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Applying inovative system in aircraft maintenance

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Abstract: Consideration of aircraft operations, including inspection, maintenance, and repair procedures is crucial in the development and application of new procedures. The main purpose of the maintenance program is to restore safety to the designed-in level before the degradation reaches a level where a failure could occur. Aircraft maintenance is an essential component of the aviation system which supports the global aviation industry. Reliability Centered Maintenance (RCM) is the process that is used to determine the most effective approach to maintenance. It involves identifying actions that, when taken, will redukce the probability of failure and which are the most cost effective. These maintenance strategies, rather than being applied independently, are integrated to take advantage of their respektive strengths in order to optimize facility and equipment operability and efficiency while minimizing life-cycle costs.

Keywords: maintenance, reliability, failure, cost, improvement

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1. Introduction

Reliability is a very broad term that focuses on the ability of a product to perform its intended function. Mathematically speaking, reliability can be defined as the probability that an item will Once these reliability and maintainability analyses have been made, it is possible to anticipate the effects of design changes and corrections in order to improve reliability. The different reliability and maintainability analyses are all related, and examine the reliability of the product or system from different perspectives, in order to determine possible problems and assist in analyzing corrections and improvements.

2. Reliability and its importance

There are several reasons why RAM ('reliability, availability and maintainability') analyses are important. A few of the most common are mentioned below:

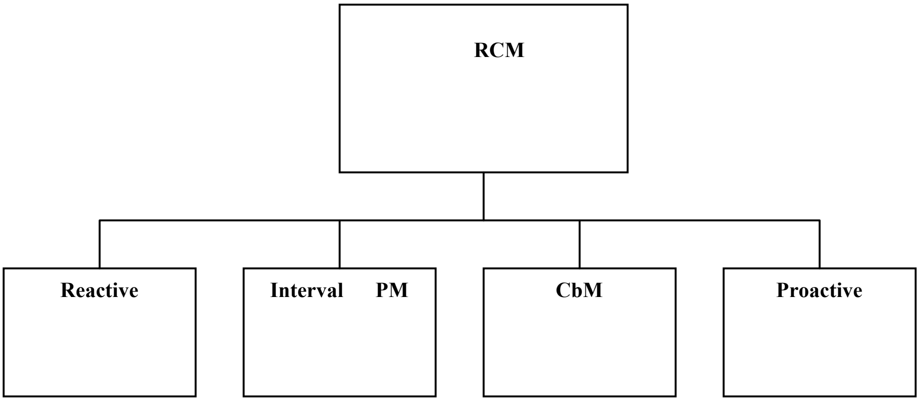
- Reputation. A company's reputation is very closely related to the reliability of their products. The more reliable a product is, the more likely the company is to have a favourable reputation.
- Warranty Costs. If a product fails to perform its function within the warranty period, the replacement and repair costs will negatively affect profits, as well as gain unwanted negative attention. Introducing RAM analyses could be an important step in taking corrective action, ultimately leading to a product that is more reliable.
- Future Business. A concentrated effort towards improved reliability shows existing customers that a manufacturer is serious about their product, and committed to customer satisfaction. This type of attitude has a positive impact on future business.
- Cost Analysis. Manufacturers may take reliability data and combine it with other cost information to illustrate the cost-effectiveness of their products. This life cycle cost analysis can prove that although the initial cost of their product might be higher, the overall lifetime cost is lower than a competitor's because their product requires fewer repairs or less maintenance.

With a few exceptions, preventive maintenance has been considered the most advanced and effective maintenance technique available for use by industrial and facility maintenance organizations. A Preventive Maintenance program is based on the assumption of a "fundamental cause-and-effect relationship between scheduled maintenance and operating reliability. This assumption was based on the intuitive belief that because mechanical parts wear out, the reliability of any equipment [is] directly related to operating age. It therefore followed that the more frequently equipment was overhauled, the better protected it was against the likelihood of failure. The only problem was in determining what age limit was necessary to assure reliable operation."

Reliability Centered Maintenance (RCM) is the concept of developing a maintenance scheme based on the reliability of the various components of the system or product in question. Implementing a preventative maintenance program using RCM can greatly reduce the the cost of ownership of a product or system.

Developing an effective RCM program requires extensive knowledge about the reliability and maintainability of the system and all of its subsequent components. Important factors include the MTTR (Mean Time To Repair) and failure rate (total number of failures within a given time period) of the product or system.

Reliability-Centered Maintenance (RCM) is the optimum mix of reactive, time- or interval-based, condition-based, and proactive maintenance practices. The basic application of each strategy is shown in Fig. 1. These principal maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to maximize facility and equipment reliability while minimizing life-cycle costs.



