



PM Optimisation

Maintenance Analysis of the Future

The Author

The author, Mr Steve Turner, is a professional engineer who has been extensively trained in RCM methods and has deployed them over a 25 year period in various roles as an airworthiness engineer, a maintenance manager, as part of a design team and as a consultant. Over the past nine years, Mr Turner has developed a process of PM Optimisation known as PMO2000™. This method is currently in use at over 100 major industrial sites across the world in most types of industrial sectors. Users include winners of the North American Maintenance Excellence Awards and companies just starting their journey to maintenance excellence.



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Introduction

Maintenance is one of the largest controllable operating costs in capital intensive industries. It is also a critical business function that impacts on commercial risk, plant output, product quality, production cost, safety, and environmental performance. For these reasons, maintenance is regarded in best practice organisations not simply as a cost to be avoided, but together with reliability engineering, as a high leverage business function. It is considered a valuable business partner contributing to asset capability and continuous improvement in asset performance.

The dilemma that many of us face (and mostly not of our own doing), is that we are managers in organisations which barely have sufficient resources to keep the plant working, let alone find ways of improving reliability.

When this is the case, scarce maintenance resources are rationed and breakdowns consume resources first. Preventive maintenance suffers, which inevitably results in more breakdowns and the cycle continues.

In addition to lost productivity through unplanned maintenance, the "fix-it-quickly" mentality promotes "band aid maintenance", or temporary repairs, that often exacerbate the situation. Temporary repairs take additional labour to correct, or in the worst case, fail before correction.

Often in an effort to control costs, personnel numbers are reduced and morale declines as the fewer remaining personnel almost give up in despair. With this, work standards drop.

The vicious cycle feeds on itself and gradually organisations become almost entirely reactive.

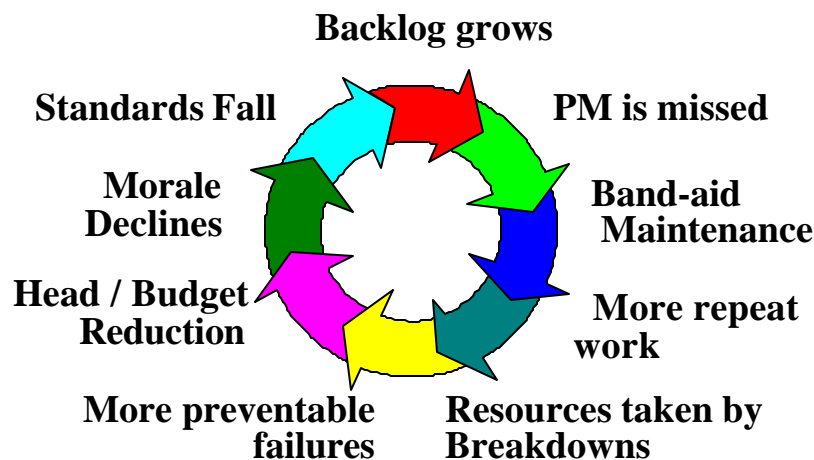


Figure 1 The Vicious Cycle of Maintenance

This situation is depicted in Figure 1.

In such organisations, it seems that the level of plant availability drops to the stage where it stabilises at a low level - a level where it is not breaking down because it is not running; ie it is being repaired!

For many, the obvious solution is to seek to increase personnel numbers. However, this approach is not often the best. In today's economic climate, the management culture is mostly focussed on cost reduction and managers seeking only to increase staff numbers, rarely succeed.

Today many Asset Managers are embarking on an improvement program focussing on improving the maintenance processes and increasing the effectiveness or productivity of asset and human resources. Improving maintenance processes involves process re-engineering and increasing resource effectiveness in the following way:

- Removing all maintenance tasks that serve no purpose or are not cost effective.
- Eliminating any duplication of effort where different groups are performing the same Preventive Maintenance (PM) to the same equipment.
- Moving to a mostly condition based maintenance philosophy.
- Adding maintenance tasks to manage economically preventable failure modes¹ that historically have been run to failure.
- Spreading the workload around the trades and operators.

The long-term vision is to adopt such process in a way that achieves this goal in a systematic way and which can remain as a 'living program' to capture the benefits of future learning and technical advances on a continuing basis.

The methodology used to address the vicious cycle of reactive maintenance has been developed over a period of five years with the co-operation of several of Australia's most notable asset intensive industries.

The program is endorsed by SIRFrt² and is the preferred maintenance analysis method of one of the World's largest mining companies. The methodology, training programs and software package are known as PMO2000. Further information can be found at www.pmoptimisation.com.

¹ Care must be taken as some failure modes cost more to prevent than the cost of failure itself.

² SIRF Roundtables Ltd was formed on 1 July 2000 out of the Strategic Industry Research Foundation Ltd as a result of the foundation's withdrawal from its industry shared learning networks (including the IMRt) and related support activities.

Aim

This paper is written in three sections.

Section 1. Plant Maintenance Optimisation (PMO) – Maintenance Analysis of the Future

The aim of Section 1 is to describe the process of PM Optimisation with specific reference to PMO2000 methodology. This section also aims to demonstrate the origins of many of the problems that today's asset manager face and how PM Optimisation can assist organisations improve their asset management.

Section 2. Comparing PM Optimisation and RCM³ methods of Maintenance Analysis

Section 2 of the paper aims to explain how PMO and RCM are quite different processes – RCM being a process developed by Nowlan and Heap (1978) for the design phase of the asset life cycle⁴ and PMO being developed for assets that have been commissioned. The paper demonstrates how PMO achieves the same analysis outcomes as RCM does but at a cost six times less and at a speed six times faster than RCM (Johnson, 1995).

Section 2 of the paper also aims to provide a defence against the series of emotive and misleading articles written by RCM consultants in an attempt to discredit any maintenance analysis process that does not comply with SAE JSA 1011 titled "Evaluation Criteria for Reliability Centered Maintenance (RCM) processes".

Section 3. Understanding Statistical Methods of Maintenance Analysis

Section 3 provides a brief insight into the strengths and weaknesses of maintenance analysis packages based on statistical methods.

³ Any reference to RCM in this paper from this point will be referring to the standard SAE JA1011.

⁴ RCM was developed by Nowlan and Heap (1978) for the purpose of defining the initial maintenance requirements of commercial aircraft (Moubray, 1997). As these aircraft must have a certified maintenance program before they can enter service, it can be said that RCM was developed as a process to be used in the design phase of an asset life cycle.

The Origins of Maintenance Problems

The Design and Commissioning Phase

Maintenance engineers commonly deal with the result of someone else's design - whether good or bad. When design is finished, construction starts and finishes, and the plant is commissioned. The Maintenance Engineer arrives somewhere through this (if he is lucky). Quickly he finds himself left with a maintenance budget being used to finish off construction / over-expenditure, a plant that is going through teething problems, spares arriving in dribs and drabs and little information about plant failure modes and the effect of failure. Rarely is the plant delivered to the maintenance department with a comprehensive and well-documented maintenance requirements analysis and a maintenance plan.

What happens in best practice organisations is that, amongst other things, a fully documented RCM based maintenance program is developed through the design phase. Unfortunately in the vast majority of capital projects in industry, any reliability engineering or failure analysis is done in an informal manner and certainly not provided to the maintenance department for use in developing asset management strategies and policies.

Post Commissioning

After commissioning, (or sometimes before) the design team disbands and its members find work on new projects. The Maintenance Engineer is left to second guess the design intent, the plant limitations, the potential failure modes, and the likely consequences of them. The operations people are, at the same time, learning how to operate the plant and experimenting with it; pushing it to its limits and occasionally well over its design intent. There is limited money or time to change obvious design or maintainability problems in the new plant.

