# RELIABILITY-CENTERED MAINTENANCE
# - An Introduction -

<u>CONTENTS</u> <u>PAGE</u>

Over the past twenty years, maintenance has changed, perhaps more so than any other management discipline. The changes are due to a huge increase in the number and variety of physical assets (plant, equipment and buildings) that must be maintained throughout the world, much more complex designs, new maintenance techniques and changing views on maintenance organization and responsibilities.

Maintenance is also responding to changing expectations. These include a rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality, and increasing pressure to achieve high plant availability and to contain costs.

The changes are testing attitudes and skills in all branches of industry to the limit. Maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. At the same time the limitations of maintenance systems are becoming increasingly apparent, no matter how much they are computerized.

In the face of this avalanche of change, managers everywhere are seeking a new approach to maintenance. They want to avoid the false starts and dead ends that always accompany major upheavals. *Instead they seek a strategic framework that synthesizes the new developments into a coherent pattern, so that they can evaluate them sensibly and apply those likely to be of most value to them and their companies.*

This paper describes a philosophy that provides just such a framework. It is called Reliability-centered Maintenance, or RCM.

If it is applied correctly, RCM transforms the relationships between the undertakings that use it, their existing physical assets and the people who operate and maintain those assets. It also enables new assets to be put into effective service with great speed, confidence and precision. The following paragraphs provide a brief introduction to RCM, starting with a look at how maintenance has evolved over the past sixty years.

Since the 1930's, the evolution of maintenance can be traced through three generations. RCM is rapidly becoming a cornerstone of the Third Generation, but this generation can only be viewed in perspective in the light of the First and Second Generations.

### *The First Generation*

The First Generation covers the period up to World War II. In those days industry was not very highly mechanized, so downtime did not matter much. This meant that the prevention of equipment failure was a low high priority in the minds of most managers. At the same time, most equipment was simple and generally over-designed. This made it reliable and easy to repair. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing and lubrication routines. The need for skills was also lower than it is today.

### *The Second Generation*

Things changed dramatically during World War II. Wartime pressures increased the demand for goods of all kinds while the supply of industrial manpower dropped sharply. This led to increased mechanization. By the 1950's machines of all types were more numerous and more complex. Industry was beginning to depend on them.

As this dependence grew, downtime came into sharper focus. This led to the idea that equipment failures could and should be prevented, which led in turn to the concept of *preventive maintenance*. In the 1960's, this consisted mainly of equipment overhauls done at fixed intervals.

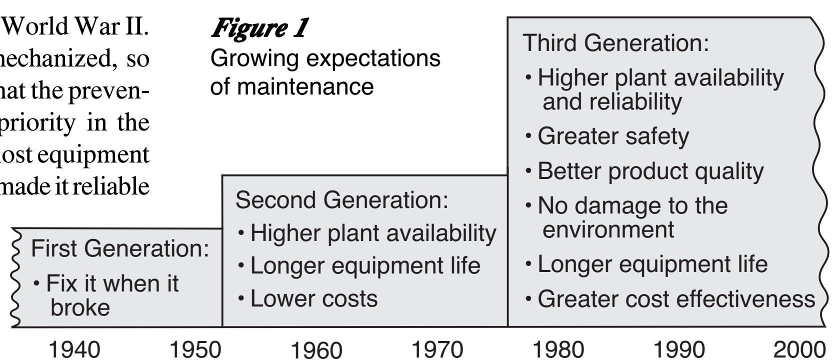
The cost of maintenance also started to rise sharply relative to other operating costs. This led to the growth of *maintenance planning and control systems.* These have helped greatly to bring maintenance under control, and are now an established part of the practice of maintenance. Finally, the amount of capital tied up in fixed assets together with a sharp increase in the cost of that capital led people to start seeking ways in which they could maximize the life of the assets.

