FIFTH EDITION


# Practical Reliability Engineering

PATRICK D. T. O'CONNOR | ANDRE KLEYNER

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*'The concept of chance enters into the very first steps of scientific activity, by virtue of the fact that no observation is absolutely correct. I think chance is a more fundamental concept than causality, for whether in a concrete case a cause–effect relationship exists can only be judged by applying the laws of chance to the observations.'*

Max Born,
*Natural Philosophy of Cause and Chance*

*'A statistical relationship, however strong and however suggestive, can never establish a causal connection. Our ideas on causation must come from outside statistics, ultimately from some theory.'*

Kendall & Stuart,
*The Advanced Theory of Statistics*

*'Reliability is, after all, engineering in its most practical form.'*

James R. Schlesinger
*Former US Secretary of State for Defense*

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**and**

**ANDRE KLEYNER**

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*To my wife Lois,*
*for encouragement and support,*
*and to the memory of Ina*

Patrick O'Connor

*To my wife and best friend Faina,*
*for her patience and unwavering support*

Andre Kleyner

# Contents

# Preface to the First Edition

This book is designed to provide an introduction to reliability engineering and management, both for students and for practising engineers and managers. The emphasis throughout is on practical applications, and the mathematical concepts described are accordingly limited to those necessary for solution of the types of problems covered. Practical approaches to problem-solving, such as the use of probability plotting techniques and computer programs, are stressed throughout. More advanced texts are cited for further reading on the mathematical and statistical aspects. The references given in the Bibliographies are limited to those considered to provide a direct continuation of the chapter material, with the emphasis on practical applications. Tables and charts are provided to complement the analytical methods described, and numerous worked examples are included.

The book describes and comments on the usage of the major national and government standards and specifications covering reliability engineering and management in the USA and the UK. It is considered that this is an important aspect of the practical approach, since so much engineering development work is now governed by such documents. The effects of current engineering, commercial and legislative developments, such as microelectronics, software-based systems, consumerism and product liability, are covered in some detail.

The requirements of the examination syllabi of the American Society for Quality Control, and the Institute of Quality Assurance (UK) in reliability engineering are covered, so the book will be suitable for use in courses leading to these qualifications. The emphasis on practical approaches to engineering and management, the comprehensive coverage of standards and specifications, and the overall layout of the book should make it equally as suitable as a general up to date reference for use in industry and in government agencies.

PATRICK O'CONNOR
1981

# Preface to the Second Edition

I have received much helpful criticism of the first edition of my book since it appeared in 1981. Whilst the reviews have generally not been unfavourable, critics have pointed out that, despite the title, the book was not quite practical enough in some areas. I have also come to realize this through my own work, particularly on the application of mathematical modelling and statistics to reliability problems. Consequently, much of the revision for the second edition has been to add to what I consider to be the practical aspects of management and engineering for reliability.

I have added to the sections on reliability prediction, demonstration and measurement, to explain and to stress the fundamental and considerable uncertainty associated with attempts to quantify and forecast a property of engineered products which is inherently non-deterministic. I believe that when people involved in reliability work manage to unshackle themselves from the tyranny of the 'numbers game' the way is cleared for the practical engineering and management approaches that are the only ways to achieve the highly reliable products demanded by the markets of today. I have not removed the descriptions of the methods for quantifying reliability, since I believe that, when these are applied with commonsense and understanding of their inherent limitations, they can help us to solve reliability problems and to design and make better products.

I have added three new chapters, all related to the practical aspects.

The first edition described how to analyse test data, but included little on how to test. I have therefore written a new chapter on reliability testing, covering environmental and stress testing and the integration of reliability and other development testing. I am indebted to Wayne Tustin for suggesting this and for his help and advice on this subject.

The quality of manufacture is obviously fundamental to achieving high reliability. This point was made in the first edition, but was not developed. I have added a complete chapter on quality assurance (QA), as well as new material on integrated management of reliability and QA programmes.

Maintenance also affects reliability, so I have added a new chapter on maintenance and maintainability, with the emphasis on how they affect reliability, how reliability affects maintenance planning and how both affect availability.

I have also added new material on the important topic of reliability analysis for repairable systems. Harry Ascher, of the US Naval Research Laboratory, has pointed out that the reliability literature, including the first edition of my book, has almost totally ignored this aspect, leading to confusion and analytical errors. How many reliability engineers and teachers know that Weibull analysis of repairable system reliability data can be quite misleading except under special, unrealistic conditions? Thanks to Harry Ascher, I know now, and I have tried to explain this in the new edition.

I have also brought other parts of the book up to date, particularly the sections on electronic and software reliability.

The third reprint of the first edition included many corrections, and more corrections are made in this edition.

I am extremely grateful to all those who have pointed out errors and have helped me to correct them. Paul Baird of Hewlett Packard, Palo Alto, was particularly generous. Colleagues at British Aerospace, particularly

Brian Collett, Norman Harris, Chris Gilders and Gene Morgan, as well as many others, also provided help, advice and inspiration.

Finally, my thanks go to my wife Ina for much patience, support and typing.

PATRICK O'CONNOR
1985

# Preface to the Third Edition

The new industrial revolution has been driven mainly by the continuing improvements in quality and productivity in nearly all industrial sectors. The key to success in every case has been the complete integration of the processes that influence quality and reliability, in product specification, design, test, manufacture, and support. The other essential has been the understanding and control of variation, in the many ways in which it can affect product performance, cost and reliability. Teachers such as W. E. Deming and G. Taguchi have continued to grow in stature and following as these imperatives become increasingly the survival kit of modern industry.

