Chapter 1

Reliability Concepts and Reliability Data

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Based on the authors' text *Statistical Methods for Reliability Data*, John Wiley & Sons Inc. 1998.

July 18, 2002
12h 24min

Chapter 1
Reliability Concepts and Reliability Data
Objectives

- Explain basic concerns relating to product reliability.
- List some reasons for collecting reliability data.
- Describe the distinguishing features of reliability data.
- Describe general models for reliability data.
- Provide examples of reliability data and describe the motivation for the collection of the 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. 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: Reliability is quality over time** (Condra 1993).

Reasons for Collecting Reliability Data

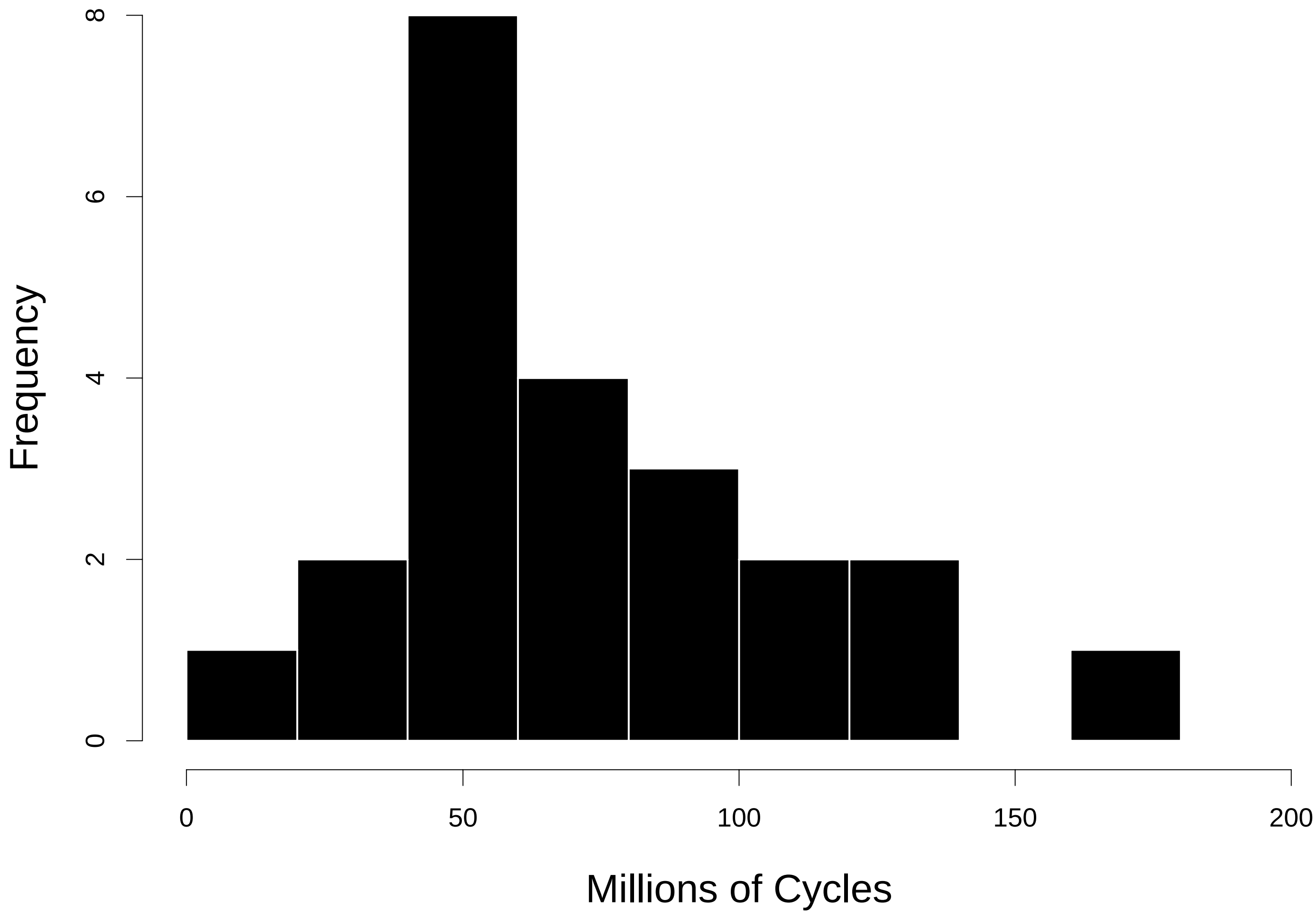
- Assessing characteristics of materials.
- Predict product reliability in design stage.
- Assessing the effect of a proposed design change.
- Comparing two or more different manufacturers.
- Assess product reliability in field.
- Checking the veracity of an advertising claim.
- Predict product warranty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

Other Common Names for Reliability Data

- Life data.
- Failure-time data.
- Survival data.
- Event-time data.

Also, degradation data (somewhat different).

Ball Bearing Failure Data
(Lieblein and Zelen 1956. Data from Lawless 1982)



Example: Ball Bearing Data

Data from fatigue endurance tests for deep–groove ball bearings from four major bearing companies (Lawless 1982).

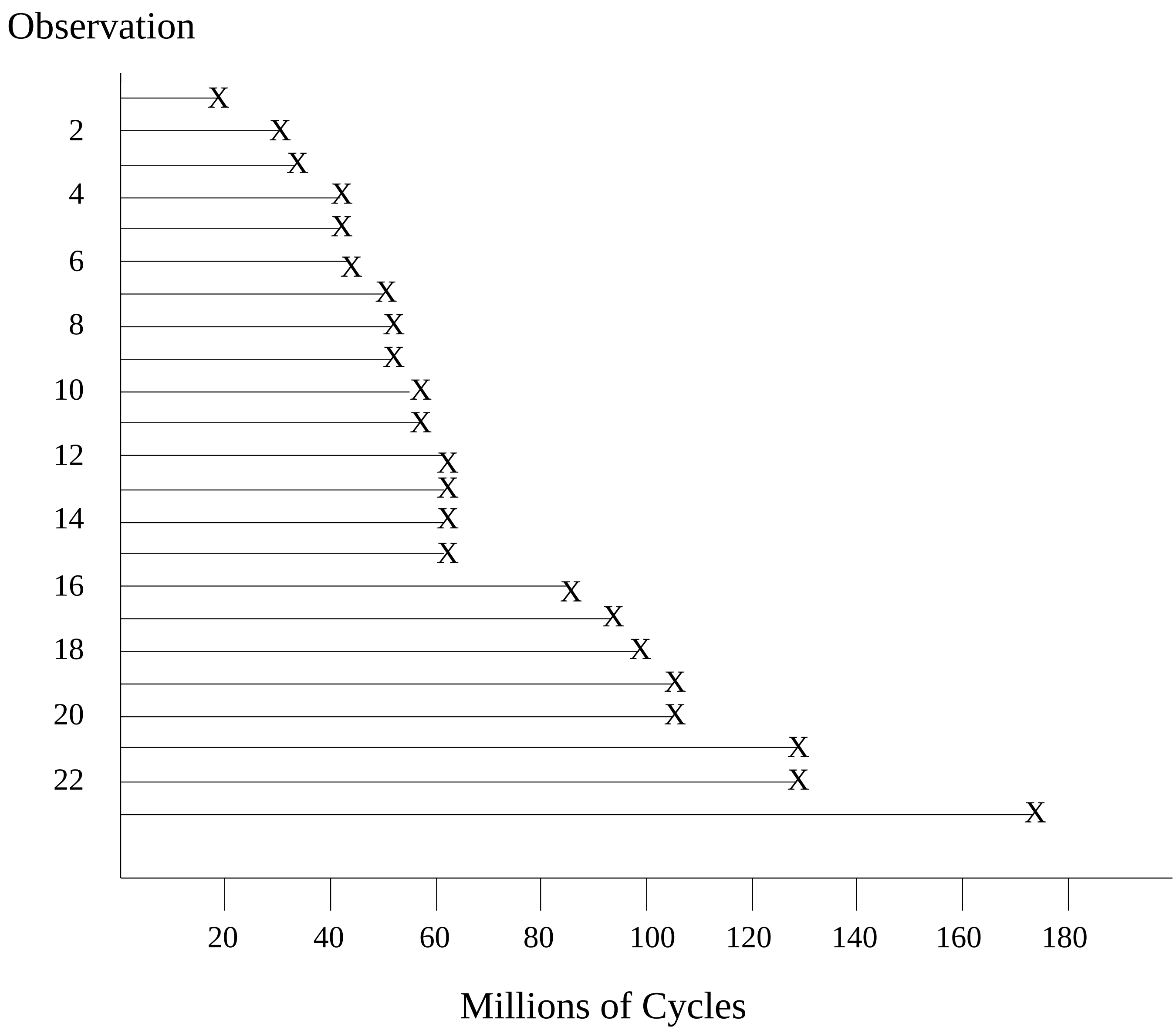
The data: Millions of revolutions to failure for each of $n = 23$ bearings before fatigue failure.

