

Contents

Preface	v
Introduction and brief historical overview	1
General notation and acronyms	13
Chapter 1. Basic concepts of Multi-State Systems	15
1.1. Multi-state systems: main definitions and properties	15
1.1.1. Generic MSS model	16
1.1.2. Main properties of MSS	21
1.1.2.1. Relevancy of the system elements	21
1.1.2.2. Coherency	22
1.1.2.3. Homogeneity	23
1.2. Multi-state system reliability and its measures	24
1.2.1. MSS acceptability function and reliability	24
1.2.2. Relevancy and coherency in MSS reliability context	25
1.2.3. MSS reliability indices	26
1.3. Types of MSS	32
1.3.1. MSS with typical simple configurations	33
1.3.1.1. Series structure	33
1.3.1.2. Parallel structure	35
1.3.1.3. Bridge structure	38
1.3.2. Systems with two failure modes	40
1.3.3. Weighted voting systems	40
1.3.4. Multi-state consecutively connected systems	42
1.3.5. Multi-state sliding window systems	44
1.3.6. Multi-state networks	45
1.3.6.1. Multi-state edges models	47
1.3.6.2. Multi-state vertices models	47
1.3.6.3. Mixed multi-state models	48
Exercises	48
References	49

Chapter 2. Extension of Boolean methods for MSS reliability analysis	51
2.1. Multi-valued structure function approach	51
2.1.1. Path and cut vectors	51
2.1.2. Multi-valued structure function	55
2.1.3. Evaluating the system reliability indices	63
2.1.4. Reliability bounding	66
2.2. Multi-state block diagrams and fault trees	67
2.2.1. Structure function representation using binary variables	67
2.2.2. MSS reliability block diagrams	68
2.2.3. MSS fault trees	72
2.2.4. Multi-valued logic trees and Boolean algebra with restrictions	74
2.2.4.1. Basic definitions of Boolean algebra with restrictions	77
2.2.4.2. Boolean reduction of multi-valued logic trees	79
2.2.4.3. Derivation of the complete base of prime implicants	83
Exercises	85
References	86
 Chapter 3. Basic random processes methods for MSS reliability assessment	 89
3.1. General concepts	89
3.2. Markov models	92
3.2.1. Main definitions and properties	92
3.2.2. Markov models for evaluating reliability of multi-state elements	95
3.2.2.1. Non-repairable multi-state elements	95
3.2.2.2. Repairable multi-state elements	102
3.2.2.3. Markov models for the multi-state element with variable demand	110
3.2.3. Markov models for evaluating the reliability of the multi-state system	116
3.3. Markov reward models	128
3.3.1. Basic definitions and model description	128
3.3.2. Computation of MSS reliability measures	132
3.3.2.1. Mean number of failures	133
3.3.2.2. Mean time to failure	135

3.4. Semi-Markov models	137
3.4.1. Definition of Semi-Markov process	137
3.4.2. Evaluation of MSS reliability indices based on semi-Markov models	142
Exercises	150
References	151

Chapter 4. Universal Generating Function (UGF) models 155

4.1. Mathematical fundamentals	155
4.1.1. Definition of universal generating function	155
4.1.2. Evaluating MSS reliability indices based on the UGF	160
4.1.3. Properties of composition operators	163
4.2. Reliability block diagram method	165
4.2.1. UGF of subsystems containing series elements	166
4.2.2. UGF of subsystems containing parallel elements	168
4.2.3. UGF of series-parallel systems	171
4.2.4. Bridge structure	177
4.2.4.1. Flow transmission MSS	177
4.2.4.2. Task processing MSS	178
4.2.4.3. Simplification technique	180
4.2.5. Combined UGF and random process technique	182
4.3. Reliability assessment for different types of MSS	187
4.3.1. Systems with Two Failure Modes	187
4.3.1.1. Flow transmission MSS (with flow dispersion)	189
4.3.1.2. Task processing MSS	190
4.3.2. Weighted voting systems and classifiers	194
4.3.2.1. Evaluating reliability of weighted voting systems	194
4.3.2.2. Simplification technique	198
4.3.2.3. Evaluating reliability of weighted voting classifiers	201
4.3.2.4. Simplification technique	207
4.3.3. Linear multi-state consecutively-connected systems	210
4.3.3.1. Connectivity model	210
4.3.3.2. Model with retransmission delays	215
4.3.3.3. Simplification technique	218
4.3.3.4. Model with variable retransmission delays	222
4.3.4. Sliding window systems	222
4.3.4.1. Evaluating availability of sliding window systems	222
4.3.4.2. Simplification technique	226
4.3.5. Multi-state networks	228
4.3.5.1. MAN connectivity model	229

4.3.5.2. MAN with constant transmission characteristics of arcs	233
4.3.6. Incorporating common cause failures into UGF models	242
4.4. UGF based method of MSS importance and sensitivity analysis	246
Exercises	252
References	254
Chapter 5. MSS reliability optimization	257
5.1. Optimization problems in reliability	257
5.2. Genetic algorithm as a universal optimization technique	259
5.3. Adaptation of genetic algorithm to specific optimization problems	268
5.3.1. Representation of solutions in GA	268
5.3.1.1. Parameter determination problems	269
5.3.1.2. Partition and allocation problems	270
5.3.1.3. Mixed partition and parameter determination problems	272
5.3.1.4. Sequencing problems	274
5.3.2. Determination of solution fitness	275
5.3.3. Crossover and mutation procedures	276
5.3.4. Determination of GA parameters	279
References	280
Chapter 6. Application Problems	283
6.1. Practical decision making based on cost-type criterion	283
6.2. MSS structure optimization	290
6.2.1. Minimal cost MSS structure subject to availability constraints	290
6.2.1.1. Problem formulation	290
6.2.1.2. Implementing the GA	291
6.2.2. Single stage expansion of MSS	294
6.2.3. Single stage replacement (modernization) of MSS elements	296
6.2.3.1. Problem formulation	296
6.2.3.2. Implementing the GA	296
6.2.4. Structure optimization of series-parallel MSS with two failure modes	301
6.2.4.1. Problem formulation	302
6.2.4.2. Implementing the GA	303

6.2.5. Optimization of MSS parameters	305
6.2.5.1. Implementing the GA	305
6.2.6. Optimal arrangement (sequencing) of MSS elements	307
6.2.6.1. Implementing the GA	307
6.2.7. Optimal allocation of MSS elements	309
6.2.7.1. Problem formulation and GA implementation	311
6.3. MSS maintenance optimization	312
6.3.1. Optimal cyclic replacement policy	312
6.3.1.1. Problem formulation	314
6.3.1.2. Implementing the GA	315
6.3.2. Joint redundancy and maintenance optimization	319
6.3.2.1. Problem formulation	319
6.3.2.2. Implementing the GA	321
6.3.3. Optimal imperfect maintenance	324
6.3.3.1. Element age reduction model	325
6.3.3.2. Problem formulation	326
6.3.3.3. Implementing the GA	327
6.4. Optimal multistage MSS expansion scheduling	331
6.4.1. Problem formulation	332
6.4.2. Implementing the GA	333
6.5. Optimization of MSS reliability growth testing	336
6.5.1. Problem formulation	337
6.5.2. Implementing the GA	338
6.6. MSS survivability optimization	342
6.6.1. Optimal separation of MSS elements	342
6.6.1.1. Problem formulation	343
6.6.1.2. Implementing the GA	344
6.6.2. Optimal allocation of MSS elements subject to survivability constraints	348
6.6.2.1. Problem formulation and GA implementation	349
References	351
Concluding remarks (further research)	353
Index	357