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RELIABILITY ENGINEERING AND PRODUCT LIFE CYCLE

1.1 RELIABILITY ENGINEERING

Reliability has a broad meaning in our daily life. In technical terms, *reliability* is defined as the probability that a product performs its intended function without failure under specified conditions for a specified period of time. The definition, which is elaborated on in Chapter 2, contains three important elements: intended function, specified period of time, and specified conditions. As reliability is quantified by probability, any attempts to measure it involve the use of probabilistic and statistical methods. Hence, probability theory and statistics are important mathematical tools for reliability engineering.

Reliability engineering is the discipline of ensuring that a product will be reliable when operated in a specified manner. In other words, the function of reliability engineering is to avoid failures. In reality, failures are inevitable; a product will fail sooner or later. Reliability engineering is implemented by taking structured and feasible actions that maximize reliability and minimize the effects of failures. In general, three steps are necessary to accomplish this objective. The first step is to build maximum reliability into a product during the design and development stage. This step is most critical in that it determines the inherent reliability. The second step is to minimize production process variation to assure that the process does not appreciably degrade the inherent reliability. Once a product is deployed, appropriate maintenance operations should be initiated to alleviate performance degradation and prolong product life. The three steps employ a large variety of reliability techniques, including, for example, reliability planning

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and specification, allocation, prediction, robust reliability design, failure mode and effects analysis (FMEA), fault tree analysis (FTA), accelerated life testing, degradation testing, reliability verification testing, stress screening, and warranty analysis. To live up to the greatest potential inherent to these reliability techniques for specific products, we must develop and implement appropriate and adequate reliability programs that synthesize these individual reliability techniques. In particular, such programs include the tasks of specifying the reliability requirements, customizing and sequencing the reliability techniques, orchestrating the implementation, and documenting the results. In subsequent chapters we describe in detail reliability programs and individual reliability techniques.

1.2 PRODUCT LIFE CYCLE

Product life cycle refers to sequential phases from product planning to disposal. Generally, it comprises six main stages, as shown in Figure 1.1. The stages, from product planning to production, take place during creation of the product and thus are collectively called the *product realization process*. The tasks in each stage are described briefly below.

Product Planning Phase Product planning is to identify customer needs, analyze business trends and market competition, and develop product proposals. In the beginning of this phase, a cross-functional team should be established that represents different functions within an organization, including marketing, financing, research, design, testing, manufacturing, service, and other roles. Sometimes supplier representatives and consultants are hired to participate in some of the planning work. In this phase, the team is chartered to conduct a number of tasks, including business trends analysis, understanding customer expectations, competitive analysis, and market projection. If the initial planning justifies further development of the product, the team will outline the benefits of the product to customers, determine product features, establish product performances, develop product proposals, and set the time to market and time lines for the completion of such tasks as design, validation, and production.

Design and Development Phase This phase usually begins with preparation of detailed product specifications on reliability, features, functionalities, economics, ergonomics, and legality. The specifications must meet the requirements defined in the product planning phase, ensure that the product will satisfy customer expectations, comply with governmental regulations, and establish strong competitive position in the marketplace. The next step is to carry out the concept design. The starting point of developing a concept is the design of a functional structure that determines the flow of energy and information and the physical interactions. The functions of subsystems within a product need to be clearly defined; the requirements regarding these functions arise from the product specifications. Functional block diagrams are always useful in this step. Once the architecture is complete,

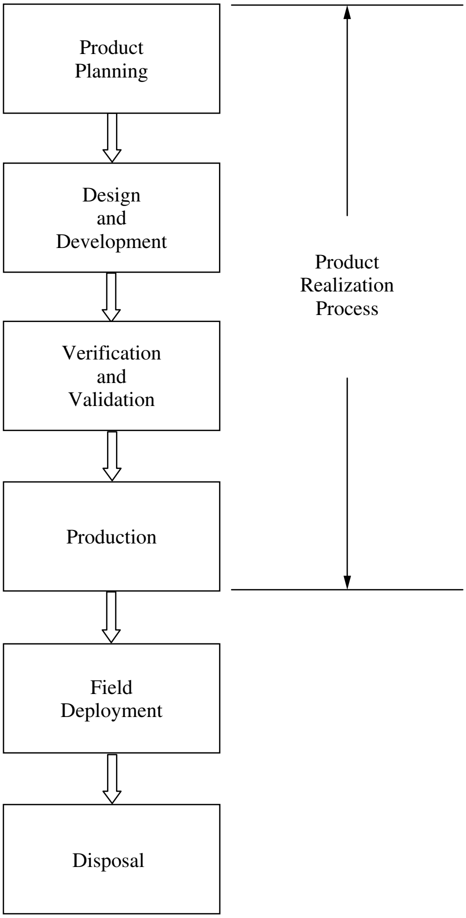

FIGURE 1.1 Phases of the product life cycle

the physical conception begins to determine how the functions of each subsystem can be fulfilled. This step benefits from the use of advanced design techniques such as TRIZ and axiomatic design (Suh, 2001; K. Yang and El-Haik, 2003) and may result in innovations in technology. Concept design is a fundamental stage that largely determines reliability, robustness, cost, and other competitive potentials.

