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Simulation Methods for Reliability and Availability of Complex Systems

Springer

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Foreword

Satisfying societal needs for energy, communications, transportation, etc. requires complex inter-connected networks and systems that continually and rapidly evolve as technology changes and improves. Furthermore, consumers demand higher and higher levels of reliability and performance; at the same time the complexity of these systems is increasing. Considering this complex and evolving atmosphere, the usage and applicability of some traditional reliability models and methodologies are becoming limited because they do not offer timely results or they require data and assumptions which may no longer be appropriate for complex modern systems. Simulation of system performance and reliability has been available for a long time as an alternative for closed-form analytical and rigorous mathematical models for predicting reliability. However, as systems evolve and become more complex, the attractiveness of simulation modeling becomes more apparent, popular, and useful. Additionally, new simulation models and philosophies are being developed to offer creative and useful enhancements to this modeling approach to study reliability and availability behavior of complex systems. New and advanced simulation models can be more rapidly altered to consider new systems, and they are much less likely to be constrained by limiting and restrictive assumptions. Thus, a more realistic modeling approach can be employed to solve diverse analytical problems.

The editors of this book (Profs. Faulin, Juan, Martorell, and Ramírez-Márquez) have successfully undertaken a remarkable challenge to include topical and interesting chapters and material describing advanced simulation methods to estimate reliability and availability of complex systems. The material included in the book covers many diverse and interesting topics, thereby providing an excellent overview of the field of simulation including both discrete event and Monte Carlo simulation models. Every contributor and author participating in this book is a respected expert in the field, including researchers such as Dr. Lawrence Leemis, Dr. Enrico Zio, and others who are among the most respected and accomplished experts in the field of reliability.

The simulation methods presented in this book are rigorous and based on sound theory. However, they are also practical and demonstrated on many real problems. As a result, this book is a valuable contribution for both theorists and practitioners for any industry or academic community.

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Preface

Complex systems are everywhere among us: telecommunication networks, computers, transport vehicles, offshore structures, nuclear power plants, and electrical appliances are well-known examples. Designing reliable systems and determining their availability are both very important tasks for managers and engineers, since reliability and availability (R&A) have a strong relationship to other concepts such as quality and safety. Furthermore, these tasks are extremely difficult, due to the fact that analytical methods can become too complicated, inefficient, or even inappropriate when dealing with real-life systems.

Different analytical approaches can be used in order to calculate the exact reliability of a time-dependent complex system. Unfortunately, when the system is highly complex, it can become extremely difficult or even impossible to obtain its exact reliability at a given target time. Similar problems arose when trying to determine the exact availability at a given target time for systems subject to maintenance policies. As some authors point out, in those situations only simulation techniques, such as Monte Carlo simulation (MCS) and discrete event simulation (DES), can be useful to obtain estimates for R&A parameters.

The main topic of this book is the use of computer simulation-based techniques and algorithms to determine reliability and/or availability levels in complex systems and to support the improvement of these levels both at the design stage and during the system operating stage.

Hardware or physical devices suffer from degradation, not only due to the passage of time but also due to their intensive use. Physical devices can be found in many real systems, to name a few: nuclear power plants, telecommunication networks, computer systems, ship and offshore structures affected by corrosion, aerospace systems, etc. These systems face working environments which impose on them significant mechanical, chemical, and radiation stresses, which challenge their integrity, stability, and functionality. But degradation processes not only affect physical systems: these processes can also be observed in intangible products such as computer software. For instance, computer network operating systems tend to stop working properly from time to time and, when that happens, they need to be reinstalled or, at least, restarted, which means that the host server will stop being available for some time. In the end, if no effective maintenance policies are taken, any product (component or system, hardware or software) will fail, meaning that it will stop being operative, at least as intended.

Reliability is often defined as the probability that a system or component will perform its intended function, under operating conditions, for a specified period of time. Moreover, availability can be defined as the probability that a system or component will be performing its intended function, at a certain future time, according to some maintenance policy and some operating conditions. During the last few decades, a lot of work has been developed regarding the design and implementation of system maintenance policies. Maintenance policies are applied to many real systems: when one component fails – or there is a high probability that it can fail soon – it is repaired or substituted by a new one, even when the component failure does not necessarily imply the global system failure or status change. For system managers and engineers, it can be very useful to be able to predict the availability function of time-dependent systems in the short, medium, or long run, and how these availability levels can be increased by improving maintenance policies, reliability of individual components or even system structure design. This information can be critical in order to ensure data integrity and safety, quality-of-service, process or service durability, and even human safety. In other words, great benefits can be obtained from efficient methods and software tools that: (1) allow predicting system availability levels at future target times and (2) provide useful information about how to improve these availability levels.

