

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, 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 with Independent Elements	41
2.2.6.1	Systems without Redundancy (series models)	41
2.2.6.2	Concept of Redundancy	42
2.2.6.3	Parallel Models	43
2.2.6.4	Series - Parallel Structures with Independent Elements	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	108
4	Maintainability Analysis	112
4.1	Maintenance, Maintainability	112
4.2	Maintenance Concept	115
4.2.1	Equipment and Systems Partitioning	116
4.2.2	Fault Detection (Recognition) and Localization	116
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 $MTTR_S$ & MDT_S	121
4.4.2	Calculation of Mean Time to Preventive Maintenance	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	293
6.10	Human Reliability	294
6.11	Risk Management for repairable Systems	299
6.11.1	Introduction	299
6.11.2	Risk Modeling, $S(t)$, $MTTFA$	301
6.11.3	Risk Avoidance and Risk Mitigation	309
7	Statistical Quality Control and Reliability (RAMS) Tests	311
7.1	Statistical Quality Control	311
7.1.1	Estimation of a Defective Probability p	312
7.1.2	Simple Two-sided Sampling Plans for Demonstration of a Def. Probability p	314
7.1.2.1	Simple Two-sided Sampling Plan	315
7.1.2.2	Sequential Test	317
7.1.3	One-sided Sampling Plans for the Demonstration of a Def. Probability p	318
7.2	Statistical Reliability (RAMS) Tests	321
7.2.1	Reliability and Availability Estimation & Demon. for a given (fixed) Mission	321
7.2.2	Availability Estimation & Demonstration for Continuous Operation (steady-state)	323
7.2.2.1	Availability Estimation (Erlangian Failure-Free and/or Repair Times)	323
7.2.2.2	Availability Demonstration (Erlangian Failure-Free and/or Repair Times)	325
7.2.2.3	Further Availability Evaluation Methods for Continuous Operation	326
7.2.3	Estimation and Demonstration of a Const. Failure Rate λ (or of $MTBF = 1/\lambda$)	328
7.2.3.1	Estimation of a Constant Failure Rate λ	330
7.2.3.2	Simple Two-sided Test for the Demonstration of λ	332
7.2.3.3	Simple One-sided Test for the Demonstration of λ	336
7.3	Estimation and Demonstration of an $MTTR$	337
7.3.1	Estimation of an $MTTR$	337
7.3.2	Demonstration of an $MTTR$	339
7.4	Accelerated Testing	341

7.5	Goodness-of-fit Tests	346
7.5.1	Kolmogorov-Smirnov Test	346
7.5.2	Chi-square Test	350
7.6	Statistical Analysis of General Reliability Data	353
7.6.1	General considerations	353
7.6.2	Tests for Nonhomogeneous Poisson Processes	355
7.6.3	Trend Tests	357
7.6.3.1	Tests of a HPP versus a NHPP with increasing intensity	357
7.6.3.2	Tests of a HPP versus a NHPP with decreasing intensity	360
7.6.3.3	Heuristic Tests to distinguish between HPP and Monotonic Trend	361
7.7	Reliability Growth	363
8	Quality & Reliability Assurance During the Production Phase (Basic Considerations)	369
8.1	Basic Activities	369
8.2	Testing and Screening of Electronic Components	370
8.2.1	Testing of Electronic Components	370
8.2.2	Screening of Electronic Components	371
8.3	Testing and Screening of Electronic Assemblies	374
8.4	Test and Screening Strategies, Economic Aspects	376
8.4.1	Basic Considerations	376
8.4.2	Quality Cost Optimization at Incoming Inspection Level	379
8.4.3	Procedure to handle first deliveries	384
 <i>Appendices (A1-A11)</i>		
A1	Terms and Definitions	385
A2	Quality and Reliability (RAMS) Standards, Story of Reliability Engineering	401
A2.1	Introduction	401
A2.2	General Requirements in the Industrial Field	402
A2.3	Requirements in the Aerospace, Railway, Defense, and Nuclear Fields	404
A2.4	A Skillful, Allegorical Story of Reliability	405
A3	Definition and Realization of Quality & Reliability (RAMS) Requirements	407
A3.1	Definition of Quality and Reliability (RAMS) Requirements	407
A3.2	Realization of Quality & Reliability (RAMS) Requirements for Complex Eq. & Syst.	409
A3.3	Elements of a Quality and Reliability (RAMS) Assurance Program	414
A3.3.1	Project Organization, Planning, and Scheduling	414
A3.3.2	Quality and Reliability (RAMS) Requirements	415
A3.3.3	Reliability, Maintainability, and Safety Analyses	415
A3.3.4	Selection & Qualification of Components, Materials, Manuf. Processes.	416
A3.3.5	Software Quality Assurance	416
A3.3.6	Configuration Management	417
A3.3.7	Quality Tests	418
A3.3.8	Quality Data Reporting System	420
A4	Checklists for Design Reviews	421
A4.1	System Design Review	421
A4.2	Preliminary Design Reviews	422
A4.3	Critical Design Review (System Level)	425
A5	Requirements for a Quality Data Reporting System	426

