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RELIABILITY EVALUATION TECHNIQUES IN THE AIR OPERATOR

Abstract

Reliability is a very broad term that focuses on the ability of a product to perform its intended function. Mathematically speaking, reliability can be defined as the probability that an item will perform its intended function without failure for a specified period of time under stated conditions. The main goal in almost all daily activities is safety. Many kinds of researches and development try to find out how to produce things easily with appropriate amount of safety especially in aircraft operation.

INTRODUCTION

From commercial to life-critical applications, the proliferation of computing systems in everyday life has substantially increased our dependence on them. Failures in air operators, aircraft maintenance organizations, air traffic control systems, or other air industry area can bring catastrophic consequences. In order to enhance the dependability of computing systems, an effective evaluation of their reliability is desired. This paper presents methods for evaluating system reliability, and indicates that stochastic modelling has provided an effective and unified framework for analysing various aspects of reliability.

1. RELIABILITY

1.1. Definitions of Reliability

The lifetime of a component is usually unknown and is characterized by a nonnegative random variable T, representing the time to failure of a system since its inception. By definition, reliability is the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered. The other definition of the reliability is a broad term that focuses on the ability of a product to perform its intended function. Mathematically speaking, assuming that an item is performing its intended function at time equals zero, reliability can be defined as the probability that an item will continue to perform its intended function without failure for a specified period of time under stated conditions.

The reliability function (or survival function) of T is defined by (1):

$$R(t) := \overline{F}(t) = P(T \ge t), \vee t \ge 0 \qquad (1)$$

For example, the reliability required for aircraft control systems has been specified as (2):

$$R(t) \ge 1 - 10^{9}, t = 1h \qquad (2)$$

A reliability prediction is simply the analysis of parts and components in an effort to predict the rate at which an item will fail. A reliability prediction is one of the most common forms of reliability analysis. A reliability prediction is usually based on an established model. These models provide procedures for calculating failure rates for components. Failure rates and mean time between failures are calculated by gathering information regarding components and calculating based on standard equations. The equations take into account various stress parameters of the components, and may include data such as device temperature, operating voltage, rated voltage, and power stress ratios.

In order to do a reliability prediction, you must gather information about the components in your system, then use this data in mathematical equations to compute the failure rate or MTBF. The complexity and required parameters of these equations varies depending on device type.

1.2. Combinatorial Methods

System failure is modelled in terms of the failures of the components of the system. Both the system and its components are often allowed to take only two possible states: a working state and a failed state. The linking of component failures to system failures can be understood in several ways. Among these are the reliability block diagram (success-oriented) and the fault tree analysis (failure-oriented). In some cases, it is possible to convert the fault tree to a reliability block diagram.

1.3. Why is Reliability Important for Maintenance organization

There are a many number of reasons why reliability is an important product attribute, including:

Reputation. A company's reputation is very closely related to the reliability of its products. The more reliable a product is, the more likely the company is to have a favorable reputation.

Customer Satisfaction. While a reliable product may not dramatically affect customer satisfaction in a positive manner, an unreliable product will negatively affect customer satisfaction severely. Thus high reliability is a mandatory requirement for customer satisfaction.

Warranty Costs. If a product fails to perform its function within the warranty period, the replacement and repair costs will negatively affect profits, as well as gain unwanted negative attention. Introducing reliability analysis is an important step in taking corrective action, ultimately leading to a product that is more reliable.

Repeat Business. A concentrated effort towards improved reliability shows existing customers that a manufacturer is serious about its product, and committed to customer satisfaction. This type of attitude has a positive impact on future business.

Cost Analysis. Manufacturers may take reliability data and combine it with other cost information to illustrate the cost-effectiveness of their products. This life cycle cost analysis can prove that although the initial cost of a product might be higher, the overall lifetime cost is lower than that of a competitor's because their product requires fewer repairs or less maintenance.

Customer Requirements. Many customers in today's market demand that their suppliers have an effective reliability program. These customers have learned the benefits of reliability analysis from experience.

Competitive Advantage. Many companies will publish their predicted reliability numbers to help gain an advantage over their competitors who either do not publish their numbers or have lower numbers.