Concept design is followed by detailed design. This step begins with the development of detailed design specifications which assure that the subsystem requirements are satisfied. Then physical details are devised to fulfill the functions of each subsystem within the product structure. The details may include physical linkage, electrical connection, nominal values, and tolerances of the functional parameters. Materials and components are also selected in this step. It is worth noting that design and development is essentially an iterative task as a result of design review and analysis. The implementation of effective reliability programs will reduce repetition.

Verification and Validation Phase This phase consists of two major steps: design verification (DV) and process validation (PV). Once a design is completed successfully, a small number of prototypes are built for DV testing to prove that the design achieves the functional, environmental, reliability, regulatory, and other requirements concerning the product as stipulated in the product specifications. Prior to DV testing, a test plan must be developed that specifies the test conditions, sample sizes, acceptance criteria, test operation procedures, and other elements. The test conditions should reflect the real-world use that the product will encounter when deployed in the field. A large sample size in DV testing is often unaffordable; however, it should be large enough so that the evidence to confirm the design achievement is statistically valid. If functional nonconformance or failure occurs, the root causes must be identified for potential design changes. The redesign must undergo DV testing until all acceptance criteria have been met completely.

Parallel to DV testing, production process planning may be initiated so that pilot production can begin once the design is verified. Process planning involves the determination of methods for manufacturing a product. In particular, we choose the steps required to manufacture the product, tooling processes, process checkpoints and control plans, machines, tools, and other requirements. A computer simulation is helpful in creating a stable and productive production process.

The next step is PV testing, whose purpose is to validate the capability of the production process. The process must not degrade the inherent reliability to an unacceptable level and must be capable of manufacturing products that meet all specifications with minimum variation. By this time, the process has been set up and is intended for production at full capacity. Thus, the test units represent the products that customers will see in the marketplace. In other words, the samples and the final products are not differentiable, because both use the same materials, components, production processes, and process monitoring and measuring techniques. The sample size may be larger than that for DV testing, due to the need to evaluate process variation. The test conditions and acceptance criteria are the same as those for DV testing.

Production Phase Once the design is verified and the process is validated, full capacity production may begin. This phase includes a series of interrelated activities such as materials handling, production of parts, assembly, and quality control and management. The end products are subject to final test and then shipped to customers.

Field Deployment Phase In this phase, products are sold to customers and realize the values built in during the product realization process. This phase involves marketing advertisement, sales service, technical support, field performance monitoring, and continuous improvement.

Disposal This is the terminal phase of a product in the life cycle. A product is discarded, scraped, or recycled when it is unable to continue service or is not cost-effective. A nonrepairable product is discarded once it fails; a repairable product may be discarded because it is not worthy of repair. The service of some repairable products is discontinued because their performance does not meet customer demands. The manufacturer must provide technical support to dispose of, dismantle, and recycle the product to minimize the associated costs and the adverse impact on the environment.

1.3 INTEGRATION OF RELIABILITY ENGINEERING INTO THE PRODUCT LIFE CYCLE

From a manufacturer's perspective in gaining a competitive advantage, the product realization process should be minimized with respect to time and cost. On the other hand, once they take ownership, customers expect products to operate reliably and to incur little maintenance cost. The conflicting interests have motivated manufacturers to integrate reliability programs into the product life cycle. As described in Chapter 3, a reliability program consists of a series of reliability tasks that are well sequenced to achieve the reliability target and customer satisfaction. The reliability tasks are customized to fit the needs of specific products and implemented throughout the product life cycle. In the product realization process, reliability tasks are especially important because of the amount of value that they can add to products. In particular, reliability techniques are aimed at building reliability into products and reducing the cost and time associated with the process. To maximize efficiency, reliability tasks should be incorporated into the engineering activities that take place in this process. A comprehensive reliability program adds value to the product life cycle even after a product enters the field deployment phase.

The functions of reliability tasks are important in each phase of the product life cycle. In the product planning phase, a multidisciplinary reliability team is organized to develop a reliability program suitable for the product, to set a reliability target, to translate customer expectations into engineering requirements, and to conceive and evaluate product proposals from a reliability perspective. Whenever possible, reliability tasks should be incorporated into other planning activities. The reliability decisions made in this phase have a tremendous impact on each stage of the product life cycle. For example, setting a reliability target has strong effects on cost, time to market, and competitiveness. An overly ambitious target would incur unaffordable design and development costs and prolong the product realization process, and thus jeopardize competitive advantages. Conversely, a low reliability target certainly undermines competitiveness simply by losing customers.

