



## Reliability Centered Maintenance

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# What is Reliability Centered Maintenance?

Reliability-Centered Maintenance (RCM) is the process of determining the most effective maintenance approach. The RCM philosophy employs Preventive Maintenance (PM), Predictive Maintenance (PdM), Real-time Monitoring (RTM<sup>1</sup>), Run-to-Failure (RTF- also called reactive maintenance) and Proactive Maintenance techniques in an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle with a minimum of maintenance. The goal of the philosophy is to provide the stated function of the facility, with the required reliability and availability at the lowest cost. RCM requires that maintenance decisions be based on maintenance requirements supported by sound technical and economic justification.

## A Brief History of RCM

Reliability Centered Maintenance originated in the Airline industry in the 1960's. By the late 1950's, the cost of Maintenance activities in this industry had become high enough to warrant a special investigation into the effectiveness of those activities. Accordingly, in 1960, a task force was formed consisting of representatives of both the airlines and the FAA to investigate the capabilities of preventive maintenance. The establishment of this task force subsequently led to the development of a series of guidelines for airlines and aircraft manufacturers to use, when establishing maintenance schedules for their aircraft.

This led to the 747 Maintenance Steering Group (MSG) document MSG-1; *Handbook: Maintenance Evaluation and Program Development* from the Air Transport Association in 1968. MSG-1 was used to develop the maintenance program for the Boeing 747 aircraft, the first maintenance program to apply RCM concepts. MSG-2, the next revision, was used to develop the maintenance programs for the Lockheed L-1011 and the Douglas DC-10. The success of this program is demonstrated by comparing maintenance requirements of a DC-8 aircraft, maintained using standard maintenance techniques, and the DC-10 aircraft, maintained using MSG-2 guidelines. The DC-8 aircraft has 339 items that require an overhaul, verses only seven items on a DC-10. Using another example, the original Boeing 747 required 66,000 labor hours on major structural inspections before a major heavy inspection at 20,000 operating hours. In comparison, the DC-8 - a smaller and less sophisticated aircraft using standard maintenance programs of the day required more than 4 million labor hours before reaching 20,000 operating hours.

In 1974 the US Department of Defense commissioned United Airlines to write a report on the processes used in the civil aviation industry for the development of maintenance programs for aircraft. This report, written by Stan Nowlan and Howard Heap and published in 1978, was entitled Reliability Centered

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<sup>1</sup> As described later in this paper RTM and PdM are often combined under the heading of Condition Based Maintenance, or CBM.

Maintenance, and has become the report upon which all subsequent Reliability Centered Maintenance approaches have been based. What Mr's Nowlan and Heap found was many types of failures could not be prevented no matter how intensive the maintenance activities. Additionally it was discovered that for many items the probability of failure did not increase with age. Consequently, a maintenance program based on age will have little, if any effect on the failure rate.

## **RCM in the Facility and Utility Arena**

As with any philosophy, there are many paths, or processes, that lead to a final goal. This is especially true for RCM where the consequences of failure can vary dramatically.

Rigorous RCM analysis has been used extensively by the aircraft, space, defense, and nuclear industries where functional failures have the potential to result in large losses of life, national security implications, and/or extreme environmental impact. A rigorous RCM analysis is based on a detailed Failure Modes and Effects Analysis (FMEA) and includes probabilities of failure and system reliability calculations. The analysis is used to determine appropriate maintenance tasks to address each of the identified failure modes and their consequences.