2. RELIABILITY CENTERED MAINTENANCE

A reliability-centered maintenance program consists of a set of scheduled tasks generated on the basis of specific reliability characteristics of the equipment they are designed to protect. Complex equipment is composed of a vast number of parts and assemblies. All these items can be expected to fail at one time or another, but some of the failures have more serious consequences than others. Certain kinds of failures have a direct effect on operating safety, and others affect the operational capability of the equipment. The consequences of a particular failure depend on the design of the item and the equipment in which it is installed. Although the environment in which the equipment is operated is sometimes an additional factor, the impact of failures on the equipment, and hence their consequences for the operating organization, are established primarily by the equipment designer. Failure consequences are therefore a primary inherent reliability characteristic. RCM is now used in other industrial sectors than the aircraft maintenance sector. In this section, the state of the art of RCM techniques in different industries is shown, to demonstrate that RCM has been successfully applied to most of them. For each kind of industry, a brief introduction, followed by a link to an extended document, has been made.

There are a great many items, of course, whose failure has no significance at the equipment level. These failures are tolerable, in the sense that the cost of preventive maintenance would outweigh the benefits to be derived from it. It is less expensive to leave these items in service until they fail than it is to try to prevent the failures. Most such failures are evident to the operating crew at the time they occur and are reported to the maintenance crew for corrective action. Some items, however, have functions whose failure will not be evident to the operating crew. Although the loss of a hidden function has no direct consequences, any uncorrected failure exposes the equipment to the consequences of a possible multiple failure as a result of some later second failure. For this reason items with hidden functions require special treatment in a scheduled-maintenance program.

The first step in the development of a maintenance program is to reduce the problem of analysis to manageable size by a quick, approximate, but conservative identification of a set of *significant items* - those items whose failure could affect operating safety or have major economic consequences. The definition of major economic consequences will vary from one operating organization to another, but in most cases it includes any failure that impairs the operational capability of the equipment or results in unusually high repair costs. At the same time all items with hidden functions must be identified, since they will be subjected to detailed analysis along with the significant items.

Although the examples from commercial transport aircraft, they provide practical guidelines that easily extend to other operating contexts and to the development of scheduled-maintenance programs for other types of complex equipment. The principle distinction in the case of aircraft has to do with design practices that are common to the aircraft industry.

In the case of commercial aircraft continuous evolution of the design requirements promulgated by airworthiness authorities and the feedback of hardware information to equipment designers by operating organizations have led to increasing capability of the equipment for safe and reliable operation. Thus most modem aircraft enter service with design features for certain items that allow easy identification of potential failures. Similarly, various parts of the airplane are designed for easy access when inspection is necessary or for easy removal and replacement of vulnerable items. A host of instruments and other indicators provide for monitoring of systems operation, and in nearly all cases essential functions are protected by some form of redundancy or by backup devices that reduce the consequences of failure to a less serious level.

Complex equipment that has not benefited from such design practices will have different and less favorable reliability characteristics, and therefore less capability for reliable operation. Since preventive maintenance is limited by the inherent characteristics of the equipment, in many cases RCM analysis can do little more than recommend the design changes that would make effective maintenance feasible.

The principles of reliability-centred maintenance still apply, and the decision questions are the same. The answers to these questions, however, must reflect the design characteristics of the equipment itself and hence will be different for equipment designed to other standards.

3. RCM PROGRAM BENEFITS

1. Reliability. The primary goal of RCM is to improve equipment reliability. This improvement comes through constant reappraisal of the existing maintenance program and improved communication between maintenance supervisors/ managers, maintenance mechanics, facility planners, building designers, and equipment manufacturers. This improved communication creates a feedback loop from the maintenance mechanic in the field all the way to the equipment manufacturers.

2. Cost. Due to the initial investment required to obtain the technological tools, training, equipment condition baselines, a new RCM program typically results in a short-term increase in maintenance costs (Figure 1). The increase is relatively short-lived. The cost of reactive maintenance decreases as failures are prevented and preventive maintenance tasks are replaced by condition monitoring. The net effect is a reduction of reactive maintenance and a reduction in total maintenance costs. As a by-product, energy savings are often realized from the use of the CM techniques that are part of any RCM program.

