

1.0 INTRODUCTION TO RELIABILITY-CENTERED MAINTENANCE

1.1 What is Reliability-Centered Maintenance (RCM)?

1.1.1 Definition

Reliability-Centered Maintenance, or RCM, is a logical, structured framework for determining the optimum mix of applicable and effective maintenance activities needed to sustain the desired level of operational reliability of systems and equipment while ensuring their safe and economical operation and support. Although RCM focuses on identifying preventive maintenance actions, corrective actions are identified by default. That is, when no preventive action is effective or applicable for a given item, then that item is run to failure assuming safety or a similarly critical consideration is not at issue. From that perspective, RCM identifies all maintenance. RCM is focused on optimizing readiness, availability, and sustainment through effective and economical maintenance.

1.1.2 Overview of Concept

Prior to the development of the RCM methodology, it was widely believed that everything had a "right" time for some form of preventive maintenance (PM), usually replacement or overhaul. A widespread belief among many maintenance personnel was that by replacing parts of a product or overhauling the product (or repairable portions thereof), that the frequency of failures during operation could be reduced.

Despite this commonly accepted view, the results seemed to tell a different story. In many instances, PM seemed to have no beneficial effects. Indeed, in many cases, PM actually made things worse by providing more opportunity for maintenance-induced failures.

The RCM approach provides a logical way of determining if PM makes sense for a given item and, if so, selecting the appropriate type of PM. The approach is based on the following precepts:

- **The objective of maintenance is to preserve an item's function(s).** RCM seeks to preserve a desired level of system or equipment functionality, not just operability for operability's sake. Redundancy improves functional reliability but increases life cycle cost in terms of procurement and support cost.
- **RCM focuses on the end system.** The RCM process focuses throughout the life cycle on the end system, from design through retirement. It seeks to preserve end system functionality, not to prevent all failures.
- **Reliability is the basis for decisions.** The failure characteristics of the item in question must be understood to determine the efficacy of preventive maintenance. RCM is not overly concerned with simple "failure rate"; it seeks to know the conditional probability of failure at specific ages (the probability that failure will occur in each given operating age bracket).
- **RCM is driven first by safety and then economics.** Safety must always be preserved. When safety (or a similarly critical consideration) is not an issue, preventive maintenance must be justified on economic grounds.

- **RCM acknowledges design limitations.** Maintenance cannot improve an item's inherent reliability – it is dictated by design. Maintenance, at best, can sustain the design level of reliability over the life of an item.
- **RCM is a continuous process.** The difference between the perceived and actual design life and failure characteristics is addressed through age (or life) exploration.

The RCM concept has completely changed the way in which PM is viewed. It is now a widely accepted fact that not all items benefit from PM. Moreover, even when PM would be effective, it is often less expensive (in all senses of that word) to allow an item to "run to failure" rather than to do PM. In the succeeding discussions, we will examine the RCM concept in more detail. We will explore the meaning of terms that are central to the RCM approach. These terms include failure characteristics, efficiency, run to failure, cost, and function.

1.2 Why is RCM Needed?

As alluded to in the previous discussion, RCM was born of pragmatism. This pragmatism took the form of an honest evaluation of the results of a maintenance philosophy in which everything had a "right age" at which it should be replaced or overhauled. This evaluation showed that safety and availability often degraded despite a comprehensive PM program. Furthermore, as products became increasingly more complex, maintenance costs soared. Finally, the more frequently an item was subjected to maintenance, the more frequently failures were inadvertently induced by that very same maintenance. Many began to question the wisdom of the prevalent philosophy and to look for an alternative and more effective approach.

1.3 Origins of RCM

Nowhere was the then-prevailing philosophy of maintenance challenged more than in the airline industry. By the late 1950's, maintenance costs in the industry had increased to a point where they had become intolerable. Meanwhile, the Federal Aviation Agency (FAA) had learned through experience that the probability of failure of certain types of engines could not be controlled by changing either the frequency or content of scheduled fixed-interval overhauls. As a result of these two factors, a task force consisting of representatives of the airlines and aircraft manufacturers was formed in 1960 to study the effectiveness of PM as being implemented within the airline industry.

The task force developed a rudimentary technique for developing a PM program. Subsequently, a Maintenance Steering Group (MSG) was formed to manage the development of the PM program for the new Boeing 747 (B747) jumbo jet. This new airliner was vastly larger and more complex than any ever built. Given the cost of maintenance on smaller aircraft already in service, the maintenance costs for the B747, using the traditional approach to PM, would have threatened the profitability, and hence the viability, of operating the new aircraft.