### *The Third Generation*

Since the mid-seventies, the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of *new expectations*, *new research* and *new techniques.*

- *New expectations:* Figure 1 shows how expectations of maintenance have evolved. *Downtime* has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. By the 1960's and 1970's, this was already a major concern in the mining, manufacturing and transport sectors. The effects of downtime have been aggravated by the worldwide move towards just-in-time inventory management - stock levels in general have been reduced to the point that minor equipment failures can now have a major impact on all sorts of logistic support systems. In recent times, the growth of automation has meant that *reliability* and *availability* have also become key issues in sectors as diverse as health care, data processing, telecommunications and building management.

***Figure 1***
Growing expectations of maintenance



Greater automation also means that more and more failures affect our ability to sustain satisfactory *quality standards.* This applies as much to standards of service as it does to product quality. For instance, equipment failures affect climate control in buildings and the punctuality of transport networks as much as they can interfere with the consistent achievement of specified tolerances in manufacturing.

More and more failures have serious *safety* or *environmental* consequences, at a time when standards in these areas are rising rapidly. In some parts of the world, the point is approaching where organizations either conform to society's safety and environmental expectations, or they cease to operate. This adds an order of magnitude to our dependence on the integrity of our physical assets – one that goes beyond cost and becomes a simple matter of organizational survival.

At the same time as our dependence on physical assets is growing, so too is their *cost – to operate* and *to own.* To secure the maximum return on the investment that they represent, they must be kept working efficiently for as long as we want them to. Finally, the *cost of maintenance* itself is still rising, in absolute terms and as a proportion of total expenditure. In some industries, it is now the second highest or even the highest element of operating costs. As a result, in only thirty years it has moved from almost nowhere to the top of the league as a cost control priority.

*New research*

Quite apart from greater expectations, new research is changing many of our most basic beliefs about age and failure. In particular, it is apparent that there is less and less connection between the operating age of most assets and how likely they are to fail.

Figure 2 shows how the earliest view of failure was simply that as things got older, they were more likely to fail. A growing awareness of 'infant mortality' led to widespread Second Generation belief in the 'bathtub' curve.

However, Third Generation research has revealed that not one or two but *six* failure patterns actually occur in practice. One of the most important conclusions to emerge from this research is a growing realization that although they may be done exactly as planned, a great many traditionally-derived maintenance tasks achieve nothing, while some are actively counterproductive and even dangerous. This is especially true of many tasks done in the name of preventive maintenance. On the other hand, many more maintenance tasks that are essential to the safe operation of modern, complex industrial systems do not appear in the associated maintenance programs.

In other words, industry in general is devoting a great deal of attention to doing maintenance work correctly (doing the job right), but much more needs to be done to ensure that the jobs that are being planned are the jobs that should be planned (doing the right job).

*New techniques*

There has been explosive growth in new maintenance concepts and techniques. Hundreds have been developed over the past twenty years, and more are emerging every week. The new developments include:

- *decision support tools,* such as hazard studies, failure modes and effects analyses and expert systems
- *new maintenance techniques,* such as condition monitoring
- *designing equipment* with a much greater emphasis on reliability and maintainability
- *a major shift in organizational thinking* towards participation, team-working and flexibility.

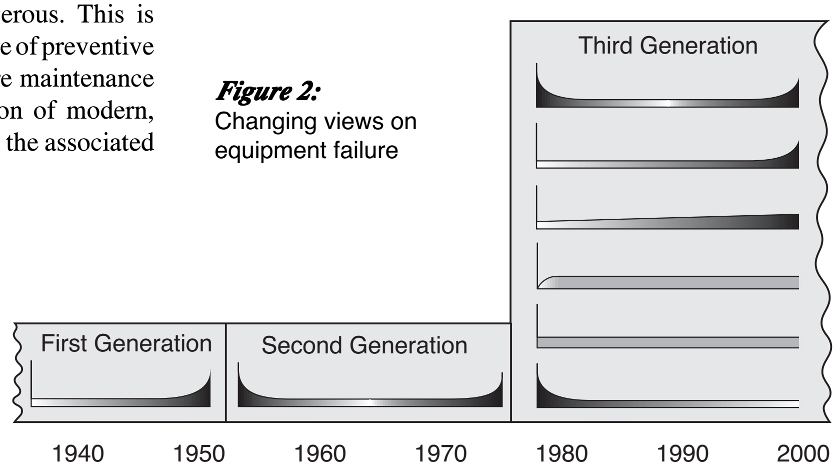
As mentioned earlier, a major challenge facing maintenance people nowadays is not only to learn what these techniques are, but to decide which are worthwhile and which are not in their own organizations. If we make the right choices, it is possible to improve asset performance and *at the same time* contain and even reduce the cost of maintenance. If we make the wrong choices, new problems are created while existing problems only get worse.

