Pattern of the Shock Absorber Data





Strategy for Data Analysis, Modeling, and Inference

- Model-free graphical data analysis
- Model fitting (parametric, including possible use of prior information)

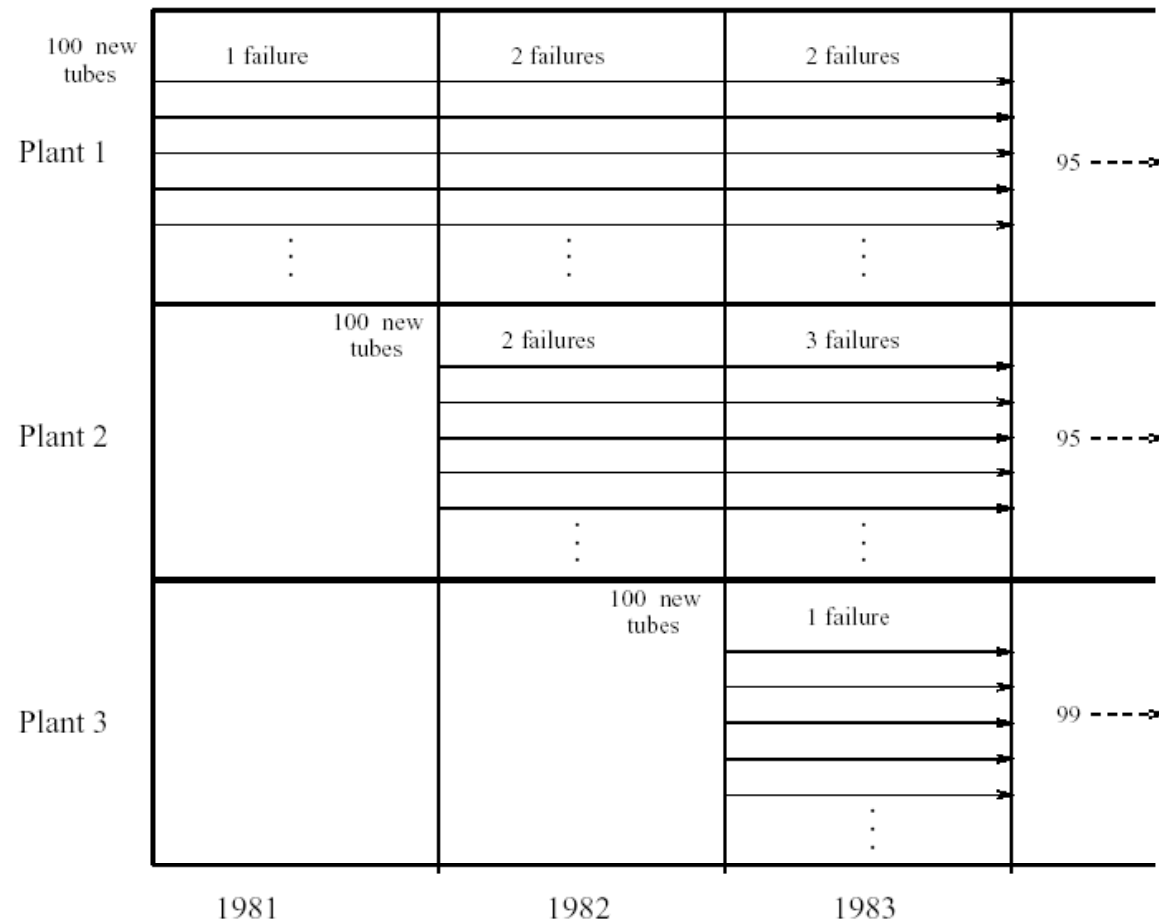
- Inference: estimation or prediction
- Graphical display of results
- Graphical and analytical diagnostics and assessment of assumptions
- Sensitivity analysis
- Conclusions

Tube Crack Data from Exchanger of Power Plant

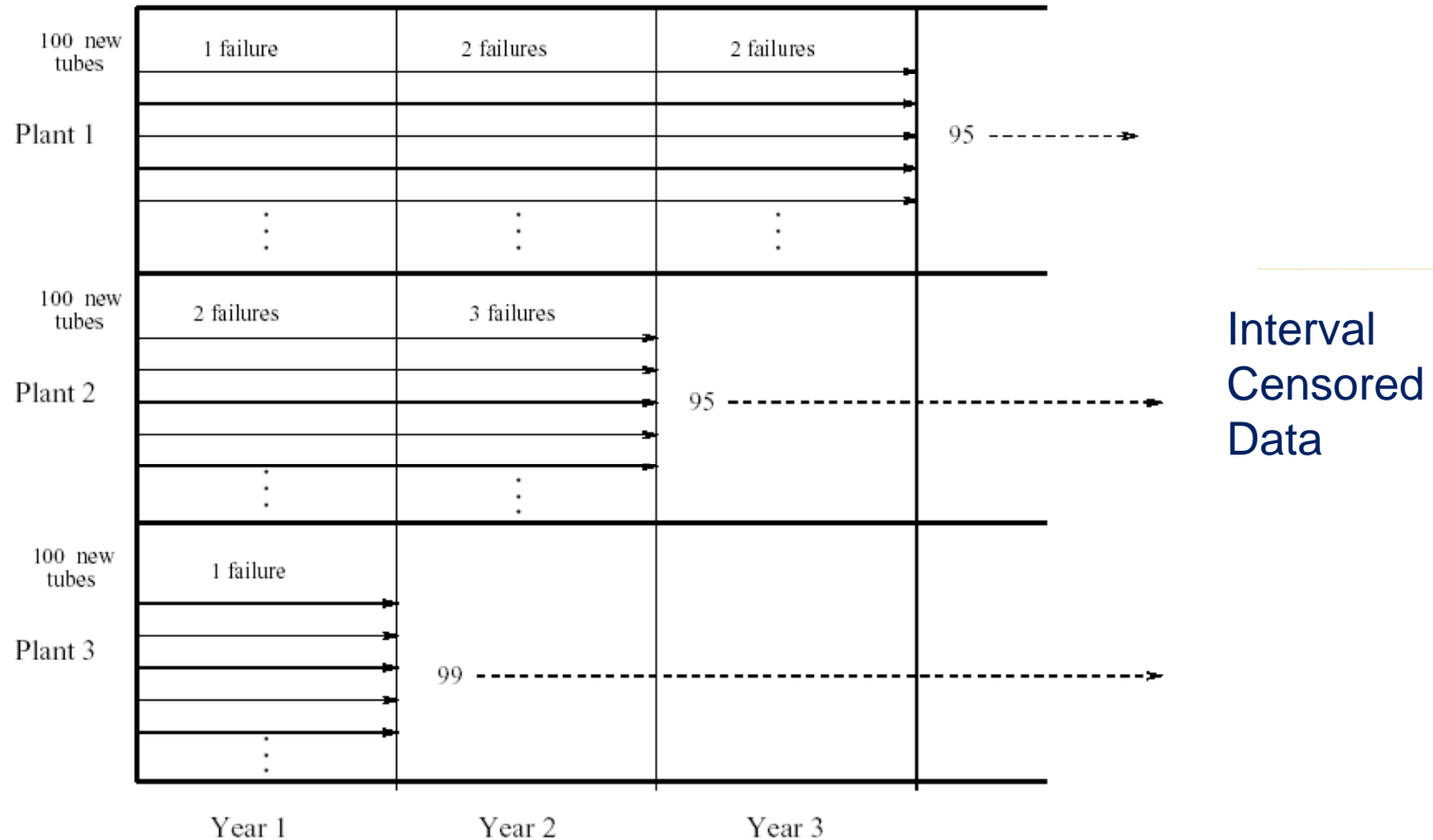
- 100 tubes in each exchanger
- Each tube inspected at the end of each year for cracks. Cracked tubes are plugged but this reduces efficiency
- Data from three plants with the same design. Each plant entered into service at different dates.