The PM program developed by the steering group, documented in a report known as MSG-1, was very successful. That is, it resulted in an affordable PM program that ensured the safe and profitable operation of the aircraft. For example, the requirement for structural inspections for the B747 was kept to 66,000 man-hours, compared to 4 million man-hours for the DC-8.

The FAA was so impressed with MSG-1 that they requested that the logic of the new approach be generalized, so that it could be applied to other aircraft. So in 1970, MSG-2, Airline Manufacturer Maintenance Program Planning Document, was issued. MSG-2 defined and standardized the logic for developing an effective and economical maintenance program. MSG-2 was first used on the L1011, DC10, and MD80 aircraft. In 1972, the European aviation industries issued EMSG (European Maintenance System Guide), which improved on MSG-2 in the structures and zonal analysis. EMSG was used on the Concorde and A300 Airbus.

The problems that the airlines and FAA had experienced with the traditional approach to maintenance were also affecting the military. Although profit was not an objective common to both the airlines and military, controlling costs and maximizing the availability of their aircraft were. Consequently, in 1978, the DoD contracted with United Airlines to conduct a study into efficient maintenance programs. The study:

- Supplemented MSG-2 by emphasizing the detection of Hidden Failures
- Moved from a process-oriented concept to a task-oriented concept

The product of the study was MSG-3, a decision logic that was called Reliability-Centered Maintenance (RCM).

Although created by the aviation industry, RCM quickly found applications in many other industries. RCM is used to develop PM programs for public utility plants, especially nuclear power plants, railroads, processing plants, and manufacturing plants. It is accurate to say that RCM is now the pre-eminent method for evaluating and developing a comprehensive maintenance program for an item. Today, a variety of documents are available on RCM. A listing of some of the more prominent documents is included in Appendix A.

1.4 Relationship of RCM to Other Disciplines

RCM is not a stand-alone activity, separate from the myriad other activities associated with designing and developing a new product, or in sustaining a product already in use. It can benefit from other analyses, provide valuable insights for designers, and contribute to the overall effectiveness of a product. This section addresses three functional areas to which RCM is related.

1.4.1 Relationship of RCM and Reliability

The fundamental requirement of the RCM approach is to understand the failure characteristics of an item. As used herein, failure characteristics include:

- The underlying probability density function
- The consequences of failure
- Whether or not the failure manifests itself and, if it does, how

It is obvious why the first word in the title of the MSG-3 approach was reliability. Much of the analysis needed for reliability provides inputs necessary for performing an RCM analysis, as will be seen in succeeding sections.

Reliability is measured in different ways, depending on one's perspective. From a designer's perspective, reliability is measured by "counting" only those failures that are design-related. When measured in this way, reliability is referred to as "inherent reliability." From a user's or operator's perspective, all events that cause the system to stop performing its intended function is a failure event. These events certainly include all design-related failures that affect the systems' function. Also included are maintenance-induced failures, no-defect found events, and other anomalies that may have been outside the designer's contractual responsibility or technical control. This type of reliability is called "operational reliability." RCM is concerned with operational reliability.

Another way in which RCM and reliability are related is seen in the equation of availability. A general definition of availability (see Appendix B for definitions of terms used in this book) is:

$$\text{Availability} = \frac{\text{Uptime}}{\text{Downtime} + \text{Uptime} (= \text{Total Time})} \quad \text{Equation 1}$$

(Note that the period of time over which this measurement of availability is made must be defined.)

Uptime is primarily a function of reliability. Essentially, the item (product, system, component, etc.) can perform its function(s) as long as nothing fails. Assuming no PM is required for the item, the item is "down" and unavailable to perform its function(s) whenever a failure occurs and remains down until corrective maintenance is complete. The length of time required to complete the maintenance depends on the maintainability characteristics of the item and whether trained repair personnel and required tools, parts, and test equipment are available. Downtime, therefore is a function of maintainability and the support system. In general, PM can be performed whenever the system is down for corrective maintenance or at convenient times when the system can be taken out of service.

