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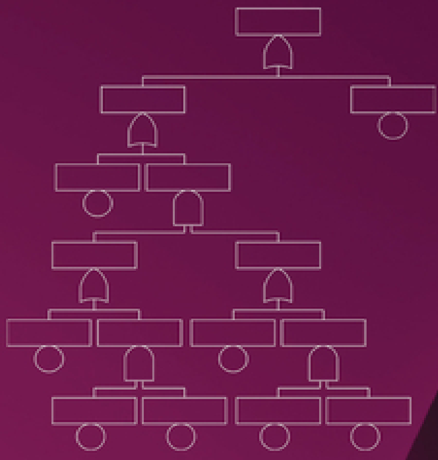
THIRD EDITION

SYSTEM RELIABILITY THEORY

MODELS, STATISTICAL METHODS, AND APPLICATIONS



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System Reliability Theory

Models, Statistical Methods, and Applications

Third Edition

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To Hella; Guro and Idunn; and Emil and Tiril
To: Nicolas; Penelope; and Garance

Contents

Preface

This book provides a basic, but rather comprehensive introduction to system reliability theory and the main methods used in reliability analyses. System reliability theory is used in many application areas. Some of these are illustrated in the book as examples and problems.

Main Changes from the Second Edition

Readers who are familiar with the second edition (Rausand and Høyland 2004) will find that the third edition is a major update and that most chapters have been rewritten. The most significant changes include:

- A new Chapter 2 defining the study object and its functions and operating context is included. System modeling by reliability block diagrams is introduced and the concept of complexity is discussed.
- A new Chapter 3 defining and discussing the concepts of failure and fault, together with several associated concepts is added. Two failure analysis techniques are presented.
- New component importance metrics are included.
- The treatment of dependent failures is significantly extended.
- Section 8.8 on complex systems in the second edition is removed from the chapter on Markov analysis where several new models are added.
- A new Chapter 12 on preventive maintenance is added. This chapter merges aspects from the previous edition with new models and methods. The presentation is supplemented by Python scripts that are found on the `book companion site`.
- Chapters 11 and 13 in the second edition on life data analysis and Bayesian reliability analysis are totally rewritten. The statistical program system R is extensively used in the presentation.

- Chapter 12 in the second edition on accelerated testing has been removed, but parts of the chapter are moved to the chapter on reliability data analysis.
- The end of chapter problems have been revised and new problems are added.
- Most of the appendices are removed. The content is partly integrated in the text and partly obsolete because of the use of R.
- An author index is provided.

Supplementary Information on the Internet

An immense amount of relevant information is today available on the Internet, and many of the topics in this book may be found as books, reports, lecture notes, or slides written by lecturers from many different universities. The quality of this information is varying and ranging from very high to rather low, the terminology is often not consistent, and it may sometimes be a challenge to read some of these Internet resources. The reader is encouraged to search the Internet for alternative presentations and compare with the book. This way, new ideas and increased insight may spring up.

With the abundance of free information on the Internet, it is pertinent to ask whether a traditional book is really needed. We strongly believe that a book may provide a more coherent knowledge and we have tried to write the book with this in mind.

Intended Audience

The book is written primarily for engineers and engineering students, and the examples and applications are related to technical systems. There are three groups that constitute our primary audience:

- The book was originally written as a textbook for university courses in system reliability at the Norwegian University of Science and Technology (NTNU) in Trondheim. This third edition is based on experience gained from use of the first two editions, at NTNU and many other universities, and also from using the book in a wide range of short courses for industry.
- The second is to be a guide for engineers and consultants who carry out practical system reliability analyses of technical systems.
- The third is to be a guide for engineers and consultants in areas where reliability is an important aspect. Such areas include risk assessment, systems engineering, maintenance planning and optimization, logistics, warranty engineering and

management, life cycle costing, quality engineering, and several more. It may be noted that several of the methods used in artificial intelligence and machine learning are treated in this book.

Readers should have a basic course in probability theory. If not, you should get hold of an introductory textbook in probability and statistics to study in parallel with reading this book. A multitude of relevant lecture notes, slides, and reports are also available on the Internet. Brief guidance to relevant sources is provided on the `book companion site`.