Exchanger	Year 1	Year 2	Year 3
1	1	2	2
2	2	3	no inspec.
3	1	no inspec.	no inspec.

Heat Exchanger Tube Crack Inspection Data in Real Time



Heat Exchanger Tube Crack Inspection Data in Operating Time



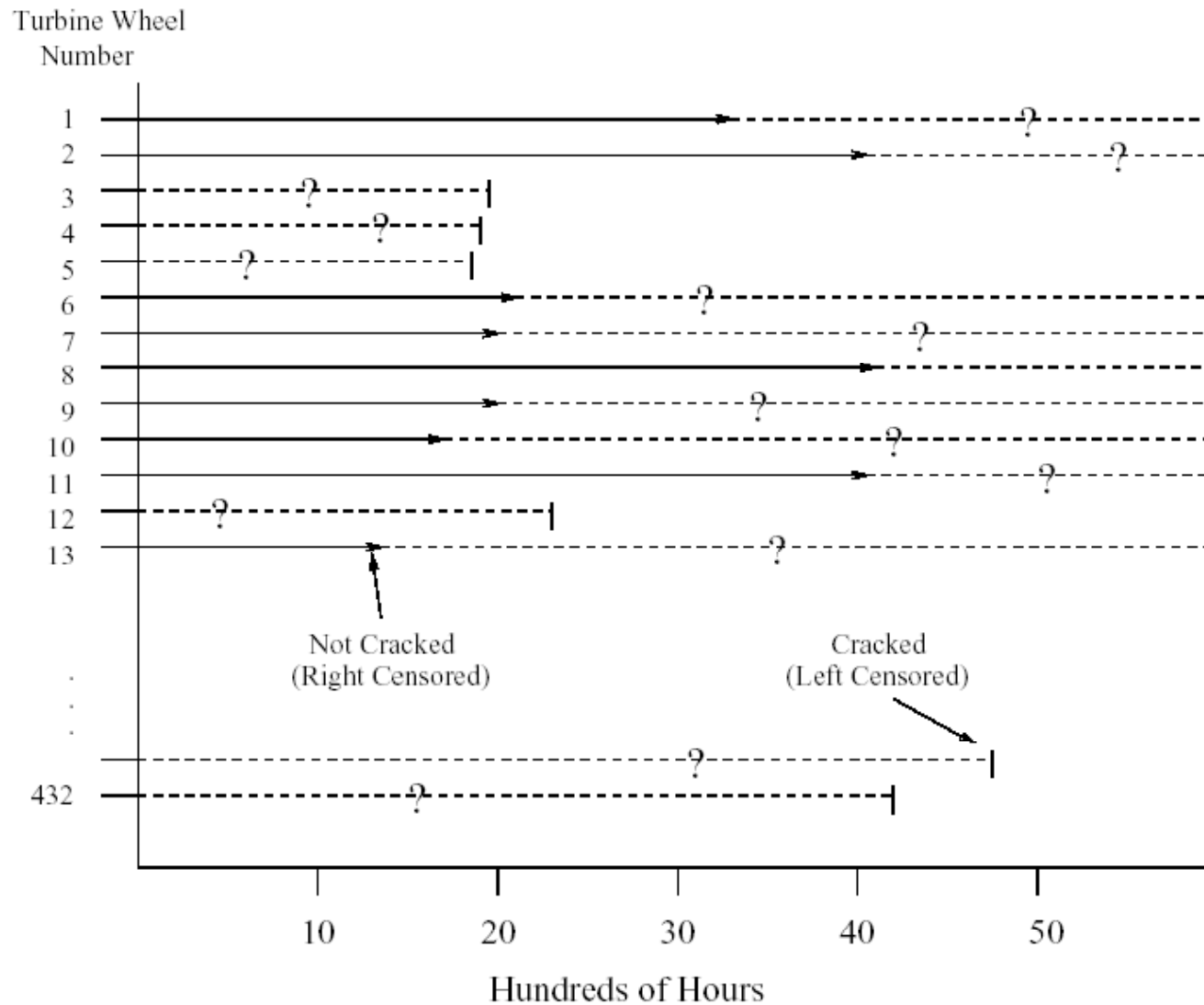
Turbine Wheel Data (Nelson 1982)

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

Turbine Wheel Inspection Data

- 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:
 - Assess the 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 gets too high.

