2. General Philosophy and Process of Reliability Prediction

Introduction

Reliability prediction is a continuing activity throughout the design and development of a project, from initial conception to production and beyond. The prediction methods that apply at any particular time may vary, but the general philosophy and principles remain common throughout. The primary objectives of this chapter are to:

- Describe the purposes of prediction and its application at different stages of a project.
- Consider the general philosophy and principles behind prediction methods.
- List the main activities comprising a prediction process.
- Indicate the main limitations of the general philosophy.

NOTE It is not the intention of this chapter to derive basic reliability expressions or to discuss probability and statistical theory. Information on these aspects is readily available in many standard textbooks.

Definitions

The definitions for those reliability terms most often used within this guide follow.

- **Reliability**.
  - The ability of an item to perform a required function without failure under stated conditions for a stated period of time.

    Or, as more commonly used in engineering applications:
  - The probability that an item can perform a required function under given conditions for a given time interval, $(t1,\ t2)$. This is normally denoted either by the letter R or by $R(t)$, with t denoting the interval $t1,\ t2$.

- **Failure**. The state of the item when it is unable to perform a required function. In the case of non-repairable items, it is the termination of the ability of an item to perform a required function.

  Note: 1. After the occurrence of a failure, the item is in a faulty condition.
  2. An occurrence of a **failure** is an event (as distinguished from a **fault**, which is a state.
  3. This concept as defined does not apply to items consisting of software only.

- **(Instantaneous) Failure Rate**. The limit, if this exists, of the ratio of the conditional probability that the instant of time, t, of a failure of an item falls within a given time interval, $(t, t + \Delta\tau)$, to the length of this interval, $\Delta\tau$, when $\Delta\tau$ tends to zero, given that the item is in an up state at the beginning of the time interval. This limit is normally denoted by $\lambda(t)$. Failure rates are often given in terms of failures per million hours (fpmh); however, some industries use an alternative measure of failures per 10^9 known as FITs (Failures in Time). Such failure rates are given in terms of failures per billion hours.

- **Mean Time To Restore**, **Mean Time To Recovery** or **Mean Time to Repair (MTTR)**. The expectation of the time to restore.

NOTE In this document, the term MTTR is frequently used. This is to maintain a measure of consistency with other work. The term **Mean Active Corrective Maintenance Time (MACMT)** may often be interchanged with **Mean Active Repair Time (MART)**.

Purposes of Prediction

The aim of prediction is to provide a quantitative forecast of the reliability that may be eventually achieved by any particular design. Prediction is therefore a fundamental activity in the overall design evaluation process. The prediction process does not in itself contribute directly to the reliability of a system, but the values produced constitute essential criteria for selecting courses of action that affect the reliability of a design.

Also, by carrying out prediction in a detailed and systematic manner, the process will help to identify potential reliability problems, including:

- Misinterpretation of requirements.
- Sources of unreliability.
- Design imbalance (from a reliability viewpoint).

Primary Purposes

The primary purposes of prediction are to:

- Evaluate whether or not a particular design concept is likely to meet a specified reliability requirement under defined conditions.
- Compare alternative design solutions.
- Provide inputs to related project activities, such as:
  - Design evaluation.
  - Trade-off studies.
  - Life cycle costs.
  - Spares provisioning.
  - Logistic and maintenance support studies.
- Assist in the identification and elimination of any potential reliability problems by imposing a systematic discipline that ensures all reliability aspects of a design are examined.
- Measure progress towards achieving the specified reliability requirements.

The prediction process is a continuing activity throughout a project, with the prediction being regularly updated as more design, test and evaluation data become available. The accuracy of any prediction depends largely upon the availability of detailed design and operating data. This is seldom available during the early stages of a project.

However, the requirement for prediction must be used to force detailed information to be made available as early as possible, particularly in critical areas, so that a more thorough and realistic pre-design assessment can be produced. Clearly, therefore, prediction must be a part of the design process and not simply a parallel activity.

Project Definition

During the feasibility and early project definition stages of a project, predictions obviously cannot be based on detailed design information. In spite of this, major decisions are made and large-scale funding is committed at this time. It is at this stage that accurate predictions would be most valuable.

It is an unfortunate fact, therefore, that the greatest uncertainty is attached to predictions during the early stages of design. Despite this, the best available methods must be employed to identify critical design areas as early as possible. Examples of such methods include comparison with similar equipment and generic parts count assessments. Such methods are described more fully in Chapter 3, “Reliability Prediction Methods”.