*The challenges facing maintenance*

The first industry to confront these challenges systematically was the commercial aviation industry. A crucial element of its response was the realization that as much effort needs to be devoted to ensuring that maintainers are doing the right job as to ensuring that they are doing the job right. This realization led in turn to the development of the comprehensive decision-making process known within aviation as MSG3, and outside it as Reliability-centered Maintenance, or RCM.

In nearly every field of organized human endeavour, RCM is now becoming as fundamental to the responsible custodianship of physical assets as double-entry bookkeeping is to the responsible custodianship of financial assets. No other comparable technique exists for identifying the true, safe minimum of tasks that must be done to preserve the functions of physical assets, especially in critical or hazardous situations.

***Figure 2:***
Changing views on equipment failure



A growing worldwide recognition of the key role played by RCM in the formulation of physical asset management strategies – and of the importance of applying RCM correctly – led the American Society of Automotive Engineers[1] to publish SAE Standard JA1011: *"Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes"*.

The RCM process described in Part 3 of this paper complies with this standard. Part 4 discusses how RCM should be applied and who should apply it, while Part 5 provides a brief summary of what RCM achieves

Before considering these issues, we first look at the meaning of the term 'maintenance', and define RCM.

## 2 Maintenance and RCM 2

From the engineering viewpoint, there are two elements 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 to 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 what its users want it to do in its present operating context.***

## 3 RCM: Seven Basic Questions 3

The RCM process entails asking seven questions about the asset or system under review, as follows:

- ***what are the functions and associated performance standards of the asset in its present operating context?***
- ***in what ways does it fail to fulfil its functions?***
- ***what causes each functional failure?***
- ***what happens when each failure occurs?***
- ***in what way does each failure matter?***
- ***what can be done to predict or prevent each failure?***
- ***what if a suitable proactive task cannot be found?***

These questions are reviewed in the following paragraphs.

### 3.1 Functions and Performance Standards

Before it is possible to apply 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, 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 is to define the functions of each asset in its operating context, together with the associated 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, economy, protection, efficiency of operation, environmental compliance and even the appearance of the asset.

The users of the assets are usually in the best position by far to know exactly what contribution each asset makes to the physical and financial well-being of the organization as a whole, so it is essential that they are involved in the RCM process from the outset.

### 3.2 Functional Failures

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 which 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:

- firstly, 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*** be-cause 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).

### 3.3 Failure Modes

As mentioned in the previous paragraph, once each functional failure has been identified, the next step is to try to identify all the *events which are reasonably likely to cause each failed state.* These events are known as ***failure modes***. '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 which are considered to be real possibilities in the context in question.

Most traditional lists of failure modes include failures caused by deterioration or normal wear and tear. However, the list should also include failures due to human errors (caused by operators or 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.

### 3.4 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:

- 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.

### 3.5 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 that 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 safe-ty consequences if it could injure or kill someone. It has environmental consequences if it could breach a corporate, national or international environmental standard.
- ***Operational consequences:*** A failure has operational consequences if it affects production (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 the maintenance function. 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 which have most effect on the performance of the organization, and diverts energy away from those which 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 we will see later that 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 proactive task. Default actions include *failure-finding, redesign* and *run-to-failure.*

## 3.6 Proactive Tasks

Many people still believe that the best way to optimize plant availability is to do some kind of proactive maintenance on a routine basis. Second Generation wisdom suggested that this should consist of overhauls or component replacements at fixed intervals. Figure 3 illustrates the fixed interval view of failure.