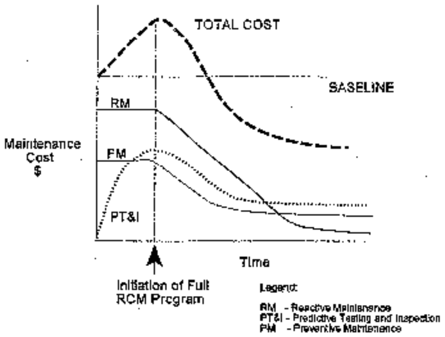

Figure 1. *Maintenance cost trends under an RCM program (Design and Manage Life Cycle Cost M.A. Prace, Farmer Grove, OR, 1978).*

3. Scheduling. The ability of a condition monitoring program to forecast certain maintenance activities provides time for planning, obtaining replacement parts, making the necessary logistical arrangements (i.e., notifying occupants of equipment downtime) before the maintenance is executed. CM reduces the unnecessary maintenance performed by a calendar-based preventive maintenance program, which tends to err consistently on the "safe" side in determining time intervals between maintenance tasks.

4. Equipment/Parts Replacement. A principal advantage of RCM is that it obtains the maximum use from the equipment. With RCM, equipment replacement is based on equipment condition, not on the calendar. This condition based approach to maintenance extends the life of the facility and its equipment.

5. Efficiency/Productivity. Safety is the primary concern of RCM. The second most important concern is cost-effectiveness. Cost-effectiveness takes into consideration the priority or mission criticality and then matches a level of cost appropriate to that priority. The flexibility of the RCM approach to maintenance ensures that the proper type of maintenance is performed when it is needed. Maintenance that is not cost-effective is identified and not performed.

4. HOW TO INITIATE RELIABILITY CENTERED MAINTENANCE

Any RCM process shall ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown below:

(a) What are the functions and associated desired standards of performance of the asset in its present operating context. (Functions).
(b) In what ways can it fail to fulfill its functions? (Functional failures)
(c) What causes each functional failure? (Failure modes)
(d) What happens when each failure occurs? (Failure effects)
(e) In what way does each failure matter? (Failure consequences)
(f) What should be done to predict or prevent each failure? (Proactive tasks and task intervals)
(g) What should be done if a suitable proactive task cannot be found? (Default actions).

After the decisions of how to monitor the failure modes are made, they need to be converted into actions which can be performed at the plant user and maintainer level in the company. This means new procedures, new equipment, new training and new scheduling requirements have to be developed, communicated and practiced.

In order for the transfer of RCM outcomes to proceed successfully into the work place every supervisor and leading hand in operations and maintenance must be supportive of the required changes to work practices. Without commitment from these levels in the organisation the implementation success of RCM will be poor.

In order for RCM to survive as managerial discipline and continue to contribute to the growth of asset management, then it will need to adapt to modern realities. In particular to the practicalities surrounding the implementation aspects of RCM, reducing the risk of impact on the organization, enabling the implementation of analyses into part of the day-to-day operations and making full use of the available technology to increase the speed, quality and permanence of the reliability initiative.

This requires a dramatic change from today's approach to performing RCM analyses, an approach that allows it to be as flexible and responsive as the organizations that it is being implemented into, as well as an approach that takes in all the aspects of the modern main-tenance environment. Today, an implementation of RCM is directed primarily at performing SAE compliant analyses. However, if we are to overcome many of the common errors that have surfaced in RCM implementations over the past 15 years, and increase the success rate, then this focus will need to change significantly.

RCM is also a methodological process. It consists in routine tasks which have to been done regularly, and default actions if a routine one is not appropriate. It is a process logical and "simple" to fallow for the employees, working under the responsibility of managers. So one of the objectives of RCM is also to make the maintenance system easier on the point of view of management.

SUMMARY

The complexity of modem equipment makes it impossible to predict with any degree of accuracy when each part or each assembly is likely to tail. For this reason it is generally more productive to focus on those reliability characteristics that can be determined from the available information than to attempt to estimate failure behavior that will not be known until the equipment enters service. In developing an initial program, therefore, only a modest attempt is made to anticipate the operating reliability of every item. Instead, the governing factor in RCM analysis is the impact of a functional failure at the equipment level, and tasks are directed at a fairly small number of significant items - those whose failure might have safety or major economic consequences.

These items, along with all hidden-function items, are subjected to intensive study, first to classify them according to their failure consequences and then to determine whether there is some form of maintenance protection against these consequences.

