

Contents

1 Basic Concepts, Quality & Reliability (RAMS) Assurance of Complex Equip. & Systems . . .	1
1.1 Introduction	1
1.2 Basic Concepts	2
1.2.1 Reliability	2
1.2.2 Failure	3
1.2.3 Failure Rate, <i>MTTF</i> , <i>MTBF</i>	4
1.2.4 Maintenance, Maintainability	8
1.2.5 Logistic Support	8
1.2.6 Availability	9
1.2.7 Safety, Risk, and Risk Acceptance	9
1.2.8 Quality	11
1.2.9 Cost and System Effectiveness.	11
1.2.10 Product Liability	15
1.2.11 Historical Development	16
1.3 Basic Tasks & Rules for Quality & Rel. (RAMS) Assurance of Complex Eq. & Systems .	17
1.3.1 Quality and Reliability (RAMS) Assurance Tasks	17
1.3.2 Basic Quality and Reliability (RAMS) Assurance Rules	19
1.3.3 Elements of a Quality Assurance System.	21
1.3.4 Motivation and Training	24
2 Reliability Analysis During the Design Phase (Nonrepairable Elements up to System Failure) . .	25
2.1 Introduction	25
2.2 Predicted Reliability of Equipment and Systems with Simple Structure	28
2.2.1 Required Function	28
2.2.2 Reliability Block Diagram	28
2.2.3 Operating Conditions at Component Level, Stress Factors	33
2.2.4 Failure Rate of Electronic Components	35
2.2.5 Reliability of One-Item Structures	39
2.2.6 Reliability of Series-Parallel Structures	41
2.2.6.1 Systems without Redundancy	41
2.2.6.2 Concept of Redundancy	42
2.2.6.3 Parallel Models	43
2.2.6.4 Series - Parallel Structures	45
2.2.6.5 Majority Redundancy	49
2.2.7 Part Count Method	51
2.3 Reliability of Systems with Complex Structure	52
2.3.1 Key Item Method	52
2.3.1.1 Bridge Structure	53
2.3.1.2 Rel. Block Diagram in which Elements Appear More than Once	54
2.3.2 Successful Path Method	55
2.3.3 State Space Method	56
2.3.4 Boolean Function Method	57
2.3.5 Parallel Models with Constant Failure Rates and Load Sharing	61
2.3.6 Elements with more than one Failure Mechanism or one Failure Mode	64
2.3.7 Basic Considerations on Fault Tolerant Structures	66
2.4 Reliability Allocation and Optimization	67

2.5	Mechanical Reliability, Drift Failures	68
2.6	Failure Modes Analyses	72
2.7	Reliability Aspects in Design Reviews	77
3	Qualification Tests for Components and Assemblies	81
3.1	Basic Selection Criteria for Electronic Components	81
3.1.1	Environment	82
3.1.2	Performance Parameters	84
3.1.3	Technology	84
3.1.4	Manufacturing Quality	86
3.1.5	Long-Term Behavior of Performance Parameters	86
3.1.6	Reliability	86
3.2	Qualification Tests for Complex Electronic Components	87
3.2.1	Electrical Test of Complex ICs	88
3.2.2	Characterization of Complex ICs	90
3.2.3	Environmental and Special Tests of Complex ICs	92
3.2.4	Reliability Tests	101
3.3	Failure Modes, Mechanisms, and Analysis of Electronic Components	101
3.3.1	Failure Modes of Electronic Components	101
3.3.2	Failure Mechanisms of Electronic Components	102
3.3.3	Failure Analysis of Electronic Components	102
3.3.4	Present VLSI Production-Related Reliability Problems	106
3.4	Qualification Tests for Electronic Assemblies	107
4	Maintainability Analysis	112
4.1	Maintenance, Maintainability	112
4.2	Maintenance Concept	115
4.2.1	Fault Detection (Recognition) and Localization.	116
4.2.2	Equipment and Systems Partitioning	118
4.2.3	User Documentation	118
4.2.4	Training of Operation and Maintenance Personnel	119
4.2.5	User Logistic Support	119
4.3	Maintainability Aspects in Design Reviews	121
4.4	Predicted Maintainability	121
4.4.1	Calculation of $MTTR_S$	121
4.4.2	Calculation of $MTTPM_S$	125
4.5	Basic Models for Spare Parts Provisioning	125
4.5.1	Centralized Logistic Support, Nonrepairable Spare Parts	125
4.5.2	Decentralized Logistic Support, Nonrepairable Spare Parts	129
4.5.3	Repairable Spare Parts	130
4.6	Maintenance Strategies	134
4.6.1	Complete renewal at each maintenance action	134
4.6.2	Block replacement with minimal repair at failure	138
4.6.3	Further considerations on maintenance strategies	139
4.7	Basic Cost Considerations	142
5	Design Guidelines for Reliability, Maintainability, and Software Quality	144
5.1	Design Guidelines for Reliability	144
5.1.1	Derating	144

