

The Aladon Network

THINK AHEAD

RELIABILITY CENTERED MAINTENANCE (RCM3™)



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1. INTRODUCTION

Reliability Centered Maintenance (RCM) finds its roots in work done by the international commercial aviation industry. Driven by the need to improve reliability while containing the cost of maintenance, this industry developed a comprehensive process for deciding what maintenance work is needed to keep aircraft airborne. This process evolved steadily since its early beginnings in 1960.

In 1978, a report[1] was prepared for the US Department of Defense describing the then current state of the process. The report was written by F Stanley Nowlan and Howard Heap of United Airlines, and it was entitled “Reliability-centered Maintenance”, or RCM. It formed the basis of the maintenance strategy formulation process called MSG3[2]. MSG3 was first promulgated in 1980, and in slightly modified form, it is used to this day by the international commercial aviation industry. In the early 1980’s, RCM as described by Nowlan and Heap also began to be used in industries other than aviation.

It soon became apparent that no other comparable technique exists for identifying the true, safe minimum of what must be done to preserve the functions of physical assets. As a result, RCM has now been used by thousands of organizations spanning nearly every major field of organized human endeavor. It is becoming as fundamental to the practice of physical asset management as double-entry bookkeeping is to financial asset management.

The growing popularity of RCM has led to the development of numerous derivatives. Some of these derivatives are refinements and enhancements of Nowlan and Heap’s original RCM process. However, less rigorous derivatives have also emerged, most of which are attempts to ‘streamline’ the maintenance strategy formulation process. This paper describes one of the most rigorous of the derivatives, known as RCM2. In order to place a RCM as a whole in context, the next section of this paper considers the recently published SAE RCM Standard[3].

2. THE SAE RCM STANDARD

As mentioned above, various derivatives of Nowlan and Heap’s RCM process have emerged since their report was published in 1978. Many of these derivatives retain the key elements of the original process. However, the widespread use of the term "RCM" led to the emergence of a number of processes that differ significantly from the original, but that their proponents also call "RCM". Many of these other processes either omit key steps of the process described by Nowlan and Heap, or change their sequence, or both. Consequently, despite claims to the contrary made by the proponents of these processes, the output differs markedly from what would be obtained by conducting a full, rigorous RCM analysis.

A growing awareness of these differences led to an increasing demand for a standard that set out the criteria any process must comply with in order to be called "RCM". Such a standard was published by the Society of Automotive Engineers (SAE) in 1999. An article4 by Dana Netherton, Chairman of the SAE RCM Committee, described the evolution of RCM between 1978 and 1990, then went on to describe the evolution of the SAE Standard as quoted in the italicized paragraphs below:

The Need for a Standard: the 1990s

Since the early 1990s, a great many more organizations have developed variations of the RCM process. Some, such as the US Naval Air Command with its ‘Guidelines for the Naval Aviation Reliability Centered Maintenance Process (NAVAIR 00-25-403[3]), and the British Royal Navy with its RCM-oriented Naval Engineering Standard (NES45[4]), have remained true to the process originally expounded by Nowlan and Heap. However, as the RCM bandwagon has started rolling, a whole new collection of processes has emerged that are called “RCM” by their proponents, but that often bear little or no resemblance to the original meticulously researched, highly structured and thoroughly proven process developed by Nowlan and Heap. As a result, if an organization said that it wanted help in using or learning

[1] Nowlan FS and Heap H: “Reliability-centered Maintenance”. Springfield, Virginia. National Technical Information Service, United States Department of Commerce

[2] Maintenance Steering Group - 3 Task Force: “Maintenance Program Development Document MSG-3”. Washington DC: Air Transport Association (ATA) of America. 1993

[3] US Naval Air Systems Command: “NAVAIR 00-25-403: Guidelines for the Naval Aviation Reliability Centered Main-tenance Process”. Philadelphia, Pennsylvania. US Department of Defense Publications

[4] Netherton D: "SAE's New Standard for RCM". *Maintenance* (UK) 15 (1) 3 - 7, 2000

how to use RCM, it could not be sure what process would be offered.

Indeed, when the US Navy recently asked for equipment vendors to use RCM when building a new ship class, one US company offered a process closely related to the 1970 MSG-2 process. It defended its offering by noting that its process used a decision-logic diagram. Since RCM also uses a decision-logic diagram, the company argued, its process was an RCM process.