Main 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 the industry on the appropriate parameter values to use.

Ball Bearing Failure Data
(Lawless 1982)



Distinguishing Features of Reliability Data

- Data are typically censored (bounds on observations).
- Positive responses (e.g., time or cycles to failure) need to be modeled. Commonly used distributions incluse the exponential, lognormal, Weibull, and gamma distributions. The normal distribution is not common.
- Model parameters **not** of primary interest (instead, failure rates, quantiles, probabilities).
- Extrapolation often required (e.g., want proportion failing at 3 years for a product in the field only one year).

Issues in Life 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.

Example: IC Data

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

.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.		

Example: IC Data

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

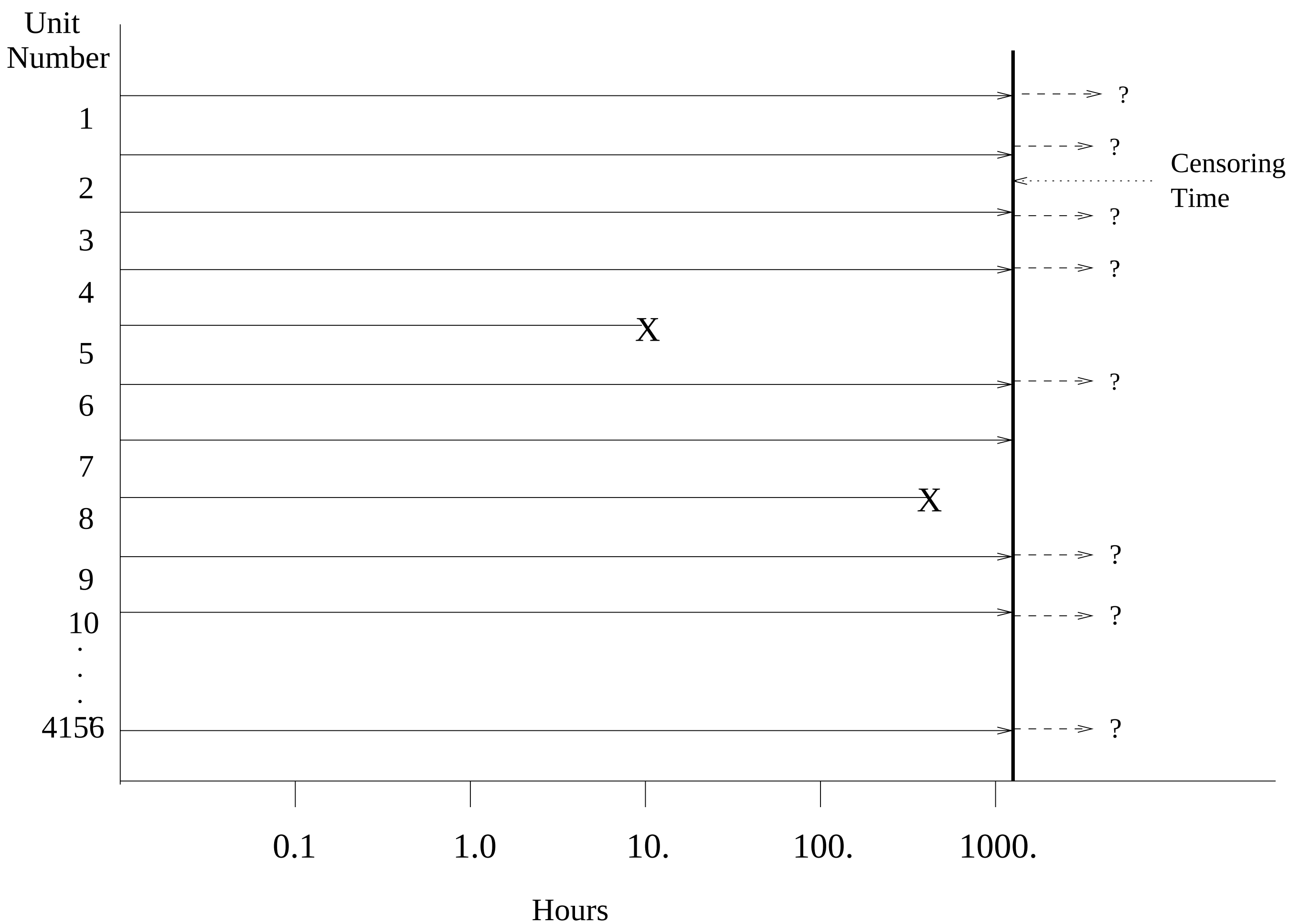
Issues:

- Simple random sampling?
- Inspection/record times?
- Explanatory variables (fixed, random)?
- Other sources of variability?

Questions:

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

Failure Pattern 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)



Repairable Systems and Nonrepairable Units

- Reliability 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.

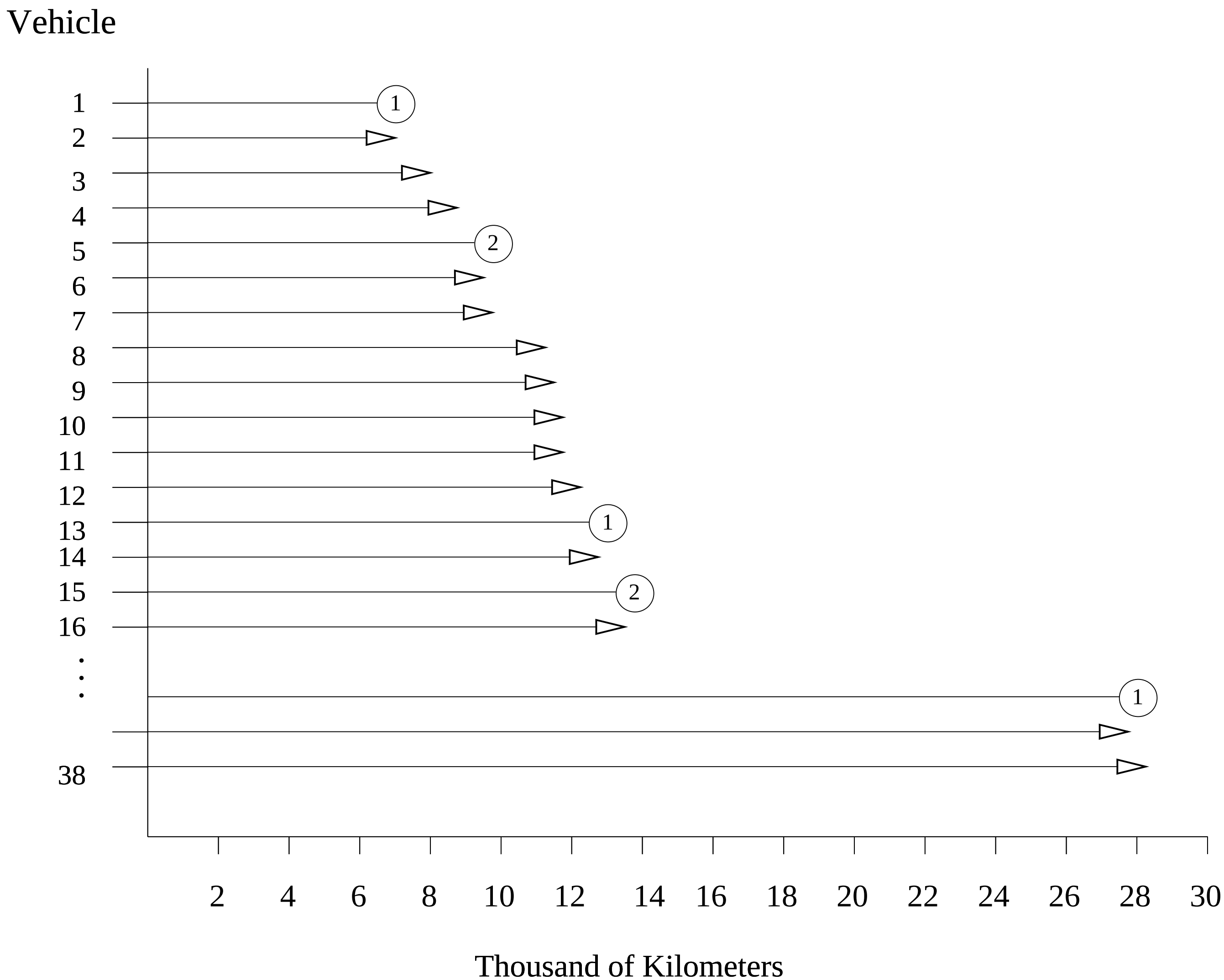
- Data on **Repairable Systems** describe the failure trends and patterns of an overall system.