5.1.2	Cooling	145
5.1.3	Moisture	147
5.1.4	Electromagnetic Compatibility, ESD Protection	148
5.1.5	Components and Assemblies	150
5.1.5.1	Component Selection	150
5.1.5.2	Component Use	150
5.1.5.3	PCB and Assembly Design	151
5.1.5.4	PCB and Assembly Manufacturing	152
5.1.5.5	Storage and Transportation	153
5.1.6	Particular Guidelines for IC Design and Manufacturing	153
5.2	Design Guidelines for Maintainability	154
5.2.1	General Guidelines	154
5.2.2	Testability	155
5.2.3	Connections, Accessibility, Exchangeability	157
5.2.4	Adjustment	158
5.2.5	Human, Ergonomic, and Safety Aspects	158
5.3	Design Guidelines for Software Quality	159
5.3.1	Guidelines for Software Defect Prevention	162
5.3.2	Configuration Management	165
5.3.3	Guidelines for Software Testing	166
5.3.4	Software Quality Growth Models	166
6	Reliability and Availability of Repairable Systems	169
6.1	Introduction, General Assumptions, Conclusions	169
6.2	One-Item Structure	175
6.2.1	One-Item Structure New at Time $t = 0$	176
6.2.1.1	Reliability Function	176
6.2.1.2	Point Availability	177
6.2.1.3	Average Availability	178
6.2.1.4	Interval Reliability	179
6.2.1.5	Special Kinds of Availability	180
6.2.2	One-Item Structure New at Time $t = 0$ and with Constant Failure Rate λ	183
6.2.3	One-Item Structure with Arbitrary Conditions at $t = 0$	184
6.2.4	Asymptotic Behavior	185
6.2.5	Steady-State Behavior	187
6.3	Systems without Redundancy	189
6.3.1	Series Structure with Constant Failure and Repair Rates	189
6.3.2	Series Structure with Constant Failure and Arbitrary Repair Rates	192
6.3.3	Series Structure with Arbitrary Failure and Repair Rates	193
6.4	1-out-of-2 Redundancy (Warm, one Repair Crew)	196
6.4.1	1-out-of-2 Redundancy with Constant Failure and Repair Rates	196
6.4.2	1-out-of-2 Redundancy with Constant Failure and Arbitrary Rep. Rates	204
6.4.3	1-out-of-2 Red. with Const. Failure Rate in Reserve State & Arbitr. Rep. Rates	207
6.5	k -out-of- n Redundancy (Warm, Identical Elements, one Repair Crew)	213
6.5.1	k -out-of- n Redundancy with Constant Failure and Repair Rates	214
6.5.2	k -out-of- n Redundancy with Constant Failure and Arbitrary Repair Rates	218
6.6	Simple Series - Parallel Structures (one Repair Crew)	220
6.7	Approximate Expressions for Large Series - Parallel Structures	226
6.7.1	Introduction	226
6.7.2	Application to a Practical Example	230

6.8	Systems with Complex Structure (one Repair Crew)	238
6.8.1	General Considerations	238
6.8.2	Preventive Maintenance	240
6.8.3	Imperfect Switching.	243
6.8.4	Incomplete Coverage	249
6.8.5	Elements with more than two States or one Failure Mode	257
6.8.6	Fault Tolerant Reconfigurable Systems	259
6.8.6.1	Ideal Case	259
6.8.6.2	Time Censored Reconfiguration (Phased-Mission Systems)	259
6.8.6.3	Failure Censored Reconfiguration	266
6.8.6.4	Reward and Frequency /Duration Aspects	270
6.8.7	Systems with Common Cause Failures	271
6.8.8	Basic Considerations on Network-Reliability	275
6.8.9	General Procedure for Modeling Complex Systems	277
6.9	Alternative Investigation Methods	280
6.9.1	Systems with Totally Independent Elements	280
6.9.2	Static and Dynamic Fault Trees	280
6.9.3	Binary Decision Diagrams	283
6.9.4	Event Trees	286
6.9.5	Petri Nets	287
6.9.6	Numerical Reliability and Availability Computation	289
6.9.6.1	Numerical Computation of System's Reliability and Availability	289
6.9.6.2	Monte Carlo Simulations	290
6.9.7	Approximate expressions for Large, Complex Systems: Basic Considerations.	293
6.10	Human Reliability	294
7	Statistical Quality Control and Reliability Tests	299
7.1	Statistical Quality Control	299
7.1.1	Estimation of a Defective Probability p	300
7.1.2	Simple Two-sided Sampling Plans for Demonstration of a Def. Probability p	302
7.1.2.1	Simple Two-sided Sampling Plan	303
7.1.2.2	Sequential Test	305
7.1.3	One-sided Sampling Plans for the Demonstration of a Def. Probability p	306
7.2	Statistical Reliability Tests	309
7.2.1	Reliability and Availability Estimation & Demon. for a given fixed Mission	309
7.2.2	Availability Estimation & Demonstration for Continuous Operation (steady-state)	311
7.2.2.1	Availability Estimation (Erlangian Failure-Free and/or Repair Times)	311
7.2.2.2	Availability Demonstration (Erlangian Failure-Free and/or Repair Times)	313
7.2.2.3	Further Availability Evaluation Methods for Continuous Operation	314
7.2.3	Estimation and Demonstration of a Const. Failure Rate λ (or of $MTBF=1/\lambda$)	316
7.2.3.1	Estimation of a Constant Failure Rate λ	318
7.2.3.2	Simple Two-sided Test for the Demonstration of λ	320
7.2.3.3	Simple One-sided Test for the Demonstration of λ	324
7.3	Statistical Maintainability Tests	325
7.3.1	Estimation of an $MTTR$	325
7.3.2	Demonstration of an $MTTR$	327
7.4	Accelerated Testing	329
7.5	Goodness-of-fit Tests	334
7.5.1	Kolmogorov-Smirnov Test	334
7.5.2	Chi-square Test	338