Turbine Wheel Inspection Data

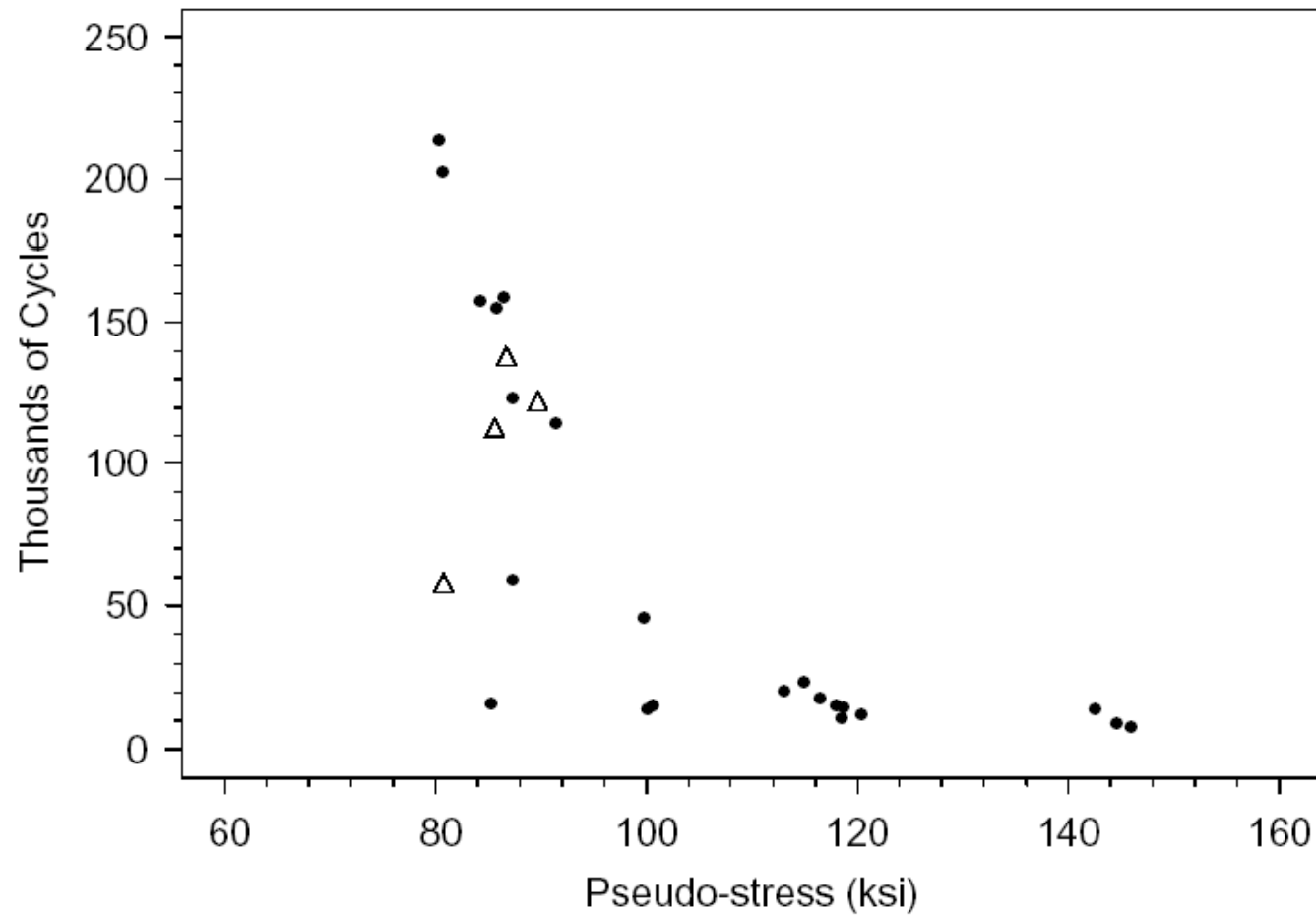


Failure Data from a Circuit Pack Field Tracking Study – Example of Truncated Data

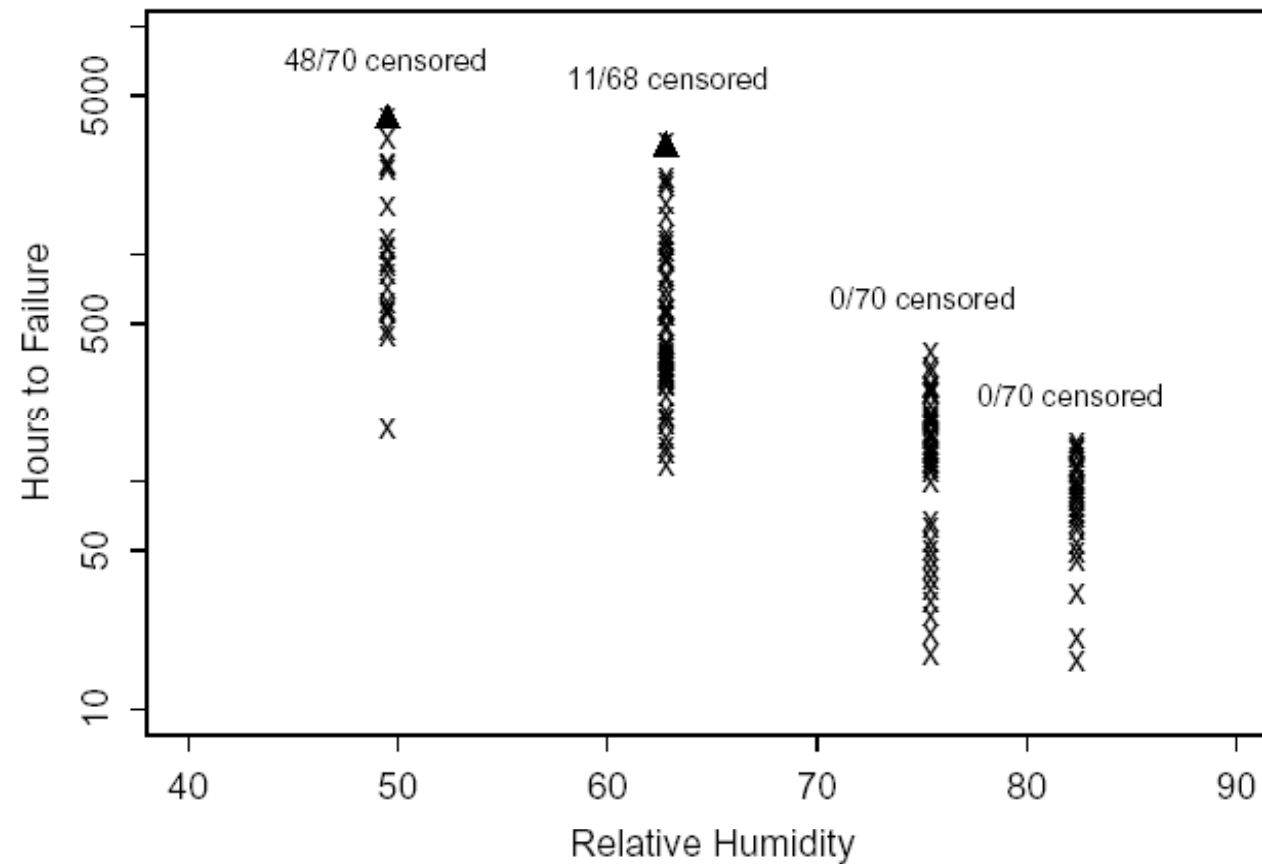
Operating Hours		Number Failing	
Interval Endpoint			
Lower	Upper	Vendor 1	Vendor 2
0	1	10	unknown
1	2	1	unknown
2	5	3	unknown
5	10	1	unknown
10	20	2	unknown
20	50	6	unknown
50	100	3	unknown
100	200	2	unknown
200	500	8	unknown
500	1,000	4	unknown
1,000	2,000	5	2
2,000	5,000	6	5
5,000	6,000	3	6
6,000	7,000	9	11
7,000	8,000	10	7
8,000	9,000	16	14
9,000	10,000	7	10
10,000	11,000	unknown	14

