Contents

Part I Fundamentals of Simulation in Reliability and Availability Issues

1 Reliability Estimation by Advanced Monte Carlo Simulation 3
E. Zio and N. Pedroni
1.1 Introduction 4
1.2 Simulation Methods Implemented in this Study 6
1.2.1 The Subset Simulation Method 6
1.2.2 The Line Sampling Method 10
1.3 Simulation Methods Considered for Comparison 13
1.3.1 The Importance Sampling Method 14
1.3.2 The Dimensionality Reduction Method 15
1.3.3 The Orthogonal Axis Method 16
1.4 Application 1: the Cracked-plate Model 17
1.4.1 The Mechanical Model 18
1.4.2 The Structural Reliability Model 18
1.4.3 Case Studies 19
1.4.4 Results 19
1.5 Application 2: Thermal-fatigue Crack Growth Model 23
1.5.1 The Mechanical Model 24
1.5.2 The Structural Reliability Model 25
1.5.3 Case Studies 26
1.5.4 Results 26
1.6 Summary and Critical Discussion of the Techniques 29
1 Markov Chain Monte Carlo Simulation 34
2 The Line Sampling Algorithm 35
References 38

2 Dynamic Fault Tree Analysis: Simulation Approach 41
K. Durga Rao, V.V.S. Sanyasi Rao, A.K. Verma, and A. Srividya
2.1 Fault Tree Analysis: Static Versus Dynamic 41
2.2 Dynamic Fault Tree Gates 42

2.3 Effect of Static Gate Representation in Place of Dynamic Gates .. 45
2.4 Solving Dynamic Fault Trees 46
2.5 Modular Solution for Dynamic Fault Trees 46
2.6 Numerical Method 48
2.6.1 PAND Gate 48
2.6.2 SEQ Gate 49
2.6.3 SPARE Gate 49
2.7 Monte Carlo Simulation Approach for Solving Dynamic Fault Trees 50
2.7.1 PAND Gate 51
2.7.2 SPARE Gate 52
2.7.3 FDEP Gate 53
2.7.4 SEQ Gate 53
2.8 Example 1: Simplified Electrical (AC) Power Supply System of Typical Nuclear Power Plant 55
2.8.1 Solution with Analytical Approach 56
2.8.2 Solution with Monte Carlo Simulation 57
2.9 Example 2: Reactor Regulation System of a Nuclear Power Plant 60
2.9.1 Dynamic Fault Tree Modeling 61
2.10 Summary 61
References 63

3 Analysis and Improvements of Path-based Methods for Monte Carlo Reliability Evaluation of Static Models 65
H. Cancela, P. L'Ecuyer, M. Lee, G. Rubino, and B. Tuffin
3.1 Introduction 66
3.2 Standard Monte Carlo Reliability Evaluation 68
3.3 A Path-based Approach 69
3.4 Robustness Analysis of the Algorithm 71
3.5 Improvement 74
3.6 Acceleration by Randomized Quasi-Monte Carlo 76
3.6.1 Quasi-Monte Carlo Methods 77
3.6.2 Randomized Quasi-Monte Carlo Methods 78
3.6.3 Application to Our Static Reliability Problem 79
3.6.4 Numerical Results 81
3.7 Conclusions 83
References 83

4 Variate Generation in Reliability 85
L.M. Leemis
4.1 Generating Random Lifetimes 85
4.1.1 Density-based Methods 87
4.1.2 Hazard-based Methods 89
4.2 Generating Stochastic Processes 91
4.2.1 Counting Processes 91
4.2.2 Poisson Processes 92

4.2.3 Renewal Processes 93
4.2.4 Alternating Renewal Processes 94
4.2.5 Nonhomogeneous Poisson Processes 94
4.2.6 Markov Models 95
4.2.7 Other Variants 95
4.2.8 Random Process Generation 96
4.3 Survival Models Involving Covariates 99
4.3.1 Accelerated Life Model 100
4.3.2 Proportional Hazards Model 100
4.3.3 Random Lifetime Generation 100
4.4 Conclusions and Further Reading 102
References 102

Part II Simulation Applications in Reliability

5 Simulation-based Methods for Studying Reliability and Preventive Maintenance of Public Infrastructure 107
A. Gosavi and S. Murray
5.1 Introduction 107
5.2 The Power of Simulation 108
5.3 Case Studies 109
5.3.1 Emergency Response 110
5.3.2 Preventive Maintenance of Bridges 114
5.4 Conclusions 119
References 120

6 Reliability Models for Data Integration Systems 123
A. Marotta, H. Cancela, V. Peralta, and R. Ruggia
6.1 Introduction 123
6.2 Data Quality Concepts 126
6.2.1 Freshness and Accuracy Definitions 126
6.2.2 Data Integration System 127
6.2.3 Data Integration Systems Quality Evaluation 129
6.3 Reliability Models for Quality Management in Data Integration Systems 131
6.3.1 Single State Quality Evaluation in Data Integration Systems 132
6.3.2 Reliability-based Quality Behavior Models 133
6.4 Monte Carlo Simulation for Evaluating Data Integration Systems Reliability 138
6.5 Conclusions 142
References 143