The task of defining the plant maintenance policy⁵ is a priority but a most daunting one. Whatever is achieved is done in a rush often using people in an opportunistic manner. The problems that emerge right from the beginning will be as follows:

- There is no consistency of analysis philosophy.
- Maintenance personnel, being risk averse, write maintenance policies which over service and use overhaul or intrusive methods as a means of prevention - often to the detriment of reliability rather than for its good⁶.
- There is no audit trail, and only those who wrote the policies know their rationale. It becomes near impossible to review the program and objectively assess its effectiveness.

Full Production

When the plant swings into full operation and breaks down, more maintenance tasks are created and some existing tasks are done more frequently. Many of these new tasks duplicate others. Often, in an attempt to be seen to be doing something about high profile reliability problems,

⁵ A maintenance policy is the combination of what is to be done, how frequently and by whom.

⁶ Particularly if the maintenance is intrusive.

maintenance personnel create and perform tasks supposed to prevent the failures but, in reality, serve no realistic purpose.

Soon the Preventive Maintenance (PM) requirements exceed the labour resource available. PM is missed, preventable failures occur and unplanned maintenance work consumes more labour than necessary. The number of temporary repairs grows out of control and the costs of revisiting them or repairing additional damage caused by them wastes more resources.

The vicious circle of breakdown maintenance, temporary repair, and reduced PM gains momentum and becomes well entrenched.

Management Consultants (often with a cost reduction focus) arrive on site and cut staff numbers and budgets. This serves only to tighten the vicious circle and increase the rpm. The end result is typically a large morale problem for the maintenance department and a poorly performing plant.

Many organisations have tried to regain control by using RCM to develop their maintenance program. This is often a pursuit with limited scope and a high failure rate. This is because RCM is highly inefficient when used as a rationalisation tool. It consumes excessive amounts of the most valuable resources on site - those being the scarce maintenance and operations personnel.

A large element of the inefficiency of RCM, is that it does not acknowledge the experience and value of the current maintenance program. It starts from scratch and builds a maintenance program from the function down.

The high failure rate of RCM amongst mature operations is not surprising when it is realised that RCM was developed by Nowlan and Heap (Nowlan and Heap, 1978) for use in the design phase of the equipment life cycle (Moubray 1997). It was not designed for use in mature industries as a rationalisation tool.

Improvement Tactics

The Dupont Experience - Four Common Strategies

In this predicament, case studies and experience suggest that, outside of cultural and behavioural initiatives, asset managers should be focussing on a few key areas. They must:

- Develop focussed maintenance policies,
- Improve planning and scheduling based on the revised policies, and
- Focus on defect elimination.

The DuPont model of Up-Time featured in the Manufacturing Game⁷ illustrates these points very well. The table below illustrates how DuPont has modelled the relative effect of various strategies on plant uptime.

⁷ *The manufacturing game is a practical learning process where participants learn in an interactive environment, the strategies which will best enhance plant uptime. The game is available through SIRF Roundtable. Information is readily available at <http://www.manufacturinggame.com>.*

DuPont analysis suggests that if companies focus on planning only they will improve their uptime by 0.5%. If they focus only on maintenance scheduling, uptime will improve by 0.8%. If they focus on preventive and predictive maintenance only, uptime will actually get worse by 2.4%. If organisations focus on all of these three aspects, they will receive a 5.1% improvement in availability.

These results may well sound appealing in their own right, but DuPont (Ledet 1994) has found that by adding defect elimination to the initiatives undertaken, then a 14.8% improvement in availability may be achieved in their plants. This information is provided in the table at Figure 2.

Strategy	Change %	Uptime %
Reactive		83.5%
Planning Only	+ 0.5%	
Scheduling Only	+0.8%	
Preventive / Predictive Only	-2.4%	
All Three Strategies	+5.1%	88.6%
Plus Defect Elimination	+14.8%	98.3%

Figure 2 Table showing the effect of different reliability engineering activities on plant availability taken from the Manufacturing Game – (Ledet 1994) <http://www.manufacturinggame.com/>

Problems with most PM Programs

The common problem with mature maintenance programs that were never designed correctly in the first place, is that between 40% and 60% of the PM tasks serve very little purpose (Moubray, 1997). The findings of many PMO reviews are that:

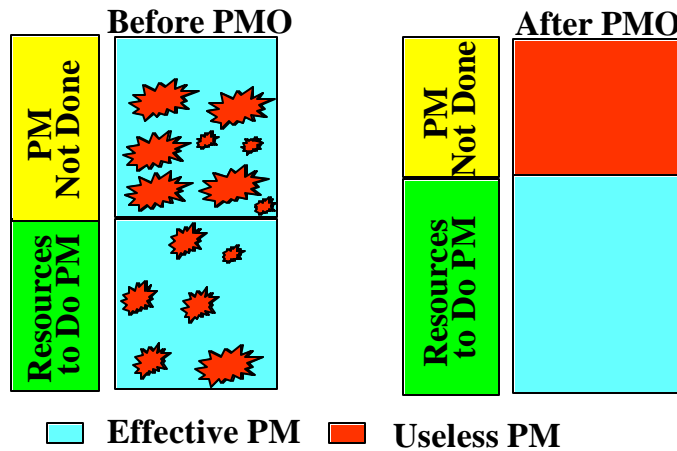
- Many tasks duplicate other tasks.
- Some tasks are done too often (and some too late).
- Some tasks serve no purpose whatsoever.
- Many tasks will be intrusive and overhaul based whereas they should be condition based.
- There are many costly preventable failures happening.

This poses a significant issue for improving productivity as no amount of perfect planning and scheduling will make up for the inefficiencies of the maintenance program itself. Achieving 100% compliance with a program that is 50% useful and 50% wasteful can not be good asset management!

The DuPont analysis indicates that a process must be implemented that:

- Can define the appropriate mix of preventive and predictive maintenance,
- Can produce a maintenance program where the servicing intervals and the tasks themselves are sound and value adding in every case, and
- Where defects which can not be maintained out of the plant can be eliminated through other means.

Figure 3 Illustration of how PMO works



What is suggested, as a fundamental building block in adopting all these strategies, is to ensure all work undertaken is based on RCM decision logic. PMO is a means of rationalising all the Preventive Maintenance work to ensure that all the work adds value and there are no duplications of effort. Figure 3 illustrates this.

PMO 2000 from A to Z.

Overview

The PMO 2000 process has nine steps. These steps are listed below and discussed in the following pages.

- Step 1 Task Compilation**
- Step 2 Failure Mode Analysis**
- Step 3 Rationalisation and FMA Review**
- Step 4 Functional Analysis (Optional)**
- Step 5 Consequence Evaluation**
- Step 6 Maintenance Policy Determination**
- Step 7 Grouping and Review**
- Step 8 Approval and Implementation**
- Step 9 Living Program**

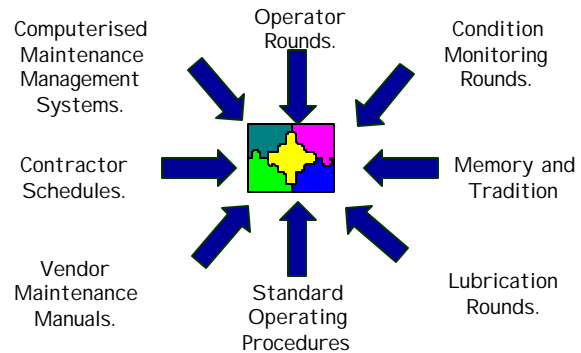
Project Ranking

It should be noted that a full PMO 2000 assignment, there may need to be some form of criticality or system ranking process. This may be done by reviewing the equipment hierarchy or work schedule hierarchy⁸, and subdividing it into appropriate systems and/or equipment items or trade filtered maintenance schedules for analysis. Having performed this task, the criticality of each of the project is identified is assessed in terms of their contribution to the client organisation’s strategic objectives. Higher criticality systems tend to be those that will have an impact in the following ways:

- ◆ Have a high perceived risk in terms of achieving safety or environmental objectives,
- ◆ Have a significant impact on plant throughput, operating or maintenance costs, or
- ◆ Are consuming excessive labour to operate and maintain.