After 10,000 hours of operation, there were 4897 unfailed packs for Vendor 1 and after 11,000 hours of operation there were 4924 unfailed packs for Vendor 2.

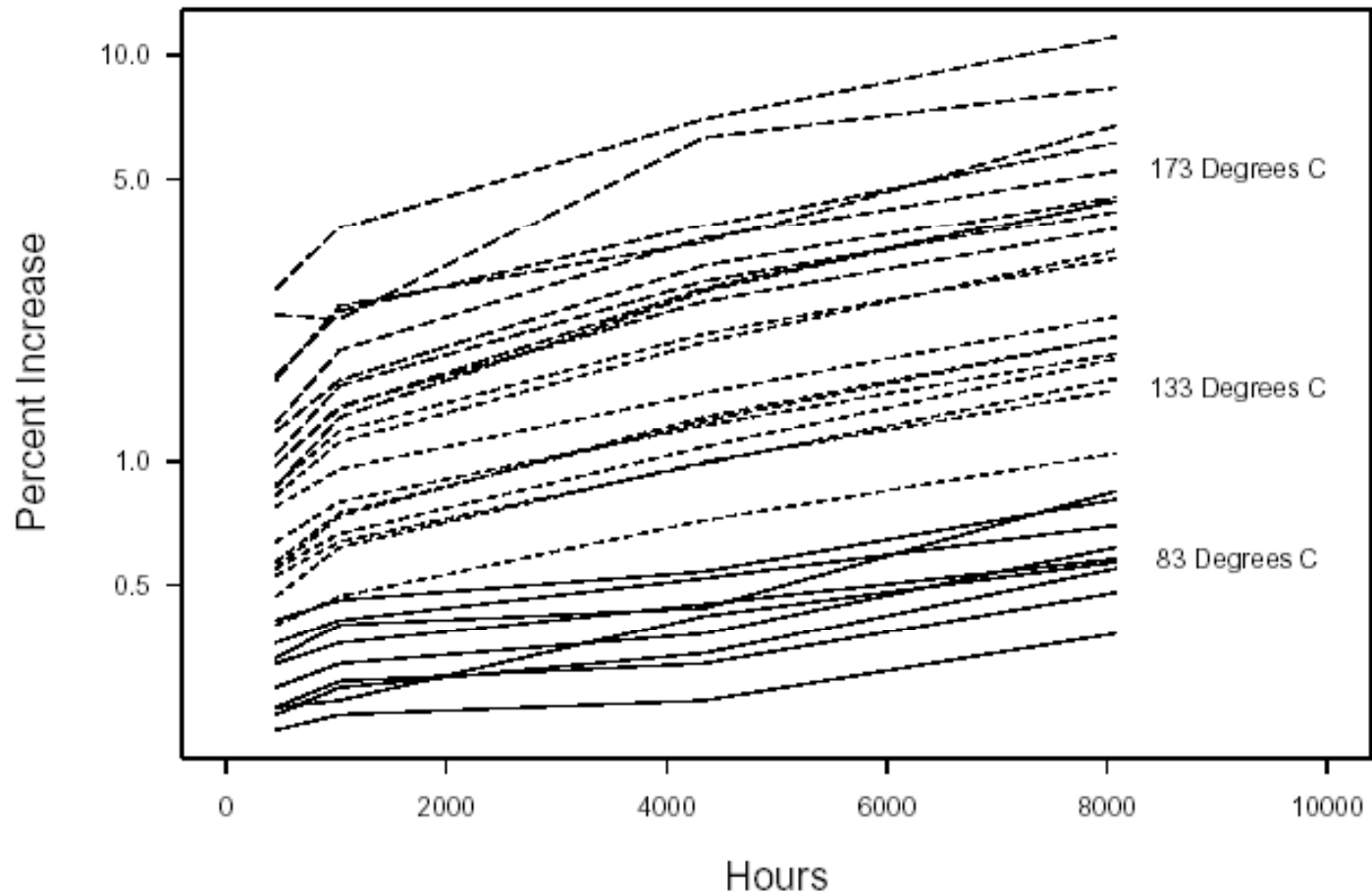
Scatter Plot of Low-Cycle Fatigue Life Versus Pseudo-Stress for Specimens of a Nickel-Base Superalloy (Nelson 1990)