Reactive:
- Small items
- Non-critical
- Inconsequential
- Unlikely to fail
- Redundant

Interval PM:
- Sub.to wearout
- Consumable replacement
- Failure pattern known

CbM:
- Random failure pattern
- Not subject to wear
- PM induced failure

Proactive:
- RCFA
- Age exploration
- FMEA
- Acceptance testing

PM – Preventive Maintenance CbM – Condition Based Maintenance

RCFA – Root Cause Failure Analysis FMEA – Failure MOdes and Effects Analysis

Fig. 1. Components of an RCM Program.

RCM includes reactive, time-based, condition-based, and proactive tasks. In addition, a user should understand system boundaries and facility envelopes, system/equipment functions, functional failures, and failure modes, all of which are critical components of the RCM program.

RCM can improve the efficiency of the system undergoing maintenance, and all other products or processes that interact with that system. Developing an effective RCM program will optimize the maintainability of the system - allowing you to anticipate the times when the system is down for maintenance, and scheduling other activities or processes accordingly.

3. Description

Preventive Maintenance (PM) assumes that failure probabilities can be determined statistically for individual machines and components, and parts can be replaced or adjustments can be performed in time to preclude failure. For example, a common practice has been to replace or renew bearings after so many operating hours assuming that bearing failure rate increases with time in service.

Computer advances in the 1990s have made it possible in many cases to identify the precursors of failure, quantify equipment condition, and schedule the appropriate repair with a higher degree of confidence than was possible when performing strictly interval-based maintenance relying upon usually erroneous estimates of when a component might fail. Also, it has been discovered recently that there are many different equipment failure characteristics, only a small number of which are age- or use-related. This new knowledge has increased the emphasis on Condition Monitoring (CM), often referred to as Condition-Based Maintenance, which has caused a reduction in the reliance upon time-based PM.

It should not be inferred from the above that all interval-based maintenance should be replaced by condition-based maintenance. In fact, interval-based maintenance is appropriate for those instances where abrasive, erosive, or corrosive wear takes place, material properties change due to fatigue, embrittlement, etc. and/or a clear correlation between age and functional reliability exists.

In addition, for those systems or components where no failure consequences in terms of mission, environment, safety, security, or Life-Cycle Cost (LCC) exist, maintenance should not be performed, i.e., the equipment should be run to failure and replaced.

The concept of RCM has been adopted across several government and industry operations as a strategy for performing maintenance. RCM applies maintenance strategies based on consequence and cost of failure. In addition, RCM seeks to minimize maintenance and improve reliability throughout the life-cycle by using proactive techniques such as improved design specifications, integration of condition monitoring in the commissioning process, and the Age Exploration (AE) process.

4. RCM Principles

The primary RCM principles are:

- RCM is Function Oriented—RCM seeks to preserve system or equipment function, not just operability for operability's sake. Redundancy of function, through multiple pieces of equipment, improves functional reliability but increases life-cycle cost in terms of procurement and operating costs.
- RCM is System Focused—RCM is more concerned with maintaining system function than with individual component function.
- RCM is Reliability Centered—RCM 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).
- RCM Acknowledges Design Limitations—RCM objective is to maintain the inherent reliability of the equipment design, recognizing that changes in inherent reliability are the province of design rather than of maintenance. Maintenance can, at best, only achieve and maintain the level of reliability for equipment that was 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.
- RCM is Driven by Safety, Security, and Economics—Safety and security must be ensured at any cost; thereafter, cost-effectiveness becomes the criterion.
- 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 but impacts quality).
- RCM Uses a Logic Tree to Screen Maintenance Tasks—This provides a consistent approach to the maintenance of all kinds of equipment.
- RCM Tasks Must Be Applicable—The tasks must address the failure mode and consider the failure mode characteristics.
- RCM Tasks Must Be Effective—The tasks must reduce the probability of failure and be cost-effective.
- RCM Acknowledges Three Types of Maintenance Tasks—These tasks are time-directed (PM), condition-directed (CM), and failure finding (one of several aspects of Proactive Maintenance). Time-directed tasks are scheduled when appropriate. Condition-directed tasks are performed when conditions indicate they are needed. Failure-finding tasks detect hidden functions that have failed without giving

evidence of pending failure. Additionally, performing no maintenance, Run-to-Failure, is a conscious decision and is acceptable for some equipment.

- RCM is a Living System—RCM 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.