Another equation for availability directly uses parameters related to the reliability and maintainability characteristics of the item as well as the support system. This equation is:

$$\text{Availability} = \frac{\text{MTBM}}{\text{MDT} + \text{MTBM}} \quad \text{Equation 2}$$

where:

MTBM is the mean time between all maintenance

MDT is the mean downtime

Equations 1 and 2 can be considered definitions of *operational availability*, A_o . A_o is the availability one expects or measures in actual use. MTBM includes all maintenance required for any reason, including repairs of actual design failures, repairs of induced failures, cases where a failure cannot be confirmed, and preventive maintenance. When only maintenance required to

correct design failures is counted and the effects of the support system are ignored, the result is *inherent availability*, A_i , which is given by Equation 3:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTTR} + \text{MTBF}} \quad \text{Equation 3}$$

where:

MTBF is the mean time between design failures

MTTR is the mean time to repair

Note that a repair may consist of replacing a failed item (or a part thereof) or repairing the item. Inherent availability is a function of the reliability and maintainability (R&M) of the item. (Equations 2 and 3 are steady state equations that are valid after an item has been operating for some finite time and are independent of time. For a discussion of the generalized time-dependent equations using R&M parameters, see Appendix C.)

1.4.2 Relationship of RCM and Quality

Quality is an elusive concept and has many different definitions. Among them are "conformance to specification," "the characteristics of a product or service that bear on its ability to satisfy stated or implied needs," "the degree to which a product or service is free of deficiencies," and "the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs."

Regardless which definition of quality is used, a common objective of any quality management system is ensure that a product (or service) satisfies the customer. A sure way to dissatisfy a customer is to provide a product that is seldom available and is expensive to maintain. So high availability and low maintenance costs generally are associated with "good" quality. Since RCM is intended to achieve the highest level of inherent availability and to minimize the costs of maintenance, RCM directly influences a customer's perception of the quality of a product.

1.4.3 Relationship of RCM and Safety

In Section 1.1.2, Overview of Concept, it was stated that one of the precepts on which the RCM approach is based, is that safety must always be preserved. Given that the RCM concept came out of the airline industry, this emphasis on ensuring safety should come as no surprise. In later sections, the manner in which the RCM logic ensures that safety is ensured will be discussed. For now, it is sufficient to note that the RCM specifically addresses safety and is intended to ensure that safety is never compromised.

In the past several years, environmental concerns and issues involving regulatory bodies have been accorded an importance in the RCM approach for some items that is equal (or nearly so) to safety. Failures of an item that can cause damage to the environment or which result in some Federal or state law being violated can pose serious consequences for the operator of the item. So the RCM logic is modified in this book to specifically address environmental or other concerns.

1.5 Benefits of RCM

We have already alluded to the benefits of using the RCM approach to develop a maintenance program for an item. In addition to developing a comprehensive and effective maintenance program, the analysis can help in developing maintenance and trouble-shooting procedures. In this section, we will examine the benefits of RCM in more detail. The benefits will be discussed from both the commercial and government perspectives.

1.5.1 Meeting Commercial Needs

The commercial sector is profit-driven. Reducing costs, while increasing revenue, maximizes profit and, therefore, is an objective common to both commercial suppliers and commercial users. However, the two parties have a slightly different perspective of revenue and costs.

For the supplier, revenue comes from sales of their product. Increasing sales increases potential profit and requires, among other things, keeping a high level of customer satisfaction. The latter factor, customer satisfaction, is determined to a varying degree, depending on the specific product and customer, by availability. Profitability depends on controlling costs. Supplier costs include:

- Fixed Costs (staff, capital equipment, facilities, etc.)
- Variable Costs (cost of quality, production quantities, etc.)
- Liability Costs (warranty, legal liability, etc.)

Suppliers can keep their fixed and variable costs low through sound and efficient engineering and quality manufacturing. Liability costs can be minimized through risk management and strong safety and reliability programs.

Customers buy products from suppliers and either use them to provide a service (e.g., airlines buy aircraft and provide air transportation) or to manufacture and sell their own products (e.g., automobile manufacturers buy assembly equipment and sell cars). They are, of course, always concerned with the purchase price of a product. However, customers also must deal with other costs that determine the life cycle cost of a product. These are:

- Operating Costs
- Maintenance Costs
- Opportunity Costs
- Liability Costs

The costs to operate and maintain a product are largely determined by the design reliability and maintainability (R&M) characteristics of the product. R&M are the primary factors that dictate the need for maintenance and the costs of doing that maintenance. Opportunity costs are those costs associated with the inability to provide the service or product when needed by the end customer. For example, an airline that must cancel a flight either due to a failure or the inability to repair the failure in the time available will lose the revenue from that flight. If such cancellations occur too frequently, the airline can potentially lose future revenues if dissatisfied passengers of

this airline start flying on another airline. Finally, airlines and auto manufacturers, to name just two industries, must also deal with liability just as their suppliers must.