Design Stages

It is during the early and detailed design stages that reliability prediction has its widest application. As more design information becomes available (e.g., component lists, application stresses, environmental conditions, etc.), more detailed predictions can be made progressively and design areas associated with potential unreliability can be identified. Examples of prediction methods used at these stages include generic parts count and parts stress analysis. These methods are also described more fully in Chapter 3, “Reliability Prediction Methods”.

Development Stages

During the development stages, there are two main types of reliability prediction activity:

- The continual updating of theoretical predictions as design changes are introduced due to shortcomings revealed by development testing and by early reliability predictions themselves.
- Predictions based on the practical results from any reliability development testing, demonstration testing, etc.. Often a **reliability growth model** is used, which enables future reliability achievement to be predicted based on cumulative test results.

Important! *It is important to note that a theoretical prediction will generally reflect the reliability of “mature” equipment (i.e., after some years in service). A prediction based on a reliability growth model, however, reflects the number of design shortcomings still present in the design of the build standard under test or in early service life.*

In-Service Stages

During in-service stages, theoretical predictions must be carried out to assess the effects on reliability of design changes introduced as modifications. Predictions based on in-service results may also be used to assess when the design may achieve **maturity** and how the achieved reliability at that stage may compare with the requirements. Such predictions are normally based on an appropriate reliability growth model as indicated above.

General Philosophy of Prediction

Reliability can be defined in conceptual and quantitative terms:

- As a concept, reliability is the ability of an item to perform its specified function without failure under stated conditions for a stated period of time, number of cycles, distance or any other variate.
- As a quantitative measure, reliability is the probability that an item will perform its specified function for a specified interval under specified conditions.

NOTE In the previous definitions, an item is **any one of enumerated things**, without regard to size or complexity. An item may therefore be a complete system at one extreme or a single component at the other.

Four elements are involved either directly or indirectly in both of these definitions of reliability:

- Probability.
- Performance requirements.
- Time (or another variate).
- Conditions under which the item is used.

To predict reliability, therefore, relationships must be established between these four elements.

Failure Rate Variation with Time

For many items (e.g., non-repairable items or items which when repaired are restored to an **as new** condition), a generally accepted model for variation of failure rate with time is the familiar **bathtub** curve shown in Figure 2-1 and Figure 2-2.

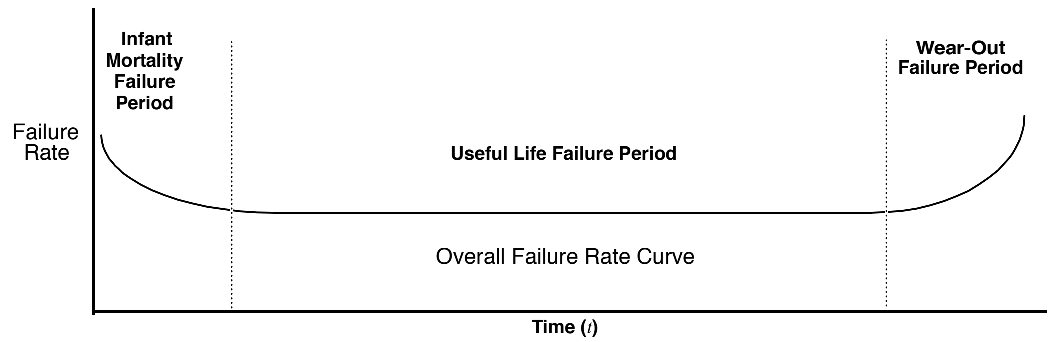

Figure 2-1. Bathtub Curve

The derivation of the bathtub curve is illustrated below. Initially, failures of an item placed in service are often seen to be dominated by ‘quality’ failures. These failures, which occur in what is known as the ‘infant mortality’ period, fade because they are fixed as they emerge. Later, as the system ‘ages’, the item enters a ‘wear-out’ period. The ‘useful life’ period, where there is often seen to be a ‘constant’ failure rate, lies between the infant mortality and wear-out periods.