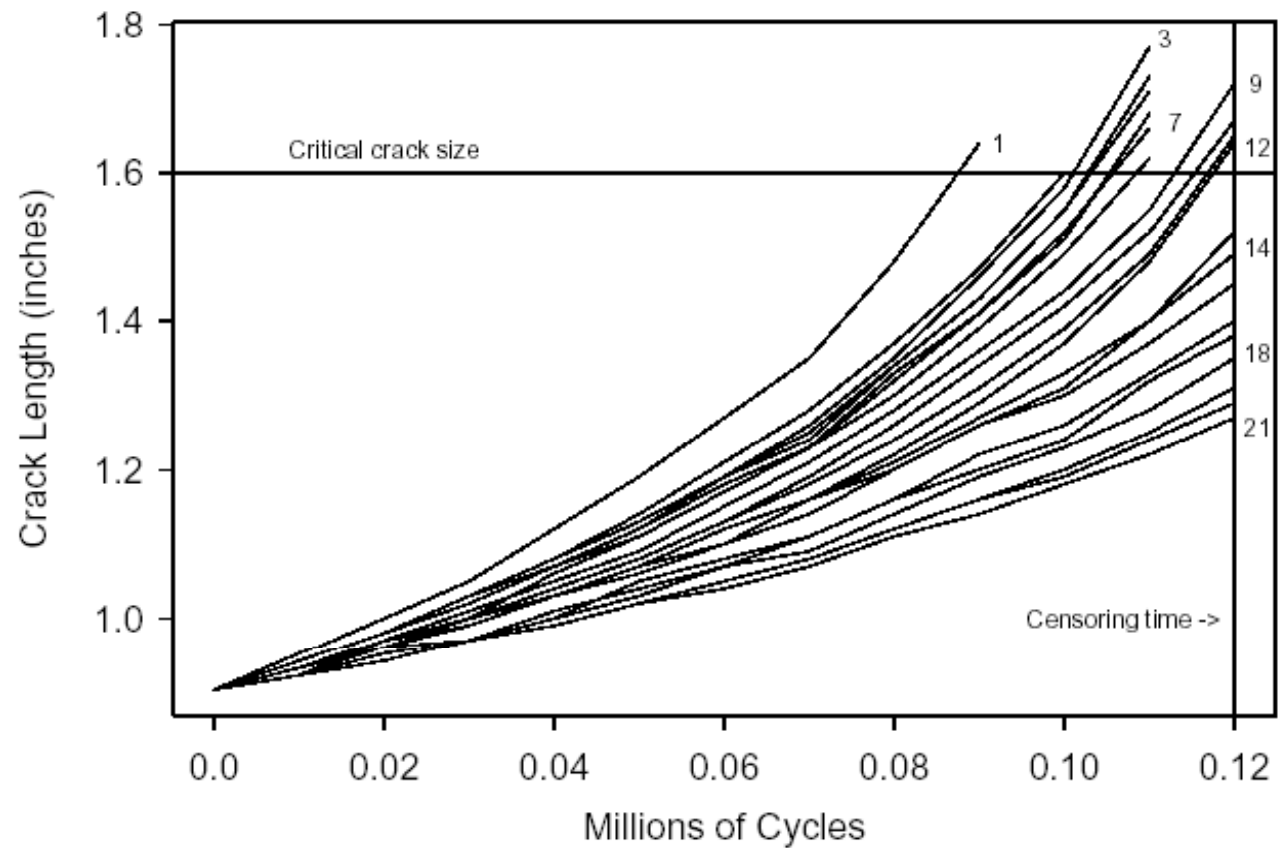
Scatter Plot of Printed Circuit Board Accelerated Life Data (Meeker & LuValle, 1995)



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



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



Degradation Data

- Provides information on progression towards 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
- Special methods of analysis needed (Chapters 13, 21, 22)

Biomedical Data

- Biomedical studies can yield data with censored structures similar to the ones observed in reliability studies
- Similarly, some of the degradation data from biomedical studies resembles degradation data from reliability studies
- Though some of the reliability methodology can be applied to biological studies, one cannot blindly apply it ignoring the distinct nature of the problem handled in these two areas

DMBA Carcinogen Data (Data from Pike, 1966. See Lawless, 1982)

Number of days until the appearance of vaginal carcinoma in $n = 19$ female rats painted with carcinogen DMBA

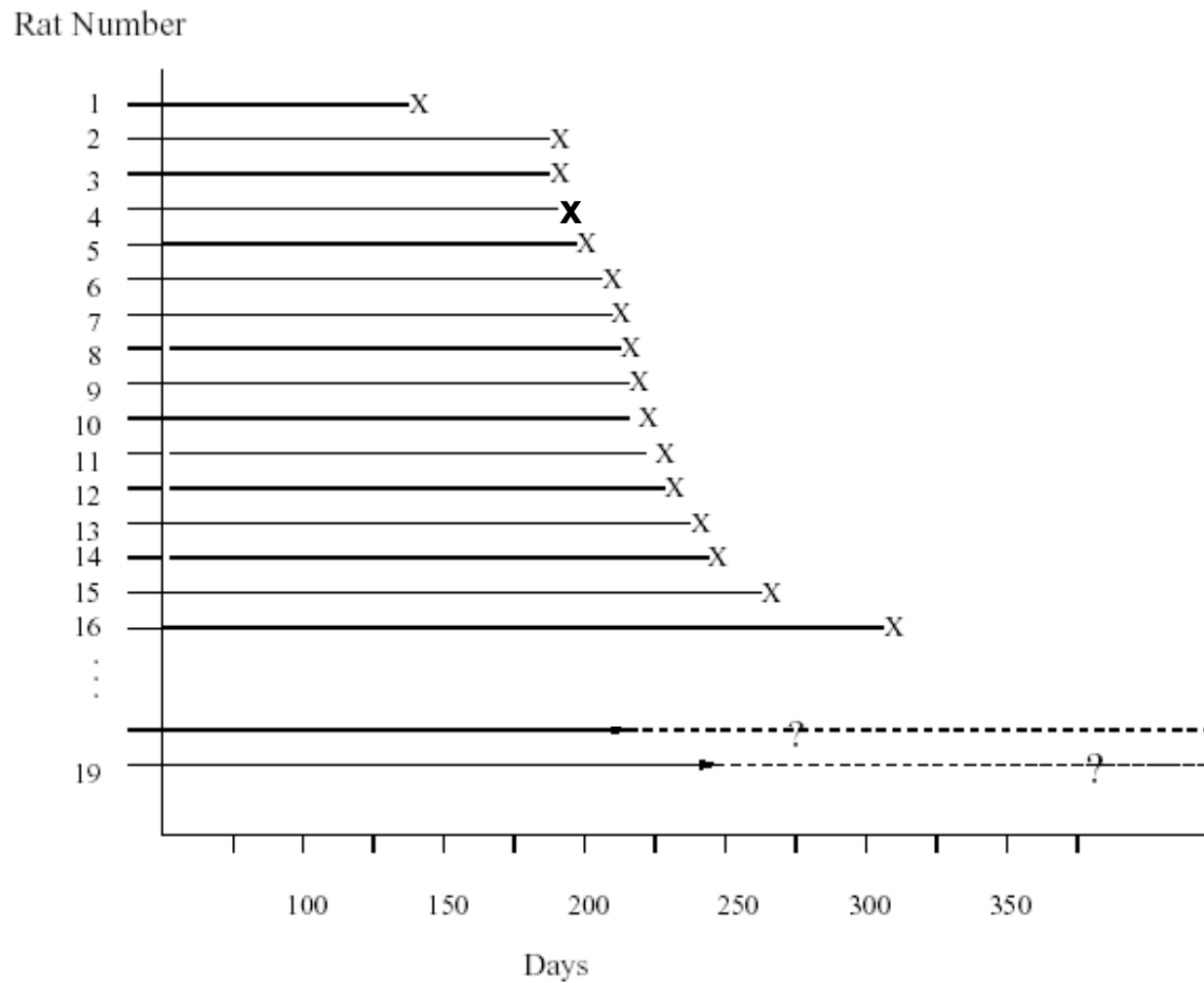
143, 164, 188, 188, 190, 192, 206, 209,
213, 216, 220, 227, 230, 234, 246, 265,
304, 216*, 244*

