Reliability Engineering

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Preface

Humans have come to depend on engineered systems to perform their daily tasks. From homes and offices to cars and cell phones, the context in which we live our lives has been largely constructed by engineers who have designed systems and brought their ideas to the marketplace.

While engineered systems have many benefits, they also present risks. How do we know that a building is safe and reliable? How do we know that a sensor in a train will work? How do we know that airbags and brakes will function in an emergency? No matter how many experts were involved in designing systems, the chance for failure always lingers. Thus, all engineering disciplines need reliability.

Today, reliability engineering is a sophisticated and demanding interdisciplinary field. All engineers must ensure the reliability of their designs and products. Moreover, they must be able to analyze a product and assess which parts of the system might be prone to failure. This requires a wide-ranging body of knowledge in the basic sciences, including physics, chemistry, and biology, and an understanding of broader issues within system integration and engineering, while at the same time considering costs and schedules.

The purpose of this book is to present an integrated approach for the design, engineering, and management of reliability activities throughout the life cycle of a product. This book is for those who are interested in gaining fundamental knowledge of the practical aspects of reliability to design, manufacture, and implement tests to ensure product reliability. It is equally helpful for those interested in pursuing a career in reliability, as well as for maintainability, safety, and supportability teams. We have thus written this book to provide students and practitioners with a comprehensive understanding of reliability engineering.

The book is organized into 19 chapters. Each chapter consists of a number of numerical examples and homework problems. References on the topics covered are presented to help the reader delve into more detail.

Chapter 1 provides an overview and discussion of the relevance of reliability engineering for the twenty-first century. This chapter presents a definition of reliability and describes the relationship between reliability, quality, and performance. The consequences of having an unreliable product, that is, a product that fails, are presented with examples. The chapter concludes with a discussion of supplier–customer reliability objectives and responsibilities. It also discusses various stakeholders in product reliability. Principles for designing and managing a reliability program for the twenty-first century are presented.

Chapter 2 presents the fundamental mathematical theory for reliability. Useful reliability measures for communicating reliability are presented. The focus is on reliability and unreliability functions, the probability density function, the hazard rate, the conditional reliability function, and key time-to-failure metrics, such as mean time to failure, median time to failure, percentiles of life, various moments of a random variable, and their usefulness in quantifying and assessing reliability. The bathtub curve and its characteristics and applications in reliability are discussed.

Chapter 3 covers basic concepts in probability related to reliability, including statistical distributions and their applications in reliability analysis. Two discrete distributions (binomial and Poisson) and five continuous distributions (exponential, normal, lognormal, gamma, and Weibull) that are commonly used in reliability modeling and hazard rate assessments are presented. The concepts of probability plotting and the graphical method for reliability estimation are also presented with examples.

Chapter 4 gives a comprehensive review of the Six Sigma methodology, including Design for Six Sigma. Six Sigma provides a set of tools to use when a focused technical breakthrough approach is required to resolve complicated technical issues, including reliability in design and manufacturing. In this chapter, an introduction to Six Sigma is provided, and the effect of process shift on long-term and short-term capabilities and process yield is explained. A historical overview of Six Sigma is provided, including a thorough discussion of the phases of quality improvement and the process of Six Sigma implementation. Optimization problems in Six Sigma quality improvement, transfer function, variance transmission, and tolerance design are presented. The chapter concludes with a discussion of the implementation of Design for Six Sigma.

Chapter 5 discusses the role of reliability engineering in product development. Product development is a process in which the perceived need for a product leads to the definition of requirements, which are then translated into a design. The chapter introduces a wide range of essential topics, including product life-cycle concepts; organizational reliability capability assessment; parts and materials selection; product qualification methods; and design improvement through root cause analysis methods such as failure modes effects and criticality analysis, fault tree analysis, and the physics-of-failure approach.

Chapter 6 covers methods for preparing and documenting the product requirements for meeting reliability targets and the associated constraints. The definition of requirements is directly derived from the needs of the market and the possible constraints in producing the product. This chapter discusses requirements, specifications, and risk tracking. The discussion also includes methods of developing qualified component suppliers and effective supply chains, product requirement specifications, and requirements tracking to achieve the reliability targets.

Chapter 7 discusses the characteristics of the life-cycle environment, definition of the life-cycle environmental profile (LCEP), steps in developing an LCEP, life-cycle phases, environmental loads and their effects, considerations and recommendations for LCEP development, and methods for developing product life-cycle profiles, based on the possible events, environmental conditions, and various types of loads on the product during its life cycle. Methods for estimating life-cycle loads and their effects on product performance are also presented.

Chapter 8 provides a discussion on the reliability capability of organizations. Capability maturity models and the eight key reliability practices, namely reliability requirements and planning, training and development, reliability analysis, reliability testing, supply chain management, failure data tracking and analysis, verification and validation, and reliability improvement, are presented.

Chapter 9 discusses parts selection and management. The key elements to a practical selection process, such as performance analysis of parts for functional adequacy, quality analysis of the production process through process capability, and average outgoing quality assessment, are presented. Then, the practices necessary to ensure continued acceptability over the product life cycle, such as the supply chain, parts change, industry change, control policies, and the concepts of risk management, are discussed.