The US Navy had no answer to this argument, because in 1994 William Perry, the US Secretary of Defense, established a new policy about US military standards and specifications, which said that the US military would no longer require industrial vendors to use the military's 'standard' or 'specific' processes. Instead it would set performance requirements, and would allow vendors to use any processes that would provide equipment that would meet these requirements.

At a stroke, this voided the US military standards and specifications that defined "RCM". The US Air Force standard was cancelled in 1995. The US Navy has been unable to invoke its standards and specifications with equipment vendors (though it continues to use them for its internal work) — and it was unable to invoke them with the US Company that wished to use MSG-2.

This development happened to coincide with the sudden interest in RCM in the industrial world. During the 1990s, magazines and conferences devoted to equipment maintenance have multiplied, and magazine articles and conference papers about RCM became more and more numerous. These have shown that very different processes are being given the same name, "RCM". So both the US military and commercial industry saw a need to define what an RCM process is.

In his 1994 memorandum, Perry said, "I encourage the Under Secretary of Defense (Acquisition and Technology) to form partnerships with industry associations to develop non-government standards for replacement of military standards where practicable." Indeed, the Technical Standards Board of the SAE has had a long and close relationship with the standards community in the US military, and has been working for several years to help develop commercial standards to replace military standards and specifications, when needed and when none already existed.

So in 1996 the SAE began working on an RCM-related standard, when it invited a group of representatives from the US Navy aviation and ship RCM communities to help it develop a standard for Scheduled Maintenance Programs. These US Navy representatives had already been meeting for about a year in an effort to develop a US Navy RCM process that might be common between the aviation and ship communities, so they had already done a considerable amount of work when they began to meet under SAE sponsorship. In late 1997, having gained members from commercial industry, the group realized that it was better to focus entirely on RCM. In 1998, the group found the best approach for its standard, and in 1999 it completed its draft of the standard, and the SAE approved it and published it.

After a brief discussion about the practical difficulties associated with attempting to develop a universal standard of this nature, Netherton went on to say:

The standard now approved by the SAE does not present a standard process. Its title is, "EvaluationCriteria for Reliability-Centered Maintenance (RCM) Processes (SAE JA1011[5])." This standard presents criterion against which a process may be compared. If the process meets the criteria, it may confidently be called an "RCM process." If it does not, it should not. (This does not necessarily mean that processes that do not comply with the SAE RCM standard are not valid processes for maintenance strategy formulation. It simply means that the term "RCM" should not be applied to them.)

The italicized paragraph below quotes Section 5 of the Standard, which summarizes the key attributes of any RCM process as follows.

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 fulfil 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)?*

To answer each of the above questions "satisfactorily", the following information shall be gathered, and the following decisions shall be made. All information and decisions shall be documented in a way which makes

[5] International Society of Automotive Engineers: "JA1011 - Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes". Warrendale, Pennsylvania, USA: SAE Publications

the information and the decisions fully available to and acceptable to the owner or user of the asset.

Subsequent sections of the Standard list the issues that any RCM process must address in order to answer each of the seven questions "satisfactorily". (In the rest of this paper, "true RCM" means any RCM process that complies with SAE Standard JA1011.)

In the mid-1980s, Aladon began applying RCM in industries other than aviation. From the technical point of view, the Aladon approach to RCM complies fully with SAE Standard JA1011. The Aladon approach also pioneered the use of facilitated review groups to the application of true RCM, and the overall approach was known as RCM2. RCM2 is described in the book "Reliability-centered Maintenance" by John Moubray[6], and it has now been applied on industrial locations in more than 80 countries around the world. RCM2 has been implemented on more sites and in more places than any other RCM process. Since the almost 30-year successful implementation of RCM2, Aladon extended the methodology with RCM3 to bring reliability mainstream with organization's asset management and risk management standards. RCM3 fully underpins the new international standards for Asset Management (ISO 55000) and Risk Management (ISO 31000). The rest of this paper describes RCM and RCM3 in more detail. Part 3 explores the meaning of the word 'maintenance', then goes on to define RCM and summarize key elements of the seven questions listed in SAE Standard JA1011. Part 4 describes how RCM3 extends the methodology and how it should be applied, and Part 5 outlines what it achieves.

3. RCM3

From the engineering viewpoint, there are two aspects to the management of any physical asset. It must be maintained and from time to time it may also need to be modified.

