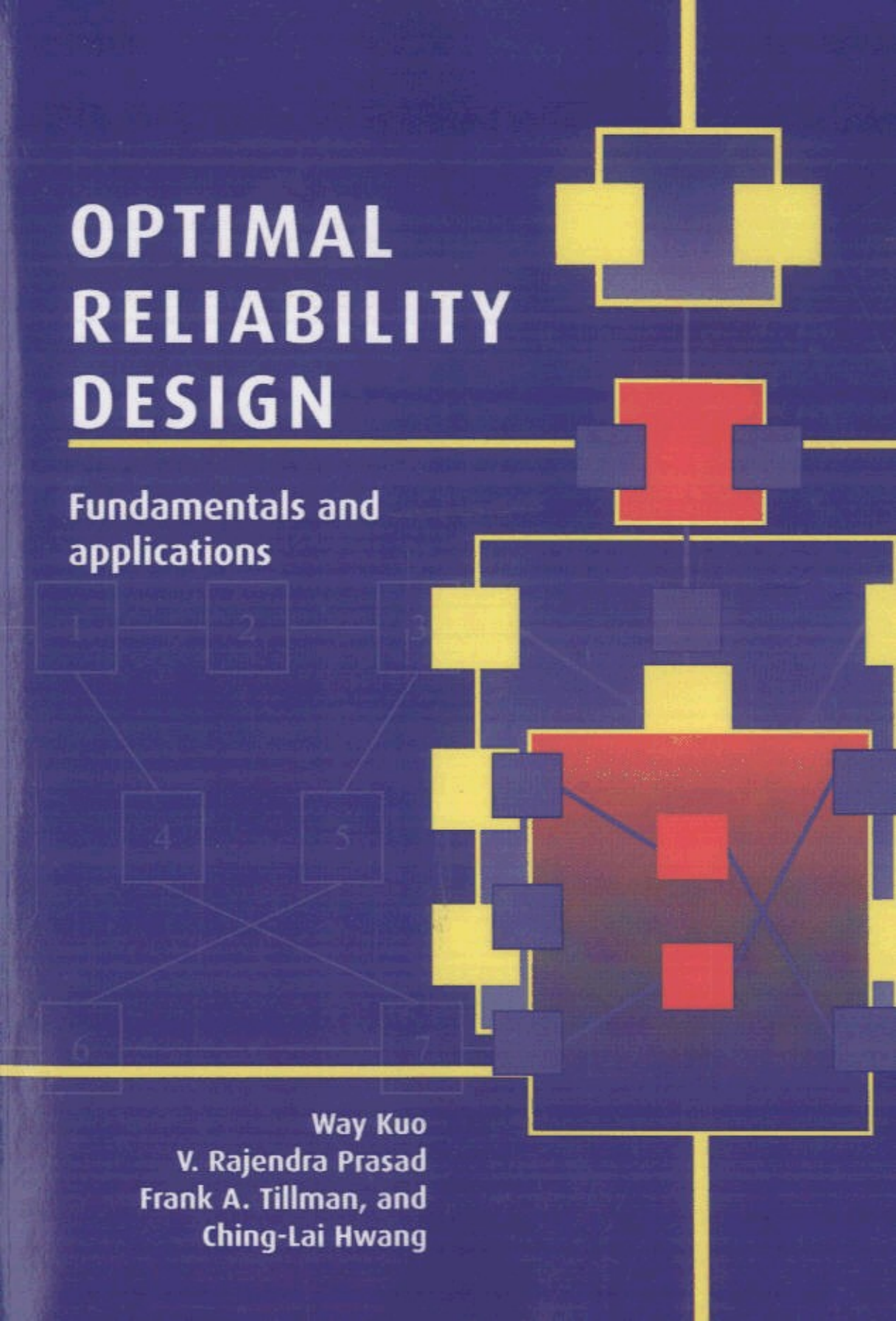
OPTIMAL RELIABILITY DESIGN

Fundamentals and applications



Way Kuo
V. Rajendra Prasad
Frank A. Tillman, and
Ching-Lai Hwang

Contents

List of figures *page* xi
List of tables xiii
Preface xvii
Acknowledgments xxi

1 Introduction to reliability systems 1

1.1 Background 1
1.2 General description of the problem 1
1.3 System hardware, human factors, software, and environment 2
1.3.1 Hardware reliability 3
1.3.2 Human factors 3
1.3.3 Software 5
1.3.4 Physical and economic constraints 5
1.4 System effectiveness models 6
1.4.1 Attributes of system effectiveness 7
1.4.2 Human factors in system effectiveness 8
1.4.3 Mission effectiveness 10
1.5 Fundamental system configurations and reliability functions 10
1.5.1 Series configuration 10
1.5.2 Parallel configuration 11
1.5.3 Series-parallel configuration 13
1.5.4 Parallel-series configuration 13
1.5.5 Hierarchical series-parallel systems 15
1.5.6 *k*-out-of-*n* systems 16
1.5.7 Complex configuration 17
1.5.8 Coherent systems 20
1.5.9 Cold standby redundancy in a single-component system 23
1.5.10 Redundancy with imperfect switching system 25
1.5.11 Multi-cause failure model 28
Exercises 29

2 Analysis and classification of reliability optimization models 33

2.1 Introduction and notation 33
2.2 Optimization models 34
2.3 Problem reduction 39
2.4 Classification of system-reliability optimization 41
2.5 Recent developments in reliability optimization 46
2.5.1 Heuristics for redundancy allocation 47
2.5.2 Metaheuristic algorithms for redundancy allocation 48
2.5.3 Exact methods for redundancy allocation 54
2.5.4 Heuristics for reliability–redundancy allocation 56
2.5.5 Multiple objective optimization in reliability systems 57
2.5.6 Optimal assignment of interchangeable components in coherent systems 59
2.5.7 Effort function optimization 61
2.6 Applications 62
2.7 Discussion 62
Exercises 64

3 Redundancy allocation by heuristic methods 66

3.1 Introduction 66