Chapter 10 presents a new methodology called failure modes, mechanisms, and effects analysis (FMMEA) which is used to identify the potential failure mechanisms and models for all potential failures modes and prioritize the failure mechanisms. Knowledge of failure mechanisms that cause product failure is essential for the implementation of appropriate design practices for the design and development of reliable products. FMMEA enhances the value of failure mode and effects analysis (FMEA) and failure mode, effects, and criticality analysis (FMECA) by identifying the "high priority failure mechanisms" to help create an action plan to mitigate their effects. Knowledge of the causes and consequences of mechanisms found through FMMEA helps to make product development efficient and cost effective. A case study describing the FMMEA process for a simple electronic circuit board assembly is presented. Methods for the identification of failure mechanisms, their prioritization for improvement and risk analysis, and a procedure for documentation are discussed. The FMMEA procedure is illustrated by a case study.

Chapter 11 covers basic models and principles to quantify and evaluate reliability during the design stage. Based on the physics of failure, the designer can understand the underlying stress and strength variables, which are random variables. This leads us to consider the increasingly popular probabilistic approach to design. Thus, we can develop the relationships between reliability and different types of safety factors. This chapter provides a review of statistical tolerances, and develops the relationship between tolerances and the characteristics of the parts and reliability.

Chapter 12 discusses the concepts of derating and uprating. This chapter demonstrates that the way in which a part is used (i.e., the part's stress level) has a direct impact on the performance and reliability of parts. This chapter introduces how users can modify the usage environment of parts based on ratings from the manufacturer, derating, and uprating. The discussion includes factors considered for determining part rating, and the methods and limitations of derating. Stress balancing is also presented.

Chapter 13 covers reliability estimation techniques. The purpose of reliability demonstration and testing is to determine the reliability levels of a product. We have to design tests in such a manner that the maximum amount of information can be obtained from the minimum amount of testing. For this, various statistical techniques are used. A major problem for the design of adequate tests is simulating the real-world environment. The product is subjected to many environmental factors during its lifetime, such as temperature, vibrations and shock, and rough handling. These stresses may be encountered individually, simultaneously, or sequentially, and there are other random factors. Methods to determine the sample size required for testing and its relationship to confidence levels are presented. Reliability estimation and the confidence intervals for success-failure tests and when the time to failure is an exponential distribution are also discussed with numerical examples. A case study is also presented for reliability test qualification.

Chapter 14 describes statistical process control and process capability. Quality in manufacturing is a measure of a product's ability to meet the design specifications and workmanship criteria of the manufacturer. Process control systems, sources of variation, and attributes that define control charts used in industry for process control are introduced. Several numerical examples are provided.

Chapter 15 discusses methods for product screening and burn-in strategies. If the manufacturing or assembly processes cannot be improved, screening and burn-in strategies are used to eliminate the weak items in the population. The chapter demonstrates the analysis of burn-in data and discusses the pros and cons of implementing burn-in tests. A case study demonstrates that having a better manufacturing process and quality control system is preferable to 100% burn-in of products.

Chapter 16 discusses root cause analysis and product failure mechanisms, presents a methodology for root cause analysis, and provides guidance for decision-making. A root cause is the most basic causal factor (or factors) that, if corrected or removed, will prevent the recurrence of a problem. It is generally understood that problem identification and correction requires the identification of the root cause. This chapter presents what exactly a root cause analysis is, what it entails, and at what point in the investigation one should stop. This chapter also reviews the possible causes and effects for no-fault-found observations and intermittent failures, and summarizes them into cause-and-effect diagrams. The relationships between several techniques for root-cause identification, such as Ishikawa diagrams, fault tree analysis, and failure mode, mechanisms, and effects analysis, are covered.

Chapter 17 describes how to combine reliability information from the system architecture to compute system-level reliability. Reliability block diagrams are preferred as a means to represent the logical system architecture and develop system reliability models. Both static and dynamic models for system reliability and their applications are presented in this chapter. Reliability block diagrams, series, parallel, stand-by, k-out-of-n, and complex system reliability models are discussed. Methods of enumeration, conditional probability, and the concepts of coherent structures are also presented.

Chapter 18 highlights the significance of health monitoring and prognostics. For many products and systems, especially those with long life-cycle reliability requirements, high in-service reliability can be a means to ensure customer satisfaction and remain competitive. Achieving higher field reliability and operational availability requires knowledge of in-service use and life-cycle operational and environmental conditions. In particular, many data collection and reliability prediction schemes are designed before in-service operational and environmental aspects of the system are entirely understood. This chapter discusses conceptual models for prognostics, the relationship between reliability and prognostics, the framework for prognostics and health management (PHM) for electronics, monitoring and reasoning of failure precursors, the application of fuses and canaries, monitoring usage profiles for damage modeling, estimation of remaining useful life, uncertainties associated with PHM, and the implementation of these concepts in complex systems.

Chapter 19 discusses warranty analysis and its relationship to reliability. A warranty is a guarantee from a manufacturer defining a responsibility with respect to the product or service provided. A warranty is a commitment to repair or replace a product or re-perform that service in a commercially acceptable manner if it fails to meet certain standards in the marketplace. Customers value a good warranty as economic protection, but a product is generally not considered good if it fails during the product's useful life (as perceived by the customer), regardless of the warranty. The chapter covers warranty return information, types of warranty policies and cost analyses, the effect of burn-in on warranty, simplified system characterization, and managerial issues with regard to warranty.

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