The major dictionaries define maintain as *cause to continue* (Oxford) or *keep in an existing state* (Webster). This suggests that maintenance means preserving something. On the other hand, they agree that to modify something means to change it in some way. The importance of this distinction is recognized in the RCM decision process. However, we focus on maintenance at this point.

When we set out to maintain something, what is it that we wish to cause to continue? What is the existing state that we wish to preserve?

The answer to these questions can be found in the fact that every physical asset is put into service because someone wants it do something. In other words, they expect it to fulfil a specific function or functions. So it follows that when we maintain an asset, the state we wish to preserve must be one in which it continues to do whatever its users want it to do.

Maintenance: Ensuring that physical assets continue to do what their users want them to do

What the users want depends on exactly where and how the asset is being used (the operating context). This leads to the following definition of Reliability Centered Maintenance:

Reliability Centered Maintenance: a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context'.

and

RCM3: a process used to define the minimum required safe amount of maintenance, engineering and other risk management strategies to ensure a tolerable level of safety, environmental integrity and cost effective operational capability as specified in the organization's asset management standard

Before any version of true RCM can be applied to any asset or system, it is necessary to decide what system is to be analyzed, establish the system boundaries, clearly define its ***operating context***, and prepare a detailed plan of action. These issues are discussed at greater length in Part 4 of this paper. This part of this paper briefly describes the RCM3 process itself.

RCM3 extended the methodology to include the operating context as a definite first step of the process and also focus on the treatment of physical and economic risk. RCM3 consists of nine steps which include the essential seven questions from the SAE standard, therefore not only making RCM3 fully compliant with the standard but extending it beyond the requirements of the SAE standard.

The application of RCM3 entails nine steps as set out below. The following sections of this paper summarize

[6] Moubray JM: "Reliability-centered Maintenance": New York, New York USA: Industrial Press

the key issues addressed when answering each of these questions.

3.1 Operating Context

The operating context is defined in SAE JA1012 as ***"the circumstances in which a physical asset or system is expected to operate"***. Technically, identical equipment will perform differently if the operating context is different. Therefore, the maintenance program for technically identical equipment can be radically different if the operating contexts are different.

It is of utmost importance that the operating context of a physical asset is defined before we attempt to establish what maintenance we should be doing.

The following typical operating parameters and conditions should be considered when developing the operating context:

- Batch process or flow process.
- Physical conditions and operating environment.
- Product or service quality standards.
- Environment and environmental standards
- Safety standards and regulatory requirements
- Shift arrangements
- Standby capacity or redundancy
- Work in progress
- Utilization
- Spares policies and logistics.
- Current asset condition
- Market demand and raw material supply
- Skills and technology available

The operating context is the basis on which a maintenance program is developed. When a decision is made to use RCM3 to develop the maintenance program, the first step is to develop the operating context.

3.2 Functions and Performance Standards

Before it is possible to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context, we need to do two things:

- determine what its users want it to do
- ensure that it can do what its users want to start with.

This is why the first step in the RCM process entails defining the functions of each asset in its operating context, together with the desired standards of performance. What users expect assets to be able to do can be split into two categories:

- *primary functions*, which summarize why the asset was acquired in the first place. This category of functions covers issues such as speed, output, carrying or storage capacity, product quality and customer service.
- *secondary functions*, which recognize that every asset is expected to do more than simply fulfil its primary functions. Users also have expectations in areas such as safety, control, containment, comfort, structural integrity, environmental compliance, economy, protection, efficiency of operation, and even the appearance of the asset.

3.3 Failed States

The objectives of maintenance are defined by the functions and associated performance expectations of the asset. But how does maintenance achieve these objectives?

The only occurrence that is likely to stop any asset performing to the standard required by its users is some kind of failure. This suggests that maintenance achieves its objectives by adopting a suitable approach to the management of failure. However, before we can apply a suitable blend of failure management tools, we need to identify what failures can occur. The RCM process does this at two levels:

- first, by identifying what circumstances amount to a failed state
- then by asking what events can cause the asset to get into a failed state.

In the world of RCM, failed states are known as functional failures because they occur when an asset is unable to fulfil a function to a standard of performance which is acceptable to the user. In addition to the total inability to function, this definition encompasses partial failures, where the asset still functions but at an unacceptable level of performance (including situations where the asset cannot sustain acceptable levels of quality or accuracy).