3.2 Definitions and examples 67
3.3 Heuristic methods with 1-neighborhood solutions 71
3.3.1 The Misra, Sharma, and Venkateswaran method 72
3.3.2 The Gopal, Aggarwal, and Gupta method 74
3.3.3 The Nakagawa–Nakashima method 76
3.3.4 An extension of the NN method for complex systems 79
3.3.5 The Dinghua method 80
3.4 Other heuristic methods 83
3.4.1 The Kohda–Inoue method 83
3.4.2 The Kim–Yum method 83
3.4.3 Ushakov's heuristic method 87
3.4.4 The Misra method 88
3.5 Discussion 89
Exercises 90

4 Redundancy allocation by dynamic programming 92

4.1 Introduction 92
4.2 The basic dynamic programming approach 95
4.3 The DP approach using Lagrange multipliers 101

4.4	The DP approach using dominating allocations	107
4.5	The DP approach for hierarchical series-parallel systems	112
4.6	Discussion	117
	Exercises	118
5	**Redundancy allocation by discrete optimization methods**	121
5.1	Introduction	121
5.2	The 0–1 linear programming formulation	123
5.3	Branch-and-bound methods	125
	5.3.1 Redundancy allocation in a series system	126
	5.3.2 Redundancy allocation in a complex system	130
5.4	A partial enumeration method	135
5.5	The lexicographic method	137
5.6	Discussion	142
	Exercises	142
6	**Reliability optimization by nonlinear programming**	145
6.1	Introduction	145
6.2	The Lagrangian method	148
6.3	Penalization methods	152
	6.3.1 The barrier method	153
	6.3.2 The penalty method	156
	6.3.3 The mixed penalty function method	158
	6.3.4 The penalization method with Lagrange multipliers	158
6.4	Discussion	163
	Exercises	164
7	**Metaheuristic algorithms for optimization in reliability systems**	166
7.1	Introduction	166
7.2	Genetic algorithms	166
	7.2.1 Genetic algorithms for system-reliability optimization	172
7.3	The simulated annealing method	188
	7.3.1 Reliability optimization by simulated annealing	191
	7.3.2 The nonequilibrium simulated annealing algorithm	195
7.4	The tabu search method	197
	7.4.1 Reliability optimization by tabu search	199
7.5	Discussion	204
	Exercises	206

