CHAPTER 1

Introduction

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System designers have always been concerned with the subject of reliability. The general approach has been, however, either intuitive or based on rule of thumb criteria derived from previous experience with similar systems. The intuitive approach has proved to be inadequate with the growth of complex military and industrial systems, where a composite of equipment, skills and techniques function as a unified entity. There has been considerable emphasis, in the past two decades, on the development of quantitative techniques and indices which respond meaningfully to the factors which actually affect the system reliability. Quantitative evaluation is achieved by building mathematical models which reasonably idealize the actual system and can be manipulated to obtain suitable measures of reliability. The role of reliability modelling and evaluation can be appreciated by examining the various stages of a general reliability program.

Reliability Planning

It is generally agreed that system reliability must be built in at the design stage of a project. The desired level of reliability can be achieved only by planning and implementing a good reliability program. A reliability program generally consists of the following elements:

1 definition of system reliability
2 overall target and allocation to subsystems
3 reliability modelling and evaluation
4 testing and data collection
5 evaluation of alternative designs
6 reliability report

This sequence is not rigid and in fact many steps may have to be repeated in an iterative fashion. A brief description of these steps is as follows.

1 Definition of System Reliability

There are several definitions of reliability quoted in the literature but the one most often stated in textbooks is ‘the probability that the system will perform its intended function for a given period of time under stated environmental conditions'. This definition is, however, inadequate for many occasions and is restrictive in its scope of application. It is more appropriate to talk of quantitative measures which when compared with reference indices, indicate expected consistency with or deviation from the required performance. Several measures are discussed in detail in Chapter 3 and a brief review of these is given here. The measures may be time specific, i.e., functions of time, or steady state when they refer to the equilibrium conditions. The former are required when the analyst is concerned with the transient behaviour of the system and the latter while considering the average behaviour over a long time.

It is usual in the literature to define reliability indices in terms of system success or failure. Many complex systems have, however, several levels of failure. For example, a large piece of complex equipment may not be simply working or not working but may have many possible output states. It is therefore appropriate to define the calculated reliability measures in terms of a subset X^+ which may contain any number of system states. In particular applications, X^+ can be referred to as success, failure or some other appropriate name.

Time Specific Domain

The following indices are commonly used for repairable systems in the transient domain:

(a) Time Specific Availability of Subset X^+

This is also called point wise availability or instant availability and is the probability of the system being in any state contained in X^+ at a particular instant of time t.

(b) Fractional Duration of Subset X^+

Also known as the interval availability, fractional duration of X^+, and is defined as the expected proportion of the interval (t_1, t_2) spent in X^+.

(c) Interval Frequency

The interval frequency is defined as the expected or mean number of times the subset X^+ is encountered in the interval (t_1, t_2).

Reliability

If the success and failure states are denoted by X^+ and X^-, then reliability is the probability of being in X^+ at the t without having entered X^-. The term reliability is used in many ways and most often in a qualitative sense to indicate concern regarding the ability of the system to perform its intended function. This approach is extended to qualitative appraisal where the term reliability is

considered as an intrinsic system parameter which can be measured by various indices. The definition given above is more specific and reliability is considered as a mathematical quantity which is itself a measure.

Steady State Domain

(a) Steady State Availability of X^+

Commonly called availability, this is the limiting value of both point wise availability and fractional duration. This can, therefore, be interpreted in two ways. The first is as the probability of being in a state contained in X^+ at some point of time remote from the origin. The second is as the time spent in X^+ as a fraction of the total time $(0,T)$ as T tends to be very large.

(b) Steady State Frequency of Encountering X^+

It is more often simply called frequency and can be defined in two ways. The first, is the mean rate at which X^+ is being encountered at some point in time remote from the origin. The second, is the average number of encounters of X^+, considered over a very large time interval.

(c) Mean Cycle Time

This is defined as the mean time between two successive encounters of X^+. It is the reciprocal of frequency.

(d) Mean Duration of X^+

It is the expected time of residence in X^+ in one cycle of X^+.

In addition to the measures defined above, two more useful measures can be calculated using the concepts outlined in Chapter 2.

(e) Mean First Passage Time

This is the time from system initiation to the first encounter of X^+ where X^+ denotes the system failure condition.

(f) Mean Passage Time

When considered in terms of system failure, the mean passage time is called the mean time to failure and is the mean time from an instant when the system is in X^- (X^- is the disjoint of X^+), chosen randomly, to the encounter of X^+.

The choice of a proper measure depends upon several factors such as the system requirements, the feasibility of calculations, measurability, and so on. The various measures respond in different ways to the system parameters and no single measure can give a complete picture of system reliability. When dealing with repairable systems in the time domain, the time specific availability, fractional duration and interval frequency are the most useful parameters. In the steady state, availability, frequency or cycle time and the mean duration provide a good measure of system adequacy. The use of multiple indices can sometimes create problems regarding decision making. A weighting or majority voting procedure can be employed in such cases. Usually one index is more important in a given physical environment due to the nature of the system function.