3.4 Failure *Modes*

As mentioned in the previous paragraph, once each functional failure (failed state) has been identified, the next step is to try to identify all the events that are reasonably likely to cause each failed state. These events are known as failure modes. Failure modes consist of failure causes and failure mechanisms. The cause is the direct reason for the loss of function while the failure mechanism is the events leading up to the cause. Events which can lead up to failure happen over a period of time (i.e. corrosion or fatigue) or events could happen suddenly such as human error or process upsets. 'Reasonably likely' failure modes include those that have occurred on the same or similar equipment operating in the same context, failures that are currently being prevented by existing maintenance regimes, and failures that have not happened yet but that are considered to be real possibilities in the context in question.

Most traditional lists of failure modes incorporate failures caused by deterioration or normal wear and tear.

However, the list should include failures caused by human errors (on the part of operators and maintainers) and design flaws so that all reasonably likely causes of equipment failure can be identified and dealt with appropriately. It is also important to identify the cause of each failure in enough detail for it to be possible to identify an appropriate failure management policy.

3.5 Failure Effects

The fourth step in the RCM process entails listing failure effects, which describe what happens when each failure mode occurs. These descriptions should include all the information needed to support the evaluation of the consequences of the failure, such as:

- when is the failure most likely to occur (startup, normal running, peak production, etc.)?
- what evidence (if any) that the failure has occurred?
- in what ways (if any) it poses a threat to safety or the environment?
- in what ways (if any) it affects production or operations?
- what physical damage (if any) is caused by the failure?
- what must be done to repair the failure?
- does it cause any secondary damage?
- what is the revenue loss (if any)?

3.6 Failure Consequences

A detailed analysis of an average industrial undertaking is likely to yield between three and ten thousand possible failure modes. Each of these failures affects the organization in some way, but in each case, the effects are different. They may affect operations. They may also affect product quality, customer service, safety or the environment. They will all take time and cost money to repair.

It is these consequences which most strongly influence the extent to which we try to prevent each failure. In other words, if a failure has serious consequences, we are likely to go to great lengths to try to avoid it. On the other hand, if it has little or no effect, then we may decide to do no routine maintenance beyond basic cleaning and lubrication.

A great strength of RCM is that it recognizes that the consequences of failures are far more important than their technical characteristics. In fact, it recognizes that the only reason for doing any kind of proactive maintenance is not to avoid failures per se, but to avoid or at least to reduce the consequences of failure. The RCM process classifies these consequences into four groups, as follows:

- *Hidden failure consequences:* Hidden failures have no direct impact, but they expose the organization to multiple failures with serious, often catastrophic, consequences.
- *Safety and environmental consequences:* A failure has safety consequences if it could injure or kill someone. It has environmental consequences if it could breach a corporate, regional, national or international environmental standard.
- *Operational consequences:* A failure has operational consequences if it affects operations (output, product quality, customer service or operating costs in addition to the direct cost of repair)
- *Non-operational consequences:* Evident failures that fall into this category affect neither safety nor production, so they involve only the direct cost of repair.

The RCM process uses these categories as the basis of a strategic framework for maintenance decision-making. By forcing a structured review of the consequences of each failure mode in terms of the above categories, it integrates the operational, environmental and safety objectives of maintenance. This helps to bring safety and the environment into the mainstream of maintenance management.

The consequence evaluation process also shifts emphasis away from the idea that all failures are bad and must be prevented. In so doing, it focuses attention on the maintenance activities that have most effect on the performance of the organization, and diverts energy away from those that have little or no effect. It also encourages us to think more broadly about different ways of managing failure, rather than to concentrate only on failure prevention. Failure management techniques are divided into two categories:

- *proactive tasks:* these are tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state. They embrace what is traditionally known as "predictive" and "preventive" maintenance, although RCM uses the terms scheduled restoration, scheduled discard and on-condition maintenance.
- *default actions:* these deal with the failed state, and are chosen when it is not possible to identify an effective pro-active task. Default actions include failure-finding, redesign and run-to-failure.

3.7 Risk identification and management

The RCM process is applied from a “zero-base” approach, in other words when performing an RCM analysis, the consideration is that no maintenance is being performed. From this, the inherent risk can be determined and more defensible recommendations will be made (based on the physical or economic risk). The robust decision logic for developing risk management strategies focus foremost on pro-active maintenance strategies before it would consider the default actions. The residual risk (once a risk management strategy has been developed) has to be within tolerable levels according to the organization’s risk management standards otherwise a one-time change will have to be implemented to reduce the risk to within tolerable levels.