A6 Basic Probability Theory	429
A6.1 Field of Events	429
A6.2 Concept of Probability	431
A6.3 Conditional Probability, Independence	434
A6.4 Fundamental Rules of Probability Theory	435
A6.4.1 Addition Theorem for Mutually Exclusive Events	435
A6.4.2 Multiplication Theorem for Two Independent Events	436
A6.4.3 Multiplication Theorem for Arbitrary Events	437
A6.4.4 Addition Theorem for Arbitrary Events	437
A6.4.5 Theorem of Total Probability	438
A6.5 Random Variables, Distribution Functions	439
A6.6 Numerical Parameters of Random Variables	445
A6.6.1 Expected Value (Mean)	445
A6.6.2 Variance	448
A6.6.3 Modal Value, Quantile, Median	450
A6.7 Multidimensional Random Variables, Conditional Distributions	450
A6.8 Numerical Parameters of Random Vectors	452
A6.8.1 Covariance Matrix, Correlation Coefficient	453
A6.8.2 Further Properties of Expected Value and Variance	454
A6.9 Distribution of the Sum of Indep. Positive Random Variables and of τ_{\min} , τ_{\max}	454
A6.10 Distribution Functions used in Reliability Analysis	457
A6.10.1 Exponential Distribution	457
A6.10.2 Weibull Distribution	458
A6.10.3 Gamma Distribution, Erlangian Distribution, and χ^2 -Distribution	460
A6.10.4 Normal Distribution	462
A6.10.5 Lognormal Distribution	463
A6.10.6 Uniform Distribution	465
A6.10.7 Binomial Distribution	465
A6.10.8 Poisson Distribution	467
A6.10.9 Geometric Distribution	469
A6.10.10 Hypergeometric Distribution	470
A6.11 Limit Theorems	470
A6.11.1 Laws of Large Numbers	471
A6.11.2 Central Limit Theorem	472
A7 Basic Stochastic-Processes Theory	476
A7.1 Introduction	476
A7.2 Renewal Processes	479
A7.2.1 Renewal Function, Renewal Density	481
A7.2.2 Recurrence Times	484
A7.2.3 Asymptotic Behavior	485
A7.2.4 Stationary Renewal Processes	487
A7.2.5 Homogeneous Poisson Processes (HPP)	488
A7.3 Alternating Renewal Processes	490
A7.4 Regenerative Processes with a Finite Number of States	494
A7.5 Markov Processes with a Finite Number of States	496
A7.5.1 Markov Chains with a Finite Number of States	496
A7.5.2 Markov Processes with a Finite Number of States	498
A7.5.3 State Probabilities and Stay Times in a Given Class of States	507
A7.5.3.1 Method of Differential Equations	507
A7.5.3.2 Method of Integral Equations	511
A7.5.3.3 Stationary State and Asymptotic Behavior	512

A7.5.4	Frequency / Duration and Reward Aspects	514
A7.5.4.1	Frequency / Duration	514
A7.5.4.2	Reward	516
A7.5.5	Birth and Death Process	517
A7.6	Semi-Markov Processes with a Finite Number of States	521
A7.7	Semi-regenerative Processes with a Finite Number of States	526
A7.8	Nonregenerative Stochastic Processes with a Countable Number of States	531
A7.8.1	General Considerations	531
A7.8.2	Nonhomogeneous Poisson Processes (NHPP)	532
A7.8.3	Superimposed Renewal Processes	536
A7.8.4	Cumulative Processes	537
A7.8.5	General Point Processes	539
A8	Basic Mathematical Statistics	541
A8.1	Empirical Methods	541
A8.1.1	Empirical Distribution Function	542
A8.1.2	Empirical Moments and Quantiles	544
A8.1.3	Further Applications of the Empirical Distribution Function	545
A8.2	Parameter Estimation	549
A8.2.1	Point Estimation	549
A8.2.2	Interval Estimation	554
A8.2.2.1	Estimation of an Unknown Probability p	554
A8.2.2.2	Estimation of Param. λ for Exp. Distrib.: Fixed T , instant. repl.	558
A8.2.2.3	Estimation of Param. λ for Exp. Distrib.: Fixed n , no repl.	559
A8.2.2.4	Availability Estimation (Erlangian Failure-Free and/or Repair Times)	561
A8.3	Testing Statistical Hypotheses	563
A8.3.1	Testing an Unknown Probability p	564
A8.3.1.1	Simple Two-sided Sampling Plan	565
A8.3.1.2	Sequential Test	566
A8.3.1.3	Simple One-sided Sampling Plan	567
A8.3.1.4	Availability Demonstr. (Erlangian Failure-Free and/or Rep. Times)	569
A8.3.2	Goodness-of-fit Tests for Completely Specified $F_0(t)$	571
A8.3.3	Goodness-of-fit Tests for $F_0(t)$ with Unknown Parameters	574
A9	Tables and Charts	577
A9.1	Standard Normal Distribution	577
A9.2	χ^2 -Distribution (Chi-Square Distribution)	578
A9.3	t -Distribution (Student distribution)	579
A9.4	F -Distribution (Fisher distribution)	580
A9.5	Table for the Kolmogorov-Smirnov Test	581
A9.6	Gamma Function	582
A9.7	Laplace Transform	583
A9.8	Probability Charts (Probability Plot Papers)	585
A9.8.1	Lognormal Probability Chart	585
A9.8.2	Weibull Probability Chart	586
A9.8.3	Normal Probability Chart	587
A10	Basic Technological Component's Properties	588
A11	Problems for Homework	592
	Acronyms	600
	References	601
	Index	627