
Contents

1	Introduction	1
1.1	Imperfect Maintenance	2
1.2	Dependence.....	4
1.3	Warranty, Dependence, Imperfect Maintenance.....	6
1.4	Criteria on Maintenance Optimization.....	7
1.5	Scope of this Book.....	7
1.5.1	General Methodologies.....	7
1.5.2	Directions.....	8
1.5.3	Framework.....	11
2	Imperfect Maintenance and Dependence	13
2.1	Imperfect Maintenance	13
2.1.1	Modeling Methods for Imperfect Maintenance.....	14
2.1.2	Typical Imperfect Maintenance Models by Maintenance Policies ...	23
2.2	Dependence.....	29
3	Maintenance Policies and Analysis	31
3.1	Introduction.....	31
3.2	Maintenance Policies for One-unit Systems	32
3.2.1	Age-dependent PM Policy	32
3.2.2	Periodic PM Policy	35
3.2.3	Failure Limit Policy	38
3.2.4	Sequential PM Policy.....	39
3.2.5	Repair Limit Policy.....	40
3.2.6	Repair Number Counting and Reference Time Policy.....	42
3.2.7	On the Maintenance Policies for Single-unit Systems	43
3.3	Maintenance Policies of Multi-unit Systems	45
3.3.1	Group Maintenance Policy	46
3.3.2	Opportunistic Maintenance Policies	47
4	A Quasi-renewal Process and Its Applications	51
4.1	A Quasi-renewal Process	52

4.1.1	Definition.....	52
4.1.2	Quasi-renewal Function.....	55
4.1.3	Associated Statistical Testing Problems	56
4.1.4	Truncated Quasi-renewal Processes	59
4.2	Periodic PM with Imperfect Maintenance	62
4.2.1	Model 1: Imperfect Repair and Perfect PM.....	62
4.2.2	Model 2: Imperfect Repair and Imperfect PM.....	63
4.2.3	Model 3: Imperfect Repair and Imperfect PM.....	64
4.2.4	Model 4: Imperfect Repair and Imperfect PM.....	68
4.2.5	Model 5: Imperfect Repair and Imperfect PM.....	70
4.2.6	Model 6: Imperfect Repair and Imperfect PM.....	72
4.3	Cost Limit Replacement Policy – Model 7	73
4.4	Age-dependent PM Policies with Imperfect Maintenance.....	76
4.4.1	Model 8: Imperfect Repair.....	76
4.4.2	Model 9: Imperfect CM and Imperfect PM	80
4.4.3	Model 10: Two Imperfect Repairs	82
4.4.4	Model 10a: Two Imperfect Repairs Considering Repair Time	85
4.4.5	Model 11: Imperfect Repair and Perfect PM	87
4.5	Concluding Discussions.....	88
5	Reliability and Optimal Maintenance of Series Systems with Imperfect Repair and Dependence	91
5.1	Introduction.....	91
5.2	System Availability Indices Modeling.....	94
5.3	Modeling of Maintenance Costs	101
5.3.1	Cost Model 1.....	101
5.3.2	Cost Model 2.....	102
5.4	Optimal System Maintenance Policies	103
5.4.1	Optimality of Availability and Maintenance Cost Rates.....	103
5.4.2	Optimal Repair Policy.....	108
5.5	Concluding Discussions.....	110
6	Opportunistic Maintenance of Multi-unit Systems.....	111
6.1	Optimal Maintenance Policies by the (p, q) Rule	114
6.1.1	Modeling of Availability and Cost Rate	115
6.1.2	Other Operating Characteristics.....	120
6.1.3	Optimization Models.....	123
6.2	Optimal Maintenance Policies by the $(p(t), q(t))$ Rule.....	124
6.2.1	Modeling of Availability and Cost Rate	124
6.2.2	Other Performance Measures.....	130
6.2.3	Optimal Maintenance Policy.....	131
6.3	Concluding Remarks.....	132
7	Optimal Preparedness Maintenance of Multi-unit Systems with Imperfect Maintenance and Economic Dependence	135
7.1	Introduction.....	135
7.2	System Maintenance Cost Rate and ‘Availability’	140