3.6 Proactive Risk Management Strategies

Many people still believe that the best way to optimize plant availability is to do some kind of proactive maintenance on a routine basis. Conventional wisdom suggested that this should consist of fixed interval overhauls or component re-placements. Figure 1 illustrates the fixed interval view of failure.

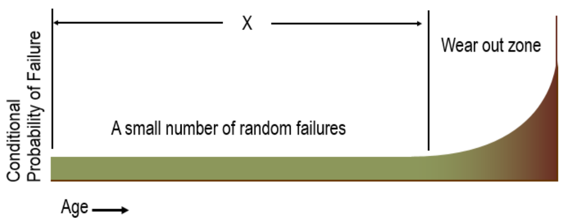


Figure 1: The Traditional View of Failure

Figure 1 is based on the assumption that most items operate reliably for a period 'X', and then wear out. Classical thinking suggests that extensive records about failure will enable us to determine this life and so make plans to take preventive action shortly before the item is due to fail in future.

This model is true for certain types of simple equipment, and for some complex items with dominant failure modes. In particular, wear-out characteristics are often found where equipment comes into direct contact with the product. Age-related failures are also often associated with fatigue, corrosion, abrasion and evaporation.

However, equipment in general is far more complex than it was thirty years ago. This has led to startling changes in the patterns of failure, as shown in Figure 2. The graphs show conditional probability of failure against operating age for a variety of electrical and mechanical items.

- pattern A is the well-known bathtub curve. It begins with high incidence of failure (known as infant mortality) followed by constant or gradually increasing conditional probability of failure, then by a wear-out zone
- pattern B shows constant or slowly increasing conditional probability of failure, ending in a wear-out zone (the same as Figure 1).
- pattern C shows slowly increasing conditional probability of failure, no identifiable wear-out age.
- pattern D shows low conditional probability of failure when the item is new or just out of the shop, then a rapid increase to a constant level
- pattern E shows a constant conditional probability of failure at all ages (random failure)
- pattern F starts with high infant mortality, dropping to a constant or slowly decreasing conditional probability of failure.

Studies done on civil aircraft showed that 4% of the items con-formed to pattern A, 2% to B, 5% to C, 7% to D, 14% to E and no fewer than 68% to pattern F. (The number of times that these patterns occur in aircraft is not necessarily the same as in industry. But there is no doubt that as assets become more complex, we see more and more of patterns E and F.)

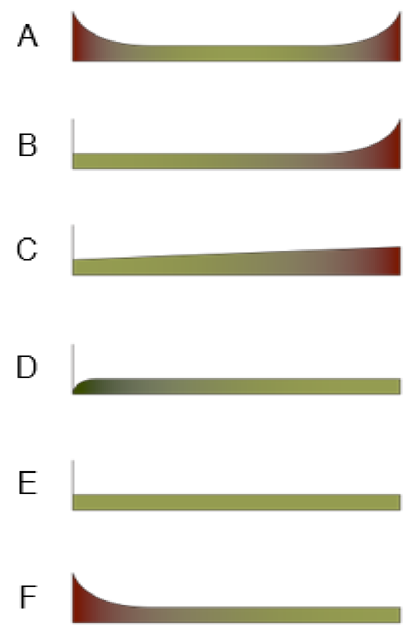


Figure 2: The Reality of Failure

These findings contradict the belief that there is always a connection between reliability and operating age. This belief led to the idea that the more often an item is overhauled, the less likely it is to fail. Nowadays, this is seldom true. Unless there is a dominant age-related failure mode, age limits do little or nothing to improve the reliability of complex items. In fact scheduled overhauls often increase overall failure rates by introducing infant mortality into otherwise stable systems. An awareness of these facts has led some organizations to abandon the idea of proactive maintenance completely. In fact, this can be the right thing to do for failures with minor consequences. But when the failure consequences are significant, something must be done to prevent or predict the failures, or at least to reduce the consequences.

This brings us back to the question of proactive tasks. As mentioned earlier, RCM divides proactive tasks into three categories, as follows:

- scheduled restoration tasks
- scheduled discard tasks
- scheduled on-condition tasks.