7.6	Statistical Analysis of General Reliability Data	341
7.6.1	General considerations	341
7.6.2	Tests for Nonhomogeneous Poisson Processes	343
7.6.3	Trend Tests	345
7.6.3.1	Tests of a HPP versus a NHPP with increasing intensity	345
7.6.3.2	Tests of a HPP versus a NHPP with decreasing intensity	348
7.6.3.3	Heuristic Tests to distinguish between HPP and Monotonic Trend	349
7.7	Reliability Growth	351
8	Quality & Reliability (RAMS) Assurance During Production Phase (Basic Considerations)	357
8.1	Basic Activities	357
8.2	Testing and Screening of Electronic Components	358
8.2.1	Testing of Electronic Components	358
8.2.2	Screening of Electronic Components	359
8.3	Testing and Screening of Electronic Assemblies	362
8.4	Test and Screening Strategies, Economic Aspects	364
8.4.1	Basic Considerations	364
8.4.2	Quality Cost Optimization at Incoming Inspection Level	367
8.4.3	Procedure to handle first deliveries	372
 Appendices (A1 - A11)		
A1	Terms and Definitions	373
A2	Quality and Reliability (RAMS) Standards	387
A2.1	Introduction	387
A2.2	General Requirements in the Industrial Field	388
A2.3	Requirements in the Aerospace, Railway, Defense, and Nuclear Fields	390
A3	Definition and Realization of Quality and Reliability (RAMS) Requirements	391
A3.1	Definition of Quality and Reliability (RAMS) Requirements	391
A3.2	Realization of Quality & Reliability (RAMS) Requirements for Complex Eq. & Syst.	393
A3.3	Elements of a Quality and Reliability (RAMS) Assurance Program	398
A3.3.1	Project Organization, Planning, and Scheduling	398
A3.3.2	Quality and Reliability (RAMS) Requirements	399
A3.3.3	Reliability, Maintainability, and Safety Analysis	399
A3.3.4	Selection and Qualification of Components, Materials, Manuf. Processes	400
A3.3.5	Software Quality Assurance	400
A3.3.6	Configuration Management	401
A3.3.7	Quality Tests	402
A3.3.8	Quality Data Reporting System	404
A4	Checklists for Design Reviews	405
A4.1	System Design Review	405
A4.2	Preliminary Design Reviews	406
A4.3	Critical Design Review (System Level)	409
A5	Requirements for Quality Data Reporting Systems	410
A6	Basic Probability Theory	413
A6.1	Field of Events	413
A6.2	Concept of Probability	415

