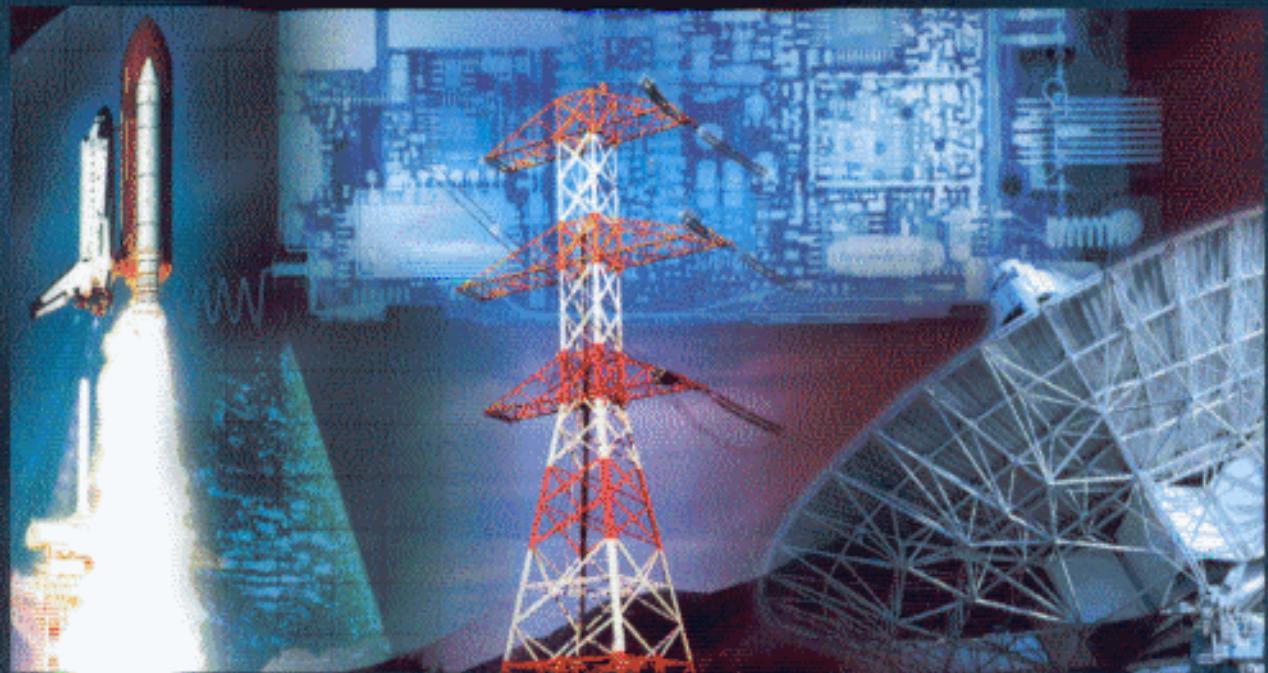


 WILEY

# Practical Reliability Engineering

Fourth Edition



PATRICK D. T. O'CONNOR

# Contents

<b>Preface to the First Edition .....</b>	xiii
<b>Preface to the Second Edition .....</b>	xv
<b>Preface to the Third Edition .....</b>	xvii
<b>Preface to Third Edition Revised .....</b>	xix
<b>Preface to Fourth Edition .....</b>	xxi
<b>Acknowledgements .....</b>	xxiii
<b>Notation and Definitions .....</b>	xxv
<b>1 Introduction to Reliability Engineering .....</b>	1
What is Reliability Engineering? .....	1
Why Teach Reliability Engineering? .....	3
Why do Engineering Items Fail? .....	4
Probabilistic Reliability .....	7
Repairable and Non-repairable Items .....	9
The Pattern of Failures with Time (Non-repairable Items) .....	10
The Pattern of Failures with Time (Repairable Items) .....	10
The Development of Reliability Engineering .....	11
Courses, Conferences and Literature .....	14
Organizations Involved in Reliability Work .....	14
Reliability as an Effectiveness Parameter .....	14
Reliability Programme Activities .....	15
Reliability Economics and Management .....	16
Bibliography .....	19
Questions .....	20
<b>2 Reliability Mathematics .....</b>	21
Introduction .....	21
Variation .....	22
Probability Concepts .....	23

