AC 2012-4278: INTRODUCING RELIABILITY AND MAINTAINABILITY IN ENGINEERING AND TECHNOLOGY

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Introducing Reliability and Maintainability in Engineering and Technology

Abstract

Engineering technology education is traditionally concerned with teaching how manufactured products work. The ways in which to avoid product and system failure, that is the theory of reliability and maintainability, are generally not taught because it is necessary to know how a product works before delving into ways in which it might fail.

The need for reliability and maintainability has been ever increasing because of competition, development of new materials and processes, safety and liability considerations, and increase in complexity of systems. It becomes necessary then that our engineering technology graduates have the basic requisite knowledge in this multi-disciplinary field. With this in view, a course on reliability and maintainability has been recently introduced in our graduate-level program.

This paper describes the course content and typical examples of assignments done by students. The paper also describes the student feedback obtained so far to help the course structure in content and delivery.

Introduction

The term 'reliability' is used a lot, in measurement science, in qualitative research and in almost all fields of engineering. In measurement science it means 'repeatability' or 'consistency'[1]. A measurement is considered reliable if it would give the same result over and over again on the same part feature with the same instrument and the same operator. It is necessary to understand the different measurement errors because errors in measurement play a key role in degrading reliability. In qualitative research, there are generally four methods of reliability each of which estimate reliability in a different way. They are: (1) inter-rater reliability that is used to assess the degree to which different raters give consistent estimates of the same phenomenon, (2) test-retest reliability that is used to assess the consistency of a measure from one time to another, (3) parallel-forms reliability that is used to assess the consistency of the results of two tests constructed in the same way from the same content domain and (4) internal consistency reliability that is used to assess the consistency of results across items within a test[1]. Cronbach's α (alpha) is a coefficient of reliability and it is commonly used as a measure of the internal consistency or reliability of a psychometric test score for a sample of examinees[2].

In engineering, reliability is "the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions[3]." Military standard definition of reliability is "The probability that an item will perform a required function without failure under stated conditions for a stated period of time"[4]. It is commonly stated in terms of Mean Time Between Failures (MTBF). For example, a TV specification may state its "MTBF is at least 20,000 hours".

The primary reason reliability in engineering field has become increasingly important since several decades is because of greater and greater pressures being put on designers and manufacturers to produce higher quality products. The pressures are due to (1) rapid advances in technology, (2) development of highly sophisticated products, (3) intense global competition, and (4) increasing customer expectations[5]. Figure 1 shows a typical process of reliability in the design and manufacture of a quality product.

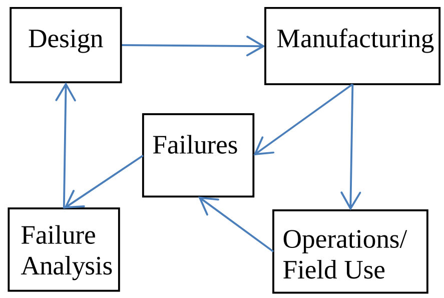

Figure 1. Typical Process of Reliability.

The type of questions that reliability theory is expected to answer in each of the blocks of Figure 1 could be, but are not limited to, the following[4]:

Design: Do the parts meet their reliability goals at design stress and, if not, how to improve their reliability? How to assess the characteristics of different materials? What are appropriate methods to estimate part reliability? How to assess the effects of a proposed design change?

Manufacturing: Can the manufacturing process produce parts that meet the reliability goals? Which vendor supplies the most reliable parts? Is burn-in necessary for all production parts to meet the reliability goals? Is the production line continuing to produce reliable parts? What specific evidence to offer our customers that our product meets reliability goals?

Operations/Field usage: What reliability tests can be shown to our customers? Are the customers going to have reliability problems if they buy the product? What are early estimates of warranty cost? How to compare two or more different manufacturing methods or two or more manufacturers? What are the methods to assess part reliability in field?

Failures and Failure Analysis: What are the different failure modes operating? What is the failure rate and cumulative failure distribution? What is the MTBF and MTTR (mean time to repair) of a part or system? Do opportunities exit to improve a part or system performance? What types of reliability testing are appropriate? What should be the accelerated stress conditions to use to induce early failures?

Today's customers demand manufacturers to produce highly reliable and easily maintainable products. Engineering education is basically deterministic[6]. But natural variability plays a vital role in determining reliability. There is variability in the materials, manufacturing processes, and in using the products. Figure 2 shows the variability in the strength (S) of product based on design and manufacture, and in the dynamic load (L) that the product is subjected to during its life cycle. Understanding the causes and effects of variability is therefore necessary for the creation of reliable products and for the solution for causes of failures[6].

