RELIABILITY THEORY AND PRACTICE

Igor Bazovsky

DOVER PUBLICATIONS, INC.
Mineola, New York

TABLE OF CONTENTS

1 THE CONCEPT OF RELIABILITY 1

The meaning of reliability in engineering. Failure frequency—a measure of reliability. Early, chance, and wearout failures. Distribution of failures in the time domain and failure probability. Probability and reality. The tossing of a well-balanced coin. True probability and estimates. Reliability is the probability of success.

2 THE DEFINITION OF RELIABILITY 11

The accepted definition. Example of the biased coin. Adequate and inadequate performance of a function. The time element in reliability. Mean time between failures. Mean number of cycles between failures. Correlation between operating time and other life parameters.

3 THE EXPONENTIAL CASE OF CHANCE FAILURES 17

The exponential reliability formula. Failure rate and mean time between failures. Useful life. The standardized exponential reliability function. System reliability vs. reliability of components. Conversion of the mean number of cycles between failures to the mean time between failures.

4 THE DERIVATION OF THE RELIABILITY FUNCTION 24

A definition of probability. Reliability and unreliability as fractions of survivors and failures. Instantaneous failure rate. The derivation of the general reliability formula. The failure density function and its integration.

5 USEFUL LIFE OF COMPONENTS 32

Randomness of chance failures. Their physical mechanism. Constant failure rate and exponential decay. Replacement and nonreplacement tests. Failure rate vs. life. Burn-in, useful life, and wearout periods. Mean wearout life. Debugging and preventive replacement.

6 WEAROUT AND RELIABILITY 36

The normal distribution of wearout failures. The normal density function. Mean wearout life and standard deviation. A priori, cumulative, and conditional probability of wearout failure. The use of normal tables. The wearout failure rate and its standardization. The logarithmic normal distribution. Choice of component replacement time and system reliability. Chance and wearout.

7 COMBINED EFFECTS OF CHANCE AND WEAROUT FAILURES 52

Conditional reliability of components and system reliability. Wearout effects. What happens when components in a system are replaced only "as they fail." The wearout replacement rate. The exponential behavior of systems with stabilized wearout failure rates.

8 EARLY FAILURES AND THE LIFE FUNCTION OF COMPONENTS 63

Substandard components. The chance mechanism of early failures. The exponential decay of substandard components in a repairable system. The mean debugging time. Perfect and nonperfect repair. Incremental failure rate. Over-all component failure rate. The life function of components.

9 THE EXPONENTIAL AND POISSON DISTRIBUTIONS 76

The exponential distribution of chance failures in debugged systems. The general equation for mean time between failures. The constant failure rate of the exponential case. The addition of exponents. Events in the time domain. The binomial distribution. The Poisson distribution. The probability of an exact number of failures.

10 RELIABILITY OF SERIES SYSTEMS 85

Components and systems. Simple probability theorems for reliability calculations. The product rule of series reliabilities. The addition of series failure rates. Stress levels. Component failure rates in system time scale. Continuously and intermittently operating components. Cycled components. Switching frequency and system reliability.

11 RELIABILITY OF PARALLEL SYSTEMS 97

Parallel redundancy. The product rule of parallel unreliabilities. Parallel system reliability and mean time between failures. Reliability gains by parallel redundancy. Effects of various maintenance policies on redundant systems. The expected number of scheduled and unscheduled replacements. The binomial expansion. Partial redundancies. Series-parallel systems. Probability that no maintenance will be required.

12 RELIABILITY OF STAND-BY SYSTEMS 112

Equal components in stand-by. The mean time between failures of stand-by systems. Failure-sensing and switchover. Unequal components in stand-by.

13 BAYES' THEOREM IN RELIABILITY 121

Reliability calculation of systems which are neither in series, parallel, nor stand-by. Bayes' probability theorem. Its application in reliability.

14 COMPONENT MODES OF FAILURE AND SYSTEM RELIABILITY 127

Components with several modes of failure. Extension of Bayes' theorem to modes of failure. Electronic switching circuit reliabilities. Reliability of load-sharing components. Switches in parallel and series operation.