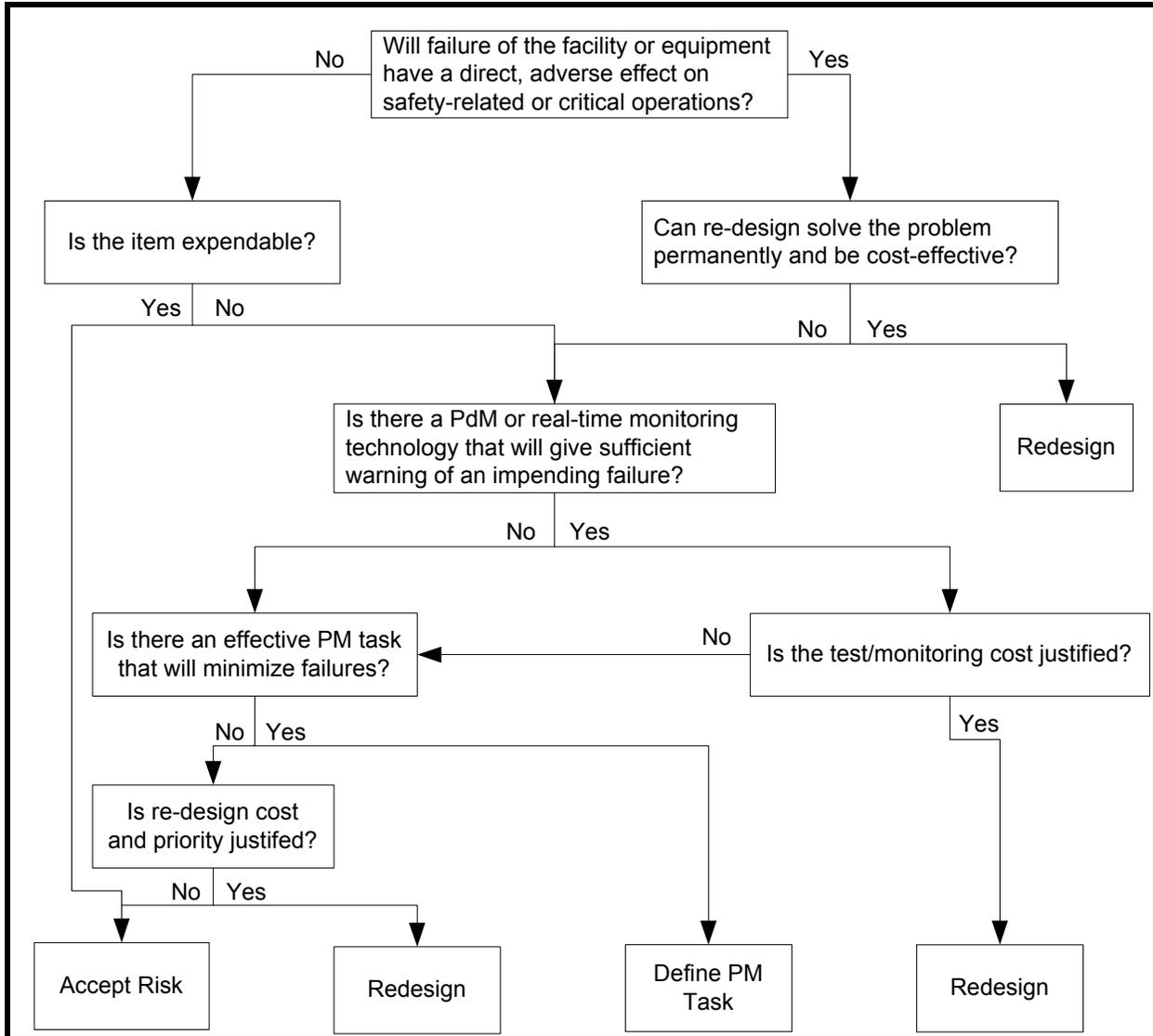
While this process is appropriate for these industries, it is not necessarily the most practical or best approach to use for facilities and utilities systems maintenance. For these systems a streamlined or intuitive RCM analysis process may be more appropriate. This is due to the high analysis cost of the rigorous approach, the relative low impact of failure of most facilities systems, the type of systems and components maintained, and the amount of redundant systems in place. The streamlined approach uses the same principles as the rigorous, but recognizes that not all failure modes will be analyzed. For most facility and utility systems the most economical and efficient approach is to use a combination of rigorous (formal) and intuitive analysis depending on system criticality and failure impact. Failure modes that result in high costs or personnel injury, or where the resultant reliability is still unacceptable in terms of safety or operational impact still receive the rigorous approach, but all other failure modes will use intuitive analysis.