Rules of Probability .....	25
Continuous Variation .....	31
Continuous Distribution Functions .....	35
Summary of Continuous Statistical Distributions .....	45
Variation in Engineering .....	45
Discrete variation .....	53
Statistical Confidence .....	58
Statistical Hypothesis Testing .....	60
Non-parametric Inferential Methods .....	65
Goodness of Fit .....	67
Series of Events (Point Processes) .....	71
Computer Software for Statistics .....	73
Practical Conclusions .....	73
Bibliography .....	75
Questions .....	76
<b>3 Probability Plotting .....</b>	<b>80</b>
Introduction .....	80
Ranking of Data .....	80
Probability Plotting Techniques .....	83
Lognormal Probability Plots .....	87
Weibull Probability Plots .....	87
Extreme Value Probability Plotting .....	95
Hazard Plotting .....	97
Choosing the Distribution and Assessing the Results .....	100
Probability Plotting for Binomial Data .....	102
Conclusions .....	109
Bibliography .....	109
Questions .....	109
<b>4 Load-strength Interference .....</b>	<b>114</b>
Introduction .....	114
Distributed Load and Strength .....	114
Analysis of Load-strength Interference .....	117
Effect of Safety Margin and Loading Roughness on Reliability (Multiple Load Applications) .....	119
Practical Aspects .....	126
Bibliography .....	128
Questions .....	129
<b>5 Statistical Experiments .....</b>	<b>130</b>
Introduction .....	130
Statistical Design of Experiments and Analysis of Variance .....	131
Non-parametric Methods .....	144
Randomizing the Data .....	145
Engineering Interpretation of Results .....	146
The Taguchi Method .....	147
Evolutionary Operation .....	151
Conclusions .....	152

Bibliography .....	154
Questions .....	154
<b>6 Reliability Prediction and Modelling .....</b>	<b>157</b>
Introduction .....	157
Fundamental Limitations of Reliability Prediction .....	158
Reliability Databases .....	162
The Practical Approach .....	163
Systems Reliability Models .....	164
Availability of Repairable Systems .....	168
Modular Design .....	172
Block Diagram Analysis .....	173
Fault Tree Analysis (FTA) .....	179
Petri Nets .....	181
State-space Analysis (Markov Analysis) .....	185
Monte Carlo Simulation .....	190
Reliability Apportionment .....	192
Standard Methods for Reliability Prediction and Modelling .....	192
Conclusions .....	193
Bibliography .....	194
Questions .....	195
<b>7 Reliability in Design .....</b>	<b>200</b>
Introduction .....	200
Computer-aided Engineering .....	200
Environments .....	201
Design Analysis Methods .....	203
Quality Function Deployment (QFD) .....	203
Load-strength Analysis (LSA) .....	205
Failure Modes, Effects and Criticality Analysis (FMECA) .....	206
Reliability Predictions for FMECA .....	214
Hazard and Operability Study (HAZOPS) .....	214
Parts, Materials and Processes (PMP) Review .....	215
Non-material Failure Modes .....	215
Human Reliability .....	216
Design Analysis for Processes .....	216
Critical Items List .....	219
Summary .....	219
Management of Design Review .....	220
Configuration Control .....	222
Bibliography .....	223
Questions .....	223
<b>8 Reliability of Mechanical Components and Systems .....</b>	<b>225</b>
Introduction .....	225
Mechanical Stress, Strength and Fracture .....	226
Fatigue .....	229
Creep .....	235
Wear .....	235

Corrosion . . . . .	237
Vibration and Shock . . . . .	238
Temperature Effects . . . . .	240
Materials . . . . .	241
Components . . . . .	242
Processes . . . . .	243
Bibliography . . . . .	243
Questions . . . . .	245
<b>9 Electronic Systems Reliability . . . . .</b>	<b>247</b>
Introduction . . . . .	247
Reliability of Electronic Components . . . . .	249
Component Types and Failure Mechanisms . . . . .	252
Summary of Device Failure Modes . . . . .	266
Circuit and System Aspects . . . . .	268
Electronic System Reliability Prediction . . . . .	270
Reliability in Electronic System Design . . . . .	271
Parameter Variation and Tolerances . . . . .	280
Design for Production, Test and Maintenance . . . . .	284
Bibliography . . . . .	285
Questions . . . . .	287
<b>10 Software Reliability . . . . .</b>	<b>289</b>
Introduction . . . . .	289
Software in Engineering Systems . . . . .	291
Software Errors . . . . .	292
Preventing Errors . . . . .	295
Software Structure and Modularity . . . . .	296
Programming Style . . . . .	298
Fault Tolerance . . . . .	298
Redundancy/Diversity . . . . .	299
Languages . . . . .	300
Data Reliability . . . . .	301
Software Checking . . . . .	301
Software Design Analysis Methods . . . . .	302
Software Testing . . . . .	303
Error Reporting . . . . .	306
Software Reliability Prediction and Measurement . . . . .	307
Hardware/Software Interfaces . . . . .	311
Conclusions . . . . .	312
Bibliography . . . . .	314
Questions . . . . .	314
<b>11 Reliability Testing . . . . .</b>	<b>316</b>
Introduction . . . . .	316
Planning Reliability Testing . . . . .	318
Test Environments . . . . .	319