5. RCM Implementation

There is no one set path for successfully implementing RCM because RCM is more than just performing a Failure Modes and Effects Analysis (FMEA), adopting condition monitoring techniques, and/or optimizing a maintenance and overhaul program through the application of an Age Exploration (AE) process.

RCM is not for everyone and very few organizations will benefit from implementing all elements of a classical RCM program. RCM like all tools/processes has an element of diminishing return. Not all the elements of RCM which are applicable to a nuclear power plant, the aircraft industry, and/or a 24/7 continuous process plant in a sold out condition, will be applicable to a batch process operation or a non-production facility. However, there are a few truths everyone should follow and there is no need to pilot or perform an FMEA analysis. They are:

1. Key performance indicators.
2. Thermography works for electrical distribution, boilers, couplings, roofing systems and building façades.
3. If your specifications for alignment, imbalance, motor circuit phase impedance, oil condition and cleanliness, and vibration are not quantified, the product you receive will have latent defects 80% of the time.
4. If you do not commission and check the sequence of operation of your equipment and buildings to a predetermined quantifiable specification, you will not get what you expect.
5. Pareto analysis is the best tool for determining where to start your RCM process. Look for the bottlenecks, the recurring failures, and follow the money.
6. RCM implementation in a team environment works better.
7. Failure modes for identical equipment are the same. It is only the consequence and probability of failure that changes.
8. The impact of poor water chemistry is underestimated in terms of energy consumption and life-cycle cost.
9. The majority of failures are random. Very few machines understand how a calendar works. Age Exploration can reveal hidden assets.
10. Celebrate and advertise your successes and address your failures. Credibility is a key to building support for long-term success.

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

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

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

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

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

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

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

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

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

The net result of this careful bounding of the decision process is a scheduled maintenance program which is based at every stage on the known reliability characteristics of the equipment in the operating context in which it is used. In short, reliability-centred maintenance is a well tested answer to the paradox of modem aircraft maintenance - the problem of how to maintain the equipment in a safe and economical fashion until we have accumulated enough information to know how to do it.

RCM will allow one to obtain the full design operating ability of the equipment. It does not necessarily identify a new series of maintenance tasks. It identifies which tasks are most applicable, which are ineffective and provides a framework for developing an optimal preventive maintenance program.

When RCM is used for aircraft the methodology is applied by the aircraft manufacturer. The preventive and predictive maintenance outcomes are written into the craft‘s operating and maintenance procedures that every aircraft owner is required by international law to adopt and follow. The manuals are rigorously adhered-to by highly skilled, licensed and independently tested technicians. What the aircraft manufacturer sets down in the aircraft maintenance schedule the operator must do at penalty of legal action resulting in gaol and fines for noncompliance.

The RCM outcomes that require design changes are the aircraft manufacturer‘s responsibility to do and to then disseminate throughout the fleet. Every design change approved by the regulating bodies must be made by the aircraft operator. Improvements in aircraft equipment and in operating and maintenance practices naturally result by the design of the regulated system in-place.

6. Conslucions

In the aircraft industry there is no choice of when a scheduled-maintenance task is done, nor of what will be done, nor of how well it must be done. When an aircraft engine or aircraft frame reaches the scheduled miles the plane must be brought in for maintenance. Already the decision has been made by the manufacturer of what parts to replace during the outage and what parts to inspect for condition. If an on-condition inspection finds a problem the plane cannot return to service until the issue is corrected. There are no options to run the plane a while longer.

The on-condition inspections are also used to gather data to extend a part‘s replacement interval. The aircraft manufacturers watch how their airplanes‘ parts age and accumulate stress. They have scientific rigor in failure monitoring and analysis. They set the limit on operating hours of parts with confidence because they know how much working life a part can expect. Only when sufficient evidence is collected across the fleet, and after a thorough scientific assessment confirms that the scheduled replacement time can be extended, are the manuals updated by the manufacturer with the new requirement. The aircraft industry has a level of quality discipline and uses business processes that ensure RCM works.

When RCM stipulates on-condition monitoring of an item it is done to minimise the chance of a breakdown by finding evidence of degradation starting. To spot failure starting in a machine the condition monitoring must be done. It is only by doing the condition observation on schedule that you can be sure the equipment is not currently at risk of failure. The inflexibility in the condition monitoring schedule is not the case for most other industries where each organisation makes its own choices when to stop production equipment and aversion to the risk of failure depends on the people present at the time the choice is made.

Concerning general aviation, there is not any initiative that would try to make aircraft owners improve maintenance standards. In the meantime, there is only one initiative regarding airlines. It is an initial black list of unsafe airlines. It is a great example to make airlines comply with high safety and maintenance standards.

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