The primary RCM principles are:

1. **RCM is Function Oriented** – It seeks to preserve system or equipment function, not just operability for operability's sake. Redundancy of function, through multiple equipment, improves functional reliability, but increases life cycle cost in terms of procurement and operating costs.
2. **RCM is System Focused** – It is more concerned with maintaining system function than individual component function.
3. **RCM is Reliability Centered** – It treats failure statistics in an actuarial manner. The relationship between operating age and the failures experienced is important. 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).
4. **RCM Acknowledges Design Limitations** – Its objective is to maintain the inherent reliability of the equipment design, recognizing that changes in inherent reliability are the province of design rather than maintenance. Maintenance can, at best, only achieve and maintain the level of reliability for equipment, which is provided for by design. However, RCM recognizes that

maintenance feedback can improve on the original design. In addition, RCM recognizes that a difference often exists between the perceived design life and the intrinsic or actual design life, and addresses this through the Age Exploration (AE) process.

5. **RCM is Driven by Safety and Economics** – Safety must be ensured at any cost; thereafter, cost-effectiveness becomes the criterion.
6. **RCM Defines Failure as Any Unsatisfactory Condition** – Therefore, failure may be either a loss of function (operation ceases) or a loss of acceptable quality (operation continues).
7. **RCM Uses a Logic Tree to Screen Maintenance Tasks** – This provides a consistent approach to the maintenance of all kinds of equipment. See Figure 1.



**Figure 1:** RCM Logic Tree

9. **RCM Tasks Must Be Applicable** – The tasks must address the failure mode and consider the failure mode characteristics.
10. **RCM Tasks Must Be Effective** – The tasks must reduce the probability of failure and be cost effective.

11. **RCM Acknowledges Three Types of Maintenance Tasks**
  - a. Time-directed (PM) – Scheduled when appropriate
  - b. Condition-directed (PdM and real-time monitoring) – Performed when conditions indicate they are needed
  - c. Failure finding (one of several aspects of Proactive Maintenance) – Equipment is run-to-failure. This is acceptable for some situations and some types of equipment.
12. **RCM is a Living System** – It gathers data from the results achieved and feeds this data back to improve design and future maintenance. This feedback is an important part of the Proactive Maintenance element of the RCM program.

The RCM analysis carefully considers the following questions:

1. What does the system or equipment do; what is its function?
2. What functional failures are likely to occur?
3. What are the likely consequences of these functional failures?
4. What can be done to reduce the probability of the failure, identify the onset of failure, or reduce the consequences of the failure?

Answers to these four questions determine the necessary actions required to maintain the systems or equipment. Figure 1 shows the RCM logic tree used to answer these questions.

## Failure

Failure can be defined in many ways. In a broad sense failure is simply an unsatisfactory condition. RCM, however, requires us to look at failure from not just an equipment standpoint, but a system standpoint as well. A piece of equipment can be operating (an HVAC unit in a clean room, for example), but if its output is less than required it would be considered failed. On the other hand, a protective relay in a power system can have failed, but if it has not taken the circuit off-line (the circuit is still energized) the function of the system is unchanged. Essentially, defining failure depends on the function of an item or system and the operating context in which the item/system is used.

## Functional Failure

A functional failure is essentially the inability of an item/system to meet its specified performance standard. A complete loss of function is a functional failure; however in the HVAC example above if the system's output is less than specified a functional failure has occurred, even if the system is still operating.

## Consequences of Failure

The consequences of failure determine the priority of maintenance activities or design improvement required to prevent occurrence. If failure of an item results in little or no consequence minimal maintenance activities are generally required. If, however, failure of an item results in a large economic hardship, personnel injury, or environmental damage maximum maintenance activities or a re-design may be called for.

# Maintenance Actions in an RCM Program

The RCM goals are to identify the most cost-effective and applicable maintenance techniques to minimize the risk and impact of failure in facility and utility equipment and systems. This allows systems and equipment functionality to be maintained in the most economical manner. Specific RCM objectives as stated by Nowlan and Heap<sup>2</sup> are:

- To ensure realization of the inherent safety and reliability levels of the equipment.
- To restore the equipment to these inherent levels when deterioration occurs.
- To obtain the information necessary for design improvement of those items whose inherent reliability proves to be inadequate.
- To accomplish these goals at a minimum total cost, including maintenance costs, support costs, and economic consequences of operational failures.