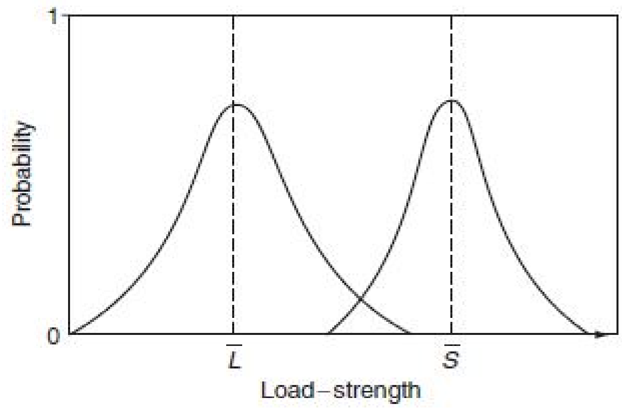

Figure 2. Overlap of the Variability in Product's Load and Strength[6].

Basic Reliability Theory

Statistical methods are used to determine part reliability using part failure data. Probability methods are used to determine system reliability using knowledge of part reliability and system structure. Commonly used distributions include the exponential, Weibull, lognormal, and gamma distributions.

Systems will fail through various means resulting from different physical phenomena leading to different failure characteristics of parts. A useful approach is to separate these failures according to the mechanisms or parts causing the failures. For example, as a result of improper machining, a gear-tooth in a vehicle's transmission breaks causing the transmission to lock up and the vehicle to crash, injuring the driver. The failure mode in this case is the jammed transmission[7].

A failure density distribution that has a constant failure rate has an exponential reliability distribution as shown in Figure 3. Many systems exhibit constant failure rates, and the exponential reliability distribution is the simplest to analyze. Some of the equations related to an exponential reliability distribution are:

$$R(t) = e^{-\lambda t} \quad (1)$$
$$\lambda = \frac{1}{MTBF} \quad (2)$$
$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \quad (3)$$

Where, $R(t)$ = Reliability at any given time t
λ = Failure rate in failures per hour or cycle.
λ_s = System failure rate, and individual λ's in equation (3) are failure rates of parts in series.

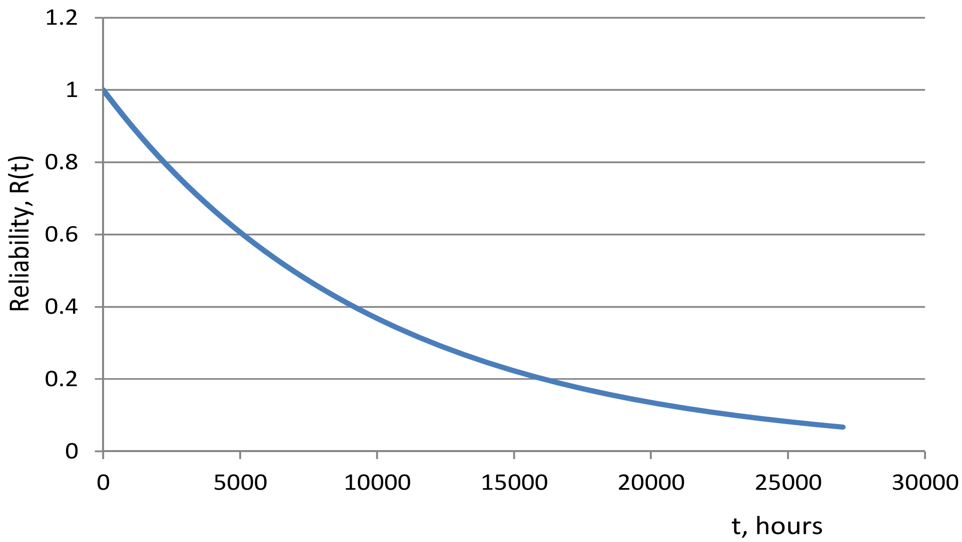

Figure 3. The Exponential Reliability Function whose MTBF is 10,000 hours.

It is interesting to note that the reliability at t = MTBF is 0.368. If a system has four components in series with MTBF of 5,000, 6,000, 4,500 and 2,000 hours, respectively, the combined system's MTBF is 918.4 hours and the reliability of the system at 200 hours of operation is 0.804 from equations (1) to (3).

