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.
• Provide examples of reliability data and describe the model.
• Describe the distinguishing features of reliability data.
• Outline a general strategy that can be used for data analysis.
• Define terms associated with reliability data.

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.
• Predicting product warranty costs.
• Predicting product reliability in design stage.
• Predicting the veracity of an advertising claim.
• Assessing the effect of a proposed design change.
• Assessing the effect of a proposed design change.
• Assessing the effect of a proposed design change.
• Assessing the effect of a proposed design change.
• Checking the veracity of an advertising claim.
• Assessing product reliability in field.
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Other Common Names for Reliability Data

• Life data.
• Failure-time data.
• Survival data.
• Event-time data.
• Degradation data (somewhat different).

Reasons for Collecting Reliability Data

• Increasing customer expectations.
• Increase global competition.
• Development of highly sophisticated products.
• New pressures on manufacturers to produce high quality products.
• Rapid advances in technology.
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.

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

Example: IC Data

Example: IC Data

Issues in Life Data Analysis

- Causes of failure and degradation leading to failure.
- Identification of time origin and time of failure.
- Definition of time scale.
- Environmental effects on reliability.
- Model parameters not of primary interest (instead, failure rates, quantiles, probabilities).
- 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 include the exponential, lognormal, Weibull, and gamma distributions. The normal distribution is not common.
  - Extrapolation often required (e.g., want proportion failing at 3 years for a product in the field only one year).
Example: IC Data

n = 4,156 ICs tested for 1,370 hours at 80°C and 80% relative humidity. There were 28 failures (Meeker 1987).

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

**Issues:**
- Simple random sampling?
- Inspection/record times?
Integrated software not available yet. Some capabilities in:

- S-PLUS / SPLIDA
- SAS
- JMP
- MINITAB
- WinSMITH (formally WeibullSMITH)
- Weibull++ 6 / ALTA 6 Standard / ALTA 6 PRO

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++ 6 are fairly complete and easy to use. For single distribution analysis, WinSMITH and Weibull++ 6 have useful capabilities.

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.

<table>
<thead>
<tr>
<th>Exchanger Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

Example: Turbine Wheel Data (Nelson 1982)

<table>
<thead>
<tr>
<th>Hours</th>
<th># Cracked</th>
<th># Not Cracked</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3</td>
<td>39</td>
</tr>
<tr>
<td>110</td>
<td>4</td>
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<td>120</td>
<td>2</td>
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<td>130</td>
<td>7</td>
<td>66</td>
</tr>
<tr>
<td>140</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>150</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>160</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>170</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>180</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>190</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Example: Heat Exchanger Tube Crack Inspection Data

100 new tubes

95 failures

1981 1982 1983

Plant 3

Plant 2

Plant 1

100 new tubes

1 failure

2 failures

2 failures
Degradation Data

- Special methods of analysis needed (Chapters 13, 21, 22).
- Important connections with physical mechanisms of failure.
- Becoming more common in certain areas of component re-
  - Provides information on progression toward failure.

Turbine Wheel Crack Initiation Data

<table>
<thead>
<tr>
<th>Count</th>
<th>Row</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 25</td>
<td></td>
</tr>
</tbody>
</table>

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

Pseudo-stress (ksi) | Thousand of Cycles
--- | ---
| 60 | 80 | 100 | 120 | 140 | 160 |
| 0 | 10 | 20 | 30 | 40 | 50 |

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

<table>
<thead>
<tr>
<th>Hours</th>
<th>Percent Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>500</td>
<td>1.0</td>
</tr>
<tr>
<td>10000</td>
<td>5.0</td>
</tr>
<tr>
<td>2000</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Test Data (Meeker & LuValle 1995)

Scatter Plot of Printed Circuit Board Accelerated Life

Relative Humidity | Hours to Failure
--- | ---
| 40 | 50 | 60 | 70 | 80 | 90 |
| 100 | 200 | 300 | 400 | 500 | 600 |

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

Millions of Cycles | Crack Length (inches)
--- | ---
| 0.0 | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 |
| 1.0 | 1.2 | 1.4 | 1.6 | 1.8 |

Degradation Data

- Provides information on progression toward failure.
- Important connections with physical mechanisms of failure.
- Becoming more common in certain areas of component re-
  - Special methods of analysis needed (Chapters 13, 21, 22).

Summary at Time of Study

- Turbine Wheel Inspection Data (Nelson 1982)
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 biomedical studies, one cannot 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.

<table>
<thead>
<tr>
<th>Days</th>
<th>Status</th>
<th>Days</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>143</td>
<td>dead</td>
<td>216</td>
<td>censored</td>
</tr>
<tr>
<td>188</td>
<td>dead</td>
<td>220</td>
<td>dead</td>
</tr>
<tr>
<td>188</td>
<td>dead</td>
<td>227</td>
<td>dead</td>
</tr>
<tr>
<td>190</td>
<td>dead</td>
<td>230</td>
<td>dead</td>
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<tr>
<td>192</td>
<td>dead</td>
<td>234</td>
<td>dead</td>
</tr>
<tr>
<td>206</td>
<td>dead</td>
<td>244</td>
<td>censored</td>
</tr>
<tr>
<td>209</td>
<td>dead</td>
<td>246</td>
<td>dead</td>
</tr>
<tr>
<td>213</td>
<td>dead</td>
<td>265</td>
<td>dead</td>
</tr>
<tr>
<td>216</td>
<td>dead</td>
<td>304</td>
<td>dead</td>
</tr>
</tbody>
</table>

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 in the nonparametric estimate of the failure-time distribution.

Example: IUD Data

Number of weeks to discontinuation of the use of an intrauterine device.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Status</th>
<th>Weeks</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>failed</td>
<td>56</td>
<td>censored</td>
</tr>
<tr>
<td>13</td>
<td>failed</td>
<td>59</td>
<td>failed</td>
</tr>
<tr>
<td>18</td>
<td>censored</td>
<td>75</td>
<td>failed</td>
</tr>
<tr>
<td>19</td>
<td>failed</td>
<td>93</td>
<td>failed</td>
</tr>
<tr>
<td>23</td>
<td>censored</td>
<td>97</td>
<td>failed</td>
</tr>
<tr>
<td>30</td>
<td>failed</td>
<td>104</td>
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<tr>
<td>36</td>
<td>censored</td>
<td>107</td>
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<td>54</td>
<td>censored</td>
<td>107</td>
<td>censored</td>
</tr>
<tr>
<td>38</td>
<td>censored</td>
<td>304</td>
<td>dead</td>
</tr>
<tr>
<td>50</td>
<td>failed</td>
<td>304</td>
<td>dead</td>
</tr>
</tbody>
</table>


Example: IUD Data

• The occurrence of irregular or prolonged 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.

• The censoring occurred because of desire of pregnancy, who had experienced two previous pregnancies, 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 the median time to discontinuation.
  ▶ Estimate the probability that a woman will stop using the device after a given period of time.
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.
- Related to failure-time.
- There is interest in knowing if the mismatch variable is related to failure-time.

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

- Times of sampling are the same for each individual. These are six different individuals in the experiment.
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Kwan, Breault, Umbenhauer, McMahon, and Duggan (1976) give data on plasma concentrations of indomethicin (mg/L) following intravenous injection.
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.
- There are twelve different individuals in the experiment.
- Theophylline serum concentrations on patients that were given oral doses of the medicine.