I tried to stress these factors in the second edition, but I have now given them greater prominence. I have emphasized the use of statistical experimentation for preventing problems, not just for solving them, and the topic is now described as a design and development activity. I have added to the chapter on production quality assurance, to include process improvement methods and more information on process control techniques. These chapters, and the chapter on management, have all been enlarged to emphasize the integration of engineering effort to identify, minimize and reduce variation and its effects. The important work of Taguchi and Shainin is described, for the first time in this book. Chris Gray gave me much valuable help in describing the Taguchi method.

I have updated several chapters, particularly those on electronic systems reliability. I have also added a new chapter on reliability of mechanical components and systems. I would like to thank Professor Dennis Carter for his advice on this chapter.

I have taken the opportunity to restructure the book, to reflect better the main sequence of engineering development, whilst stressing the importance of an integrated, iterative approach.

I have once more been helped by many people who have contributed kind criticisms of the earlier edition, and I have tried to take these into account. I also would like to record with thanks my continuing debt to Norman Harris for his contributions to bridging the gap between engineering and statistics, and for helping me to express his ideas.

Finally, my heartfelt thanks go to my wife and boys for their forebearance, patience, and support. Having an author at home must place severe demands on love and tolerance.

PATRICK O'CONNOR
1990

# Preface to the Third Edition Revised

This revised edition has been produced in response to numerous suggestions that the book would be of greater value to students and teachers if it included exercise questions. David Newton and Richard Bromley have therefore teamed up with me to produce exercises appropriate to each chapter of the book.

The exercises cover nearly all of the types of questions that occur in the reliability examinations set by the UK Institute of Quality Assurance (IQA) and by the American Society for Quality Control (ASQC). The ASQC examination questions are of the multiple-choice type, which is not the format used here, but this should make no difference to the value of the exercises in preparing for the ASQC examination.

A solutions manual is available to teachers, free of charge, by writing to John Wiley and Sons Ltd in Chichester.

I would like to thank David Newton and Richard Bromley for their enthusiastic support in preparing this revised edition.

PATRICK O'CONNOR
1995

# Preface to the Fourth Edition

It is over ten years since the last major revision and update to my book. Inevitably in that time there have been developments in engineering technology and in reliability methods. In this new edition I have tried to include all of the important changes that affect reliability engineering and management today. In keeping with the original aims of the book, I have emphasised those with practical implications.

The main changes and additions include:

- Updated and more detailed descriptions of how engineering products fail (Chapters 1, 8 and 9).
- More detailed description of the nature of variation in engineering (Chapter 2).
- Descriptions of the Petri net and M(t) methods (Chapters 6 and 12).
- More detailed description of the particular aspects of software in engineering systems, and updated descriptions of design, analysis and test methods (Chapter 10).
- Expanded descriptions of accelerated test methods for development and manufacturing (Chapters 11 and 13).
- Updated and expanded descriptions of test methods for electronics and acceptance sampling (Chapter 13).
- More detailed descriptions of management aspects, including standards, "six sigma", and supplier management (Chapter 15).
- Updated references to standards, and updated and expanded bibliographies.

Some of the new material is adapted from my book "Test Engineering", with permission from the publisher.

The questions and the answers manual (available separately from the publisher) have been augmented to cover the new material.

An Internet homepage has been created for the book, at www.pat-oconnor.co.uk/practicalreliability.htm. The homepage includes listings of suppliers of reliability engineering related services and software.

I would like to express my gratitude to Prof. S.K. Yang for his kind assistance with the description of the Petri net method, Dr. Gregg Hobbs for his teaching and help on HALT/HASS testing, Prof. Jörgen Möltoft for helping with the description of the M(t) method, and Jim McLinn for providing additional material, questions and answers on aspects of accelerated testing and data analysis. I also thank all who have provided suggestions and pointed out errors. Last but certainly not least I thank my wife, Ina, again.

Patrick O'Connor
2001

# Preface to the Fifth Edition

Another ten years have elapsed since publication of the fourth edition. In that interval there have been further significant developments in reliability engineering methods, mainly related to the use of software to perform analysis of designs and of reliability data. Of course there have also been developments in engineering that affect reliability. The internet has added a new dimension to the availability of information and tools.

In order to describe many of these developments, Andre Kleyner has taken on the role of joint author and the two of us have worked together to create this new edition. Andre has contributed most of the new material. In particular, he has provided the software-based solutions to many of the examples, supplementing or replacing manual and graphical methods. He has also updated some of the technology aspects and contributed new sections on data analysis and other topics.

The main changes and additions include:

- Software implementation of statistical methods, including probability plotting and a wider use of common software tools such as Microsoft Excel®.
- Expanded description and applications of Monte Carlo simulation methods, in a new chapter.
- More detailed descriptions of reliability prediction methods.
- Expanded treatment of accelerated test data analysis.
- Analysis of warranty data.
- Expanded description of reliability demonstration methods, in a new chapter.
- Course instructors who adapted this book can request the Solutions Mannual at: www.wiley.com/go/oconnor_reliability5.
- General updating of references, including published papers and internet links.
- The Questions sections, originally developed with major contributions from David Newton and Richard Bromley, have been revised and expanded.

A solutions manual for the end-of-chapter questions and instructor's PowerPoint slides are available as a free download, to course tutors only at: www.wiley.com/go/oconnor_reliability5.

We hope that the new edition will maintain the value of *Practical Reliability Engineering* to engineers, managers, teachers and students.

PATRICK O'CONNOR
2011

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We remain deeply indebted to the people who provided valuable help and advice on the first edition. Their generous efforts still enhance the book. In particular Dr. Ralph Evans, Kenneth Blemel and Norman Harris provided insights and assistance. Professor Dennis Carter was the originator of the load-strength concepts described in Chapter 5. Professor Bev Littlewood helped with the software reliability modelling descriptions in Chapter 10.

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2011