Having conducted the criticality assessment, this is used as the basis for assessing which projects should be analysed first, and the overall level of rigour required for each analysis.

Sources of Preventive Maintenance



STEP 1- Task Compilation

PM Optimisation starts by collecting or documenting the existing maintenance program (formal or informal) and loading it into a database via a spreadsheet. It is important to realise that maintenance is performed by a wide cross section of people including operators. It is also important to realise that in many organisations, most of the Preventive Maintenance program is done by the initiative of the tradesmen or operators and not documented formally. In this situation, task compilation is a simple matter of writing down what the people are doing. It is common for organisations to have an informal PM system in operation whilst it is rare for an organisation to have no PM at all.

Figure 4 - Sources of PM Programs

Figure 4 illustrates the sources of PM programs.

Step 2 - Failure Mode Analysis

Step 2 involves people from the shop floor working in cross-functional teams identifying what failure mode(s) each maintenance task (or inspection) is meant to address. Figure 5 illustrates the output of Step 2.

Task	Interval	Trade	Failure
Task 1	Daily	Operator	Failure A
Task 2	Daily	Operator	Failure B
Task 3	6 Months	Fitter	Failure C
Task 4	6 Months	Fitter	Failure A
Task 5	Annual	Electrician	Failure B
Task 6	Weekly	Operator	Failure C

Figure 5 - Illustration of Step 2

⁸ PMO can be conducted on any trade schedule such as lube rounds or operator rounds and can also be used to analyse the PM needs of a major shut down.

Step 3 - Rationalisation and Failure Mode Review

Through grouping the data by failure mode, task duplication can be easily identified. Task duplication is where the same failure mode is managed by PM conducted by more than one section, and is most commonly found between operators and trades, and trades and condition monitoring specialists.

In this step, the team reviews the failure modes generated through the Failure Mode Analysis and adds missing failures to the list. The list of missing failures is generated through an analysis of failure history, technical documentation (usually Piping and Instrument Diagrams, (P&IDs)) or the experience of the team. Figure 6 illustrates the output of Step 3. Note the addition of a new failure cause “D” that has been identified during this step. Failure D could have come from failure history or scrutiny of technical documentation.

Task	Trade	Cause
Task 1	Operator	Failure A
Task 4	Fitter	Failure A
Task 7	Greaser	Failure A
Task 2	Operator	Failure B
Task 5	Electrician	Failure B
Task 3	Fitter	Failure C
Task 6	Operator	Failure C
		Failure D

Figure 6 - Illustration of Step 3

Step 4 - Functional Analysis

The functions lost due to each failure mode can be established in this step. This task is optional, and may be justified for analyses on highly critical or very complex equipment items, where sound understanding of all the equipment functions is an essential part of ensuring a comprehensive

Task	Trade	Cause	Function
Task 1	Operator	Failure A	Function 1
Task 4	Fitter	Failure A	
Task 7	Greaser	Failure A	
Task 2	Operator	Failure B	Function 1
Task 5	Electrician	Failure B	
Task 3	Fitter	Failure C	Function 2
Task 6	Operator	Failure C	
		Failure D	Function 1

Figure 7 - Illustration of Step 4

maintenance program. For less critical items, or simple systems, identifying all of the functions of an equipment item adds cost and time, but yields no benefits. Figure 7 illustrates Step 4.

Step 5 - Consequence Evaluation

In Step 5, each failure mode is analysed to determine whether or not the failure is hidden or evident. For evident failures a further determination of hazard or operational consequence is made. Figure 8 illustrates Step 5.

Task	Trade	Cause	Function	Effect
Task 1	Operator	Failure A	Function 1	Operation
Task 4	Fitter	Failure A		
Task 7	Greaser	Failure A		
Task 2	Operator	Failure B	Function 1	Operation
Task 5	Electrician	Failure B		
Task 3	Fitter	Failure C	Function 2	Hidden
Task 6	Operator	Failure C		
		Failure D	Function 1	Operation

Figure 8 Illustration of Step 5

Step 6 - Maintenance Policy Determination

Modern maintenance philosophy stems from the premise that successful maintenance programs have more to do with the consequences of failures than the asset itself.

In this step, each failure mode is analysed using Reliability Centred Maintenance (RCM) principles. This step establishes new or revised maintenance policies. During this step the following become evident:

- The elements of the current maintenance program that are cost effective, and those that are not (and need to be eliminated),
- What tasks would be more effective and less costly if they were condition based rather than overhaul based and vice versa,
- What tasks serve no purpose and need to be removed from the program,
- What tasks would be more effective if they were done at different frequencies,
- What failures would be better managed by using simpler or more advanced technology,
- What data should be collected to be able to predict equipment life more accurately, and
- What defects should be eliminated by root cause analysis.

Cause	Function	Effect	Policy	Interval
Failure A	Function 1	Operation	Inspect	Daily
Failure B	Function 1	Operation	No PM	
Failure C	Function 2	Hidden	Test	Annually
Failure D	Function 1	Operation	Inspect	Weekly

Figure 9 Illustration of Step 6

Figure 9 illustrates Step 6.

Step 7 - Grouping and Review

Once task analysis has been completed, the team establishes the most efficient and effective method for managing the maintenance of the asset given local production factors and other constraints. In this step it is likely that tasks will be transferred between trades and operations people for efficiency and productivity gains.

Step 8 - Approval and Implementation

In Step 8, the analysis is communicated to local stakeholders for review and comment. The group often does this via a presentation and an automatic report generated from the PM Optimisation software. This software details all the changes and the justification for each.

Following approval, the most important aspect of PMO 2000 then commences with implementation. Implementation is the step that is most time consuming and most likely to face difficulties. Strong leadership and attention to detail are required to be successful in this step.

The difficulty of this step increases markedly with more shifts and also with organisations that have not experienced much change.

Step9 - Living Program

Through Steps 1 to 9, the PM Optimisation process has established a framework of rational and cost effective PM. In the "Living Program", the PM program is consolidated and the plant is brought under control. This occurs as reactive maintenance is replaced by planned maintenance. From this point improvement can be easily accelerated as resources are freed to focus on plant design defects or inherent operational limitations.

During this step, several vital processes for the efficient management of assets can be devised or fine tuned as the rate of improvement accelerates.

These processes include the following:

- Production / maintenance strategy,
- Performance measurement,
- Failure history reporting and defect elimination,
- Planning and scheduling,
- Spares assessing, and
- Workshop and maintenance practices.

In this step it is the intention to create an organisation that constantly seeks to improve its methods by continued appraisal of every task it undertakes and every unplanned failure that occurs. To achieve this requires a program where the workforce is adequately trained in analysis techniques and is encouraged to change practices to improve their own job satisfaction and to reduce the reduce the unit cost of production.

Implementing a Successful PM Optimisation Program

Selling Maintenance as a Process rather than a Department

Change programs are not easy to implement particularly when an organisation has entered the vicious circle of maintenance.

The author's experience is that in most cases there needs to be some fundamental shifts in behaviour and motives at all levels across the organisation. This almost invariably involves modifying the behaviour and decision-making priorities for middle managers too. Above all, there needs to be a commitment to the long term and if there needs to be some short-term losses, then these will often be well worth it if returns can be generated quickly from the investment in the future.

The most important aspects of managing a PM Optimisation change program to break the vicious cycle, are described in the following paragraphs:

Choose projects that do not focus solely on one aspect.

There needs to be a combination of projects that are likely to result in:

- increased uptime, and
- reduced labour requirements.

In many cases, this means tackling reliability problems in the process bottleneck as well as looking at maintenance intensive item categories⁹ that are prolific on site.

The reasons behind tackling projects that carry labour productivity rather than machine uptime is that

- First line supervisors will contribute to the program if they see that there is a return on investment in labour terms. A target of returning five days labour per annum for every one invested should be the lowest acceptable limit.
- Returns on labour productivity are compounding (they can be reinvested in more productivity) whereas uptime improvements are finite.