Reliability tasks play an especially important role in the design and development phase; reliability activities usually add more value to a product in this phase than in any other phase. The objective of reliability tasks in this phase is to design-in the reliability of the product while designing-out potential failure modes. This may be accomplished by allocating the product reliability target to the integral subsystems or components and assuring achievement of the respective reliability goals through the implementation of reliability design techniques such as robust reliability design, FMEA, FTA, and design controls. These proactive reliability tasks are aimed at designing things right the first time. Doing so would cut off the design–test–fix loop, which was a typical design model in the old days and unfortunately is still sometimes used. Clearly, a reliability program can accelerate the design and development cycle and save the associated costs.

Reliability tasks are vital elements of DV and PV. In the DV stage, reliability verification testing is performed to demonstrate that the design meets the reliability requirements. In the PV step, the test is intended to prove the capability of the production process. The process must be capable of manufacturing final products that fulfill the reliability target that has been specified. The determination of economic and statistically significant sample size and test time is a challenge to almost all manufacturers. The reliability techniques described in Chapter 9 have the power to make the best trade-off. The function of reliability tasks in this phase is more than testing. For example, life and performance data analysis is often necessary to arrive at meaningful conclusions about the conformability of the design and process under evaluation.

The reliability tasks in the production phase are intended to assure that the process results in the manufacture of uniform and reliable products. To maintain a stable process over time, process control plans and charts are implemented to monitor the process and help identify special causes as soon as they emerge. Sometimes, reactive reliability methods are needed in the production phase. For example, acceptance sampling may determine whether or not to accept a particular production lot being concerned. Products may be subjected to an environmental stress screening to precipitate defective units before being shipped to customers.

The reliability tasks involved in the field deployment phase include the collection and analysis of warranty data, identification and projection of failure trends, customer feedback analysis, and failure analysis of warrantied parts. Six-sigma projects are often initiated in this phase to determine the causes of significant failure modes and to recommend containment and permanent corrective actions.

1.4 RELIABILITY IN THE CONCURRENT PRODUCT REALIZATION PROCESS

A conventional product realization process is serial; that is, a step starts only after the preceding step has been completed. In the sequential model, the information flows in succession from phase to phase. Design engineers in the upstream part of the process usually do not address the manufacturability, testability, and serviceability in their design adequately because of a lack of knowledge. Once the design is verified and the process fails to be validated due to inadequate manufacturability, design changes in this phase will increase cost substantially compared to making the changes in the design and development phase. In general, cost to fix a design increases an order of magnitude with each subsequent phase (Levin and Kalal, 2003).

The application of concurrent engineering to a product realization process is the solution to problems associated with the sequential model. In the framework of concurrent engineering, a cross-functional team is established representing every aspect of the product, including design, manufacturing process, reliability and quality planning, marketing and sales, purchasing, cost accounting, material handling, material control, data management and communication, service, testing, and others. The team relays information to design engineers concerning all aspects of the product so that from the very beginning the engineers will address any potential issues that would otherwise be ignored. The information flow is multidirectional between all functional areas, as stated above, and continues throughout the entire product realization process. As a result, other phases in addition to design and development also benefit from the concurrent involvement. For example, test plans can be developed in the design and development phase, with valuable input from design engineers and other team members. If a testability problem is discovered in this phase, design engineers are more likely to make design changes. Under concurrent engineering, most phases of the product realization process can take place simultaneously. The resulting benefits are twofold: maximization of the chance of doing things right the first time, and reducing the time to market. Ireson et al. (1996) and Usher et al. (1998) describe concurrent engineering in greater detail and present application examples in different industries.

In the environment of concurrent engineering, a multidisciplinary reliability team is required to perform effective reliability tasks. The team is an integral part of the engineering team and participates in decision making so that reliability objectives and constraints are considered. Because reliability tasks are incorporated into engineering activities, a concurrent product realization process entails multiple reliability tasks to be conducted simultaneously. The environment allows reliability tasks to be implemented in the upfront phases of the process to consider the potential influences that might be manifested in subsequent phases. For example, the reliability allocation performed at the beginning of the process should take into account the technological feasibility of achieving the reliability, economics of demonstrating the reliability, and manufacturability of components. Although being concurrent is always desirable, some reliability tasks must be performed sequentially. For example, a process FMEA usually starts after a design FMEA has been completed because the former utilizes the outputs of the latter. In these situations, we should understand the interrelationships between the reliability tasks and sequence the tasks to maximize the temporal overlap.

PROBLEMS

1.1 Explain the concept of reliability and the function of reliability engineering.

1.2 Describe the key engineering tasks and reliability roles in each phase of a product life cycle.

1.3 Explain the important differences between serial and concurrent product realization processes.

1.4 How should a reliability program be organized in the environment of concurrent engineering?