A maintenance program developed by suppliers using a reliability-centered maintenance approach results in more satisfied customers and ensures that safety (liability) does not become an issue. The customers of suppliers who implement and continually assess and improve an RCM-based maintenance program will realize the highest levels of availability possible given the inherent design characteristics of the product. Thus, their revenues will be maximized and their own customers kept satisfied. Liability risks will also be kept to a minimum.

1.5.2 Meeting Government Needs

Although the government is not profit-driven, controlling costs is just as important as it is in the commercial sector. For many government agencies, system availability is also a key concern.

- **Availability and Readiness.** Availability of products used by the government is measured in much the same way as it is in the commercial sector. In addition, the military uses the concept of readiness. Readiness can be defined as the preparedness of our military forces to accomplish their objectives. It includes the equipment and systems, people, support, and training needed to accomplish the objectives. RCM directly affects availability and readiness by helping to define an effective and efficient maintenance program for a given product, minimizing downtime and maximizing the use of scarce resources. See Appendix C for additional information on readiness and availability.
- **LCC and Affordability.** The total costs to acquire, operate, maintain, support, and dispose of a product constitute the life cycle cost (LCC) of that product. Many products are used by the government, especially the military, for years, often decades. Consequently, the costs to operate and maintain such products often far exceed the acquisition costs and drive the product's LCC. By helping define an effective and efficient maintenance program, RCM directly affects LCC.

Affordability is a concept primarily used within and by the military community and defense contractors. The concept addresses not only the issue of being able to afford to purchase the necessary quantity of weapons but also the issue of being able to afford the support of these systems over very long periods of time. Expressed from a slightly different perspective, affordability is a function of cost and the capability attained. In this context, capability includes both the system and the support of that system over its life cycle. In other words, the DoD acquires *capabilities* and it is these capabilities that must be affordable. RCM directly affects affordability, again through the development of an efficient and effective maintenance program.

- **Supportability.** Supportability can be defined as the "sum" of design maintainability and the logistics support provided for the product. In this context, it is a function of both the design characteristics of the product and the resources budgeted for the support of the product. In implementing an RCM approach, many design shortcomings regarding maintenance previously overlooked can be identified. In addition, an RCM-based maintenance program requires the least expenditure of resources.

1.6 RCM as Part of the Systems Engineering Process

System or product development was once implemented as a series of sequential steps. The results of each step were passed on from organization to organization with little communication or coordination among them, each concentrating on its own functional responsibilities. So, for example, the design organization would design the product, performing whatever analyses and testing was required. The finished design would then be given to the manufacturing organization so that the processes for creating the product could be developed and established.

This sequential approach to product development and manufacturing was fraught with problems. Foremost among these problems was that it often drove up costs and resulted in a product that was less capable than what could have been reasonably achieved. To address the problems of the sequential approach, new organizational forms emerged that emphasized an approach of coordination and communication. Various terms have been used to describe the new approach; among them are concurrent engineering, simultaneous engineering, and integrated product development. Common to all the definitions is a focus on systems engineering, multi-disciplinary design teams, and real-time communications.

Systems engineering is a top down iterative process involving requirements definition, functional analysis and allocation, synthesis and design, test and evaluation. Although RCM analysis is usually done after completing an initial Failure Modes and Effects Analysis (FMEA), integrating RCM into the overall system engineering effort ensures that maintenance will be addressed with other performance requirements. In addition, in implementing an RCM approach, many maintenance-related design shortcomings that were previously overlooked can be identified, leading to a design that requires a maintenance program with the least expenditure of resources. Also, RCM will be integrated with other engineering and design activities, avoiding duplicative effort and making the best use of activity outputs.

Although RCM is best applied during the development of a product, it can be effectively used to optimize the maintenance for products already in use, for which RCM was not applied during development. When applied to such products, actual data from operation and maintenance can be used to supplement any needed analysis.

1.7 Scope of this Document

This document is primarily based on MSG-3 but includes information and concepts from the references in Section A.1 of Appendix A. The methodology presented is not limited to a specific type of system or product but is generally applicable. The focus of this document is on understanding and implementing the RCM methodology. Information on related and supporting methods, such as economic analysis, is addressed only in the level of detail needed to understand how they relate to RCM.