Collect data about the before and after case

Collecting data about plant reliability achieves many things. The two major benefits are as follows:

- Steering the analysis in the area of opportunity, and
- Providing the basis for the project teams to demonstrate the value of the work that has been done.

Create cross functional teams from the shop floor

PM Optimisation is not a back office function of statistical perfection. It is an empirically based process of considering preventive maintenance options, and task rationalisation. Involving the people who will be left to do the work is constructive in gaining commitment to make the changes happen. Leaving them out of the analysis creates barriers to implementation.

Integrate operations and maintenance work management systems

In redistributing the workload, it is important that the various systems of maintenance scheduling come from the same origin or database. In most organisations this is not the case as the operations department has a system that works in isolation from the trades groups.

Implement outcomes as quickly as possible

There is a temptation to celebrate project success after the analysis and move on to new projects leaving implementation to drift and become poorly managed. This is a very bad outcome

⁹ *le; fans gearboxes, conveyors, machine tooling, pumps, electric motors, instrumentation - where there could be hundreds of similar items. Saving labour on one item multiplies across the whole of the site.*

because the project has consumed scarce resources and wasted them. Without successful implementation, the work has created a cost and the workforce expectations have not been met. The workforce will correctly blame the middle management and participation in future projects will be more difficult to obtain.

Dysfunctional Organisational Structures

The organisational structure of most capital intensive industries can be described as being departmentalised with maintenance and operations having separate budgets, performance measures, and management structures. There are advantages associated with departmentalised organisational structures; however, such structures often lose efficiency through:

- Conflicting goals and objectives of each department that sometimes result in decisions which are not congruent with the overall business goals. The most common being short-term production goals that often clash with the maintenance objective of reducing the overall cost of maintenance.
- Duplication of effort with many departments attempting to achieve the same result but in isolation of each other. Electrical, mechanical and production PM schedules commonly fall into this category with each department checking the same machine for the same failure modes.
- An overly bureaucratic decision making and approval process at all levels. This is often a result of conflicting objectives between managers.
- Excessive demarcation of roles and responsibilities. Though becoming less prevalent, the inability to take responsibility for certain work due to past traditions prevents efficient use of resources at many sites.
- A proliferation of independent systems and databases. The most common instance is where operations and maintenance personnel work through their own logbooks and records that are kept independently of the Computerised Maintenance Management System (CMMS).
- The process of defect elimination is seen largely as an engineering pursuit where problems often have multiple contributing factors and must be solved by cross functional teams. Many factors are not necessarily obvious and many are due to shop floor people taking practical measures to combat other problems that have secondary effects elsewhere.

Conclusion

There are a number of contributing factors to the difficulties faced by the modern asset manager. To be effective at making changes to the performance of a maintenance function, the asset manager should understand how these factors have arisen, how they impact on the business performance and how they can be effectively tackled. There is a way out of the vicious cycle of maintenance and the Optimisation or Rationalisation of Maintenance tasks is a fundamental strategy in this process.

To break the vicious cycle of maintenance, asset managers should focus on the areas of preventive maintenance and defect elimination. To improve their preventive maintenance organisations, there must be a shift to an environment where there is no duplication of PM effort, every PM task serves a purpose, all PM tasks are completed at the right interval, and with the right mix of condition based maintenance and overhaul.

SECTION 1. PMOPTIMISATION – MAINTENANCE ANALYSIS OF THE FUTURE

Organisations that have mature PM programs and are struggling to complete them should take steps to rationalise what they have, rather than embarking on a “green field” approach such as the traditional approaches to RCM.

There are many statistically based maintenance analysis tools available, however, users should be careful in their choice. They should be mindful that they could be spending a lot of money on expensive packages and consuming a lot of time collecting vague data which, after years of effort, produces a meaningless result.

Comparing PMO and RCM Methods of Maintenance Analysis

Methods of defining Initial Maintenance Requirements

The common methods for defining the initial maintenance requirements for plant and equipment are as follows:

- RCM,
- Streamlined RCM,
- Statistical Methods, or
- Experience, trial and error.

The origin of the processes is briefly discussed below.

RCM

Nowlan and Heap (1978) coined the term Reliability Centred Maintenance (RCM) and developed the original method. RCM was not designed for use for “in service” assets. However, in the absence of better methods since 1978, it has been applied retrospectively in many organisations after the plant has been commissioned. In over 20 year since its derivation, RCM has failed to become a day to day activity performed by most organisations. Few organisations have applied RCM to anything other than their most critical assets which indicates there are serious difficulties associated with applying RCM in organisations with mature plant.

Streamlined RCM

Due to a perception that RCM was a very time consuming and labour intensive activity, a number of shortened versions of RCM have been devised in an attempt to speed up the analysis or increase the overall value of the time committed to analysis. Many of these methods have used the acronym, RCM to describe the process but do not conform to the works of Nowlan and Heap (1978) nor the SAE Standard for RCM. These streamlined approaches are known as streamlined RCM techniques.

Statistical Methods

There are three main types of statistical maintenance analysis programs known to the author.

1. One of these is based on MILSTD 2173 and works from the premise that no inspection task is 100% effective. The algorithms adjust the interval of “on condition” tasks to account for less than perfect inspection methods.
2. Another is based on the notion that the more frequent the inspection the higher the cost of maintenance but the lower the chances of failure. The objective of maintenance under this algorithm is to determine the lowest overall cost of maintenance. This algorithm is flawed if inspection is near 100% reliable or is fail safe¹⁰ as, providing the inspection is inside the PF¹¹

¹⁰ Any incorrect sample will suggest there is a failure when in fact there is not. Oil analysis or vibration analysis are examples where most of the problems are fail-safe.

SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

interval, more inspections only add to the cost of maintenance but not reduce the chances of failure.

3. The third statistical method has uses to Weibull analysis as a basis. This method suffers mostly from poor data integrity.

The overwhelming problem with statistical methods in the vast majority of industrial plant is that the failure history data is so unreliable and incomplete that any statistical inferences drawn from such data are wildly inaccurate and lack any worthwhile statistical confidence. The algorithms are also reliant on accounting inputs such as the cost of PM, repair and failure. All of these inputs are subject to the vagaries of the accounting systems deployed.

The second large problem is that statistical methods tend to be used by engineers or contractors who are not sufficiently familiar with the equipment in the manner that it is used on site. Often the result is a misguided program which is totally discredited by the tradesmen and operators because of its low quality and secondly because they were not sufficiently involved in its derivation.

Some explanation of the first two methods is contained at Section 3 of this paper.

Experience, Trial and Error

In many cases, capital acquisition programs fail to recognise the need to define the maintenance program prior to the "Operation" stage of the equipment life cycle. Often, the plant is installed and operated without a formal maintenance program. Over time, the operations and maintenance staff begin to conduct inspections and perform various maintenance activities largely at their own initiative. Failures occur and the maintenance program has tasks added to it. In some organisations, the work is formalised by generating electronic or paper based maintenance schedules. In other organisations, the work continues to be done in a completely informal manner. Even though some managers may believe that there is no preventive maintenance done within their plant, this situation is highly unlikely. The confusion is often that the preventive maintenance is not appreciated, as there is no documentation.

Methods of Reviewing Maintenance Requirements

PM Optimisation

Regardless of how a maintenance program has been developed, there is a constant need to review and update the program based on failure history, changing operating circumstances and the advent of new predictive maintenance technologies. The generic process used to perform such analyses is known as PM Optimisation (PMO). PMO has been performed, no doubt, since the world became mechanised and humans realised the benefits of performing preventive maintenance. PMO as a technique has been refined to reflect the RCM decision logic since the formulation of RCM in 1978.

There are a number of methods that have been created under the acronym PMO. One of these has been applied in the US Nuclear power industry for over 8 years and has been recognised as a major benefit by the North American Nuclear Regulatory Commission (Johnson 1995).