Availability is the ability of a part to be in a state to perform a required function at a given instant of time or at any instant of time within a given time interval. Availability, A is given by:

$$A = \frac{MTBF}{MTBF+MTTR} \qquad (4)$$

If reliability or MTBF cannot be increased due to budget constraints, it becomes necessary to improve maintainability by reducing MTTR to increase availability. If the availability is 0.87 when MTBF is 80 hours and MTTR = 12 hours, then to increase availability to 0.92 to meet production needs, the MTTR should be reduced to 7 hours.

The Weibull analysis is a widely used technique in reliability engineering because the Weibull distribution has a great variety of shapes, enabling it to fit many kinds of data, especially data relating to product life[3]. This distribution has two important parameters as given in equation (5): (1) β is the shape parameter because it defines the shape of the distribution and (2) θ is the scale parameter, defining the spread of the distribution. The β parameter represents the failure pattern of the part, for instance if $\beta < 1$ the part is failing in the early life, if $\beta = 1$ the failure rate is constant and the part is failing in the section of useful life of the bath-tub curve as shown in Figure 4, and if $\beta > 1$ the part is failing due to wearout. The Weibull reliability function is given as:

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \qquad (5)$$

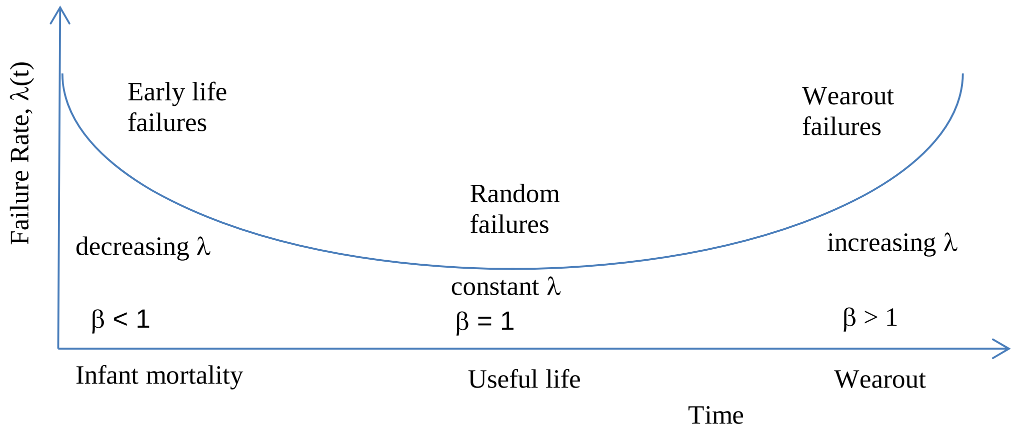

Figure 4. Bath-Tub Curve of Failure Rates Through a Typical Life Cycle of a Product[3].

Current State of Teaching Reliability

Due to the increasing need for engineering graduates to know and apply reliability theory, there are currently numerous colleges teaching reliability primarily in mechanical, aerospace, industrial, electrical, systems, computer, structural and chemical engineering disciplines. Some teach the subject in statistics and nuclear science departments. Some of these universities are: Iowa State University, University of Arizona Tucson, University of Illinois at Urbana-Champaign, MIT, John Hopkins, University of Central Florida, University of California Irvine, Purdue University, Wayne State University, UCLA, University of Kansas, Kettering University, Colorado State University, and University of Washington.

University of Maryland offers M.S. and PhD in reliability engineering. University of Tennessee Knoxville offers M.S. in reliability and maintainability engineering. Arizona State University offers a graduate degree in quality and reliability engineering. Vanderbilt University has a multidisciplinary doctoral program in Reliability and Risk Engineering and Management. University of Akron has started a new undergraduate degree program in corrosion and reliability engineering. North Carolina State University offers an advanced diploma in maintenance and reliability management.

But there is no known engineering technology program that teaches reliability theory. It is necessary that our engineering technology graduates as well have the basic requisite knowledge in this multi-disciplinary, widely-used subject. With this in view, a course on reliability and maintainability has been recently introduced in our graduate technology program.

This course provides an intensive and comprehensive introduction to all essential aspects of maintenance and reliability. Students learn theory of reliability, including methods to evaluate system reliability such as fault tree analysis (example given below in Figure 5), series and parallel system configurations, redundancy, economic analysis and life cycle costs, failure analysis including RPN concept described below, FMEA, data collection and empirical methods of determining reliability, fitting of different distributions to the failure data, reliability testing, burn-in testing, and growth testing, statistical tests of Chi-Square, Bartlett, Mann, and Kolmogorov-Smirnov, Reliability-Centered Maintenance, P-F curve, and root cause analysis.