2 Overall Target and Allocation to Subsystems

The overall reliability target for a given system is normally determined by consultation between management, planning and design functions within the organization. The selected target is based on the state of the art and the need and desire for further improvements. Target selection consists of setting a specific probability, frequency or some other reliability indices as the goals for the project reliability program. In general, the targets should be optimistic but should also be physically achievable. Reliability is like other parameters such as speed, weight and cost and as such it is subject to trade-off with these other parameters. For example, the reliability of a particular pumping system may be greatly improved by installing spare pumps, but the cost may be prohibitive. Once an overall target for the system has been defined, the next step is to allocate the targets for the different subsystems which make up the total system. This can involve a considerable amount of effort and in this regard, the following techniques are helpful.

Similar Familiar System Technique

This approach is based on experience and objective judgement and is very useful in the conceptual design stage prior to total definition of the system. The allocation is based on the state of the art of similar systems performing the same basic function. When using this technique, the following factors must be carefully considered when making the projection:

(i) system physical and performance comparison
(ii) design similarity
(iii) manufacturing similarity

All assumptions and conditions required to meet the predicted target figure and their implications to the program must be examined and defined.

Factors of Influence Method

This technique is used when there is an overall reliability goal and the system or equipment design is new, or when the system is a modification of an existing system for which operating experience data are not available:

(i) for each system considered, assigning weights to the following factors:

(a) complexity/time of operation
(b) environmental conditions
(c) state of the art
(d) criticality

(ii) for each system, adding the above weights to obtain the system weight
(iii) obtaining the relative system weight for each system by normalization
(iv) apportioning the overall targets according to the relative system weights.

3 Reliability Modelling and Evaluation

This is an important element in any reliability program because the selected model provides the basis for predicting the reliability measures. Various techniques of reliability modelling and evaluation are discussed in detail in this book. These techniques are either direct analytical modelling or simulation or a mixture of the two approaches. In the direct analytical modelling method a model is built which reasonably idealizes the physical system and is also amenable to calculation. The reliability measures are then obtained by manipulating the model. This approach is superior to simulation and should be used wherever possible. Simulation also employs a mathematical model but proceeds by performing sampling experiments on this model. It is more flexible but is also more time-consuming and less accurate. Simulation can be used to provide estimates of the same basic measures which would be obtained by a direct analytical approach.

In the initial stages of design, when only a general system outline is available, the analyst may have to be satisfied with rudimentary failure modes, effects and criticality analysis (FMECA). This technique can be used to systematically study the modes of failure and their effects on the system. The various failure modes can be arranged in order of their criticality to the system requirements and provide some very useful design modification data. The reliability model is in general modified and improved as the design progresses and becomes solidified.

There is one pitfall which every reliability engineer must guard against. Repeating experiments with a mathematical model on a computer can generate confidence in the reliability measures so obtained. A closer look at the input data and at the model used may prove that this sense of confidence is not really justified. The assumptions built into any model and the validity of the data used must be carefully considered when interpreting the results provided by the model.

4 Testing and Data Collection

In many research and development projects, tests will be made at component, assembly and system level. A systematic procedure should be adopted for collecting data from these trials in a cumulative manner. In many projects it may not be possible to conduct tests, and data from other sources having similar units may be used. Data collection activities are a vital part of reliability evaluation since without valid data, excessive sophistication in model building may be simply an intellectual exercise.

5 Evaluation of Alternative Designs

Theoretically, a number of designs should be prepared and the one having maximum reliability and satisfying the other constraints should be selected. In some cases, the number of alternatives may be relatively small due to physical constraints. Reliability analysis provides an additional degree of consistency to the evaluation of alternate proposals. In many cases, the decision is based upon lowest total cost and therefore the function of the reliability analyst is to ensure that the system or design selected does satisfy the required targets. Reliability evaluation should provide useful input at the design decision points. If the analysis is not done as the design progresses, it does not provide this initial function and therefore becomes a bookkeeping exercise after the fact.

6 Reliability Report

The final step in any reliability study should be the preparation of a detailed report containing information on the reliability program, the trials made and the results obtained. The report must contain the assumptions made in developing the reliability model and also indicate the level of confidence in the data used. The report should be an objective assessment and should enable the top management to obtain a proper appraisal of the expected system reliability.

Scope of This Book

The general application of reliability engineering concepts is an extremely wide field as illustrated by the six broad topics noted earlier. This book makes no attempt to deal with all these topics and is devoted entirely to the concepts, philosophy and techniques for reliability modelling and evaluation. The systems analyst and the reliability expert must be capable of developing valid models for reliability evaluation of a system. The necessary background in probability and stochastic processes is therefore essential and is reviewed in some detail in Chapter 2. The book emphasizes the calculation of more than one reliability measure as a single index may not provide a complete picture of the system reliability. The book covers both constant transition rate and non-Markovian systems. A special chapter is devoted to the problems encountered in reliability evaluation of large systems and several solutions are proposed. Reliability analysis is an integral part of economic system design. It is extremely important that reliability be considered in quantitative rather than qualitative terms and therefore provide a consistent and responsive indicator of system adequacy.