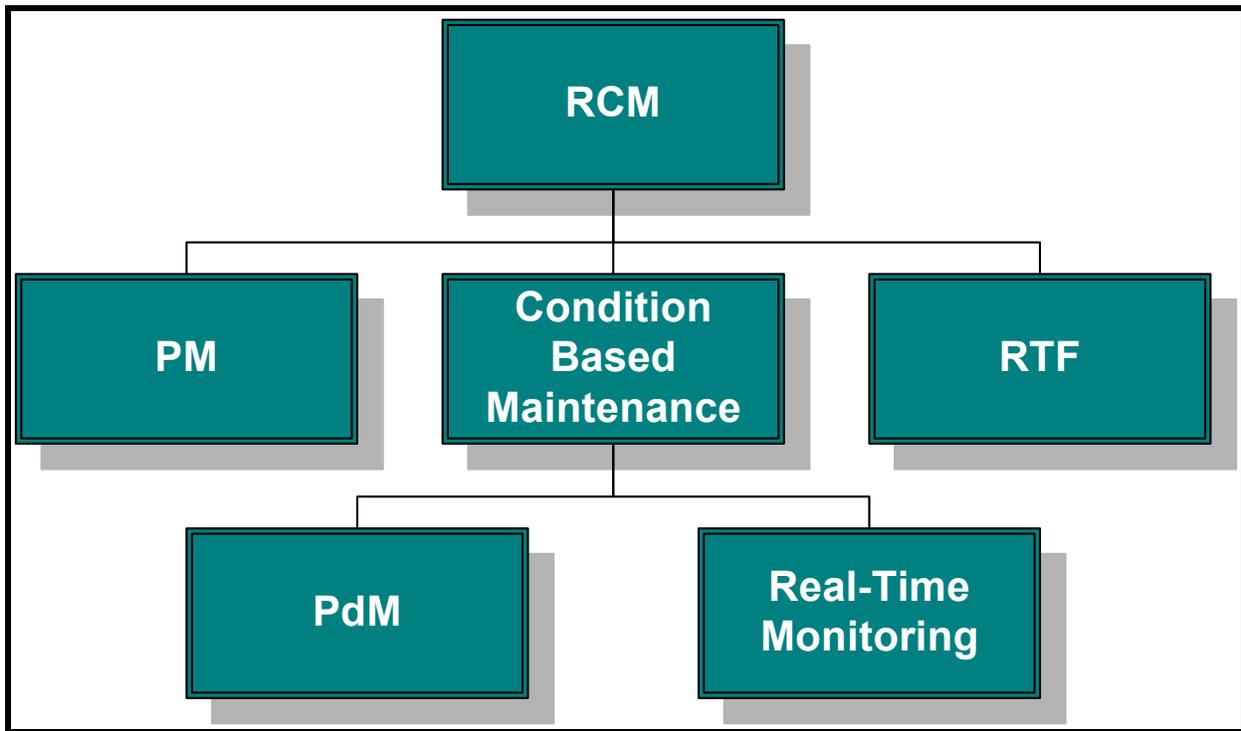
To this end there are four outcomes from an RCM analysis:

1. Perform no Maintenance – This is referred to as Reactive maintenance, repair, fix-on-fail, or **Run-To-Fail (RTF)**. This type of maintenance assumes that failure is equally likely to occur in any part, and that a failure is not detrimental to the operation. When this is the sole type of maintenance practiced high failure rates, large parts inventories, and excessive amounts of overtime become common. A purely RTF maintenance program ignores many of the opportunities to influence equipment survivability.
2. Perform **Preventive Maintenance (PM)** – PM consists of regularly scheduled inspections, adjustments, cleanings, lubrication, and replacement of components and equipment. PM is also referred to as time-driven or interval-based maintenance. It is performed without regard to equipment condition. PM schedules inspection and maintenance at pre-defined intervals in an attempt to reduce equipment failures. However, as Nowlan and Heap discovered, a PM program can result in a significant increase in inspections and cost without any increase in reliability.
3. Perform **Condition Based Maintenance (CBM)** – CBM consists of Predictive Maintenance (PdM) and real-time monitoring. PdM primarily uses non-intrusive testing techniques to measure and trend equipment performance. Real-time monitoring uses current performance data to assess machinery condition. CBM replaces arbitrarily timed maintenance tasks with maintenance that is scheduled only when warranted by equipment condition. Continuing analysis of equipment condition data allows for planning and scheduling maintenance activities or repairs prior to functional or catastrophic failure.
4. Redesign - when failure of a system or piece of equipment is an unacceptable risk and none of the above tasks can help mitigate the failure a redesign of the equipment or system is in order. In most cases adding redundancy eliminates the risk and adds very little to overall maintenance costs.

