Preface

Reliability theory is a multidisciplinary science aiming to develop complex technical and informational systems that are resistant to failures. Traditional reliability theory considered only two possible states for a system and its components—perfect functioning and complete failure. In real world, many components and systems can perform their tasks with various distinctive levels of efficiency usually referred to as performance rates. Such systems are called multi-state systems (MSS). In MSS reliability analysis, the great number of system states that need to be evaluated makes it difficult and often impossible to use traditional binary reliability techniques.

Since the mid-1970s numerous research studies have been published that focus on MSS reliability. Additional experience has also been gathered from industrial settings. Thus, recently MSS reliability has emerged as one of the main fields not only for scientists and researchers but also for engineers and industrial managers.

This book covers the recent developments in multi-state system reliability. It presents new theoretical issues that were not previously presented in the literature, as well as the solutions of important practical problems and case studies illustrating the application methodology.

The book is a collective work by a number of leading scientists, analysts, mathematicians, and engineers who have been working on the front end of reliability science and engineering. All chapters in the book are written by leading researchers and practitioners in their respective fields of expertise and present a plethora of innovative methods, approaches and solutions not covered before in the literature.

Despite the large number of contributing authors, this manuscript presents a continuous story of the modern multi-state system reliability theory and its applications in engineering. An important peculiarity of the book is the presentation some real-world problem solutions.

This book has been divided into two logically contiguous parts.

Part I Modern Mathematical Methods for Multi-state System Reliability Analysis

In this part new theoretical methods are presented that were not published till now.

Chapter "Reliability of a Network with Heterogeneous Components" investigates reliability of network-type systems under the assumption that the network has K types of of i.i.d. components. The method suggested for this purpose is an extension of the D-spectra method to K dimensions and it is based on Monte Carlo simulation.

Chapter "Reliability Analysis of Complex Multi-state System with Common Cause Failure Based on DS Evidence Theory and Bayesian Network" introduces a reliability analysis method for complex MSS with epistemic uncertainty based on Bayesian network and evidence theory.

Chapter "A D-MMAP to Model a Complex Multi-state System with Loss of Units" presents a multi-state model for complex system subject to various types of failures, to which preventive maintenance is applied. The model suggested is using a Markovian Arrival Process with Marked arrivals.

Chapter "Modeling and Inference for Multi-state Systems" focuses on multi-state systems modeled by means of a special type of semi-Markov processes. A special parametrization is proposed for the parameters describing the system, taking into account various types of dependencies of the parameters on the states of the system.

Chapter "Optimizing Availability and Performance of a Two-Unit Redundant Multi-State Deteriorating System" considers a redundant multi-state deteriorating system under maintenance. The system's evolution in time is described through a semi-Markov process and its availability, the expected downtime and the expected cost due to maintenance and unavailability are computed under all possible scenarios.

Chapter "Phase-Type Models and Their Extension to Competing Risks" presents an extension of the phase-type methodology for modeling of lifetime distributions to include the case of competing risks. This is done by considering finite state Markov chains in continuous time with more than one absorbing state, letting each absorbing state correspond to a particular risk.

Chapter "A Study on Repairable Series Systems with Markov Repairable Units" investigates repairable multi-state series systems by using matrix method which has been widely used in aggregated stochastic processes especially in Ion channel modeling and aggregated repairable systems. The formulas for reliability, instantaneous and interval availabilities are given in matrix form for four kinds of repairable series systems.

Chapter "Dynamic Performance of Series Parallel Multi-state Systems with Standby Subsystems or Repairable Binary Elements" presents a method for evaluating performance of multi-state systems with a general series parallel structure. The system components can be either repairable binary elements with given time-to-failure and repair time distributions, or 1-out-of-N warm standby configurations of heterogeneous binary elements characterized by different performances and time-to-failure distributions. Iterative algorithms are presented for determining performance stochastic processes of individual components.

Chapter "Optimal Imperfect Maintenance in a Multi-state System" considers a model with both imperfect preventive and imperfect corrective maintenance actions. A sequential failure limits preventive maintenance policy with infinite planning horizon for both maintenance actions is used to formulate a cost optimization problem.

Chapter "Reliability Evaluation of Non-repairable Multi-state Systems Considering Survival-death Markov Processes" proposes two models of modified "death" Markov processes considering components start-up failures. They are referred to as "survival-death" Markov processes and they differ in that the first model considers only a completely successful or failed start-up, whereas the second model considers also partially successful start-up. L_Z-transform technique is used for evaluating dynamic reliability of non-repairable MSS with start-up failures.

Chapter "Reliability Assessment of Systems with Dependent Degradation Processes Based on Piecewise-Deterministic Markov Process" presents a reliability assessment framework for multi-component systems whose degradation processes are modeled by multi-state and physics-based models. The piecewise-deterministic Markov process modeling approach is employed to treat dependencies between the degradation processes within one component or/and among components.

Chapter "Trade-Off Between Redundancy, Protections, and Imperfect False Targets in Defending Parallel Systems" considers systems that may be destroyed by unintentional impacts or intentional attacks. It studies trade-off between building redundant genuine elements, protections and deploying imperfect false elements in the defense of a capacitated parallel system.

Chapter "Optimal Testing Resources Allocation for Improving Reliability Assessment of Non-repairable Multi-state Systems" studies the testing resources allocation problem for MSSs in order to optimally distribute the limited reliability testing resources to improve the accuracy of reliability estimation/prediction.

Chapter "Topological Analysis of Multi-state Systems Based on Direct Partial Logic Derivatives" deals with the evaluation of influence of the system components on system operation by using Direct Partial Logic Derivatives (DPLDs). It develops a new method for DPLDs computation for multi-state systems that can be decomposed into disjoint modules.

Part II Applications and Case Studies

In this part several solutions are presented for real-world problems from different industrial areas.

Chapters "Short-Term Reliability Analysis of Power Plants with Several Combined Cycle Units" and "Reliability Analysis of a Modified IEEE 6BUS

RBTS Multi-state System" are devoted to power system analysis by using MSS models.

Chapter "Short-term Reliability Analysis of Power Plants with Several Combined Cycle Units" presents an application of *Lz*-transform method to a short-term reliability analysis of power plants consisting of several combined cycle generating units. Each generating unit is presented by 8-state Markov model. Such reliability indices as loss of load probability, availability, expected energy not supplied to consumers, etc. are calculated for the entire power plant.

Chapter "Reliability Analysis of a Modified IEEE 6BUS RBTS Multi-state System" is devoted to performance evaluation of a modified IEEE 6BUS RBTS. It was shown that the recommended modification contributes to the improvement of the system performance by increasing the reliability of operation within the required limits. The modification of the system aims to the reduction of failure rates maintaining the power output specifications.

Chapter "Lz-Transform Approach for Fault Tolerance Assessment of Various Traction Drives Topologies of Hybrid-Electric Helicopter" is devoted to the application of *Lz*-transform approach to fault tolerance assessment of different traction drives topologies of hybrid-electric helicopters.

Chapter "Patient Diagnostic State Evolution During Hospitalization: Developing a Model for Measuring Clinical Diagnostic Dynamics" considers a medical application of MSS reliability theory. It presents a model for measuring clinical diagnostic dynamics during patient hospitalization.

Finally, Chapter "Automated Development of the Markovian Chains to Assess the Availability and Performance of Multi-state Multiprocessor System" presents a method for automated development of the Markov chain for availability and performance assessment of multi-state multiprocessor systems.

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