Fault tree analysis (FTA) is used to focus on failures that may create safety hazards. The objective is to determine during design how these failures are likely to occur, to estimate their probability of occurrence, and to take corrective action. Often safety-related failure modes have a low probability of occurrence and are difficult to estimate[3]. An example of how FTA is applied is shown in Figure 5. An equivalent fault tree is determined using Boolean algebra to identify those combinations of events that will cause the top event, generally a failure, to occur.

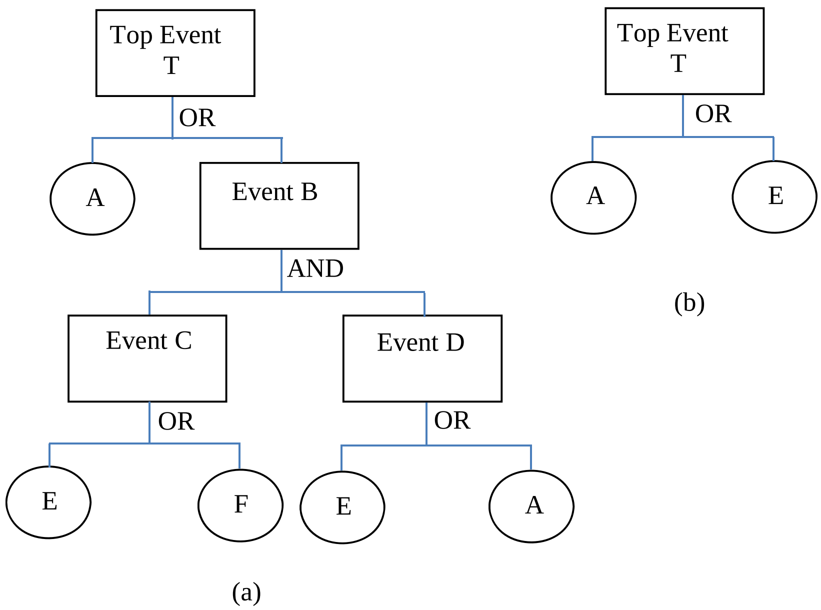

Figure 5. Fault Tree (a) with Redundant Events (b) Equivalent Fault Tree diagram of (a)[3].

For example in Figure 5, the top event T will occur when either A or E occurs as shown below.

$$T = A \cup B = A \cup (C \cap D) = A \cup [(E \cup F) \cap (E \cup A) = A \cup [E \cup (F \cap A)] = A \cup E.$$

There is a quantitative measure of the criticality of the failure mode that combines the probability of the failure mode’s occurrence, the likelihood of its detection, and the severity of its effect. The risk priority number (RPN) has been one of the popular indices to compute criticality of failure. The RPN is the product of the severity ranking (S), the probability of occurrence (O), and the detection ranking (D) given as[3]:

$$RPN = (S) \times (O) \times (D) \tag{6}$$

Obviously, the failure modes and their causes with high RPN numbers should receive the most attention.

The class assignments and project work allow students to integrate and apply the above knowledge. The M.S. in Technology program has students who have done undergraduate engineering or engineering technology at different times in the past and are from different universities. As their background in the necessary concepts of calculus and statistics varies, sufficient class time is spent on revising these concepts as and when they are needed. Due to this course arrangement, there is not enough time to cover all the important topics in reliability and maintainability theory to the satisfaction of all students.

Some of the major comments received from the past students are given below:

1. Review all the required concepts of differential and integral calculus, probability and statistics, and Boolean Algebra using the online system available for this course.
2. Take some practical examples or industrial data of failures or warranty costs to demonstrate application of reliability theory.
3. Include physics of failure using corrosion, temperature, vibration, and other factors.
4. Discuss the case studies available in the text book[3] or elsewhere in the literature.

Conclusions

There is a greater need of reliability in the performance of products and equipment as the demands of the global economy require manufacturers to produce highly reliable and easily maintainable products. It is equally important to teach this subject to the graduates of engineering technology. System failures increase the probability of having a catastrophic safety-related accident.

Both the strong competitive environment and the current world financial crisis are forcing organizations to explore ways to reduce operating costs and still attain high levels of quality. Disruptions in industry due to failures decrease productivity. Reliability and maintainability are the two disciplines that show the methods to achieve high productivity, high quality with utmost safety.

The Reliability and Maintainability course recently introduced in the engineering technology curriculum attempts to impart requisite knowledge on this subject.

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