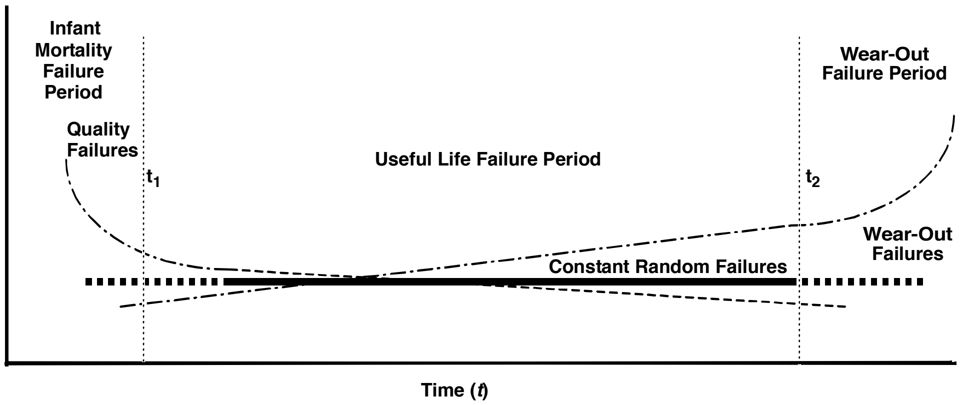

Figure 2-2. Derivation of Bathtub Curve

Infant Mortality Failure Period

In its early life, an item population exhibits a high failure rate, due mainly to manufacturing weaknesses, including:

- Poor joints and connections.
- Damaged components.
- Chemical impurities.
- Dirt and contamination.
- Assembly errors.

NOTE The failure rate decreases rapidly during the early life period and, at time t_1 say, stabilises at a certain value.

Normally, the quality weaknesses are revealed soon after the item is put to use. Therefore, as part of the quality control process, it is increasingly common for stress screening tests to be used to eliminate these weaknesses by simulating in the factory a period t_1 of use. However, stress screening is not always universally applied, and early life failures can cause problems in prediction because prediction generally claims to apply only to the useful life failure period.

Useful Life Failure Period

During the useful life failure period, t_1 to t_2, the failure rate remains substantially constant, and, although some failures may still arise from manufacturing weaknesses or wear-out, the majority of failures are caused by the operating stresses to which the item is subject in its particular application (e.g., temperature, electrical and environmental stresses) and occur randomly (without any time-dependent pattern). During this period, when the failure rate is considered to be constant, the negative exponential distribution describes the times to failure.

The useful life failure period is the interval of most interest from a reliability prediction standpoint because, if a rigorous reliability programme is applied throughout a project lifetime, it is assumed that:

- The majority of early life failures will normally be eliminated before an item enters service.
- An in-service maintenance policy will ensure that items are replaced **before** wear-out becomes a significant problem.

Important! *Note that, because of these assumptions, a prediction based on the exponential distribution will, in general, represent the reliability of a 'mature' design whose failure rate comprises mainly stress-related failures. Where the assumptions above are not given proper consideration, predictions will be substantially optimistic.*

Wear-Out Failure Period

During the wear-out failure period, the failure rate increases due mainly to deterioration of the item through prolonged exposure to operating and environmental stresses, which may include:

- Insulation breakdown.
- Wear or fatigue.
- Corrosion.
- Oxidation.

Normally, wear-out failures are avoided by replacing an item, either on the basis of fixed life replacement or **on-condition** monitoring. Even so, eventually the system becomes troublesome in use and is probably best replaced.

Derivation of Failure Rate Data

Prediction methods use unit or component failure rate data to produce a reliability characteristic or Mean Time To Failure (MTTF) value for the equipment being analysed. This data is usually derived from the following sources:

- In-house data derived from similar products.
- Manufacturers' data.
- Historical data from databases such as MIL-HDBK-217, Telcordia (formerly Bellcore), etc..

NOTE Appendix A, "Data Tables", contains failure rate data.

When To Carry Out Predictions

Reliability predictions should be carried out at all stages during the development of a project. By being continuously updated as the design progresses, reliability predictions can indicate whether the design reliability criteria are being met and also whether any elements that detract from the inherent reliability of the product have been eliminated.

The accuracy of reliability predictions depends largely upon the availability of detailed design and operating data. This information may not be available early in a design. However, the requirement for prediction must be used to force detailed information to be made available as early as possible, particularly in critical areas, so that a more thorough and realistic pre-design assessment can be produced. Predictions must therefore be an integral part of the design process from start to finish and not simply a parallel activity.

~~Reliability Function~~

~~Assuming that the conditions described in "Useful Life Failure Period" on page 2-7 apply so that the failure rate is constant, the relationship between reliability, failure rate and time is given by the expression:~~

~~**Equation**~~ $$\cancel{R(t) = e^{-\lambda t}} \qquad \cancel{(2.1)}$$

~~Where:~~

$\cancel{R(t)}$ = ~~Reliability, i.e., the probability that an item will survive for time *t* under the specified operating conditions.~~

$\cancel{e}$ = ~~The base of the natural logarithms (approximately 2.7183).~~

$\cancel{\lambda}$ = ~~The item failure rate under the specified operating conditions of temperature, stress, environment, etc.. It is constant for at least time *t*.~~

$\cancel{t}$ = ~~The time that the item is at risk under the specified operating conditions. This is sometimes called the mission time.~~