Aims and Delimitation

The book is intended to give a thorough introduction to system reliability. Detailed objectives and associated delimitations are found in Section 1.8. The study object may range from a single component up to a rather complicated technical system. The study object is delimited to items that are mainly based on mechanical, electrical, or electronic technology. An increasing number of modern items have a lot of embedded software. Functions that earlier were carried out by mechanical and electromechanical technology are today software-based functions. A family car that was built when the second edition was published is, for example, very different from a modern car, which is sometimes characterized as a "computer on wheels." Software reliability is different from hardware reliability in many ways and we, therefore, consider pure software reliability to be outside the scope of the book. Many software-based functions may, however, be treated with the methods presented.

Many modern systems are getting more and more complex. Chapter 2 introduces three categories of systems: simple, complicated, and complex systems. Complex systems are here defined to be systems that do not meet all the requirements of the Newtonian–Cartesian paradigm and therefore cannot be adequately analyzed with traditional methods. The complexity theory and the approaches to study complex systems is considered to be outside the scope of the book.

The objective of this book is to help the reader to *understand* the basic theory of system reliability and to become familiar with the most commonly used analytical methods. We have focused on producing reliability results by hand-calculation, sometimes assisted by simple R and Python programs. When you carry out practical reliability analyses of large systems, you usually need some special computer programs, such as fault tree analysis programs and simulation programs. A high number of programs are available on the market. We do not present any of these special programs in the book, but supply a list of the main vendors of such programs on the `book companion site`. To use a specific program, you need to study the user manual. This book should help you understand the content of such manuals and the sources of uncertainty of the results produced.

A wide range of theories and methods have been developed for system reliability analysis. All these cannot be covered in an introductory text. When selecting material to cover, we have focused on methods that:

- Are commonly used in industry or in other relevant application areas
- Give the analyst insights that increase her understanding of the system (such that system weaknesses can be identified at an early stage of the analysis)
- Provide the analyst with genuine insight into system behavior
- Can be used for hand-calculation (at least for small systems)
- Can be explained rather easily to, and be understood by nonreliability engineers and managers.

The authors have mainly been engaged in applications related to the offshore oil and gas industry and many examples therefore come from this industry. The methods described and many of the examples are equally suitable for other industries and application areas.

Authors

The first edition of the book (Høyland and Rausand 1994) was written with joint efforts from Arnljot Høyland and Marvin Rausand. Arnljot sorrily passed away in 2002. The second edition (Rausand and Høyland 2004), was therefore prepared by Marvin alone and represented a major update of the first edition. Marvin retired from his professorship at NTNU in 2015 and when Wiley wanted an updated version, he asked Anne Barros to help preparing this third edition. Due to unforeseen practical constraints, Anne could not devote as much time to this project as she wanted. Anne's contribution to this edition is mainly related to Chapters 11 and 12, the end of chapter problems, in addition to reviewing and proposing improvements to other chapters.

Acknowledgments

First of all, we express our deepest thanks to Professor Arnljot Høyland. Professor Høyland passed away in December 2002, 78 years old, and could not participate in writing any further editions of the book. We hope that he would have approved and appreciated the changes and additions we have made.

The authors sincerely thank a high number of students at NTNU, and lecturers and students at many other universities around the world for comments to the previous edition and for suggesting improvements. We have done our best to implement these suggestions. Special thanks go to Professor Bruno Castanier, Université d'Angers, for making significant contributions to Section 12.3, and to Per Hokstad, SINTEF, for many inputs to Chapter 8.

Many definitions used in the book are from, or are inspired by, the International Electrotechnical Vocabulary (IEV) www.electropedia.org. We appreciate the initiative of the International Electrotechnical Commission (IEC) to make this vocabulary freely available. References to the vocabulary are given in the text as the IEV ref. number (e.g. IEV 192-01-24 for the term reliability).

Last, but not least, we are grateful to the editorial and production staff at John Wiley & Sons for their careful, effective, and professional work. In particular, we would like to thank our main contacts in the final stages of preparing the book, Sarah Keegan, Kathleen Santoloci, and Viniprammia Premkumar.

Trondheim, 2020 *Marvin Rausand and Anne Barros*

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