The first step in this process is to organize the problem by partitioning the equipment into object categories according to areas of engineering expertise. Within each of these areas the equipment is further partitioned in decreasing order of complexity to identify significant items (those whose failure may have serious consequences for the equipment as a whole), items with hidden functions (those whose failure will not be evident and might therefore go undetected), and non-significant items (those whose failure has no impact on operating capability). As this last group encompasses many thousands of items on an aircraft, this procedure focuses the problem of analysis on those items whose functions must be protected to ensure safe and reliable operation.

The next step is a detailed analysis of the failure consequences in each case. Each function of the item under consideration is examined to determine whether its failure will be evident to the operating crew; if not, a scheduled-maintenance task is required to find and correct hidden failures. Each failure mode of the item is then examined to determine whether it has safety or other serious consequences. If safety is involved, scheduled maintenance is required to avoid the risk of a critical failure. If there is no direct threat to safety, but a second failure in a chain of events would have safety consequences, then the first failure must be corrected at once and therefore has operational consequences. In this case the consequences are economic, but they include the cost of lost operating capability as well as the cost of repair.

Thus scheduled maintenance may be desirable on economic grounds, provided that its cost is less than the combined costs of failure. The consequences of a non-operational failure are also economic, but they involve only the direct cost of repair. This classification by failure consequences also establishes the framework for evaluating proposed maintenance tasks. In the case of critical failures - those with direct safety consequences - a task is considered effective only if it reduces the likelihood of a functional failure to an acceptable level of risk. Although hidden failures, by definition, have no direct impact on safety or operating capability, the criterion in this case is also risk; a task qualifies as effective only if it ensures adequate protection against the risk of a multiple failure. In the case of both operational and non-operational failures task effectiveness is measured in economic terms. Thus a task may be applicable if it reduces the failure rate (and hence the frequency of the economic consequences), but it must also be cost-effective - that is, the total cost of scheduled maintenance must be less than the cost of the failures it prevents.

Whereas the criterion for task effectiveness depends on the failure consequences the task is intended to prevent, the applicability of each form of preventive maintenance depends on the failure characteristics of the item itself. For an on-condition task to be applicable there must be a definable potential failure condition and a reasonably predictable age interval between the point of potential failure and the point of functional failure. For a scheduled rework task to be applicable the reliability of the item must in fact be related to operating age; the age-reliability relationship must show an increase in the conditional probability of failure at some identifiable age (wearout) and most units of the item must survive to that age. The applicability of discard tasks also depends on the age reliability relationship, except that for safelife items the life limit is set at some fraction of the average age at failure. Failure finding tasks are applicable to all hidden function items not covered by other tasks.

The process of developing an RCM program consists of determining which of these scheduled tasks, if any, are both applicable and effective for a given item. The fact that failure consequences govern the entire decision process makes it possible to use a structured decision diagram approach, both to establish maintenance requirements and to evaluate proposed tasks. The binary form of a decision diagram allows a clear focus of engineering judgment on each issue. It also provides the basic structure for a default strategy - the course of action to be taken if there is insufficient information to answer the question or if the study group is unable to reach a consensus. Thus if there is any uncertainty about whether a particular failure might have safety consequences, the default answer will be yes; similarly, if there is no basis for determining whether a proposed task will prove applicable, the answer, at least in an initial maintenance program, will be yes for on-condition tasks and no for rework tasks.

It is important to realize that the decision structure itself is specifically designed for the need to make decisions even with minimal information. For example, if the default strategy demands redesign and this is not feasible in the given timetable, then one alternative is to seek out more information in order to resolve the problem. However, this is the exception rather than the rule. In most cases the default path leads to no scheduled maintenance, and the correction, if any, comes naturally as real and applicable data come into being as a result of actual use of the equipment in service.

The decision logic also plays the important role of specifying its own information requirements. The first three questions assure us that all failures will be detected and that any failures that might affect safety or operating capability will receive first priority. The remaining steps provide for the selection of all applicable and effective tasks, but only those tasks that meet these criteria are included. Again, real data from operating experience will provide the basis for adjusting default decisions made in the absence of information. Thus a prior-to-service program consists primarily of on-condition and sample inspections, failure finding inspections for hidden function items, and a few safe life discard tasks. As information is gathered to evaluate age reliability relationships and actual operating costs, rework and discard tasks are gradually added to the program where they are justified.

The net result of this careful bounding of the decision process is a scheduled maintenance program which is based at every stage on the known reliability characteristics of the equipment in the operating context in which it is used. In short, reliability-centred maintenance is a well tested answer to the paradox of modem aircraft maintenance.

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