An RCM program will include all four of the above analysis outcomes, as no one is more important than another. Figure 2 shows the relationship maintenance activities have to RCM.

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<sup>2</sup> Reliability-Centered Maintenance, F. Stanley Nowlan and Howard F. Heap, 1978, United Airlines.



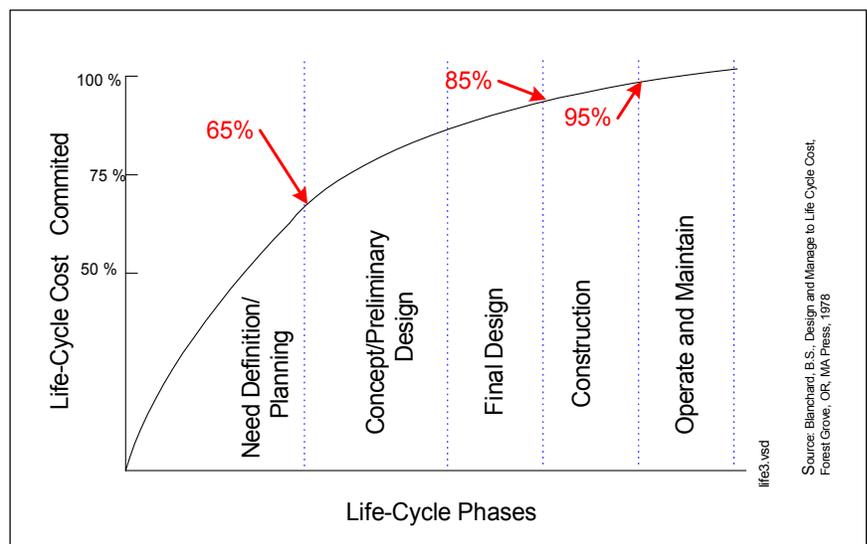
**Figure 2:** Elements of RCM

## Impact of RCM on a Facilities Life Cycle

A facilities life cycle is often divided into two broad stages: acquisition (planning, design, and construction) and operations. RCM affects all phases of the acquisition and operations stages to some degree.

Decisions made early in the acquisition cycle profoundly affect the life-cycle cost of a facility. Even though expenditures for plant and equipment may occur later during the acquisition process, their cost is committed at an early stage. As shown conceptually in Figure 3, planning (including conceptual design) fixes two-thirds of the facility's overall life-cycle costs. The subsequent design phases determine an additional 29% of the life-cycle cost, leaving only about 5% of the life-cycle cost that can be impacted by the later phases.

Thus, the decision to include a facility in an RCM program, including condition monitoring, which will have a major impact on its life-cycle cost, is best made during the planning phase. As RCM decisions are made later in the life



**Figure 3:** Life cycle costs

cycle, it becomes more difficult to achieve the maximum possible benefit from the RCM program.

Even though maintenance is a relatively small portion of the overall life-cycle cost, typically 3% to 5% of a facility's operating cost, RCM is still capable of introducing significant savings during the O&M phase of the facility's life. Savings of 30% to 50% in the annual maintenance budget are often obtained through the introduction of a balanced RCM program.

## Conclusion

Reliability-Centered Maintenance is the process of determining the most effective maintenance approach. As the airline industry showed 40 years ago, RCM can not only improve the reliability of a system, it can significantly reduce the required maintenance. In today's competitive world economy that translates into monies saved, both from reduced failures and reduced work. And a properly implimented RCM program will continue saving money year after year. To remain competitive most companies can no longer afford to remain on the sidelines doing things like they've always done. Let RCM move your maintenance program into the 21st century.

## References

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3. *Introduction to Reliability-Centered Maintenance*, a white paper by William Steele, July 1999, The Colinson Corporation.