7 Power Distribution System Reliability Evaluation Using Both Analytical Reliability Network Equivalent Technique and Time-sequential Simulation Approach 145
P. Wang and L. Goel
7.1 Introduction 145
7.2 Basic Distribution System Reliability Indices 147
7.2.1 Basic Load Point Indices 147
7.2.2 Basic System Indices 148
7.3 Analytical Reliability Network Equivalent Technique 149
7.3.1 Definition of a General Feeder 150
7.3.2 Basic Formulas for a General Feeder 150
7.3.3 Network Reliability Equivalent 153
7.3.4 Evaluation Procedure 154
7.3.5 Example 155
7.4 Time-sequential Simulation Technique 158
7.4.1 Element Models and Parameters 158
7.4.2 Probability Distributions of the Element Parameters 159
7.4.3 Exponential Distribution 160
7.4.4 Generation of Random Numbers 161
7.4.5 Determination of Failed Load Point 161
7.4.6 Consideration of Overlapping Times 163
7.4.7 Reliability Indices and Their Distributions 163
7.4.8 Simulation Procedure 164
7.4.9 Stopping Rules 165
7.4.10 Example 165
7.4.11 Load Point and System Indices 165
7.4.12 Probability Distributions of the Load Point Indices 166
7.5 Summary 170
References 171

8 Application of Reliability, Availability, and Maintainability Simulation to Process Industries: a Case Study 173
A. Shaikh and A. Mettas
8.1 Introduction 173
8.2 Reliability, Availability, and Maintainability Analysis 174
8.3 Reliability Engineering in the Process Industry 174
8.4 Applicability of RAM Analysis to the Process Industry 175
8.5 Features of the Present Work 176
8.5.1 Software Used 177
8.6 Case Study 177
8.6.1 Natural-gas Processing Plant Reliability Block Diagram Modeling 178
8.6.2 Failure and Repair Data 184
8.6.3 Phase Diagram and Variable Throughput 185
8.6.4 Hidden and Degraded Failures Modeling 186

8.6.5 Maintenance Modeling 187
8.6.6 Crews and Spares Resources 190
8.6.7 Results 191
8.6.8 Bad Actors Identification 192
8.6.9 Cost Analysis 193
8.6.10 Sensitivity Analysis 194
8.7 Conclusion 195
References 196

9 Potential Applications of Discrete-event Simulation and Fuzzy Rule-based Systems to Structural Reliability and Availability 199
A. Juan, A. Ferrer, C. Serrat, J. Faulin, G. Beliakov, and J. Hester
9.1 Introduction 200
9.2 Basic Concepts on Structural Reliability 200
9.3 Component-level Versus Structural-level Reliability 201
9.4 Contribution of Probabilistic-based Approaches 202
9.5 Analytical Versus Simulation-based Approaches 202
9.6 Use of Simulation in Structural Reliability 203
9.7 Our Approach to the Structural Reliability Problem 204
9.8 Numerical Example 1: Structural Reliability 206
9.9 Numerical Example 2: Structural Availability 209
9.10 Future Work: Adding Fuzzy Rule-based Systems 211
9.11 Conclusions 212
References 213

Part III Simulation Applications in Availability and Maintenance

10 Maintenance Manpower Modeling: A Tool for Human Systems Integration Practitioners to Estimate Manpower, Personnel, and Training Requirements 217
M. Gosakan and S. Murray
10.1 Introduction 217
10.2 IMPRINT – an Human Systems Integration and MANPRINT Tool 218
10.3 Understanding the Maintenance Module 219
10.3.1 System Data 220
10.3.2 Scenario Data 222
10.4 Maintenance Modeling Architecture 223
10.4.1 The Static Model – the Brain Behind It All 224
10.4.2 A Simple Example – Putting It All Together 227
10.5 Results 228
10.6 Additional Powerful Features 229
10.6.1 System Data Importing Capabilities 229
10.6.2 Performance Moderator Effects on Repair Times 229
10.6.3 Visualization 230
10.7 Summary 230

References 231

11 Application of Monte Carlo Simulation for the Estimation of Production Availability in Offshore Installations 233
K.P. Chang, D. Chang, and E. Zio
11.1 Introduction 233
11.1.1 Offshore Installations 233
11.1.2 Reliability Engineering Features of Offshore Installations 234
11.1.3 Production Availability for Offshore Installations 235
11.2 Availability Estimation by Monte Carlo Simulation 236
11.3 A Pilot Case Study: Production Availability Estimation 241
11.3.1 System Functional Description 242
11.3.2 Component Failures and Repair Rates 243
11.3.3 Production Reconfiguration 244
11.3.4 Maintenance Strategies 244
11.3.5 Operational Information 247
11.3.6 Monte Carlo Simulation Model 247
11.4 Commercial Tools 250
11.5 Conclusions 251
References 252

12 Simulation of Maintained Multicomponent Systems for Dependability Assessment 253
V. Zille, C. Bérenguer, A. Grall and A. Despujols
12.1 Maintenance Modeling for Availability Assessment 253
12.2 A Generic Approach to Model Complex Maintained Systems 255
12.3 Use of Petri Nets for Maintained System Modeling 257
12.3.1 Petri Nets Basics 257
12.3.2 Component Modeling 258
12.3.3 System Modeling 262
12.4 Model Simulation and Dependability Performance Assessment 264
12.5 Performance Assessment of a Turbo-lubricating System 265
12.5.1 Presentation of the Case Study 265
12.5.2 Assessment of the Maintained System Unavailability 268
12.5.3 Other Dependability Analysis 269
12.6 Conclusion 270
References 271

13 Availability Estimation via Simulation for Optical Wireless Communication 273
F. Nadeem and E. Leitgeb
13.1 Introduction 273
13.2 Availability 274
13.3 Availability Estimation 275
13.3.1 Fog Models 275

13.3.2 Rain Model 277
13.3.3 Snow Model 278
13.3.4 Link Budget Consideration 278
13.3.5 Measurement Setup and Availability Estimation via Simulation for Fog Events 279
13.3.6 Measurement Setup and Availability Estimation via Simulation for Rain Events 286
13.3.7 Availability Estimation via Simulation for Snow Events 288
13.3.8 Availability Estimation of Hybrid Networks: an Attempt to Improve Availability 290
13.3.9 Simulation Effects on Analysis 292
13.4 Conclusion 294
References 294

Index 311