By the end of the study only 17 out of the 19 rats had developed carcinoma, so that two of the times (marked *) are censoring times.

DMBA Carcinogen Data

- DMBA is a carcinogen
- Interest on the nonparametric estimate of the time-to-carcinoma distribution
- There is also interest in the possibility of modeling these data with a Weibull distribution

DMBA Carcinogen Data



IUD Data (Data from WHO, 1987)

Number of weeks from the moment of initial IUD use until discontinuation because of bleeding problems in $n = 18$ women

10, 13*, 18*, 19, 23*, 30, 36, 38*,
54*, 56*, 59, 75, 93, 97, 104*, 107,
107*, 107*

By the end of the study only 9 out of the 18 women had developed bleeding, so that 9 of the times (marked *) are censoring times.

IUD Data

- The occurrence of irregular or prolonged bleeding is an important criterion in the evaluation of modern contraceptive devices
- A total of 18 women, aged between 18 and 35 years and who have experienced two previous pregnancies
- The censoring occurred because of desire of pregnancy, or no need of the device, or simply for lost to follow-up

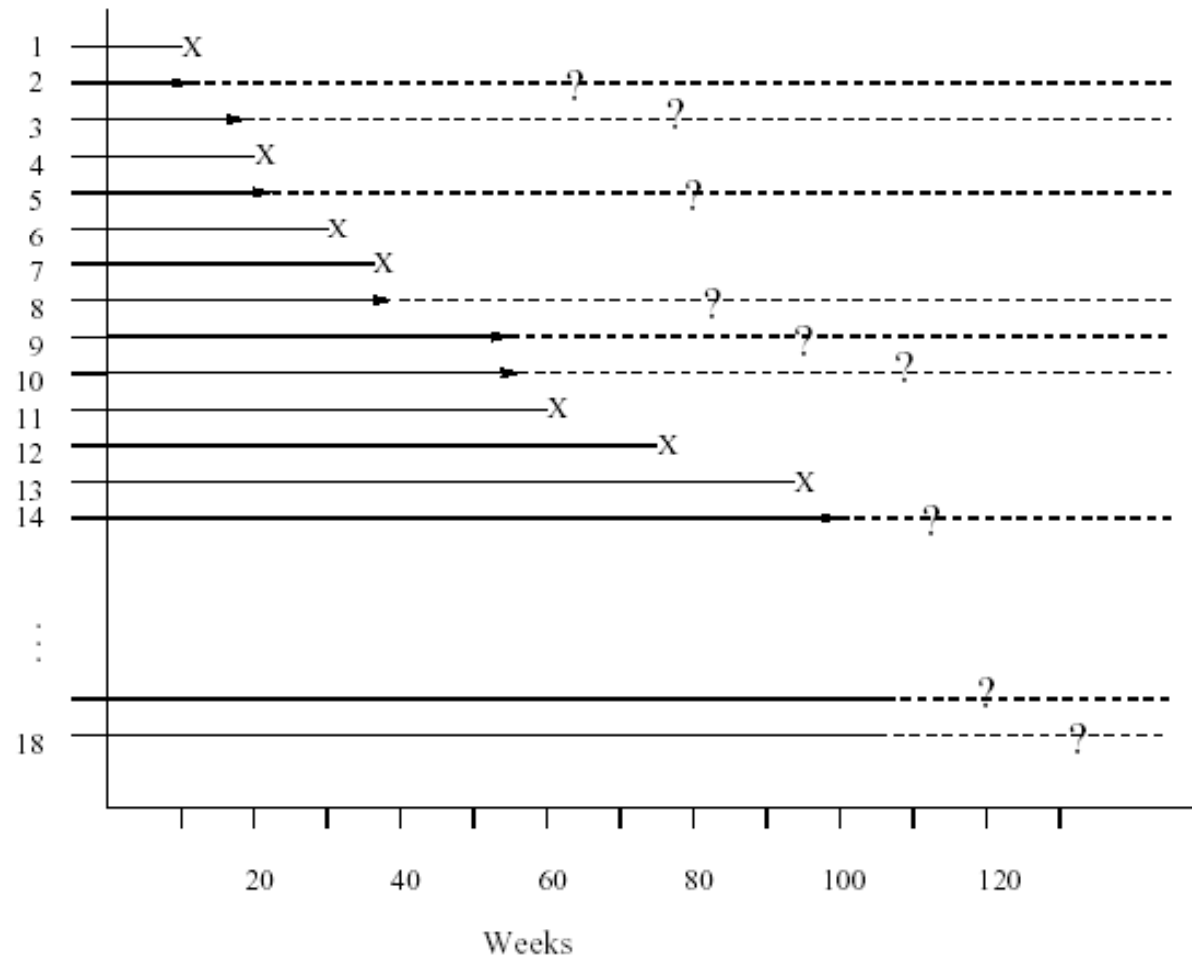
IUD Data Questions

It is of interest to estimate the distribution of discontinuation time to:

- Estimate median time to discontinuation
- Estimate the probability that a woman will stop using the device after a given period of time

IUD Data Summary (Collett 1994)

Patient



Stanford Heart Transplant Data (SHTD) (Miller and Halpern, 1982)