A6.3	Conditional Probability, Independence	418
A6.4	Fundamental Rules of Probability Theory	419
A6.4.1	Addition Theorem for Mutually Exclusive Events	419
A6.4.2	Multiplication Theorem for Two Independent Events	420
A6.4.3	Multiplication Theorem for Arbitrary Events	421
A6.4.4	Addition Theorem for Arbitrary Events	421
A6.4.5	Theorem of Total Probability	422
A6.5	Random Variables, Distribution Functions	423
A6.6	Numerical Parameters of Random Variables	429
A6.6.1	Expected Value (Mean)	429
A6.6.2	Variance	432
A6.6.3	Modal Value, Quantile, Median	434
A6.7	Multidimensional Random Variables, Conditional Distributions	434
A6.8	Numerical Parameters of Random Vectors	436
A6.8.1	Covariance Matrix, Correlation Coefficient	437
A6.8.2	Further Properties of Expected Value and Variance	438
A6.9	Distribution of the Sum of Indep. Positive Random Variables and of τ_{\min}, τ_{\max}	438
A6.10	Distribution Functions used in Reliability Analysis	441
A6.10.1	Exponential Distribution	441
A6.10.2	Weibull Distribution	442
A6.10.3	Gamma Distribution, Erlangian Distribution, and χ^2 -Distribution	444
A6.10.4	Normal Distribution	446
A6.10.5	Lognormal Distribution	447
A6.10.6	Uniform Distribution	449
A6.10.7	Binomial Distribution	449
A6.10.8	Poisson Distribution	451
A6.10.9	Geometric Distribution	453
A6.10.10	Hypergeometric Distribution	454
A6.11	Limit Theorems	454
A6.11.1	Laws of Large Numbers	455
A6.11.2	Central Limit Theorem	456
A7	Basic Stochastic-Processes Theory	460
A7.1	Introduction	460
A7.2	Renewal Processes	463
A7.2.1	Renewal Function, Renewal Density	465
A7.2.2	Recurrence Times	468
A7.2.3	Asymptotic Behavior	469
A7.2.4	Stationary Renewal Processes	471
A7.2.5	Homogeneous Poisson Processes (HPP)	472
A7.3	Alternating Renewal Processes	474
A7.4	Regenerative Processes with a Finite Number of States.	478
A7.5	Markov Processes with a Finite Number of States.	480
A7.5.1	Markov Chains with a Finite Number of States	480
A7.5.2	Markov Processes with a Finite Number of States	482
A7.5.3	State Probabilities and Stay Times in a Given Class of States.	491
A7.5.3.1	Method of Differential Equations	491
A7.5.3.2	Method of Integral Equations	495
A7.5.3.3	Stationary State and Asymptotic Behavior	496
A7.5.4	Frequency / Duration and Reward Aspects	498
A7.5.4.1	Frequency / Duration	498
A7.5.4.2	Reward	500

A7.5.5 Birth and Death Process 501

A7.6 Semi-Markov Processes with a Finite Number of States 505

A7.7 Semi-regenerative Processes with a Finite Number of States. 510

A7.8 Nonregenerative Stochastic Processes with a Countable Number of States 515

 A7.8.1 General Considerations 515

 A7.8.2 Nonhomogeneous Poisson Processes (NHPP) 516

 A7.8.3 Superimposed Renewal Processes 520

 A7.8.4 Cumulative Processes 521

 A7.8.5 General Point Processes 523

A8 Basic Mathematical Statistics 525

 A8.1 Empirical Methods 525

 A8.1.1 Empirical Distribution Function 526

 A8.1.2 Empirical Moments and Quantiles 528

 A8.1.3 Further Applications of the Empirical Distribution Function 529

 A8.2 Parameter Estimation 533

 A8.2.1 Point Estimation 533

 A8.2.2 Interval Estimation 538

 A8.2.2.1 Estimation of an Unknown Probability p 538

 A8.2.2.2 Estimation of Param. λ for Exp. Distrib.: Fixed T , instant. repl. . 542

 A8.2.2.3 Estimation of Param. λ for Exp. Distrib.: Fixed n , no repl. . . 543

 A8.2.2.4 Availability Estimation (Erlangian Failure-Free and/or Repair Times) 545

 A8.3 Testing Statistical Hypotheses 547

 A8.3.1 Testing an Unknown Probability p 548

 A8.3.1.1 Simple Two-sided Sampling Plan 549

 A8.3.1.2 Sequential Test 550

 A8.3.1.3 Simple One-sided Sampling Plan 551

 A8.3.1.4 Availability Demonstr. (Erlangian Failure-Free and/or Rep. Times) . 553

 A8.3.2 Goodness-of-fit Tests for Completely Specified $F_0(t)$ 555

 A8.3.3 Goodness-of-fit Tests for $F_0(t)$ with Unknown Parameters 558

A9 Tables and Charts 561

 A9.1 Standard Normal Distribution 561

 A9.2 χ^2 -Distribution (Chi-Square Distribution) 562

 A9.3 t -Distribution (Student distribution) 563

 A9.4 F -Distribution (Fisher distribution) 564

 A9.5 Table for the Kolmogorov-Smirnov Test 565

 A9.6 Gamma Function 566

 A9.7 Laplace Transform 567

 A9.8 Probability Charts (Probability Plot Papers) 569

 A9.8.1 Lognormal Probability Chart 569

 A9.8.2 Weibull Probability Chart 570

 A9.8.3 Normal Probability Chart 571

A10 Basic Technological Component's Properties 572

A11 Problems for Homework 576

Acronyms 582

References 583

Index 605