Scheduled restoration and scheduled discard tasks

Scheduled restoration entails remanufacturing a component or overhauling an assembly at or before a specified age limit, regardless of its condition at the time. Similarly, scheduled discard entails discarding an item at or before a specified life limit, regardless of its condition at the time.

Collectively, these two types of tasks are now generally known as preventive maintenance. They used to be by far the most widely used form of proactive maintenance. However, for the reasons discussed above, they are much less widely used than they were twenty years ago.

On-condition tasks

The continuing need to prevent certain types of failure, and the growing inability of classical techniques to do so, are behind the growth of new types of failure management. The majority of these techniques rely on the fact that most failures give some warning of the fact that they are about to occur. These warnings are known as potential failures, and are defined as identifiable physical conditions which indicate that a functional failure is about to occur or is in the process of occurring.

The new techniques are used to detect potential failures so that action can be taken to reduce or eliminate the consequences that could occur if they were to degenerate into functional failures. They are called on-condition tasks, and include all forms of condition-based maintenance, predictive maintenance and condition monitoring.)

Used appropriately, on-condition tasks are a very good way of managing failures, but they can also be an expensive waste of time. RCM enables decisions in this area to be made with particular confidence.

3.8 Default Actions and One-time Changes

RCM recognizes three major categories of default action:

- *failure-finding:* Failure-finding entails checking hidden functions to find out if they have failed (as opposed to the on-condition tasks described above, which entail checking if something is failing). The rapid growth in the use of built-in protective devices means that this category of tasks is likely to become as big a maintenance management issue in the next ten years as condition monitoring has been in the last decade. RCM provides powerful, risk-based rules for establishing whether, how often and by whom these tasks should be done
- *one-time change:* A one-time change entails making sure the inherent reliability of the system is capable to fulfill the requirements as defined by the user. This may include modifications to hardware and changes to procedures. (Note that the RCM process considers the maintenance requirements of each asset before asking whether it is necessary to change the design. This is because the maintenance person who is on duty today has to maintain the asset as it exists today, not what should be there or what might be there at some stage in the future. However, if it transpires that an asset simply cannot deliver the desired performance, RCM helps to focus redesign efforts on the real problems)
- *no scheduled maintenance:* as the name suggests, this default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur and then repaired. This default is also called run-to-failure.

3.9 The RCM Risk Management Strategy Selection Process (Task Selection)

A great strength of RCM is the way it provides precise and easily understood criteria for deciding which (if any) of the proactive tasks is technically feasible in any context, and if so for deciding how often and by whom they should be done. Whether or not a proactive task is technically feasible is governed by the technical characteristics of the task and of the failure that it is meant to prevent. Whether it is worth doing is governed by how well it deals with the consequences of the failure. If a proactive task cannot be found that is both technically feasible and worth doing, then suitable default action must be taken. The essence of the task selection process is as follows:

- for *hidden failures*, a proactive task is worth doing if it reduces the risk of the multiple failure associated with that function to a tolerably low level. If such a task cannot be found, then a scheduled failure-finding task must be pre-scribed. If a suitable failure-finding task cannot be found, then the secondary default decision is that the item may have to be redesigned (depending on the consequences of the multiple failure).
- for failures with *safety or environmental consequences*, a proactive task is only worth doing if it reduces the risk of that failure on its own to a very low level indeed, if it does not eliminate it altogether. If a task cannot be found that reduces the risk of the failure to a tolerable level, the item must be redesigned or the process must be changed.
- if the failure has *operational consequences*, a proactive task is only worth doing if the total cost of doing it over a period of time is less than the cost of the operational consequences and the cost of repair over the same period. In other words, the task must be justified on economic grounds. If it is not justified, the initial default decision is no scheduled maintenance. (If this occurs and the operational consequences are still unacceptable then the secondary default decision is again redesign).
- if a failure has *non-operational consequences* a proactive task is only worth doing if the cost of the task over a period of time is less than the cost of repair over the same period. So these tasks must also be justified on economic grounds. If it is not justified, the initial default decision is again no scheduled maintenance, and if the repair costs are

too high, the secondary default decision is once again redesign.

This approach means that proactive tasks are only specified for failures that really need them, which in turn leads to substantial reductions in routine workloads. Less routine work also means that the remaining tasks are more likely to be done properly. This together with the elimination of counterproductive tasks leads to more effective maintenance.