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.
- One might be interested in the distribution of time to failure for mode M1, mode M2, or in the overall failure-time distribution of the part.

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 (e.g., statistical intervals to reflect statistical uncertainty/variability).
- Graphical display of results.
- Graphical and analytical diagnostics and assessment of assumptions.
- Sensitivity Analysis.
- Conclusions.

Computer Software

Integrated software not available yet. Some capabilities in:

- S-PLUS / SPLIDA
- SAS
- JMP
- MINITAB
- WinSMITH (formally WeibullSMITH)
- Weibull++ / ALTMA

With S-PLUS or SAS one can accomplish most of the data analyses needed for this course. MINITAB and JMP also have useful capabilities.

For single distribution analysis WeibullSMITH and Weibull++ are fairly complete and easy to use.

Example: Heat Exchanger Tube Crack Data

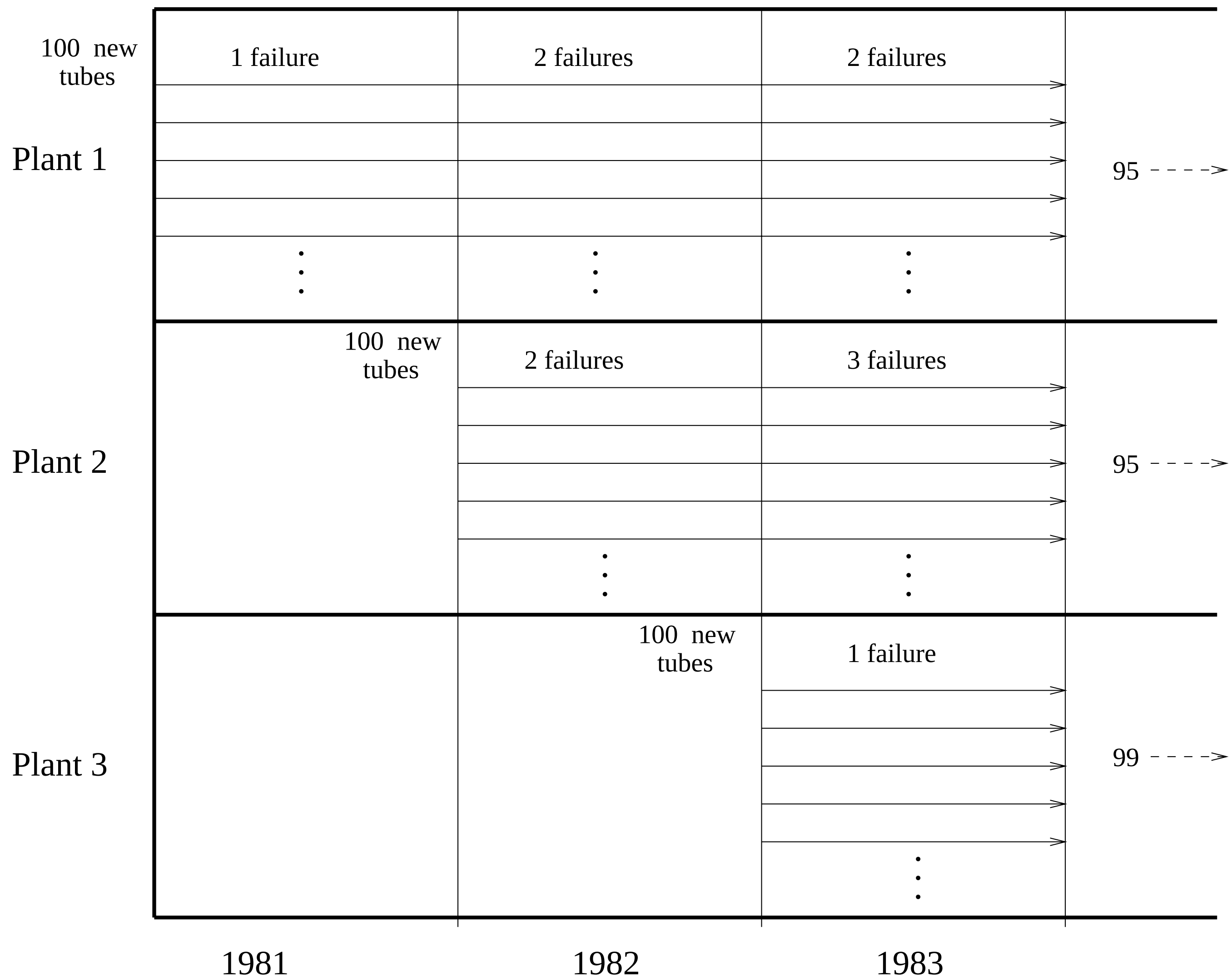
Data from heat exchangers from power plants.

- 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 3 plants with same design. Each plant entered into service at different dates.

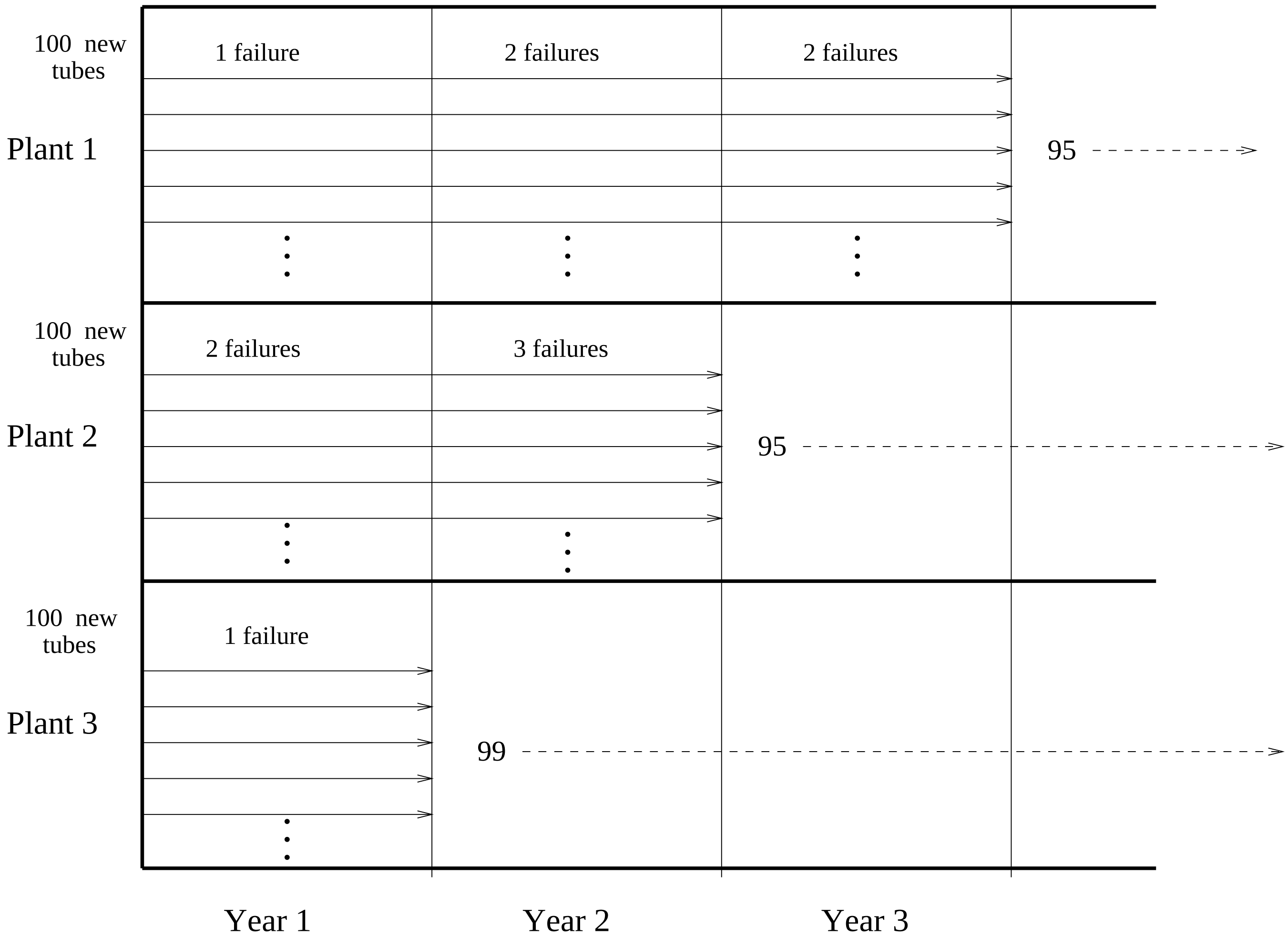
Cracked tubes at the end of each year,

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



Example: Turbine Wheel Data (Nelson 1982)
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