8	**Reliability–redundancy allocation**	208
8.1	Introduction	208
8.2	The method of Tillman, Hwang, and Kuo	211
8.3	The method of Gopal, Aggarwal, and Gupta	211
8.4	The method of Kuo, Lin, Xu, and Zhang	215
8.5	The method of Xu, Kuo, and Lin	216
8.6	The surrogate constraints method	219
	8.6.1 The DP approach to solve surrogate problem S(**u**)	224
8.7	Evolutionary algorithms	226
	8.7.1 The genetic algorithm for reliability–redundancy optimization	227
	8.7.2 The evolutionary algorithm for reliability–redundancy optimization	228
8.8	Discussion	232
	Exercises	233
9	**Component assignment in reliability systems**	236
9.1	Introduction	236
9.2	Optimal assignment of components in series-parallel systems	237
	9.2.1 Optimal allocation of components in series-parallel systems	238
	9.2.2 A heuristic approach for optimal assignment of components	246
	9.2.3 Optimal assignment for two path sets: bicriteria approach	249
9.3	Optimal assignment of components in parallel-series systems	251
	9.3.1 Optimal allocation of components in parallel-series systems	252
	9.3.2 Optimal assignment in two cut sets: bicriterion approach	257
9.4	Component assignment in coherent systems	262
	9.4.1 Optimal component assignment through pairwise interchanges	263
	9.4.2 The Malon greedy algorithm	265
	9.4.3 The greedy algorithm of Lin and Kuo	265
	9.4.4 Invariant optimal assignments	269
9.5	Discussion	271
	Exercises	272
10	**Reliability systems with multiple objectives**	275
10.1	Introduction	275
10.2	Classification of multiple objective decision making	278
10.3	MODM solutions	279
10.4	Multiple objective reliability problems	282
10.5	Reliability–redundancy allocation with multiple objectives	283
	10.5.1 Problem description	283
	10.5.2 The multiple objective optimization approach	287

10.6 Fuzzy multiple objective optimization 289
10.7 Discussion 293
Exercises 294

11 Other methods for system-reliability optimization 296

11.1 Introduction 296
11.2 Optimization of effort function 296
11.2.1 Albert method for a series system 297
11.2.2 The Dale–Winterbottom method for a general coherent system 299
11.3 Discussion 301
Exercises 301

12 Burn-in optimization under limited capacity 302

12.1 Introduction 302
12.2 Statement of the problem 303
12.2.1 Objective function and reliability constraints 304
12.2.2 Burn-in capacity 305
12.2.3 Problem formulation 306
12.3 Optimization and the decision tree 306
12.4 Application to an electronic product 309
12.4.1 Assumptions 309
12.4.2 Unconstrained minimization 310
12.4.3 System reliability 311
12.4.4 Constrained minimization 311
12.5 Discussion 313
Exercises 314

13 Case study on design for software reliability optimization 317

13.1 Introduction 317
13.2 The basic execution time model 317
13.3 Resource usage 318
13.4 Reliability modeling 319
13.4.1 The two-component model 320
13.4.2 The three-component model 323
13.5 Formulation of the software reliability optimization problem 324
13.5.1 A pure software system 325
13.5.2 A hardware and software mixed system 325

13.6 Discussion 329
Exercises 329

14 Case study on an optimal scheduled-maintenance policy 332

14.1 Introduction 332
14.2 Criteria functions 333
14.3 The strictest selection 335
14.4 The lexicographic method 335
14.5 The Waltz lexicographic method 337
14.6 SEMOPS: an interactive method 339
14.7 Discussion 341

15 Case studies on reliability optimization 343

15.1 Case study on maintenance for mission effectiveness 343
15.2 Case study on PWR coolant system 346
15.3 Case study on design of a gas pipe line 351
Exercises 357

Appendices 358

Appendix 1 Outline of dynamic programming 358
Appendix 2 The Hooke–Jeeves (H–J) algorithm 360
Appendix 3 Derivation of polytope U^{k+1} from U^k 362
Appendix 4 Consecutive k-out-of-n systems 364

References 367
Index 385