Testing for Reliability and Durability: Accelerated Test .....	324
Failure Reporting, Analysis and Corrective Action Systems (FRACAS) .....	333
Bibliography .....	334
Questions .....	335
<b>12 Analysing Reliability Data .....</b>	<b>336</b>
Introduction .....	336
Pareto Analysis .....	336
Accelerated Test Data Analysis .....	338
Reliability Analysis of Repairable Systems .....	341
CUSUM Charts .....	346
Exploratory Data Analysis and Proportional Hazards Modelling .....	349
Reliability Demonstration .....	351
Combining Results Using Bayesian Statistics .....	358
Non-parametric Methods .....	359
Reliability Growth Monitoring .....	360
Making Reliability Grow .....	370
Bibliography .....	372
Questions .....	372
<b>13 Reliability in Manufacture .....</b>	<b>376</b>
Introduction .....	376
Control of Production Variability .....	376
Control of Human Variation .....	380
Acceptance Sampling .....	381
Improving the Process .....	386
Quality Control in Electronics Production .....	391
Stress Screening .....	394
Production Failure Reporting Analysis and Corrective Action System (FRACAS) .....	396
Conclusions .....	397
Bibliography .....	398
Questions .....	398
<b>14 Maintainability, Maintenance and Availability .....</b>	<b>401</b>
Introduction .....	401
Maintenance Time Distributions .....	402
Preventive Maintenance Strategy .....	403
FMECA and FTA in Maintenance Planning .....	407
Maintenance Schedules .....	407
Technology Aspects .....	408
Calibration .....	410
Maintainability Prediction .....	410
Maintainability Demonstration .....	410
Design for Maintainability .....	411
Integrated Logistic Support .....	411
Bibliography .....	412
Questions .....	412

<b>15 Reliability Management . . . . .</b>	<b>414</b>
Corporate Policy for Reliability . . . . .	414
Integrated Reliability Programmes . . . . .	414
Reliability and Costs . . . . .	417
Safety and Product Liability . . . . .	423
Standards for Reliability, Quality and Safety . . . . .	423
Specifying Reliability . . . . .	427
Contracting for Reliability Achievement . . . . .	430
Managing Lower-Level Suppliers . . . . .	432
The Reliability Manual . . . . .	433
The Project Reliability Plan . . . . .	434
Use of External Services . . . . .	435
Customer Management of Reliability . . . . .	436
Selecting and Training for Reliability . . . . .	439
Organization for Reliability . . . . .	440
Managing Production Quality . . . . .	443
Quality Audit . . . . .	445
Quality Management Approaches . . . . .	446
Choosing the Methods: Strategy and Tactics . . . . .	448
Conclusions: Greed, Fear and Freedom . . . . .	449
Bibliography . . . . .	452
Questions . . . . .	452
<b>Appendix 1 The Standard Cumulative Normal Distribution Function . . . . .</b>	<b>455</b>
<b>Appendix 2 Values of <math>y = \exp(-x)</math> . . . . .</b>	<b>457</b>
<b>Appendix 3 Percentiles of the <math>\chi^2</math> Distribution . . . . .</b>	<b>458</b>
<b>Appendix 4 Values of the F-distribution . . . . .</b>	<b>461</b>
<b>Appendix 5 Kolmogorov-Smirnov Tables . . . . .</b>	<b>479</b>
<b>Appendix 6 Rank Tables (Median, 5%, 95%) . . . . .</b>	<b>481</b>
<b>Appendix 7 Matrix Algebra Revision . . . . .</b>	<b>493</b>
<b>Appendix 8 Failure Reporting, Analysis and Corrective Action System (FRACAS) . . . . .</b>	<b>495</b>
<b>Appendix 9 Reliability, Maintainability (and Safety) Plan Example . . . . .</b>	<b>497</b>
<b>Index . . . . .</b>	<b>505</b>