Example: Turbine Wheel Data

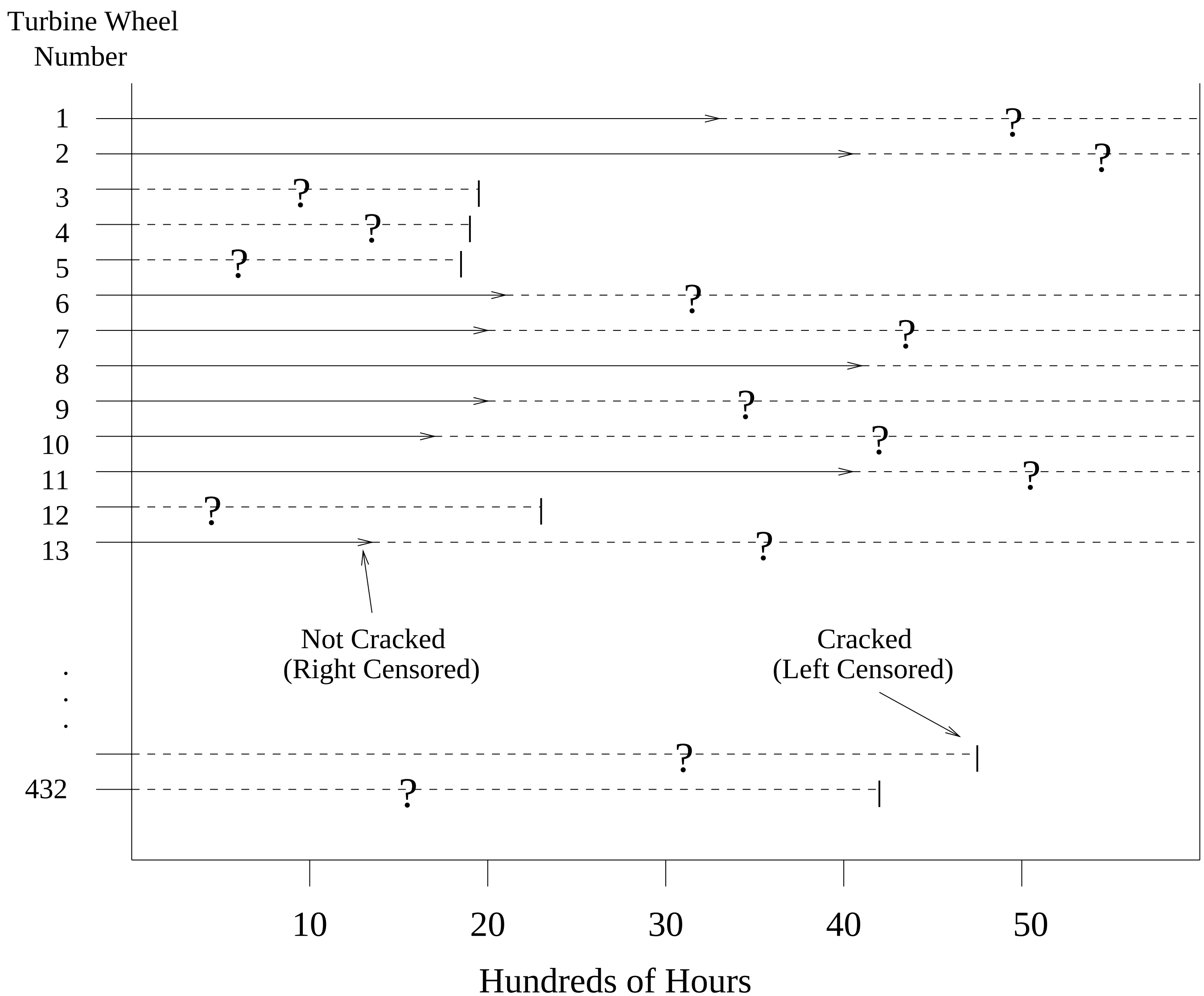
Each of $n = 432$ wheels was inspected once to determine if it had started to crack or not. Wheels had different ages at inspection (Nelson 1982).

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

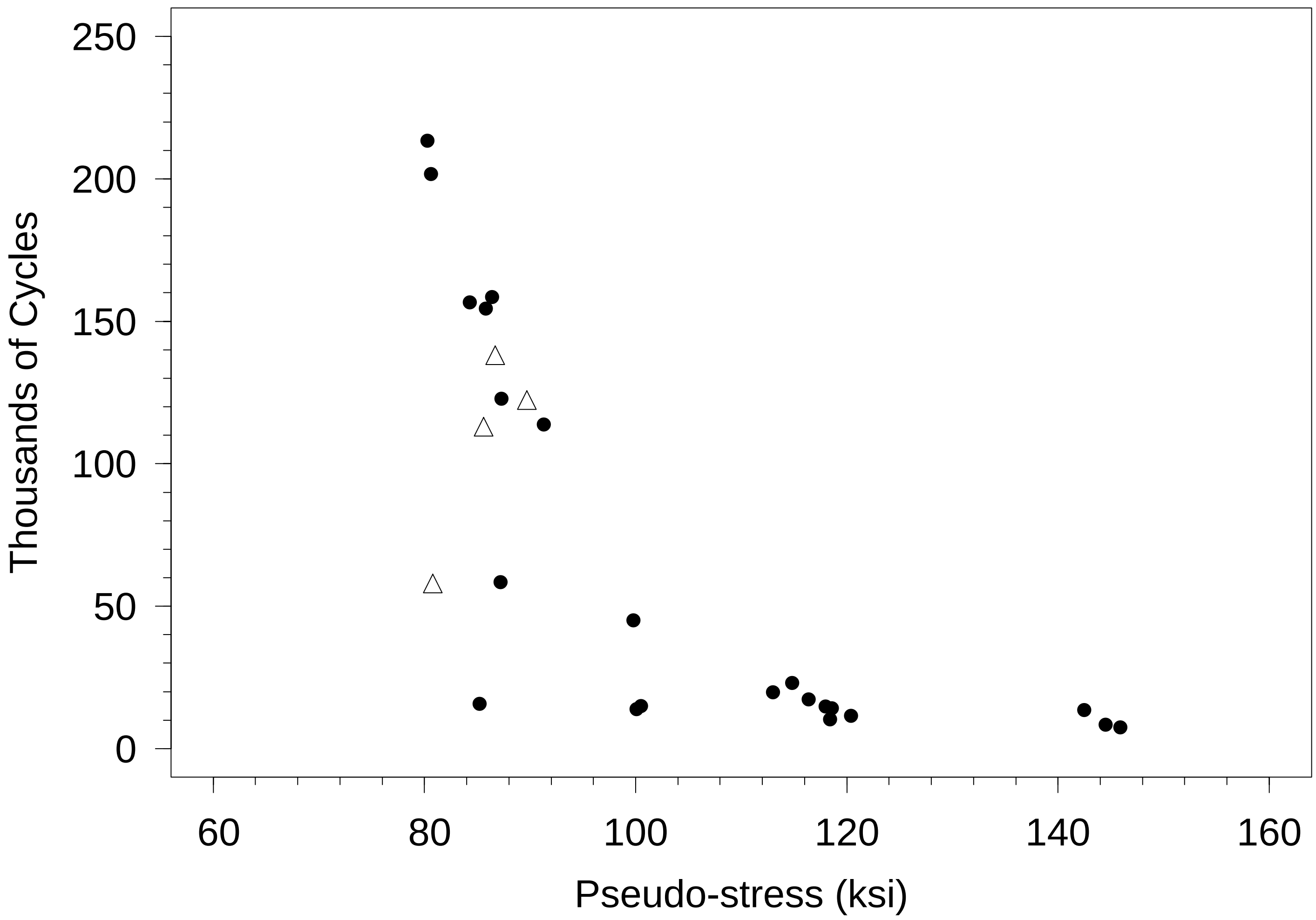
- Need to schedule regular inspections.
- Estimate the distribution of time to crack.
- Is the reliability of the wheels getting worse as the wheels age?