15 COMPONENT FAILURE RATES AT SYSTEM STRESS LEVELS 142

Component life parameters. The common time factor. Component duty cycles in system operating time scale. Sequence operation of systems. The physical processes of component failure. The stress spectrum and failure frequency. Interaction between component strength and applied stresses. Environmental and operating stresses. The importance of temperature. Failure rate derating curves and their use in design work. The effects of storage. A model equation for failure rate transfer. Testing at three stress levels. Operating stress level analysis.

16 SAFETY AND RELIABILITY OF AIRCRAFT AND AIRBORNE SYSTEMS 155

Operational reliability. System safety as a probability concept. Safety functions, essential functions, and convenience functions. Minimum requirements for safety and reliability of aircraft. Conditional probabilities in system reliability calculations. System reliability as a product of function reliabilities. Aircraft reliability for nonstop flights and flights with intermediate stops. Airworthiness.

17 SYSTEM MAINTENANCE, AVAILABILITY, AND DEPENDABILITY 165

Regular and off-schedule maintenance. Expected number of in-service failures. Manhour calculations. Maintenance clock time and down time. System utilization factor. Redundant systems. In-service repair. Space system reliability and maintainability design. System reliabilities independent of the operating time. Regular inspections. Estimation of the maintenance manhour requirements for redundant systems. Equations for system availability and dependability.

18 RELIABILITY DESIGN CONSIDERATIONS 176

Performance and reliability design. The designer's reliability control program. Designing for numerical reliability requirements. Preliminary design reliability analysis. Choice of most reliable design. Circuit analysis and stress analysis. Application of failure rate derating techniques. When to use redundancy. Prototype reliability tests. Management attitude to reliability. Reliability support organization. Collection of component reliability characteristics. Component life and drift of parameters. Tolerant design. Design simplification.

19 DESIGN ANALYSIS EXAMPLES 186

The reliability block diagram and analysis of an airborne radio communication system. Failure rate derating and effects of redundancy. Reliability analysis of three configurations of twin-engine aircraft, variable-speed, constant-frequency generating systems. Use of Bayes' theorem. Reliability analysis of an aircraft hydraulic-brake system.

20 OVERHAULS AND PART REPLACEMENTS 195

Choice of regular overhaul times. Mean time between scheduled and unscheduled overhauls. Extension of the time between overhauls and probability of wearout failures. Equipment design life. Parts replacement schedules. The mean time between failures of regularly inspected and maintained systems. The concept of the constant average failure rate. Equations for regularly maintained stand-by and parallel systems. Preventive maintenance and the mean time between wearout failures.

21 COMPONENT RELIABILITY MEASUREMENTS 208

Evaluation of statistical data and estimates. Simulated environment tests. Nonreplacement, per cent survival and replacement tests for exponential components. Censorship. Sample sizes. Component mean wearout life and standard deviation measurements.

Truncated normal tests. Storage tests. Degradation and permanent tolerance drift tests.

22 CONFIDENCE LIMITS 227

Confidence levels and intervals for estimated mean wearout life and standard deviation. Tables for one-sided and two-sided confidence limits. Overhaul and replacement times based on confidence limits. Confidence limits for truncated normal tests. The chi-square confidence limits for exponential mean times between failures. Lower confidence limits on reliability estimates. Graph for confidence limits evaluation. Confidence in spare parts availability.

23 SYSTEM RELIABILITY MEASUREMENTS 245

Repairable and nonrecoverable systems. Maintenance specification and system wearout prevention. Tests for the mean time between failures of exponential systems. Systems containing redundancy. Nonparametric estimation of the reliability function.

24 SEQUENTIAL RELIABILITY TESTS 254

The probability of an exact number of failures. Probability ratios. Consumer's and producer's risks. Rules for making decisions in sequential tests. Minimum test times for accept and reject decisions. Test truncation. The graphical procedure. Accumulated test time computations. Failure definition. Sequential tests for mean wearout life and standard deviation. Binomial reliability tests. Accelerated tests.

25 THE IMPLEMENTATION OF RELIABILITY 274

A historical review. The designer's responsibility in reliability. The status of a reliability organization. The role of quality control. Quality and reliability. Production and inspection. Reliability education. The financial benefits of reliability.

26 THE STATE-OF-ART OF RELIABILITY 283

Mathematical statistics and the probability theory. Approximations to reality. The pressing problem of component failure rates. The role of physicists in reliability. How reliable are "high reliability" components? Testing and no guessing. A brief summary.

INDEX 287