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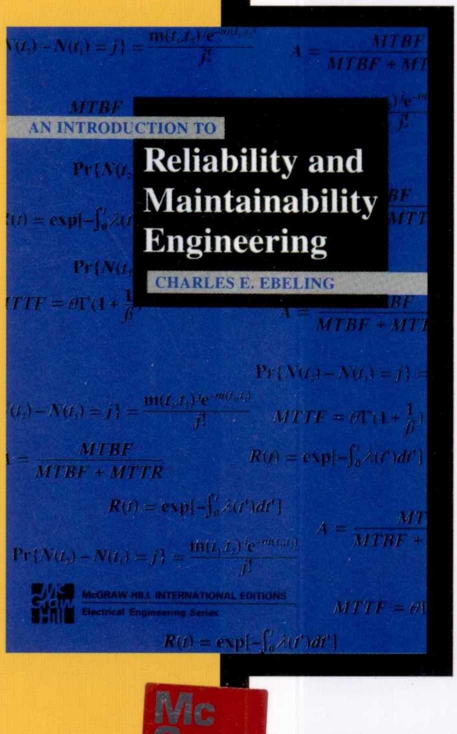
国外大学优秀教材——工业工程系列（影印版）

Charles E. Ebeling

可靠性与维修性工程概论

An Introduction to Reliability and Maintainability Engineering



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本书是在国外被广泛采用的可靠性工程方面的入门教材，对概念、模型、方法等的阐述清晰易懂。内容主要有3部分：第1部分为基本模型，包括失效分布与模型、系统可靠性、可靠性物理模型、可靠性与维修性设计、可用性分析等；第2部分为失效数据分析，包括可靠性试验、可靠性增长试验、失效与维修分布识别、拟合优度检验等；第3部分为应用案例与实施。

本书可作为工业工程、安全工程、机械工程以及其他涉及可靠性和安全等专业的本科生教材，也可作为研究生和工程技术人员的教材或参考书。

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PREFACE

ABOUT THE BOOK

This is an introductory textbook on reliability and maintainability engineering. It is written at the undergraduate senior and first-year graduate levels. The majority of this text may be covered in a one-semester course, or the entire text may be covered in two academic quarters. The text is divided into three parts. The first part covers reliability and maintainability modeling, the second part addresses the analysis of failure and repair data, and the third part provides examples and applications of reliability engineering and considers implementation of reliability and maintainability programs. Current textbooks on reliability have typically focused on either the modeling or on the statistical analysis of failure data. Many are written at an advanced level that requires extensive background in probability and statistics on the part of the student. It is the intent of this book to provide a broad coverage of the important concepts in reliability and maintainability and to avoid the more formal theory-proof approach. The student interested in additional depth is encouraged to read some of the more advanced texts available as well as appropriate technical journals.

Available with the text is MS-DOS software that may be used for problem-solving. Since failure and repair data analysis is computationally intensive, this software spares the student the burden of performing numerous and tedious calculations. Students fortunate to have one of the many commercial software reliability packages available are encouraged to use it. The practicing reliability or maintainability engineer will need to make extensive use of the computer in performing data analysis. Therefore, computer applications should be included as part of any study in reliability. The available software is intended for educational use only.

OBJECTIVE

The primary objective of this text is to introduce the subject of reliability and maintainability engineering to the engineering student, practicing engineer, or technical manager who has had a very limited formal education in probability and statistics. Hopefully, this is accomplished in part by the introduction of probability and statistics concepts within the context of their use in reliability. Additionally, derivations of many of the formulas are relegated to appendices so that the primary focus is on concepts and applications. Notation has been kept as simple as possible while attempting to adhere to convention. References to more advanced material are provided in appropriate places. Nevertheless, it is certainly true that those students who have had a formal introductory course or course in probability and statistics will benefit the most from this text. A secondary objective is to prepare the student for more advanced study in reliability and maintainability engineering and to enable the student to access the increasing amount of technical material available in the literature.

It is hoped that the material in this text will enable the student to collect and analyze failure and repair data, derive appropriate reliability and maintainability models, and apply these models in the design of products, components, and systems. The end result should be products and systems having improved reliability and maintainability characteristics.

ACKNOWLEDGMENTS

I wish to thank the several (anonymous) reviewers for their many helpful suggestions. To the extent that I have been able to respond to their criticism, the text has been immeasurably improved. If I fell short of their expectations, the limitation has been mine alone. I would be remiss if I did not acknowledge the help of several graduate students. Ken Beasley and Colleen Donohue have especially helped throughout this effort in numerous ways. The following individuals have contributed examples, exercises, or verified solutions: Wilbur Bhagat, Annette Clayton, David Gels, Ronald Niehaus, John Stahl, and James Wafzig. Special thanks go to the editorial and production staff at McGraw-Hill and at Publication Services. Their suggestions and editorial comments have been invaluable in producing a readable textbook. Finally, a special thanks to my wife, Patricia, who gave up several well-earned vacations and many evenings out while I worked on this manuscript. It is to her that I dedicate this book.

COURSE SOFTWARE

INSTRUCTIONS ON THE USE OF THE SOFTWARE TO ACCOMPANY THE TEXT

Available for use with this text is an MS-DOS executable file (REL.EXE) that may be run under DOS or under Windows as a non-Windows application. This software is available from the instructor and is included as part of the *Solutions Manual.* To execute the file, simply (1) type REL at the DOS prompt while in the directory the file is resident in; or (2) if not in the same directory as the file, include the path to the file (for example, >A:REL); or (3) when operating from Windows, double click on REL.EXE while in the file manager or Windows Explorer (Windows 95).