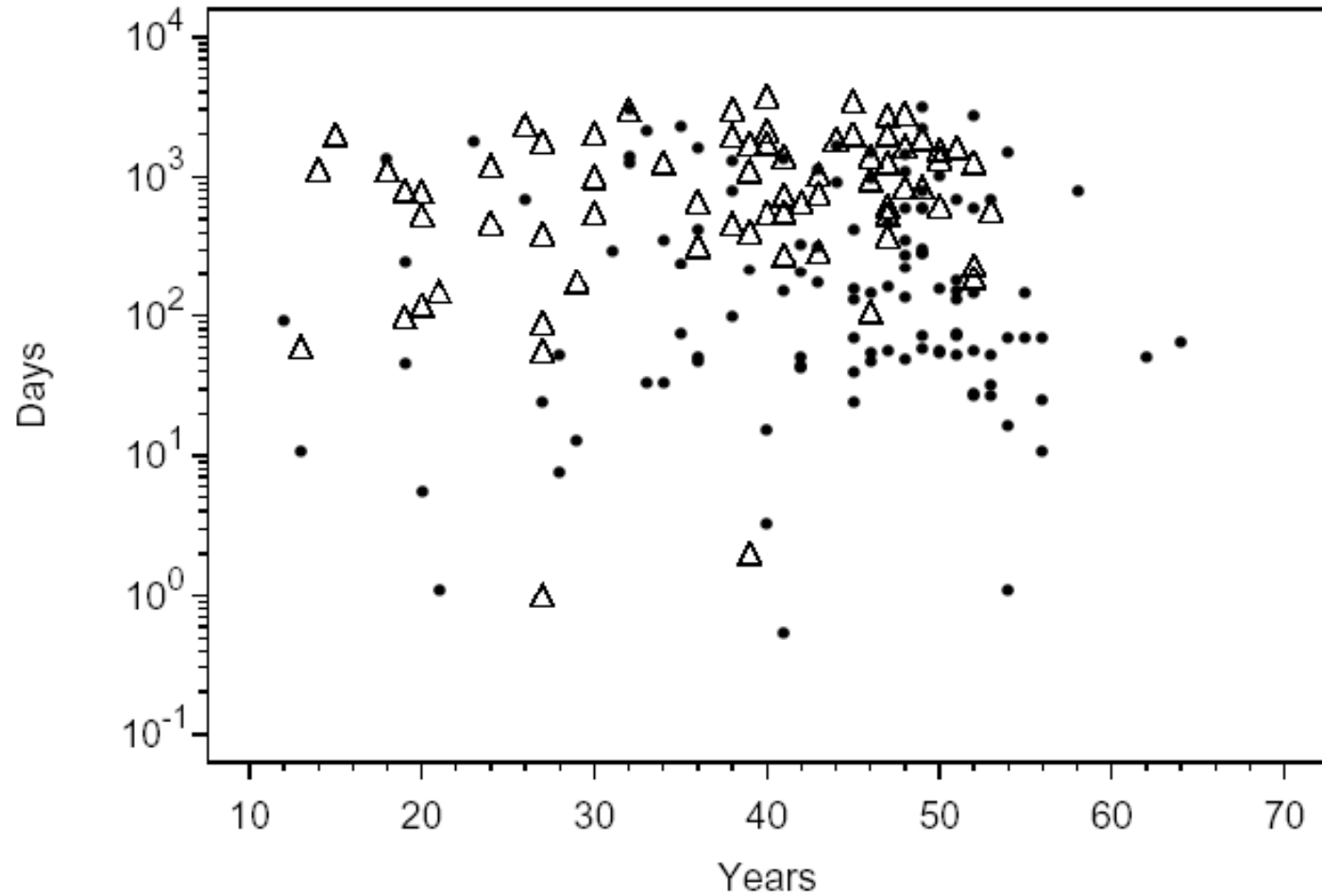
- They use the SHTD available in February of 1980 to compare the results from using semiparametric methods of estimation
- The data set contained 184 transplant cases, with the following variables
 - Time measured in days from date of transplant
 - Status code (dead or alive)
 - Age in years of patient at first transplant
 - T_5 a mismatch score (missing for 27 of the cases)

Stanford Heart Transplant Data (SHTD)

There is interest in knowing

- If the mismatch variable is related to time to death
- The effect that patient age (at first transplant) has on time to death

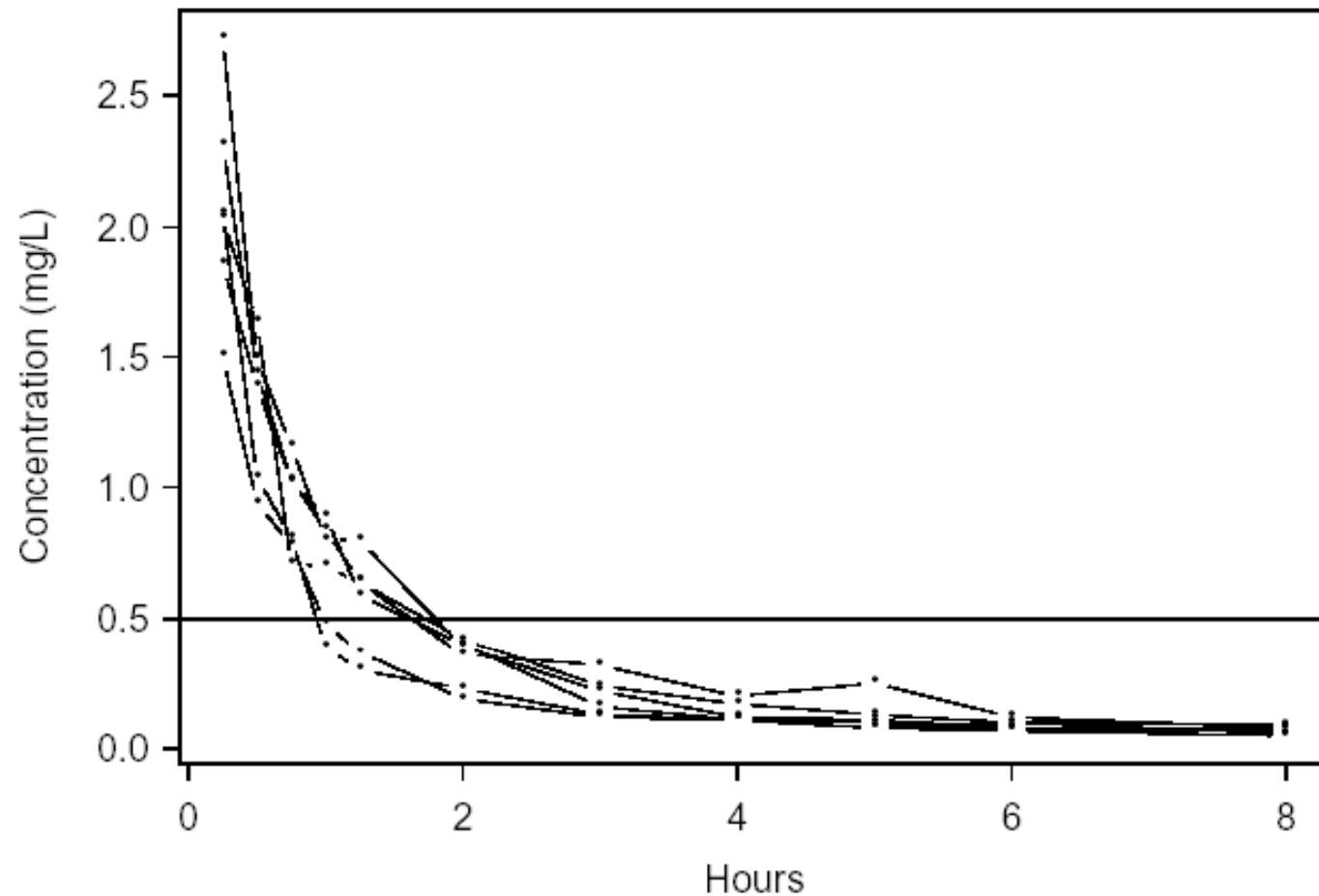
Stanford Heart Transplant Data (SHTD)