Many authors point out that, when dealing with real complex systems, only simulation techniques, such as MCS and, especially, DES, can be useful to obtain credible predictions for R&A parameters. In fact, simulation has been revealed as a powerful tool in solving many engineering problems. This is due to the fact that simulation methods tend to be simpler to implement than analytic ones and, more importantly, to the fact that simulation methods can model real-systems behavior with great detail. Additionally, simulation methods can provide supplementary information about system internal behavior or about critical components from a reliability/availability point of view. These methods are not perfect either, since they can be computationally intensive and they do not provide exact results, only estimated ones. Applications of simulation techniques in the R&A fields allow modeling details such as multiple-state systems, component dependencies, non-perfect repairs, dysfunctional behavior of components, etc. Simulation-based techniques have also been proposed to study complex systems availability. In fact, during the last few years, several commercial simulators have been developed to study the R&A of complex systems.

Every system built by humans is unreliable in the sense that it degrades with age and/or usage. A system is said to fail when it is no longer capable of delivering the designed outputs. Some failures can be catastrophic in the sense that they can result in serious economic losses, affect humans and do serious damage to the environment. Therefore, the accurate estimation of failures in order to study the R&A of complex systems has revealed as one of the most challenging tasks of research. Taking into account the importance of this type of study and its difficulties, we think that apart from the traditional exact methods in R&A, the use of a very popular tool such as simulation can be a meaningful contribution in the development of new protocols to study complex systems.

Thus, this book deals with both simulation and R&A of complex systems, topics which are not commonly presented together. It is divided into three major parts:

Part I Fundamentals of Simulation in Reliability and Availability Issues;
Part II Simulation Applications in Reliability;
Part III Simulation Applications in Availability and Maintenance.

Each of these three parts covers different contents with the following intentions:

Part I: To describe, in detail, some ways of performing simulation in different theoretical arenas related to R&A.
Part II: To present some meaningful applications of the use of simulation in the study of different scenarios related to reliability decisions.
Part III: To discuss some interesting applications of the use of simulation in the study of different cases related to availability decisions.

Part I presents some new theoretical results setting up the fundamentals of the use of simulation in R&A. This part consists of four chapters. The first, by Zio and Pedroni, describes some interesting uses of MCS to make accurate estimations of Reliability. The second, by K. Durga Rao *et al.*, makes use of simulation to develop a dynamic fault tree analysis providing meaningful examples. Cancela *et al.* develop some improvements of the path-based methods for Monte Carlo reliability evaluation in the third chapter. The fourth, by Leemis, concludes this part by introducing some descriptive simulation methods to generate variates. This part constitutes the core of the book and develops a master view of the use of simulation in the R&A field.

Parts II and III are closely connected. Both of them present simulation applications in two main topics of the book: reliability and availability. Part II is devoted to simulation applications in reliability and Part III presents other simulation applications in availability and maintenance. Nevertheless, this classification cannot be strict because both topics are closely connected.

Part II has five chapters, which present some real applications of simulation in selected cases of reliability. Thus, Chapter 5 (Gosavi and Murray) describes the simulation analysis of the reliability and preventive maintenance of a public infrastructure. Marotta *et al.* discuss reliability models for data integration systems in the following chapter, giving a complementary view of the previous chapter. Chapter 7 makes a comparison between the results given by analytical methods and given by simulation of the power distribution system reliability. This is one of the most meaningful applications of the book. Chapter 8 (Aijaz Shaikh) presents the use of the software Reliasoft to analyse process industries. Chapter 9 (Angel A. Juan *et al.*) concludes this part by explaining some applications of discrete event simulation and fuzzy sets to study structural Reliability in building and civil engineering.

Finally, Part III consists of four chapters. Chapter 10 describes maintenance manpower modeling using simulation. It is a good application of some traditional tools of simulation to describe maintenance problems. Kwang Pil Chang *et al.* present in

Chapter 11 another interesting application in the world of estimating availability in offshore installations. This challenging case is worth reading carefully. Zille *et al.* explain in the twelfth chapter the use of simulation to study the maintained multi-component systems. Last but not least, Farukh Nadeem and Erich Leitgeb describe a simulation model to study availability in optical wireless communication.

The book has been written for a wide audience. This includes practitioners from industry (systems engineers and managers) and researchers investigating various aspects of R&A. Also, it is suitable for use by Ph.D. students who want to look into specialized topics of R&A.

We would like to thank the authors of the chapters for their collaboration and prompt responses to our enquiries which enabled completion of this handbook on time. We gratefully acknowledge the help and encouragement of the editor at Springer, Anthony Doyle. Also, our thanks go to Claire Protherough and the staff involved with the production of the book.

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