This software is intended for use in Part II of the text. It performs analysis on failure and repair data. Analysis options include:

- Empirical models for ungrouped and grouped complete and singly censored data and for multiply censored data, including life tables (multiply censored grouped data). For multiply censored data the models include the incremental rank method, the Kaplan-Miers product-limit estimator, and an alternative product-limit estimator.
- Least-squares analysis for fitting exponential, Weibull, normal, and lognormal distributions to either complete or censored data.
- The Duane reliability growth model.
- Nonhomogeneous Poisson processes (NHPP) (such as the AMSAA growth model).
- Maximum likelihood estimation for exponential, Weibull, normal, and lognormal distributions with complete or censored data.
- Goodness-of-fit tests including the chi-square, Bartlett (exponential), Mann (Weibull), Komogorov-Smirnov (normal and lognormal), and Cramer–von Mises (NHPP) with a test for trend.

Upon execution, the following main menu will appear:

```
MAIN MENU
INPUT/SAVE/OUTPUT OPTIONS
EMPIRICAL ANALYSIS
REL GROWTH NHPP POWER/LAW MODELS
LEAST-SQUARES CURVE FIT (PROB-PLOT)
MAXIMUM LIKELIHOOD ESTIMATE (MLE)
GOODNESS-OF-FIT TEST
QUIT
```

Entering data to the program is accomplished by selecting **INPUT/SAVE/OUTPUT OPTIONS** from the main menu. The **DATA/INPUT/DISPLAY MENU** shown below will appear. Initially data must be entered from the keyboard or from a compatible file provided with the text or created by the instructor. However, once you have entered data, they may be saved in a new file for subsequent use. To input data, the number of units at risk (or number of repair observations) is entered followed by the failure and censor (if applicable) times or repair times. Censored times are entered as negative values. Once the data have been entered, they may be displayed and corrections may be made if necessary. With three exceptions, input is accomplished through the input module, in which individual (or cumulative) failure or repair times are inserted. This allows the user to conduct several tests on the same data set without reentering the data. The three exceptions are group data and life tables, the Duane growth curve, and a manual input mode for the chi-square goodness-of-fit test. Each of these requires insertion of interval data at the respective module. Input data files carry the file extension .DAT, which is supplied by the program.

Output is generated and displayed on the screen by invoking the various modules. The output may also be selectively saved in a text file by selecting the **TURN ON/OFF WRITE OPTION** on the input menu and entering an S (SAVE) after each output display. This file can then be read by a word processor, edited, and printed. The output file has the file extension .TXT. The program automatically attaches the extension to the file when the user supplies the file name.

```
DATA INPUT/DISPLAY MENU
INPUT FROM A FILE
INPUT FROM KEYBOARD
UPDATE/DISPLAY DATA
SAVE INPUT DATA TO A FILE
TURN ON/OFF WRITE OPTION
```

Data Sets

Four data sets are included with the software for the student to use in becoming familiar with this software. The data were randomly generated from the distributions shown in the following table.

File (.DAT)	Sample size	Distribution	Parameters	Data type
EX1	50 at risk, 40 failures	Exponential	$\lambda = 0.001$	Multiply censored
EX2	35 at risk, 22 failures	Weibull	$\beta = 2; \theta = 500$	Type II censored
EX3	30 failures	Normal	$\mu = 5000; \sigma = 250$	Complete
EX4	22 repair times	Lognormal	$t_{med} = 3.5; s = 0.7$	Complete

CONTENTS

CHAPTER 1

Introduction

Things fail. During the past two years this author has experienced a lawn-mower casing crack, a washing machine fail, a car battery go dead, a toaster oven electrical plug burn, a water-heater leak, a floppy disk drive go bad, a TV remote control quit functioning, a stereo amplifier quit, an automobile engine starter fail, and a house roof leak. The cracked lawn-mower casing was a result of its aluminum construction having insufficient strength to withstand the stresses placed on it. The car battery, the engine starter, and the washing-machine motor experienced wearout after a "normal" life. The toaster oven plug was a poor design, considering the amount of current passing through it. Corrosion of the hot water tank caused it to leak. The corrosion was partly attributed to the lack of preventive maintenance, which required periodical draining of the bottom of the tank. The failure of the disk drive was a result of an unknown (premature) mechanical failure, and the TV remote control's failure was caused by a "random" electronic component failure. On the other hand, the stereo amplifier failure was caused by an open at a solder joint. Poor construction resulted in the house roof leaking adjacent to the dormers. Some of these failures caused much inconvenience in addition to their economic impact. Several of the failures raised concerns about personal safety, although no injuries resulted from them.

Many failures, however, are much more significant in both their economic and safety effects. For example, in 1946 the entire fleet of Lockheed Constellation aircraft was grounded following a crash killing four of the five crew members. The crash was attributed to a faulty design in an electrical conduit that caused the fuselage to burn. In 1979 the left engine of a DC-10 broke away from the aircraft during takeoff, killing 271 people. Poor maintenance procedures and a bad design led to the crash. Engine removal procedures introduced unacceptable stresses on the pylons. The Ford Pinto, introduced in 1971, was recalled by Ford in 1978 for modifications to the fuel tank to reduce fuel leakage and fires resulting from rear-end collisions. Numerous reported deaths, lawsuits, and the negative publicity eventually contributed to Ford discontinuing production of the Pinto. Firestone's steel-belted radials, introduced in 1972, failed at an abnormal rate as a result of the outer tread