Each of the PMO methods has differences and there is no accepted standard for PMO. Discussions contained in this paper are therefore, based on the method of PMO known as

¹¹ *The period between the point at which a fault can be first detected and the point where it is considered to have functionally failed.*

SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

PMO2000. Some of the comments and comparisons made between PMO and other methods may not apply to methods of PMO.

The PMO2000 process has been developed over a five-year period by OMCS with the assistance of several Australian Companies. There are now 12 users of PMO2000 in the Australia Pacific Region. The PMO2000 process is endorsed by SIRF Roundtables Ltd and is the global maintenance analysis tool of choice for one of the world's largest mining companies. PMO2000 is the intellectual property of OMCS. The methodology is described in detail at Section 1.

Comparing RCM and PMO

What is RCM

According to the standard SAEJA1011, any RCM program should ensure that all of the following seven questions are answered satisfactorily and are answered in the sequence shown:

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfil its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?

What is PM Optimisation

The questions answered in completing a PMO2000 analysis are as follows:

- 1) What maintenance tasks are being undertaken by the operations and maintenance personnel (task compilation)?
- 2) What are the failure modes associated with the plant being examined (failure mode analysis)?
 - a) What is (are) the failure mode(s) that each existing task is meant to prevent or detect
 - b) What other failure modes have occurred in the past that have not been listed or have not occurred and could give rise to a hazardous situation.
- 3) What functions would be lost if each failure were to occur unexpectedly (functions)? [optional question]
- 4) What happens when each failure occurs (failure effects)?
- 5) In what way does each failure matter (failure consequences)?
- 6) What should be done to predict or prevent each failure (proactive tasks and task intervals)?

7) What should be done if a suitable proactive task cannot be found (default actions)?

The complete PMO2000 methodology has nine steps. The seven questions listed above are a subset of the complete PMO2000 methodology. The additional steps in PMO2000 not listed above are as follows:

- Grouping and Review
- Approval and Implementation
- Living Program

These final three steps are necessary to implement the analysis outputs and ensure that the PMO analysis does not stop once the first review has been completed. These steps are not considered relevant to this paper as it is assumed that RCM analysis must also perform these steps to ensure a successful outcome. RCM and PMO are considered identical in this regard.

Functional Differences between RCM and PMO

RCM and PMO are completely different products with the same aim; to define the maintenance requirements of physical assets. Asset managers should be aware however, they have been designed for use in completely different situations. RCM was designed to develop the initial maintenance program during the design stages of the asset life cycle (Moubray 1997) whereas PMO has been designed for use where the asset is in use.

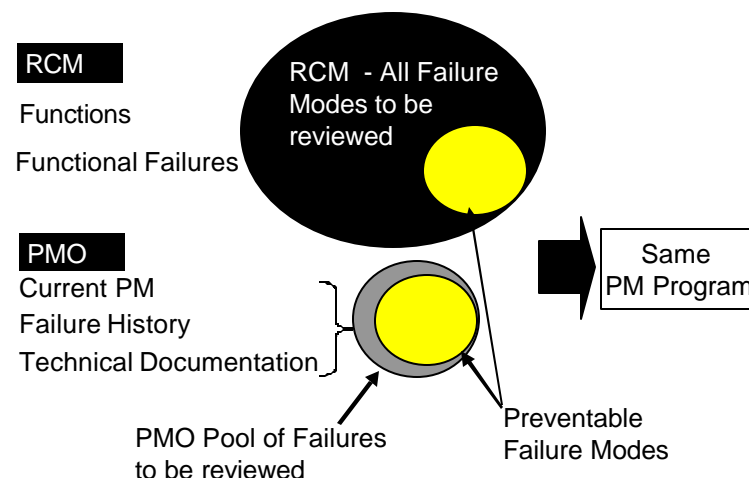
As a result, PMO is a method of review whereas RCM is a process of establishment. Whilst arriving at the same maintenance program, PMO is far more efficient and flexible in analysis than RCM where there is a reasonably good maintenance program in place and where there is some experience with the plant operation and failure characteristics.

Methodology differences between RCM and PMO

The central difference between RCM and PMO is the way in which failure modes are generated.

- RCM generates a list of failure modes from a rigorous assessment of all functions, a consideration of all functional failures and then an assessment of each of the failure modes that relate to each functional failure. RCM seeks to analyse every failure mode on every piece of equipment within the system being analysed.
- PMO generates a list of failure modes from the current maintenance

Figure 10 Comparison of PMO and RCM



SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

program, an assessment of known failures and by scrutiny of technical documentation - primarily Piping and Instrumentation Diagrams (P&IDs).

The differences in the two approaches mean that PMO deals with significantly less failure modes than RCM and arrives at the failure modes in a far quicker time frame. Experience in the US Nuclear Power Industry was that over a large number of analyses, PMO was on average six times faster than RCM (Johnson, 1995). The methodological differences between RCM and PMO are illustrated at Figure 10.

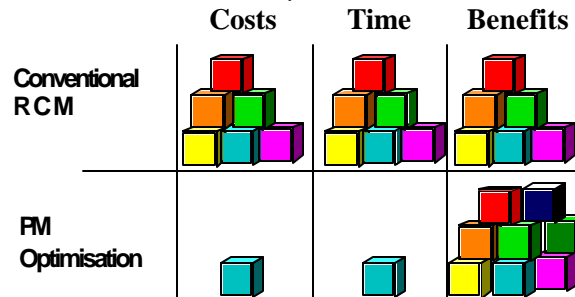
How and why PMO is faster than RCM

Overview

The main reasons why PMO is faster than RCM are summarised below. The points are discussed in detail later in the paper.

1. Insignificant failure modes are not analysed by PMO whereas RCM analyses all likely failure modes.
2. Using PMO, many failure modes can be rolled up and analysed together whereas with RCM, failure modes are analysed separately.
3. With PMO, a detailed functional analysis is an optional step. The function of the equipment is completed as part of Consequence Evaluation because a consequence of any failure is a loss of function by definition.

Source: US Nuclear Power Industry



Comparison of the costs, time and benefits of RCM compared with PMO

How and why failure mode analysis of insignificant failures is avoided by PMO.

The equipment design and the way it is operated determine the type and likelihood of failure modes. In the context of maintenance analysis, failure modes can be broken into categories based on the following:

- their likelihood,
- their consequences, and
- the practicality and feasibility of preventing or predicting them. This point is illustrated in Figure 11.

Figure 11 Considerations required for maintenance analysis.

Likelihood	Consequences	PM Feasibility
High	Hazard	Feasible
Medium	High Cost	Not Feasible
Low	Low Cost	

A PM program is targeted at the conditions listed in the grey areas of the table. These comprise the minority of failures, as the intent of design is to engineer out hazards and high cost failures particularly when their likelihood is high.

The focus of good equipment design is to ensure high levels of reliability, maintainability and operability. This means eliminating high likelihood and high consequence failures.

It is therefore, not surprising that when reviewing the complete set of likely failure modes using RCM analysis, that by far the greatest number of outcomes, or recommendations, are No Scheduled Maintenance. This is to say that for the failure modes left in the design in question, either

- Their likelihood is very low,
- There is no technically feasible predictive or preventive maintenance task known to manage them, or
- The task that is known costs more to do than the cost of the cost of unexpected failure. The less critical the equipment is to productive capacity, the more likely that the cost of the maintenance outweighs the costs of the failure over a given life cycle.