Compare this with the traditional approach to the development of maintenance policies. Traditionally, the maintenance requirements of each asset are assessed in terms of its real or assumed technical characteristics, with-out considering the consequences of failure. The resulting schedules are used for all similar assets, again without considering that different consequences apply in different operating contexts. This results in large numbers of schedules that are wasted, not because they are 'wrong' in the technical sense, but because they achieve nothing.

Correctly applied, RCM leads to remarkable improvements in maintenance effectiveness, and often does so surprisingly quickly. However, as with any fundamental change management project, RCM is much more likely to succeed if proper attention is paid to thorough planning, how and by whom the analysis is performed, auditing and implementation. These issues are discussed in the following paragraphs.

4. APPLYING RCM3

Prioritizing assets and establishing objectives

Part 5 of this paper explains that RCM can improve organizational performance in a host of different ways, tangible and intangible. Tangible benefits include greater safety, improved environmental integrity, improved availability and reliability, better product quality and customer service and reduced operating and maintenance costs. Intangible benefits include better understanding about how the equipment works on the part of operators and maintainers, improved team-working and higher morale.

RCM should be applied first to systems where it is likely to yield the highest returns relative to the effort required in any or all of the above areas. If these systems are not self-evident, it may be necessary to prioritize RCM projects on a more formal basis. When this has been done, it is then essential to plan each project in detail.

Planning

The successful application of RCM depends first and perhaps foremost on meticulous planning and preparation. The key elements of the planning process are as follows:

- Define the scope and boundaries of each project
- Define and wherever possible quantify the objectives of each project (now state and desired end state)
- Estimate the amount of time (number of meetings) needed to review the equipment in each area
- Identify project manager and facilitator(s)
- Identify participants (by title and by name)
- Plan training for participants and facilitators
- Plan date, time and location of each meeting
- Plan management audits of RCM recommendations
- Plan to implement the recommendations (maintenance tasks, design changes, changes to operating procedures)

Review groups

We have seen how the RCM process embodies seven basic questions. In practice, maintenance people simply cannot answer all these questions on their own. This is because many (if not most) of the answers can only be supplied by production or operations people. This applies especially to questions concerning functions, desired performance, failure effects and failure consequences.

For this reason, a review of the maintenance requirements of any asset should be done by small teams that include at least one person from the maintenance function and one from the operations function. The seniority of the group members is less important than the fact that they should have a thorough knowledge of the asset under review. Each group member should also have been trained in RCM. The make-up of a typical RCM2 review group is shown in Figure 3.

Figure 3: A Typical RCM3 Review Group

The use of these groups not only enables management to gain access to the knowledge and expertise of each member of the group on a systematic basis, but the members themselves learn a great deal about how the asset works.

Facilitators

RCM review groups work under the guidance of highly trained specialists in RCM, known as facilitators. The facilitators are the most important people in the RCM review process. Their role is to ensure that:

- the RCM analysis is carried out at the right level, that system boundaries are clearly defined, that no important items are overlooked and that the results of the analysis are properly recorded
- RCM is correctly understood and applied by the group
- the group reaches consensus in a brisk and orderly fashion, while retaining their enthusiasm and commitment
- the analysis progresses as planned and finishes on time.

Facilitators also work with RCM project managers or sponsors to ensure that each analysis is properly planned and receives appropriate managerial and logistic support.

The outcomes of an RCM analysis

If it is applied in the manner suggested above, an RCM analysis results in three tangible outcomes, as follows:

- schedules to be done by the maintenance department
- revised operating procedures for the operators of the asset
- a list of areas where one-time changes must be made to the design of the asset or the way it is operated to deal with situations where the asset cannot deliver the desired performance in its current configuration.

A less tangible but very valuable outcome is that participants in the process tend to start functioning much better as multi-disciplinary teams after their analyses have been completed.

Auditing

After the review has been completed for each asset, senior managers with overall responsibility for the equipment must satisfy themselves that the review is sensible and defensible. This entails deciding whether they agree with the definition of functions and performance standards, the identification of failure modes and the description of failure effects, the assessment of failure consequences and the selection of tasks.

Implementation

Once the RCM review has been audited and approved, the final step is to implement the tasks, procedures and one-time changes. The revised tasks and procedures must be documented in a way that ensures that they will be easily under-stood and performed safely by the people who do the work.