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

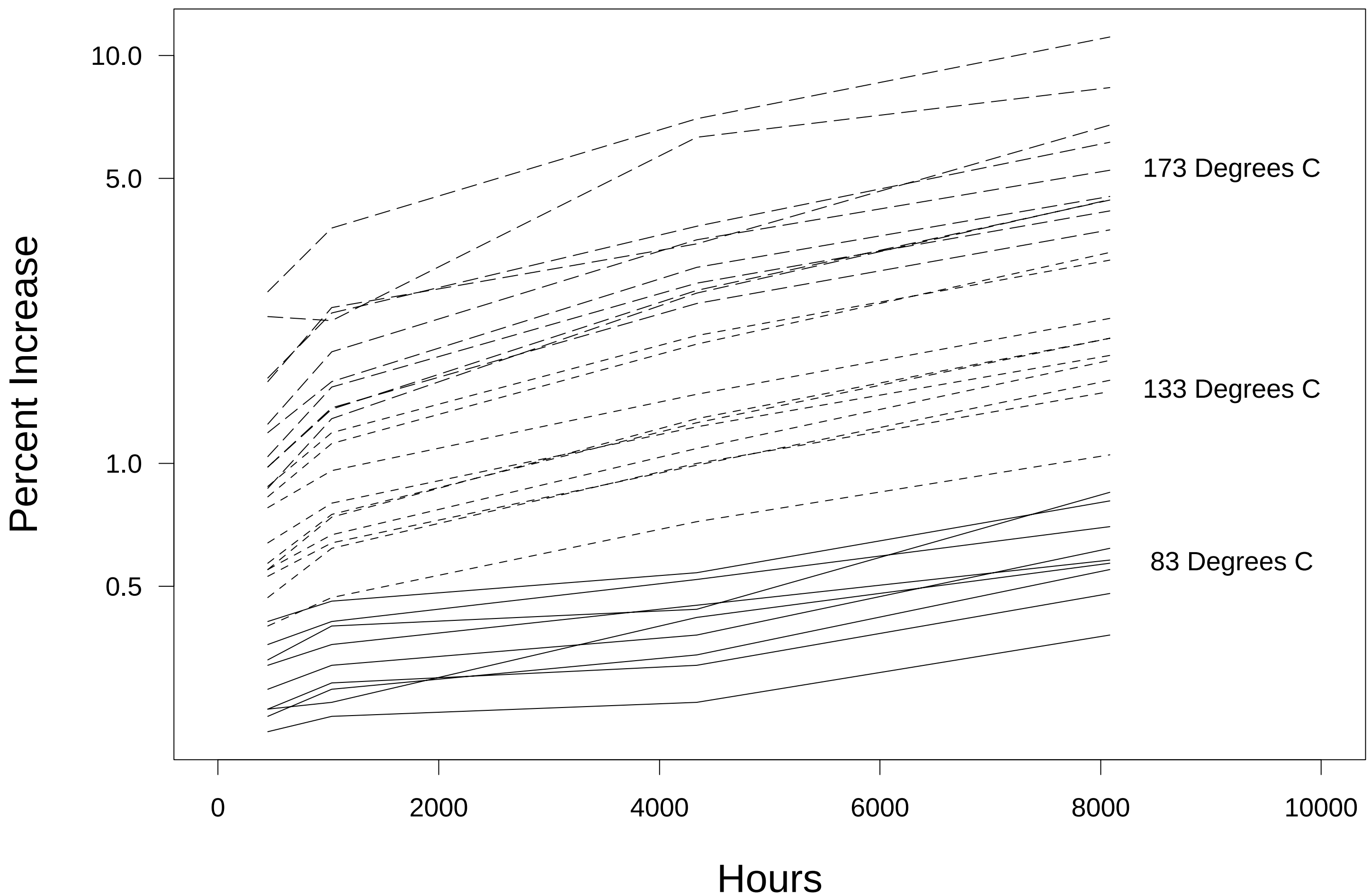
Turbine Wheel Inspection Data (Nelson 1982)
Summary at Time of Study



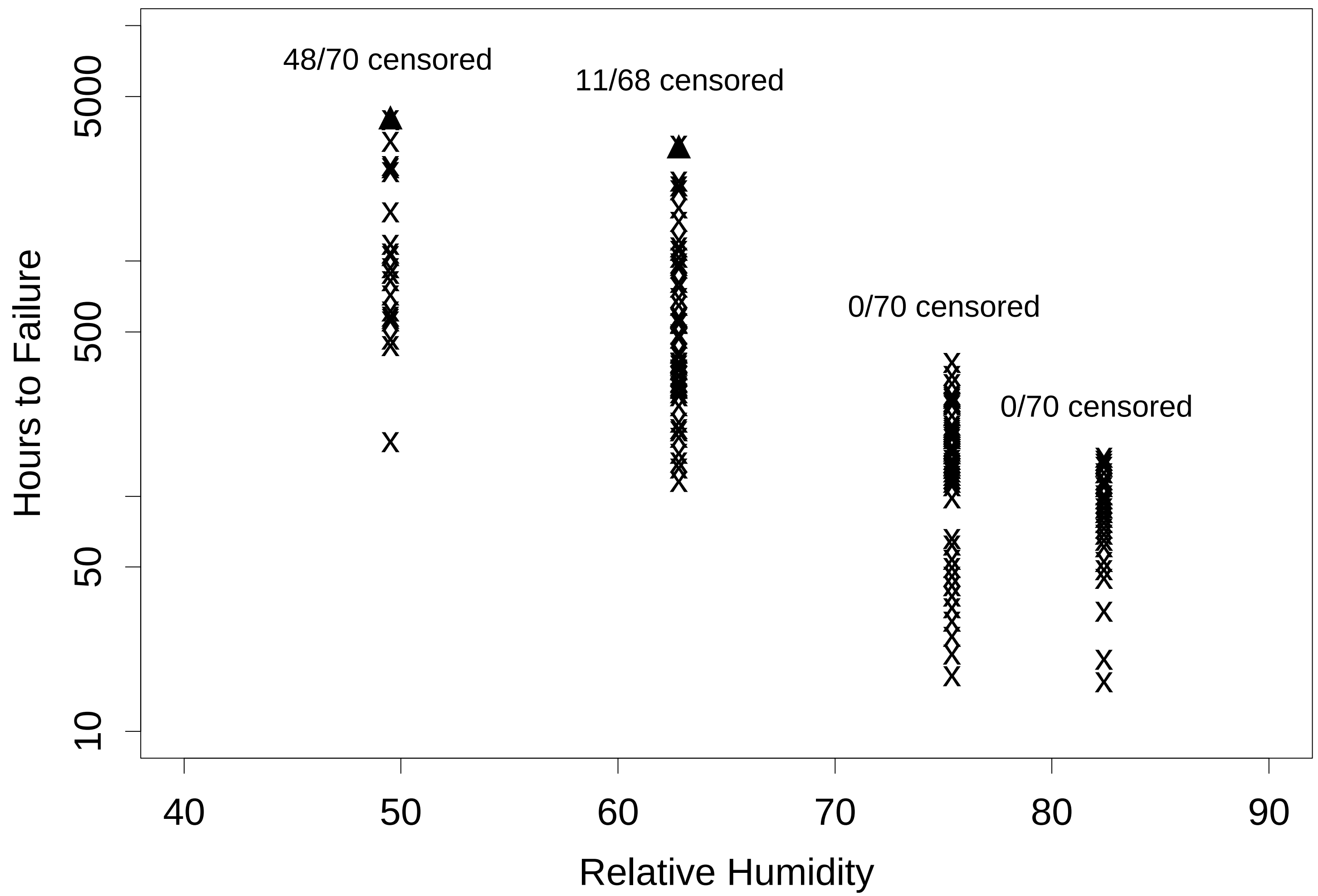
Scatter Plot of Low-Cycle Fatigue Life Versus Pseudo-Stress for Specimens of a Nickel-Base Superalloy (Nelson 1990)