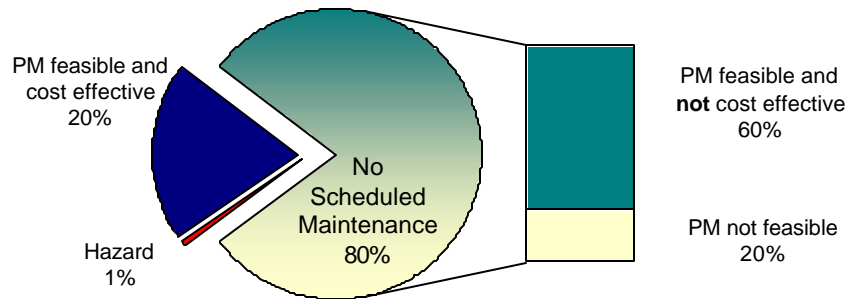
In the author’s experience, full RCM analysis of equipment shows that, on average, about 80% of failure modes result with the policy of No Scheduled Maintenance¹². This information is presented in Figure 12. This number rises with electronic equipment such as a Programmable Logic Controller (PLC) and falls with equipment that has a high number of moving parts such as a conveyor.

It therefore follows that, if the objective of a maintenance analysis workshop is to define the maintenance program, and all the likely failure modes are analysed, around 80% of the analysis

¹² This figure will vary markedly with some equipment having a 50% return. The other variable is the propensity for teams to “black box” and by-pass certain parts of the system because, from experience, these items are known to have few or no failure modes that are preventable or predictable or are hidden. Whilst reducing the ratio of No Scheduled Maintenance outcomes, such bypassing streamlines the RCM process and therefore is a non conformance to the standard.

will be low value adding (or a complete waste of time). This is because the analysis finds that there is no maintenance solution for 80% of the failure modes. Those failure modes could have been culled at the start with no loss of analysis quality.

Figure 12 Approximate Breakdown of Outcomes for Equipment Failure Modes



With this same objective in mind it is therefore logical to seek a process which limits the analysis to those 20% of failure modes that are likely to yield a maintenance solution and no more. In practice this is not completely feasible, as that pool of failure modes that receive PM is not defined until the analysis is performed.

If the failure modes are low consequence and infrequent, then there is unlikely to be any cost-effective modifications either.

The missing element here is failure modes that have hazardous consequences but have not happened before. It is accepted that the downside of this approach is that failure modes that could result in a hazard may be omitted so therefore it is wise to obtain the technical documentation and perform a “desk top¹³” FMECA to trap these hazards if they exist. PMO2000 therefore errs on the side of caution and lists the failure modes that have the following attributes:

- Are currently the subject of Preventive Maintenance,
- Have happened before, or
- Are likely to happen and may cause a hazard.

How and why using PMO many failure modes can be rolled up and analysed together

RCM treats each failure mode independently resulting in the same analysis and tasks being written many times. PMO starts from the maintenance task and therefore many failure modes can be listed against the one task. This significantly reduces the analysis time by reducing the records that need to be dealt with. The concept can be best described by reference to the following example.

¹³ Review the technical documentation assessing if consequences of any failure would lead to a hazardous situation.

SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

Using PMO

Task	Failure mode analysed (rolled up)
Perform Vibration Analysis on the Gearbox	Gear wears, or cracks. Gear bearing fails due to wear. Gearbox mounting bolts come loose due to vibration. Gearbox coupling fails due to wear.

Providing vibration analysis was a technically feasible task to prevent all these failure modes from occurring unexpectedly, PMO would consider the failure modes as a group and set the task interval to the lowest common interval of inspection.

Using RCM

Function	Functional Failure	Failure modes
To provide 20 hp of power to the fan such that the fan spins at 200 rpm.	No power whatsoever	Gear wears.
	No power whatsoever	Gear cracks due to fatigue.
	No power whatsoever	Coupling fails due to wear.
	No power whatsoever	Gearbox bearings fail due to wear.
To secure the gearbox to the plinth.	Gearbox comes loose	Gearbox mounting bolts come loose due to vibration.

The above tables show how, right from the outset, RCM has created a lengthy analysis process compared to PMO. The resulting maintenance program will be the same with vibration analysis being selected as the best form of maintenance to manage all the failure modes. The only difference is that RCM has analysed five independent failure modes where as PMO has analysed them together.

How and why using PMO, rigorous functional analysis is optional

RCM begins with a complete functional analysis of the equipment whereas with PMO2000¹⁴ the effort expended on functional analysis is variable or discretionary. The reasons why PMO2000 allows this are as follows:

- Consequence evaluation is performed at Question 5 of PMO2000. As consequence evaluation implicitly involves understanding what loss of function is incurred, a functional assessment is performed at this stage as part of consequence evaluation. To perform a separate functional analysis is a duplication¹⁵ of effort.
- In some cases, the precise functionality of equipment is almost impossible to determine and / or practically meaningless. A case in point is the function of a fan in a cooling system. Its function is likely to be to supply a certain cooling capacity of air measured in BTU's per hour or equivalent dimension. This becomes an equation based on ambient temperature and flow rates. To source this information would normally be very time consuming. The practical value or usefulness would be very low as there is not likely to be a gauge on the fan that measures BTU/hr to assess whether the fan is serviceable or not according to the precise function. To the operators, the performance standard written in BTU/hr would be a completely foreign concept.
- Task selection or task type is determined by practical and economic parameters and in practice has nothing to do with the asset function. Given that the consequences of failure have been assessed correctly, there are some circumstances, where variations in functionality can still effect the interval of both Condition Monitoring and Scheduled Discard and Restoration tasks. For condition monitoring, this is because the PF interval¹⁶ may be shorter if assets are expected to operate closer to their inherent capability. For Scheduled Restoration and Scheduled Discard tasks, where there is a constant rate of deterioration, the life of the asset may be shortened again due to the lower margin between design a functional expectation. In practice however, most of these cases will be resolved by the failure data collected or by asking the right people the right questions about the asset in its operating context. Both data and experiential assessments of life and PF will take into account the functionality of the asset being studied.

To apply RCM in accordance with the standard, a functional analysis can consume 30% of the total analysis time. If the objective of a maintenance analysis workshop is to define the appropriate maintenance policy for the equipment, then a full functional analysis consumes a lot of time, but adds little value.

¹⁴ *Not a feature of most other PMO processes.*

¹⁵ *This point is also relevant where functions are hidden, as the loss of hidden functions will result in consequences that are conditional on some other failure occurring.*

¹⁶ *The interval between when the time the symptoms of failure can be first detected and the point of functional failure.*

Strengths and benefits of PMO compared with RCM

PMO is a method with enormous flexibility

RCM analysis can not regulate or filter which failure modes are analysed at which time therefore RCM analysis requires the presence of all trades simultaneously as the failure modes come out in a rather random manner. With PMO it is possible to review the activities of a particular trade on a particular piece of equipment or site because PMO begins with maintenance tasks which can be filtered on the field, trade. This is particularly useful when it is considered that the activities of one trade are ineffective or inefficient.

There have been highly successful PMO analyses performed exclusively on either operator rounds, on instrumentation rounds, on lubrication rounds, on vibration analysis rounds etc. This type of focus is not possible using RCM.

PMO is self regulating in terms of investment and return

PMO is highly effective where equipment has numerous failure modes but where the vast majority of these are either random, instantaneous or not of high consequence. A simple example would be a mobile telephone. Mobile phones have hundreds of functions. To define the functions of a mobile phone would take at least one day depending on how rigorous the group was in defining performance standards.

The other point here is that RCM would require the input of specialist electronics engineers to define the failure modes properly whereas PMO would require only the operators. PMO on the other hand, would take no more that 20 minutes to complete the analysis in total and realise that the only maintenance that is required is to do with managing the consequences of battery deterioration.

