

DATA ANALYSIS FOR PRODUCT REPAIRS AND OTHER RECURRENT-EVENTS APPLICATIONS

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Most reliability and survival data analyses deal with data with one event for each sample unit, end of life. However, in many applications, sample units can undergo repeated events, such as repairs of products, recurrences of tumors, consumer purchases on the Internet, remarriages, and reincarcerations. This course presents analyses of such recurrent-events data that include costs, not just counts, of recurrences, which do not yet appear in most texts. The course is based on Wayne Nelson's new book *RECURRENT-EVENTS DATA ANALYSIS FOR PRODUCT REPAIRS, DISEASE RECURRENCES, AND OTHER APPLICATIONS*, published by ASA-SIAM in 2003, www.siam.org. The course and book content follow.

1. INTRODUCTION TO RECURRENT EVENTS DATA AND APPLICATIONS

This chapter describes recurrent events data on a sample of units from a population and the information sought from such data. Such data are illustrated with three data sets: transmission repairs on cars, bladder tumor recurrences, and births of children to statisticians. The first two sets contain exactly observed event and censoring times; the third contains interval (grouped) data. Methods for graphically displaying such data are given. This chapter also lists other applications and overviews the book.

2. POPULATION MODEL, MCF, AND BASIC CONCEPTS

This chapter presents the population model for such recurrent-events data -- a simplified stochastic process model consisting of a cumulative history function for each population unit. These population functions are summarized with the population Mean Cumulative Function (MCF) for the "cost" or number of recurrences. The MCF yields most information of interest in applications, for example, the number of transmission repairs on warranty and the repair rate as a function of population age. The model extends to continuous history functions and to left censored and interval data, and is illustrated with other applications.

3. ESTIMATE OF THE MCF FOR EXACT DATA

This chapter presents a nonparametric estimate of the MCF, its plot, and the plot's interpretation. It shows how to calculate and plot the MCF estimate for exact data (exact values of event and censoring times). The MCF estimate is illustrated with the transmission and bladder tumor data. This chapter shows how to interpret a plot to get, among other information,

- the behavior of the recurrence rate (increasing or decreasing) as the population ages, important for product burn-in, overhaul, and retirement decisions,
- a prediction of the number or cost of recurrences for sample units in a future time period,
- an estimate of the average number or cost of recurrences up to a specified age, such as warranty age or at infinity,
- a comparison of data sets from different product designs, medical treatments, subpopulations, etc.,
- unexpected useful information, a great advantage of data plots.

This includes a survey of computer programs that calculate and plot the MCF estimate. A technical section explains the underlying assumptions and properties of the MCF estimate and typical difficulties in applications.

4. CONFIDENCE LIMITS FOR THE MCF

This chapter presents approximate confidence limits for the MCF for exact data. They are illustrated with the transmission and tumor data. This chapter surveys computer programs that calculate and plot the MCF estimate and confidence limits. Technical details include the underlying assumptions and properties of the limits.

5. ANALYSIS OF DATA WITH A MIX OF EVENTS

This chapter deals with data with a mix of events; for example, a product may fail from a number of causes and a birth may be a boy or girl. Usually one seeks to estimate the MCF

- for all events combined,
- separately for a particular event (say, a particular failure mode),
- for certain combinations of events (say, all types of failures on a particular subsystem),
- for the population when certain events are eliminated (say, through a product redesign that eliminates failure modes).

These estimates are illustrated with data on subway car motors and naval turbines.

6. ESTIMATE OF THE MCF FOR INTERVAL DATA

This chapter provides an estimate of the MCF for interval data, where event and censoring times are grouped into intervals. The estimate is illustrated with the childbirth data, which includes a comparison of the MCFs of men and women and data on refrigerator defrost controls.

7. COMPARISON OF SAMPLES

This chapter provides confidence limits and a plot to compare two sample MCFs. This is illustrated with the transmission and tumor data sets. The chapter surveys computer programs that calculate and make the plot. A technical section explains the underlying assumptions and properties of the method.

8. SURVEY OF FURTHER METHODS

This chapter surveys parametric methods for analysis of recurrence data. Topics include

- the Poisson and nonhomogeneous Poisson models, data analyses, and software,
- reliability growth models, data analyses, and software,
- renewal models and data analyses,
- models and data analyses for a single observed unit, rather than a sample of units,
- Poisson models with covariates, data analyses, and software,
- Cox model for recurrent events with covariates, data analyses, and software.

REFERENCES

INSTRUCTOR. Dr. Wayne Nelson is a leading expert on reliability and accelerated test data analysis. Formerly with General Electric Research & Development for 23 years, he now consults on and teaches engineering applications of Statistics for many companies, professional societies, and universities. For his contributions to reliability data analysis and accelerated testing, he was elected a Fellow of the Inst. of Electrical and Electronics Engineers, the Amer. Soc. for Quality, and the Amer. Statistical Assoc. He authored two other well-known Wiley books *ACCELERATED TESTING* and *APPLIED LIFE DATA ANALYSIS*. Among his 120+ publications, he received the Brumbaugh, Wilcoxon, and Youden Prizes of ASQ and eight outstanding presentation awards from ASA. His email address is WNconsult@aol.com.

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