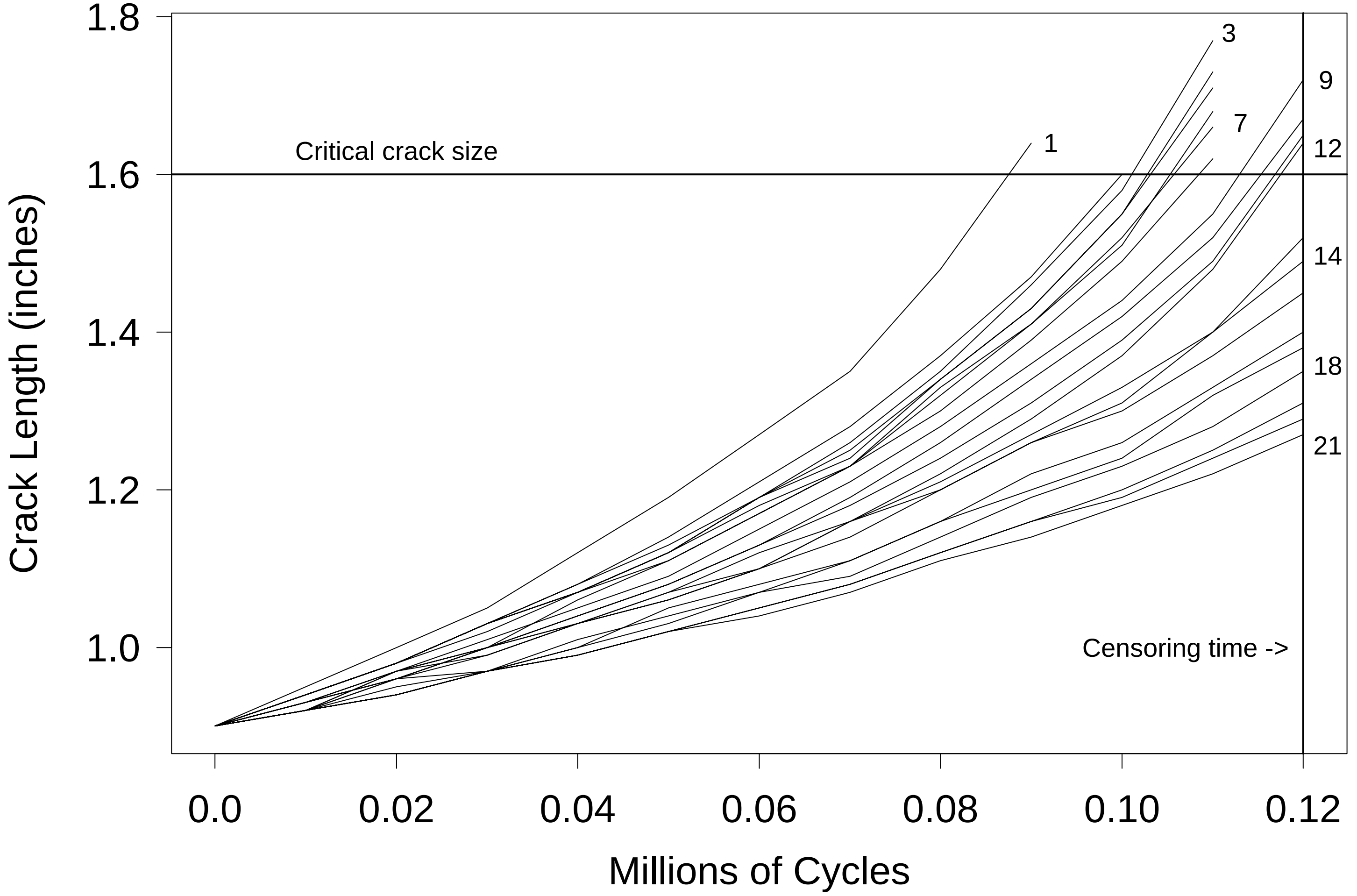
Change in Resistance Over Time of Carbon-Film Resistors (Shiomi & Yanagisawa 1979)



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



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



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.
- 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 can not blindly apply it ignoring the distinct nature of the problem handled in these two areas.

Example: DMBA Data

Number of days until the appearance of a carcinoma in 19 rats painted with carcinogen DMBA.

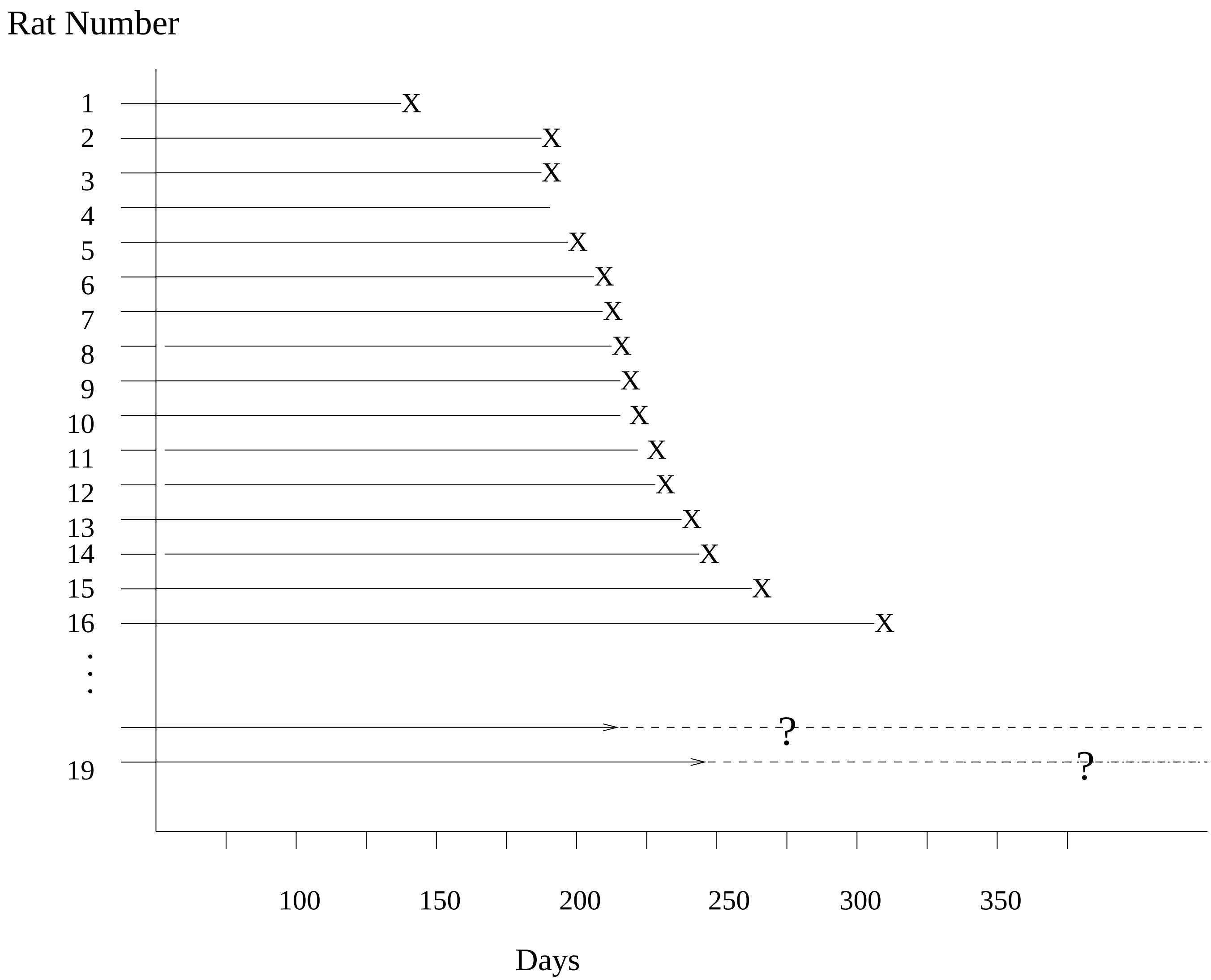
Days	Status	Days	Status
143	dead	216	censored
188	dead	220	dead
188	dead	227	dead
190	dead	230	dead
192	dead	234	dead
206	dead	244	censored
209	dead	246	dead
213	dead	265	dead
216	dead	304	dead

Data from Pike (1966). See Lawless (1982).

Example: DMBA Data

- DMBA is a carcinogen.
- $n = 19$ rats observed and 17 have developed a carcinoma by the time the data were collected.
- Interested on the nonparametric estimate of of the failure-time distribution.
- There is also interest in the possibility of modeling these data with a Weibull distribution.

DMBA Data Summary
(Lawless 1982)



Example: IUD Data

Number of weeks to discontinuation of the use of an intra-uterine device.