PMO is six times faster than RCM

The positive effect of deploying a process of maintenance analysis that is six times faster than RCM for the same given outcome can not be overstated. The benefits are listed below:

- Resources to perform analysis are generally the most scarce on the site. PMO will allow the analysis team to cover six times the area with the same given resource thus having a much lesser impact on the normal operation of the plant. PMO also allows the organisation to be implementation intensive rather than analysis intensive.
- Maintenance analysis like many other investments is subject to diminishing returns. Using a costly and resource intensive program such as RCM reduces the scope and ability of maintenance analysis to those areas of plant that are in the bottlenecks. Because PMO is far less costly to do than RCM, it can be done economically on considerably more assets within the plant; typically where the gains from analysis will be less, but not insignificant.
- Where the maintenance of failure modes that have safety or environmental consequences¹⁷. is considered suspect, the use of PMO will allow these issues to be dealt with much faster than by using RCM

¹⁷ It should be noted that neither PMO nor RCM provide adequate protection against the consequences of equipment failure where two evident failures occur simultaneously. This is an occurrence that has been a significant factor in a large number of the world's recent disasters particularly when a combination of in appropriate human action and plant failures coincide.

Weaknesses of PMO

The only valid weakness of PMO compared to RCM for plants that have been in operation for some time, is that PMO does not list the complete set of failure modes. This may be important from a spares assessing perspective. However, if the motivation for performing maintenance analysis is to generate a focussed and effective PM program, then this weakness is irrelevant.

Discussion of common misconceptions about PMO

In recent times, there have been a series of attacks launched against any process that does not conform to SAEJ1011. The most prominent being written by Moubray (Moubray, 2001). These issues are discussed in the following paragraphs of this Section.

Because as standard has been set for RCM, asset managers must use that process across their whole plant to be safe from prosecution.	False
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In August 1999, SAE JA1011 entitled "Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes" was issued. The sole purpose of this standard was to provide criteria for people to be able to determine what is RCM and what is not. This is evidenced on the front page of the Standard by the following passage:

Quote "This document describes the minimum criteria that any process must comply with to be called "RCM." It does not attempt to define a specific process" unquote

The first point is that many of the attacks on PMO have been based on misconceptions on how the process works and are based on unsubstantiated and incorrect data and assumptions. These false statements are corrected in the questions that are part of this section of the paper.

The second point is that the logic used does not pass careful scrutiny. For example the logic used by Moubray (Moubray 2001) goes this way.

1. Society has reacted to equipment failure and accidents producing serious consequences by enacting laws seeking to call individuals and corporations to account. **[No Objection]**
2. Everyone involved in the management of physical assets needs to take greater care than ever before. **[No Objection]**
3. RCM is the most rigorous method of defining the maintenance requirements of physical assets. **[No Objection]** Any method that streamlines the RCM method is by definition missing something and therefore exposing the user to excessive risk. **[Incorrect and no evidence to support this premise]**
4. There has been a standard written to allow purchasers of equipment to write contracts that specify the use of RCM, to be sure that what they are purchasing conforms to a known standard. **[Irrelevant]**
5. Now that there is a standard for RCM, all asset managers must use the standard across every asset in their plant if they want to be immune from prosecution in court should an industrial accident occur in the plant. **[Based either on an irrelevant point or argument or an incorrect and unsupported premise]**

PMO is unsafe to use, as it does not adequately investigate failure modes that may lead to hazards in the plant.	False
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There are several important points that deal with the issue of safety and environmental consequences of failure and the use of RCM or PMO to treat these concerns. The most important point being that neither PMO nor RCM offer adequate protection from the causes of multiple evident failures. Asset managers should therefore, consider using HAZOP or similar techniques as their primary hazard management process. The three main points are discussed below.

Point 1

Except for hidden functions, the RCM analysis technique considers only the first order effects of failure. This is evidenced by the fact RCM treats all failure modes “on their own”. It does not consider the consequences of two or more evident failures occurring simultaneously. As catastrophes are generally the result of several compounding failures, RCM can not, of itself, be regarded as a comprehensive defence against prosecution when plant failure contributes to a disaster. Managers should not undertake RCM in the belief that they will be immune from prosecution by doing so. It can be said that due to these omissions, RCM is a streamlined version of a comprehensive safety analysis program and therefore fails the same tests that its supporters claim to be its virtues.

Point 2

Anecdotal evidence regarding the causes of recent disasters raises some observations.

Firstly, the greater the disaster it seems, the more numerous were the contributing factors.

Secondly, few if any of the disasters of recent times have been caused by a lack of a preventive maintenance program. Where plant failure has contributed to the disaster, the failures had been known to the company, but the company chose not to rectify them. This is a most uncomfortable but common scenario found in today’s industrial maintenance climate. This was a case in point in the recent Esso disaster at the Longford Plant where what would normally be considered abnormal became normalised over time (Hopkins, 2000). There were numerous items of equipment known to be in an unserviceable condition but no action was taken to repair them.

Managers find it acceptable to live with a high level of broken or badly performing equipment, and more disturbingly, find it acceptable to treat preventive maintenance as an optional activity. PM is frequently skipped without any real assessment of the risks being exposed. The greatest threat to industrial safety therefore, is not the lack of a PM program, but the lack of resources required to complete the program and perform the corrective maintenance to bring the plant to an acceptable operating condition. In this predicament, responsible managers will not pour their valuable resources into a long-winded RCM program that will deliver them a better PM program over a long period. Rather they will take on a shorter program that delivers the same analytical results, but allows significant productivity gains to be made thereby allowing the backlog of corrective maintenance to be recovered and the PM program to be achieved.

Point 3.

Failure modes that are listed as having a hazardous consequence occur approximately¹⁸ once in every two hundred. In facilitating analysis of over 15,000 failure modes over a period of eight years, I have only once found a failure mode with potentially hazardous consequences that was not already the subject of PM. In all likelihood this failure mode would have been detected through PMO during the technical documentation review. This means that PMO provides close to the same defence against equipment failure, as does RCM.

The other issue here is the time it may take to detect the rare failure modes that may be the difference between using RCM and PMO. Finding that one in 15,000 failure mode carries a cost of 15,000 man hours¹⁹ or 8.5 man years. Few managers would consider that to be a good return for a program aimed at improving safety.

PMO assumes that all the failure modes associated with equipment are covered by the existing maintenance program	False
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PMO recognises that there are many failure modes that are not covered by the maintenance program and therefore includes a step to add to the list generated by the PM analysis, those failure that have occurred in the past and those that may occur and potentially result in a hazard. It is usual during a PMO workshop to add 10% to 30% to the total program because of preventable failure that have been managed as unplanned occurrences in the past.

PMO is a method that analyses 20% of the failures and gets 80% of the results that RCM achieves.	False
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PMO2000 analyses around 40% of the failure modes that RCM would however the resulting maintenance program is the same regardless of whether RCM or PMO2000 is used. The objective of PMO2000 is to provide a comprehensive maintenance program covering all the failure modes for which there is a technically feasible, cost-effective maintenance solution.

When applying PMO, it is often very difficult to identify exactly what failure cause motivated the selection of a particular task, so much so that either inordinate amounts of time are wasted trying to establish the real connection, or sweeping assumptions are made that very often prove to be wrong.	False
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This misconception is most easily dealt with by example. Consider the following tasks and assess for yourself the difficulty in identifying the correct failure mode. Then open the maintenance schedule for your motor car and try some others for yourself.

¹⁸ Source is the author's experience. It must be recognised that there are several factors that impact on this ratio. These are mainly due to the types of asset studied and the guidance of the facilitator. The point here is that most plant failures can result in a hazard if the analysis team considers a wide array of other evident failures such as human error that may compound the original problem. There is also a line of thought that says that any equipment is not fit for use if there are high levels of hazards left in by design. One would expect that equipment designers are not so poor as to have a situation where 5% or more of failure modes are likely to cause hazards if they fail unexpectedly.

¹⁹ Assuming three team members and a facilitator working at 1 failure mode every 15 minutes.

SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

Listed Task	Failure Mode Analysed
Inspect the fan belt for signs of wear.	Fan belt wears.
Inspect the brake pads for wear.	Brake pads wear.
Replace the spark plugs.	Spark plugs wear.
Change the oil in the sump.	Sump oil deteriorates due to wear or ageing.