The maintenance tasks are then fed into suitable planning and scheduling systems, while revised operating procedures are usually incorporated into standard operating procedure manuals. Proposals for modifications are dealt with by the engineering or project management function in most organizations.

5. WHAT RCM3 ACHIEVES

Desirable as they are, the outcomes listed above should only be seen as a means to an end. Specifically, they should enable the maintenance function to fulfil all the expectations listed in Figure 1 at the beginning of this paper. How they do so is summarized in the following paragraphs.

- *Greater safety and environmental integrity:* RCM considers the safety and environmental implications of every failure mode before considering its effect on operations. This means that steps are taken to minimize all identifiable equipment-related safety and environmental hazards, if not eliminate them altogether. By integrating safety into the mainstream of maintenance decision-making, RCM also improves attitudes to safety.
- *Improved operating performance (output, product quality and customer service):* RCM recognizes that all types of maintenance have some value, and provides rules for deciding which is most suitable in every situation. By doing so, it helps ensure that only the most effective forms of maintenance are chosen for each asset, and that suitable action is taken in cases where maintenance cannot help. This much more tightly focused maintenance effort leads to quantum jumps in the performance of existing assets where these are sought.
- RCM was developed to help airlines draw up maintenance programs for new types of aircraft before they enter service. As a result, it is an ideal way to develop such programs for new assets, especially complex equipment for which no historical information is available. This saves much of the trial and error that is so often part of the development of new maintenance programs – trial that is time-consuming and frustrating, and error that can be very costly.
- *Greater maintenance cost-effectiveness:* RCM continually focuses attention on the maintenance activities that have most effect on the performance of the plant. This helps to ensure that everything spent on maintenance is spent where it will do the most good.

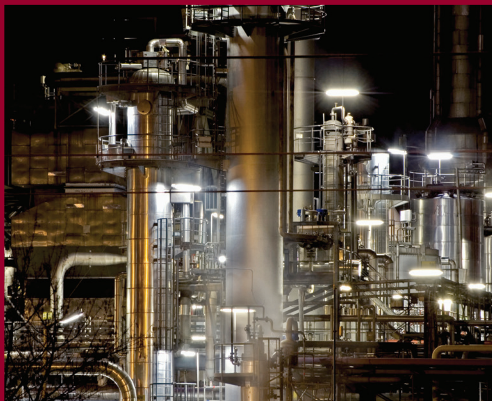
In addition, if RCM is correctly applied to existing maintenance systems, it reduces the amount of routine work (in other words, maintenance tasks to be undertaken on a cyclic basis) issued in each period, usually by 40% to 70%. On the other hand, if RCM is used to develop a new maintenance program, the resulting scheduled workload is much lower than if the program is developed by traditional methods.

- *A comprehensive database:* An RCM review ends with a comprehensive and fully documented record of the maintenance requirements of all the significant assets used by the organization. This makes it possible to adapt to changing circumstances (such as changing shift patterns or new technology) without having to reconsider all maintenance policies from scratch. It also enables equipment users to demonstrate that their maintenance programs are built on rational foundations (the audit trail required by more and more regulators). Finally, the information stored on RCM worksheets reduces the effects of staff turnover with its attendant loss of experience and expertise.
- An RCM review of the maintenance requirements of each asset also provides a much clearer view of the skills required to maintain each asset, and for deciding what spares should be held in stock.
- *Greater motivation of individuals,* especially people who are involved in the review process. This is accompanied by much wider ‘ownership’ of maintenance problems and their solutions. It also means that solutions are more likely to endure.
- *Better teamwork:* RCM provides a common, easily understood technical language for everyone who has any-thing to do with maintenance. This gives maintenance and operations people a better understanding of what maintenance can (and cannot) achieve and what must be done to achieve it.

All of these issues are part of the mainstream of maintenance management, and many are already the target of improvement programs. A major feature of RCM is that it provides an effective step-by-step framework for tack-ling all of them at once, and for involving everyone who has anything to do with the equipment in the process.

RCM yields results very quickly. In fact, if they are correctly focused and correctly applied, RCM analyses can pay for themselves in a matter of months and sometimes even a matter of weeks. The process transforms both the perceived maintenance requirements of the physical assets used by the organization and the way in which the maintenance function as a whole is perceived. The result is more cost-effective, more harmonious and much more successful maintenance.

Notes:



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