7.3 Other Operating Characteristics.....	146
7.4 Optimization Models	149
7.5 Concluding Discussions.....	150
8 Optimal Opportunistic Maintenance Policies of k-out-of-n Systems	151
8.1 Introduction.....	151
8.2 Perfect PM	155
8.3 Imperfect PM: Case 1	159
8.4 Imperfect PM: Case 2	161
8.5 Special Cases	163
8.6 Optimization Problems	166
8.7 Numerical Example	167
8.8 Concluding Discussions.....	169
9 Reliability and Optimal Inspection-maintenance Models of Multi-degraded Systems.....	171
9.1 Reliability Modeling	174
9.1.1 System Description and Modeling Methodologies	174
9.1.2 Reliability Modeling	179
9.1.3 Numerical Examples	180
9.2 Optimal Inspection-maintenance	185
9.2.1 A General Inspection-maintenance Policy	187
9.2.2 Average Long-run Maintenance Cost Analysis	189
9.2.3 Algorithms for Optimal Inspection-maintenance Policy.....	196
9.2.4 Numerical Example.....	199
10 Warranty Cost Models with Dependence and Imperfect Repair	203
10.1 RFSW Policies for Multi-component Systems	207
10.1.1 Background	207
10.1.2 Model Details.....	208
10.1.3 RFSW for Series Systems	210
10.1.4 RFSW for Parallel Systems.....	215
10.1.5 RFSW for Series-parallel Systems	216
10.1.6 RFSW for Parallel-series Systems	218
10.1.7 A Numerical Example and Sensitivity Study.....	222
10.2 DWC for Minimally Repaired Series Systems	225
10.2.1 Preliminary Results	227
10.2.2 DWC Under an FRW Policy.....	228
10.2.3 DWC Under an PRW Policy	231
10.2.4 Numerical Examples	231
10.2.5 Future Research	235
10.3 RLRFW Policies with Imperfect Repair	236
10.3.1 Introduction.....	236
10.3.2 Analysis of Repair-limit Risk-free Warranties.....	237
10.3.3 Special Cases	240
10.3.4 Numerical Examples and Sensitivity Analysis	242
10.3.5 Concluding Remarks.....	244

10.4 Optimal RRLRFW Policies with Minimal Repair	245
10.4.1 A General Optimization Model.....	247
10.4.2 Cost Analysis of RRLRFW Policy	249
10.4.3 Optimal RRLRFW Policy	252
10.4.4 Remarks	253
10.5 On Warranty Policies and their Comparison	254
11 Software Reliability, Cost, and Optimization Models	259
11.1 Introduction.....	259
11.2 Use of Quasi-renewal Process in Software Reliability	261
11.3 Software Reliability and Cost Modeling.....	261
11.3.1 Model 1	262
11.3.2 Model 2	265
11.4 Optimization Models	269
11.5 Concluding Discussions.....	274
12 Monte Carlo Reliability Simulation of Complex Systems.....	275
12.1 Introduction.....	275
12.2 Typical Monte Carlo Algorithms for Reliability	277
12.2.1 K-R Method	277
12.2.2 R-M Method.....	280
12.2.3 C-H Method	282
12.2.4 L-D-L Method.....	283
12.2.5 L-D Method	284
12.2.6 Other Methods for Non-repairable Systems.....	284
12.2.7 Monte Carlo Methods for Repairable Systems	286
12.3 Variance Reduction and Random Number Generation.....	288
12.4 On Monte Carlo Reliability Simulation	290
12.5 Commercial Monte Carlo Reliability Simulation Tools	292
12.6 A General Monte Carlo Reliability Procedure.....	293
Appendix Elements of Reliability and Probability	295
A.1 Reliability Measures	295
A.2 Common Probability Distribution Functions	296
A.2.1 Discrete Random Variable Distributions	296
A.2.2 Continuous Random Variable Distributions	298
A.3 Stochastic Processes Concepts.....	302
A.3.1 Markov Processes	302
A.3.2 Counting Processes	303
A.3.3 Poisson Processes.....	303
A.3.4 Renewal Processes	304
A.3.5 Non-homogeneous Poisson Processes.....	305
References	309
Index	341