In reassessing the consequences of each failure mode, it is still necessary to ask whether “the loss of function caused by the failure mode will become evident to the operating crew under normal circumstances”. This question can only be answered by establishing what function is actually lost when the failure occurs. This in turn means that the people doing the analysis have to start identifying functions anyway, but they are now trying to do so on an ad hoc basis halfway through the analysis.	True but unimportant
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This is correct but it in no way makes the analysis neither onerous nor difficult or time consuming. The point here is that 30% of the analysis time is not spent defining functions when this is not required.

PMO is weak on specifying appropriate maintenance for protective devices. This is because in many existing maintenance programs only one third of protective devices are currently receiving any form of maintenance, one third are known but do not receive any form of maintenance and the final one third are not known as protective devices.	False
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Point 1

PMO2000 is no weaker than RCM in this regard. Using PMO2000, protective devices that are receiving no PM are found during the review of the technical documentation in exactly the same way as RCM would find them. The most common means is to trace piping and instrumentation diagrams looking for hidden failures.

Point 2

The statistics presented to support this claim are dramatically opposed to the author's experience. It is true that some maintenance departments do not know of some protective devices and some are known but do not receive any testing. However my observation is this. Firstly the number of unmaintained protective devices is more likely to be about 10% rather than 66% and secondly of the 10%, the likelihood and consequence of multiple failure do not warrant frequent testing.

PMO focuses on maintenance workload reduction rather than plant performance improvement. Since the returns generated by using RCM purely as a tool to reduce maintenance costs are usually lower than the returns generated by using it to improve reliability, the use of PMO becomes self defeating on economic grounds, in that it virtually guarantees much lower returns than RCM.	True and False
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PMO2000 focuses on many measures. One is machine reliability and one is human productivity. It is our experience that one of the greatest threats to industrial disaster is the considerable

SECTION 2. COMPARING PMO AND RCM METHODS OF MAINTENANCE ANALYSIS

backlog of corrective²⁰ and preventive maintenance work that many maintenance departments carry. Indeed many of the recent catastrophes have been caused, or were compounded, by equipment failures that were known but not rectified.

The second point is that many organisations are caught in a vicious cycle of reactive maintenance. This is where PM is missed resulting in breakdown that consumes more labour resources than the failure would have if it had been repaired earlier and in a planned manner. This then reduces the labour available to perform PM and thus the cycle continues. For this reason it is strategically sound to focus on the elimination of unnecessary work and redirect these resources to work that adds value. This strategy has a compounding effect that in the long run far outweighs the reliability improvement that tends to be fixed return in perpetuity rather than a compounding one.

The final point is that maintenance analysis consumes valuable resources, those being the people that know the equipment best. The supervisors who release these people are often caught in a dilemma. Releasing those people for workshops means that the backlog is going to get worse in the short term. Unless those supervisors feel confident that the investment in the program will recover the manhours invested quickly, the supervisory level becomes uncooperative and this has a wide ranging destabilising effect on the program as a whole. In short, a focus on human productivity is an essential ingredient in implementing a successful maintenance analysis program. With this in mind it is imperative that the analysis time is not wasted on low value adding activities such as the analysis of failure modes that result in no scheduled maintenance and the exhaustive activity of functional analysis.

²⁰ *Corrective maintenance is defined as a fault that is known and reported and rectified in a planned rather than reactive manner.*

Understanding Statistical Methods of Maintenance Analysis

There are two groups of approaches to determining task frequencies. One of them is statistical in nature and the other is more empirical. There are significant differences between the two approaches and some of these are discussed in the following paragraphs.

Mil STD 2173 (AS)

Mil STD 2173 (AS) shows that for random failures²¹, the optimal Condition Monitoring frequency is given by the following formula:

$$n = \ln \left[\frac{\frac{-\text{MTBF}}{T} C_i}{(C_{n\text{pm}} - C_{\text{pf}})\ln(1-S)} \right] \frac{1}{\ln(1-S)}$$

Where

- T = Age (time) between the point at which the failure can be first detected and the actual failure - also known as PF interval.
- n = Number of inspections during the PF interval T.
- MTBF = Mean Time Between Failure
- C_i = Cost of one inspection task
- C_{pf} = Costs of correcting one potential failure
- C_{npm} = Cost of not doing preventive maintenance inclusive of the operational costs of failure.
- S = Probability of detecting the failure in one inspection (task effectiveness).

²¹ A similar but more complex formula can be applied where the failure pattern is not random.

Cost Optimisation Algorithms

Another common algorithm seeks to find the optimal task interval by determining the minimum overall cost of maintenance. It uses the formula below:

$$C_t = C_f + C_{pa} + C_{sa}$$

Where

- C_t is the product of the **cost of actual failure** and the **probability of failure**
- C_{pa} is the **cost of the primary maintenance action** multiplied by the analysis period divided by the frequency of the primary maintenance action
- C_{sa} is the cost of the **secondary action** multiplied **by the analysis period** divided by the frequency of primary **action multiplied by the probability of failure** divided by the **period of analysis**

The Impracticality of Statistical Methods

The body of data required to generate accurate numbers for the above equations rarely exists in industry. For example:

- ◆ The value of **T** itself can only be determined by running equipment to absolute failure sufficient times to gain a statistically significant sample - a practice that is rarely justifiable.
- ◆ Determining the **probability of failure** or **MTBF** is precluded for similar reasons to determining **T**.
- ◆ There are no simple and reliable methods for determining the **task effectiveness S**.
- ◆ All the cost factors in the formulae are subject to the vagueness of the accounting and cost allocation methods employed.

Whilst the formulae for optimisation may be mathematically correct they are practically useless for all but a few applications where the variables can be determined with some certainty. Furthermore, they require the employment of people skilled in mathematics and statistics and hence such approaches, when applied in industry can easily develop into a back office pursuit of statistical perfection and lead to a program completely out of touch with reality.

Such programs have also been responsible for the relentless pursuit of accurate data that in reality takes decades of consistent operation for it to be of any realistic use as a tool for deriving maintenance task intervals.²²

²² *The author understands that failure history is essential for defect elimination however its use as a determinant for maintenance task interval is widely overstated in industry.*

Empirical Methods

Empirical methods arise from the concept that to prevent a failure from occurring unexpectedly, the warning condition must be inspected at an interval that is less than the period of decay (the PF Interval). What happens in practice is that analysts estimate PF intervals based on their experience of actual or similar equipment. The task interval is determined by applying a safety factor of two; or perhaps three, if the consequences of the failure are very high.

The reasons why empirical methods are widely used and effective are as follows:

- It is far more simple and practical to ask the maintenance fitter "How long will that bearing last once it starts to make a noise?" and inspecting the bearing for noise inside that interval, than collecting years of failure history on that bearing, deciding all the various costs, determining the shape of failure pattern.
- Shop floor maintenance personnel are typically not trained in statistics or complex mathematics and statisticians lack the understanding of the plant. Experience shows that a far better result is produced if the shop floor person is provided with a sensible but simple method rather than trying to train the statistician in the nuances of the plant.
- Empirical methods yield much faster results than statistical methods
- Empirical methods can be easily applied without using computers whereas most statistical methods require software packages to run them.
- Statistical methods often produce ridiculous outputs particularly if the input data is suspect.
- In conclusion, it remains a puzzle why engineers persist with statistical methods where the empirical approaches are far quicker and much more reliable.

Condition Monitoring Intervals

Doing more condition monitoring is a waste of time if the inspection method is totally reliable.

The inspection need only be done once within the PF interval to prevent the failure occurring unexpectedly.

Failure Mode -Bearing Wear

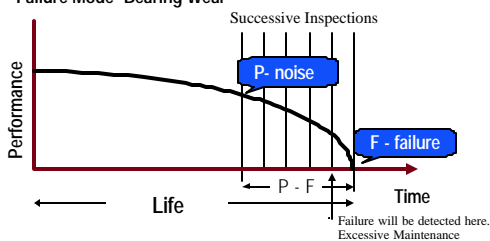


Figure 13 Setting Condition Monitoring Intervals

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