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Reducing business risk through
World Class Reliability Assurance

Halving Maintenance Related Downtime

using Planned Maintenance Optimisation

OMCS Asia-Pacific Sdn. Bhd.

OMCS Asia-Pacific Sdn. Bhd.
Suite 4005 4th Floor President House
Jalan Sultan Ismail
Kuala Lumpur Malaysia 50250
Telephone: +6 03 2144 6455
Facsimile: +6 03 2164 3944
Agust Tan
Mobile: +6 019 382 7699
agust@omcsap.com

Malaysia
Mark Jones
Mobile: +6 019 664 7699
mark@omcsap.com

Indonesia
Tony Hartono
Mobile: +628 1115 3159
tony@omcsap.com

Australia
Steve Turner
Mobile: +614 1939 7035
steve@omcsap.com

Singapore
Jeffrey Huan
Mobile: +65 9690 1968
jeffrey@omcsap.com

www.reliabilityassurance.com

Table of Contents

1

Halving Maintenance Related Downtime
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Author:

Mr. Steve Turner BEng MBA
Director and Principal Consultant
OMCS International

Presented by:

Mr. Tony Hartono BEng MBA
OMCS Asia Pacific Sdn. Bhd.

Abstract

PM Optimisation[1] is a process that has become very popular worldwide as a cost effective and practical alternative to RCM[2]. It has found great success in the following instances:

- In organisations that have existing plants with existing maintenance programs, where the situation requires a rationalisation and review of current PM reliability rather than a zero-based start-again method, and
- In organisations that are expanding or replacing current assets and have a need to build reliability program for these assets. They can do this quickly and effectively based on the knowledge that they, or someone else, currently have by virtue of owning or operating similar assets.

Aim

The aim of this paper is to explain how PM Optimisation works, where it differs from RCM and where it will be most effective as an alternate approach.

[1] The acronym PM, when used with the word Optimisation will mean Planned Maintenance Optimisation as this is the generic term commonly used for processes like PMO2000(tm) that start analysis with the current maintenance program. Otherwise PM will mean Preventive Maintenance.

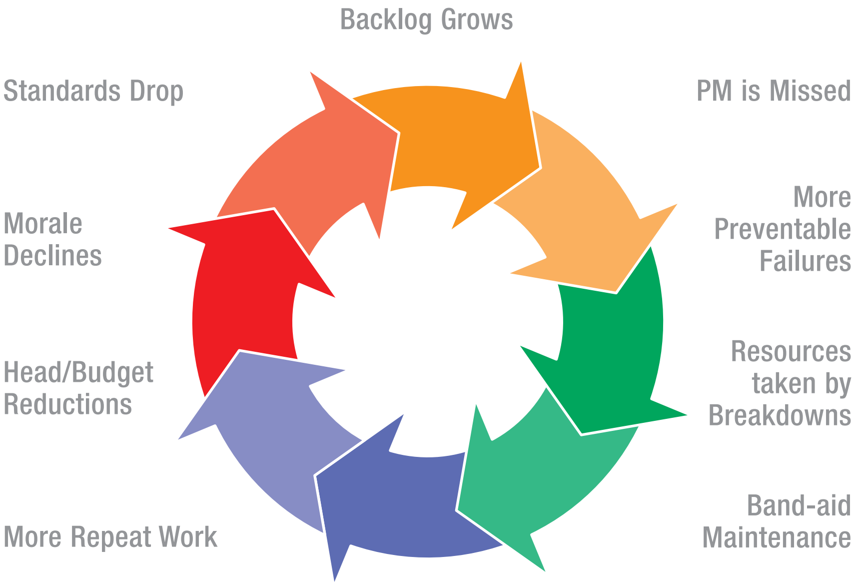
[2] For the purpose of the paper, all reference to RCM will mean reference to a process that meets the SAE standard for RCM which is SAE JA1011.

Common Challenges in Today's Maintenance Environment

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. 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.

Figure 1:

The Vicious Cycle of Reactive Maintenance™



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 of reactive maintenance feeds on itself with the level of reactive maintenance in such organisations being far greater than necessary. In some organisations, the situation declines to the stage that nearly all maintenance activity is breakdown work. This situation is depicted in Figure 1.

3 How the Problems Emerge

Problems in Design and Commissioning

Maintenance engineers commonly deal with the result of someone else's design - good or bad. When design is finished, construction starts and finishes, and the plant is commissioned. The Maintenance Engineer arrives someway through this (if he is lucky). He quickly 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 are the plant delivered to the maintenance department with a comprehensive and well-documented maintenance requirements analysis and a maintenance plan.

Problems after 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 policy[3] is a priority but a most daunting one. Whatever is achieved is done in a rush often using people in an opportunistic manner. Problems emerge right from the beginning. Typically, a rushed job with no training in RCM techniques results in the following problems:

- Task omissions where PM should be prescribed,
- Over servicing and under servicing,
- Prescribing tasks that add no value,
- Duplication of effort particularly between trades, and
- Prescribing overhaul where condition based maintenance would be far more cost effective.