Weeks	Status	Weeks	Status
10	failed	56	censored
13	censored	59	failed
18	censored	75	failed
19	failed	93	failed
23	censored	97	failed
30	failed	104	censored
36	failed	107	failed
38	censored	107	censored
54	censored	107	censored

Data from WHO (1987). See Collett (1994).

Example: IUD Data

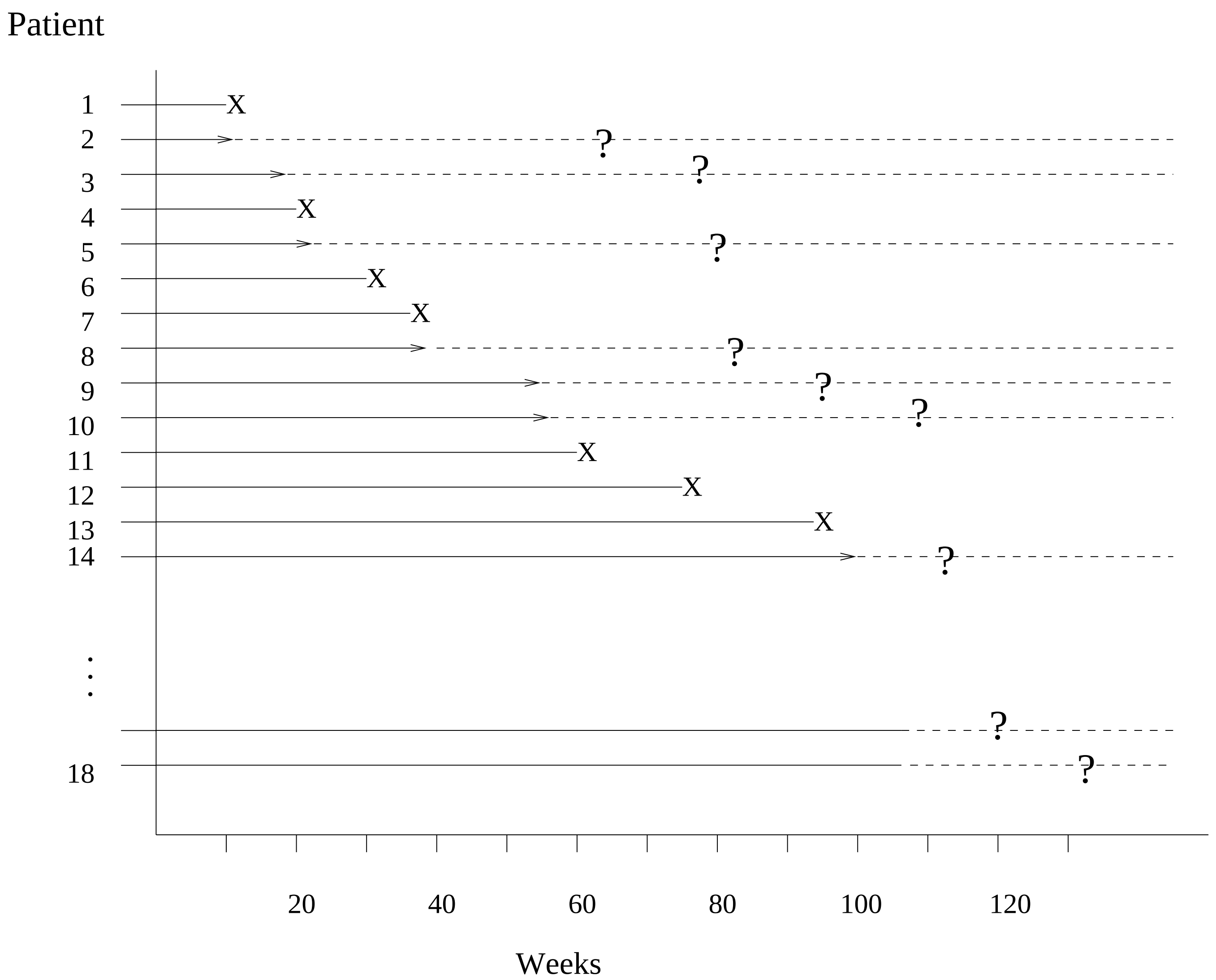
The occurrence of irregular or prolongated bleeding is an important criterion in the evaluation of modern contraceptive devices.

- The data are weeks from the moment of use of an IUD (Multiload 250) until discontinuation because of bleeding problems.
- A total of 18 women, aged between 18 and 35 years and who had 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.

- 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)



Example: Stanford Heart Transplant Data (SHTD) (Miller and Halpern 1982)

Miller and Halpern (1982) 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:

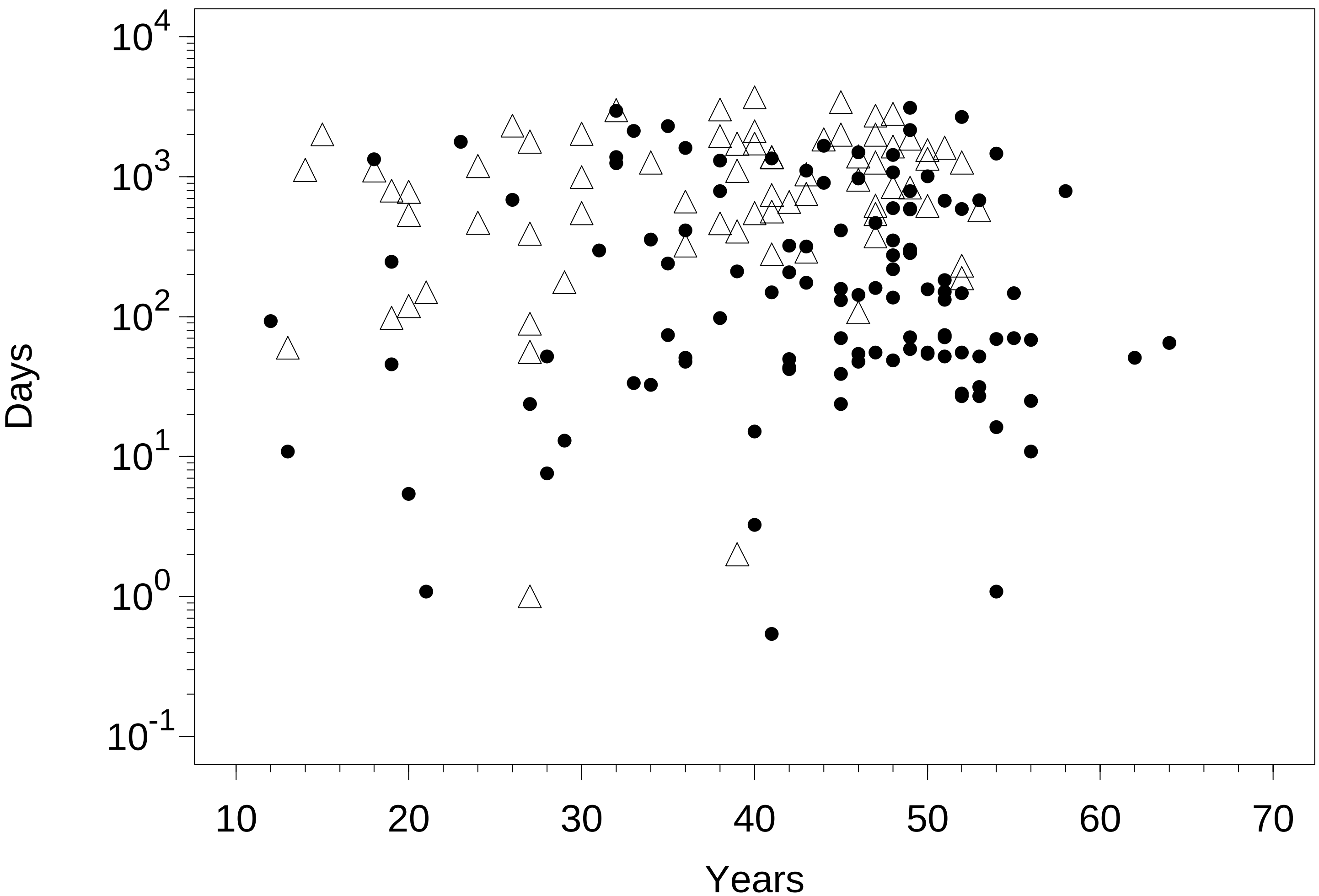
- Time, measured in days from date of transplant.
- Status code (dead or alive).
- Age in years of patient at first transplant.
- T_5 a mismatch score (missing for 27 of the cases).