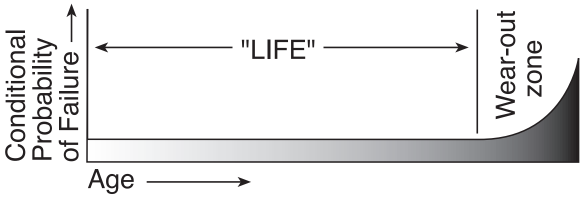



***Figure 3:*** The traditional view of failure

Figure 3 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 age-related 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 4. The graphs show conditional probability of failure against operating age for a variety of electrical and mechanical items.

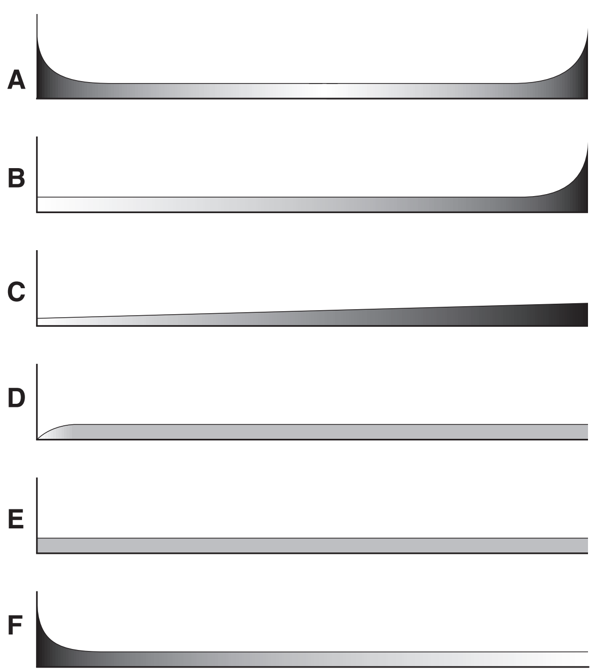



***Figure 4:*** Six patterns of failure

- pattern A is the well-known bathtub curve. It begins with a high incidence of failure (known as *infant mortality*) followed by a 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 3).
- pattern C shows slowly increasing conditional probability of failure, but there is 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 on commercial aircraft showed that 4% of the failures conformed 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 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.)

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 altogether. 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 which 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.

## 3.7 Default Actions

RCM recognizes three major categories of default action:

- *failure-finding:* Failure-finding entails checking hidden functions to find out whether 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-focused rules for establishing whether, how often and by whom these tasks should be done
- *redesign:* redesign entails making any one-time change to the built-in capability of a system. This includes 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, so those failures are simply allowed to occur and then repaired. This default is also called *run-to-failure.*

## 3.8 The RCM Task Selection Process

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 prescribed. 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, without 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

*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 equipment 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 teamworking 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.

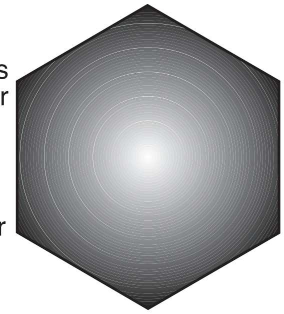



***Figure 5:*** A typical RCM review group

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 RCM review group is shown in Figure 5.

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 in which 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 understood and performed safely by the people who do the work.

The maintenance tasks are then fed into suitable high- and low-frequency maintenance planning and control 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 RCM Achieves 5

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.

- ***Longer useful life of expensive items,*** due to a carefully focused emphasis on the use of on-condition maintenance.

- 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 anything 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 tackling *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.

1 International Society of Automotive Engineers: *JA1011 - Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes:* Warrendale, Pennsylvania, USA: SAE Publications