Indomethacin Data

- Kwan, Breault, Umbenhauer, McMahon, and Duggan (1976) give data on plasma concentrations of indomethacin (mg/L) following intravenous injection
 - There were six different individuals in the experiment
 - Times of sampling are the same for each individual. These times range from 15 minutes post injection to 8 hours post injection.

Plasma Concentrations of Indomethacin Following Intravenous Injection

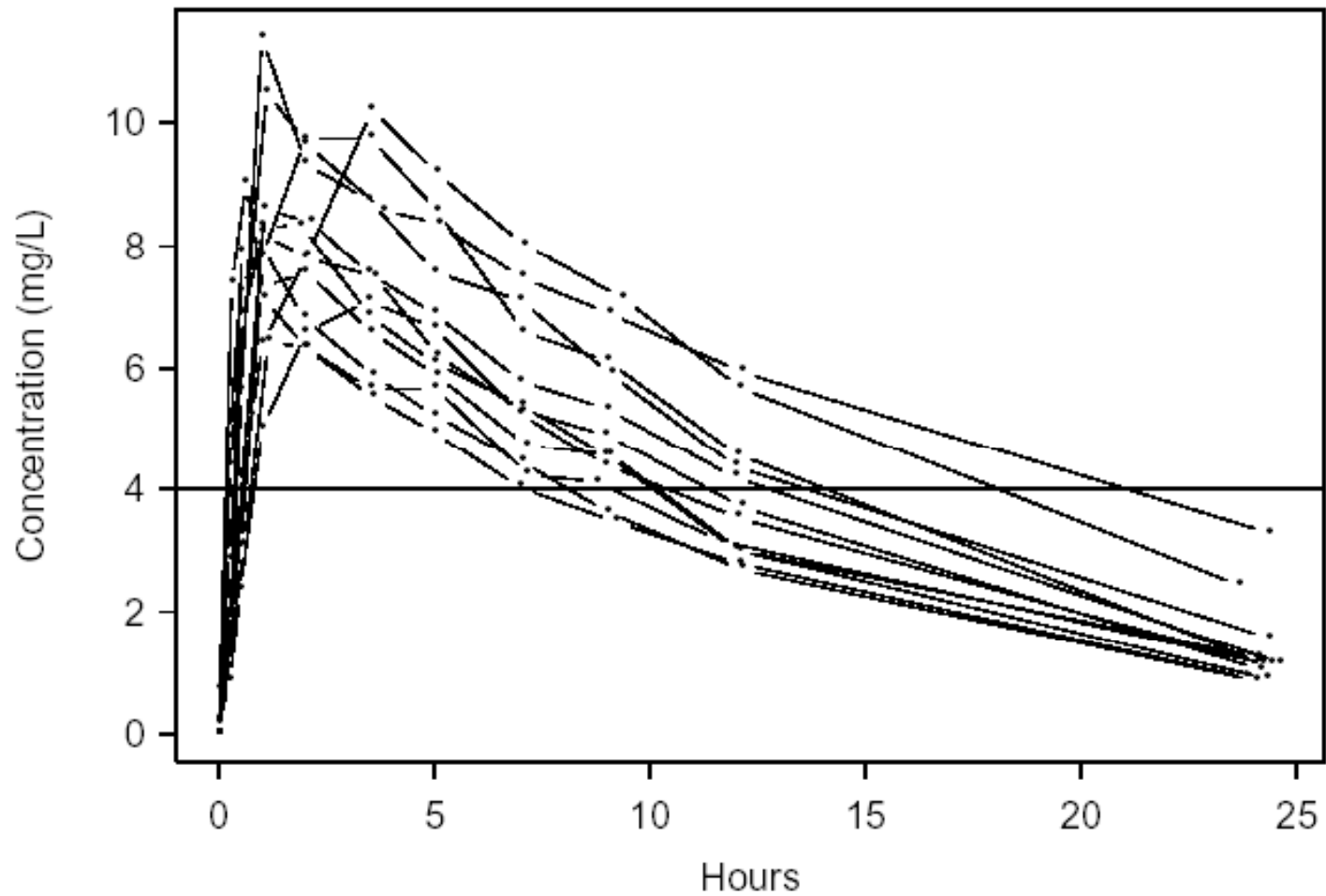


Theophylline Data

Robert Upton (see Davidian and Giltinan, 1995) gives Theophylline serum concentrations on patients that were given oral doses of the medicine.

- There are twelve different individuals in the experiment
- Times of sampling are the same for each individual. The concentrations were measured at 11 time points over 25 hours after administration of the medicine.

Theophylline Data



Other Data Sets from Chapter 1

- Transmitter vacuum tube data
 - Interval censored data
- Accelerated test of spacecraft nickel-cadmium battery cells
 - Eight experimental factors
 - The first five factors were environmental or accelerating factors
 - The other three factors were product-design factors that could be adjusted in the product design to optimize performance and reliability of the batteries to be manufactured.
 - The experiment ran 82 batteries, each with 5 cells
 - Each battery was tested at a combination of factor levels determined according to a central composite experimental plan.