Example: Stanford Heart Transplant Data (Continued)

- There is interest in knowing if the mismatch variable is related to failure-time.

- Want to know the effect that patient Age (at first transplant) has on failure-time.

Stanford Heart Transplant Data
(Miller and Halpern 1982)



Example: Indomethicin Data

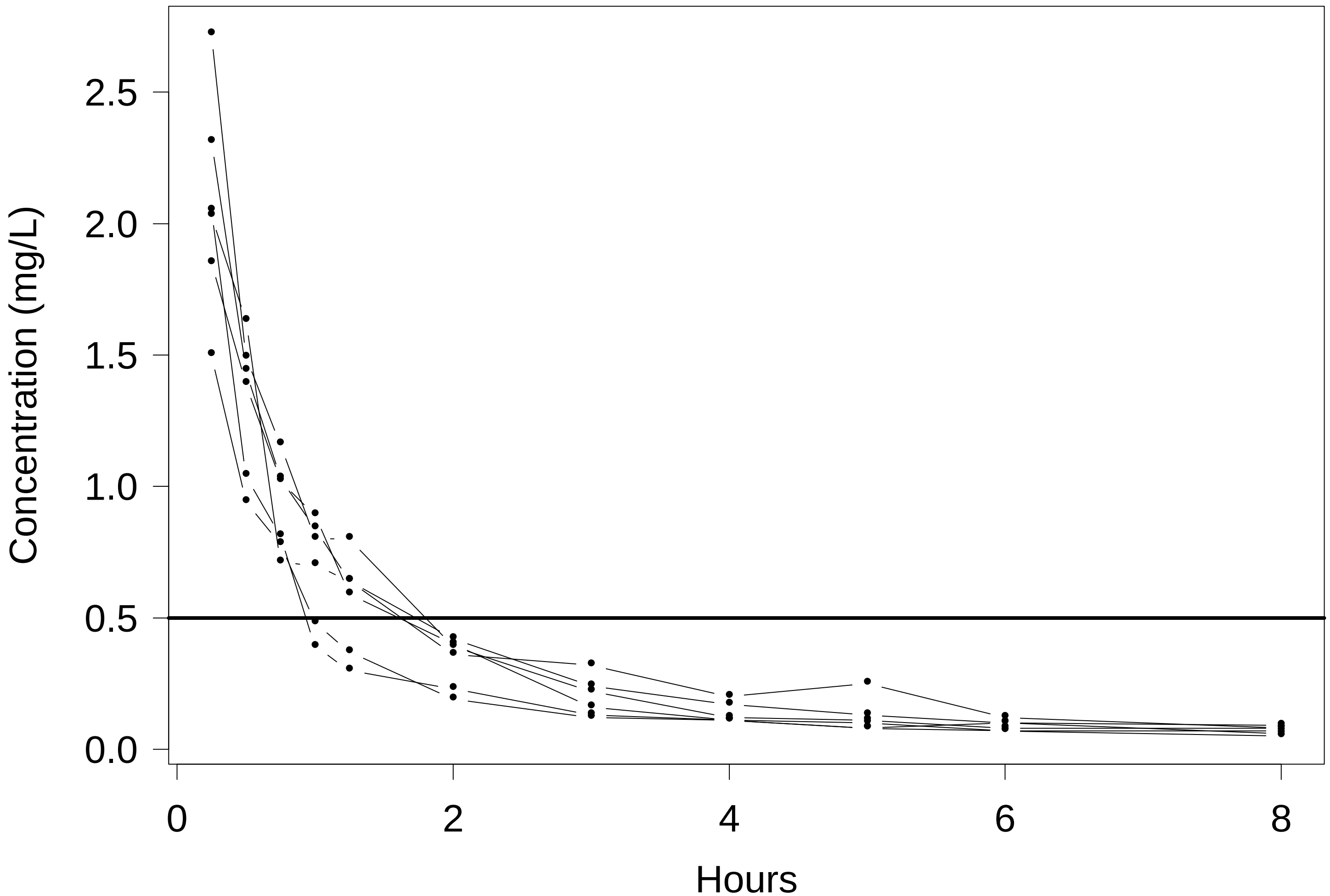
Kwan, Breault, Umbenhauer, McMahon, and Duggan (1976) give data on plasma concentrations of indomethicin (mg/L) following intravenous injection.

- There are 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 Indomethicin Following Intravenous Injection

(Kwan, Breault, Umbenhauer, McMahon, and Duggan 1976)



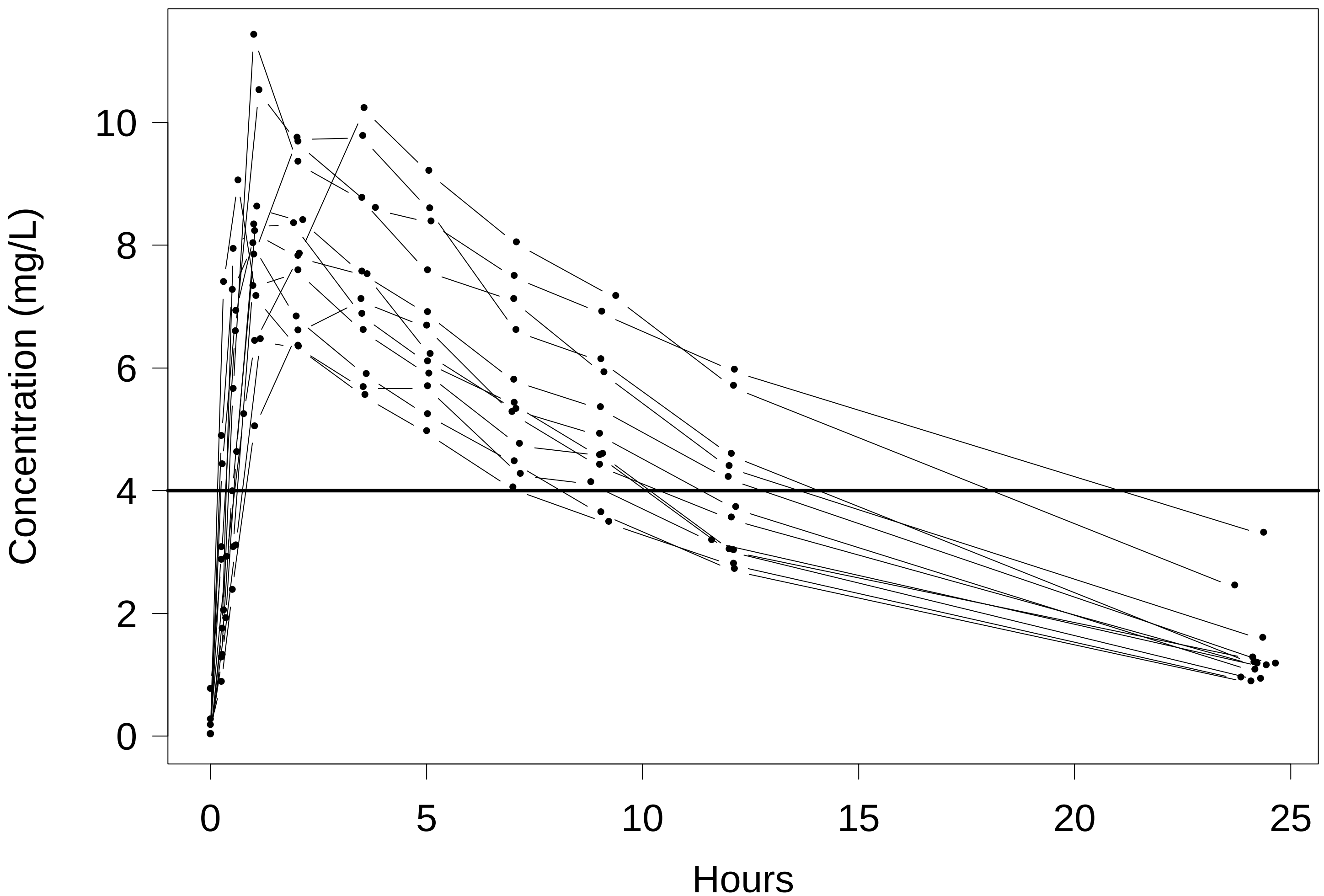
Example: Theophylline Data

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 Serum Concentrations
(Davidian and Giltinan 1995)



Other Data Sets from Chapter 1

- Circuit pack reliability field trial.
- Transmitter vacuum tube data.
- Accelerated test of spacecraft nickel-cadmium battery cells.