Almost inevitably this situation results in a PM program that is poorly focussed. To compound this there is usually no audit trail, and only those who wrote the policies know their rationale. It becomes nearly impossible to review the program and objectively assess its effectiveness.

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

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

Rather than being rationalised, the maintenance program grows, and this impacts on the availability of the asset for its intended purpose - production. Production managers become reluctant to cooperate with the maintenance program, having experienced many occasions where production supplies serviceable plant to maintenance for preventive work only to receive it back in a less reliable condition than it was before the maintenance. In short, the organisation begins to behave as a reactive organisation due to the belief that there is little value in the PM program.

As the PM requirements grow they start to exceed the labour resource available. In addition production windows can shrink under pressure to meet targets. With less and less PM being done, breakdown maintenance starts to become a way of life and a culture develops where it is normal to miss PM. The vicious cycle of reactive maintenance previously described gains momentum and becomes entrenched.

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 (Ledet. 1994) featured in the Manufacturing Game[4] illustrates these points very well. The table below illustrates how DuPont has modelled the relative effect of various strategies on plant uptime.

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, a 14.8% improvement in availability may be achieved in their plants. This information is provided in Table 1.

Put another way, Ledet's model suggests that about 30% of downtime can be reduced by having a focussed PM program and having good planning and scheduling to support it. In addition, 90% of the downtime can be eliminated by adopting a good defect elimination strategy on top of this.

PMO2000™ methodology is built around this model. Indeed, the results of seven years of implementation programs by the author support the model.

Table 1:

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

Strategy	Change %	Uptime %	Downtime Reduction %
Reactive		83.5%	0%
Planning Only	+0.5%		
Scheduling Only	+0.8%		
Preventive/ Predictive Only	-2.4%		
All Three Strategies	+5.1%	88.6%	31%
Plus Defect Elimination	+14.8%	98.3%	90%

[4] 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.

In short, PMO2000™ involves the following:

- 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 or incorporating modifications to manage failures that history shows are a problem.
- Spreading the workload around the trades and operators.
- Adopting this process in a systematic way so that the knowledge is accessible and remains as a framework for future reviews.
- Creating a culture of continual review of plant failures and the maintenance strategy.
- Defect elimination by applying root cause analysis or similar techniques.
- Improving Planning and Scheduling
- Setting appropriate failure history collection and performance measures.

7 The Evolution of PMO

It is most likely that PM Optimisation has been conducted since the world began using tools and found that Preventive Maintenance improved the performance and reliability of the tools. They most likely also saw the value of reviewing their strategy over time.

It can be hypothesised therefore, that PM Optimisation is not a process developed by a few individuals at some point in history. Rather it has been a process developed more by evolution than breakthrough.

There have however been two notable events that have led to the acceptance of PMO as a legitimate process particularly in Australia.

1. First was the recognition of PMO by the North American Nuclear Regulatory Commission (Johnson,1995), and
2. Second was the initiative taken by Strategic Industry Research Foundation to promote the PMO process in Australia starting in 1997 and for some members of the Industrial Maintenance Round table to try it.

The process is now used at over 40 sites worldwide and the training material is written in three languages. It is fully supported by software and a host of implementation experiences.

There is no standard for PMO hence any reference to PMO from this point will be based on PMO2000™ the process developed by OMCS International Pty Ltd.

The PMO 2000 process has nine steps. These steps are listed below.

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

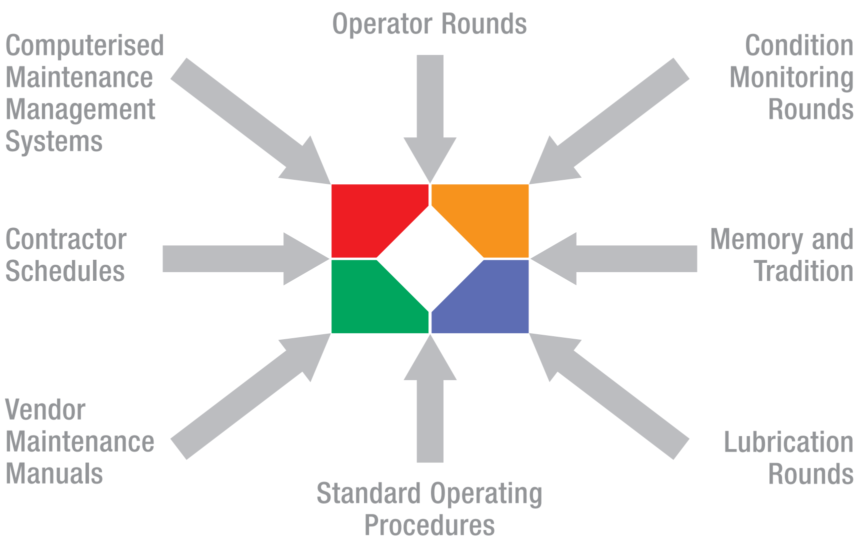
Step 9 Living Program

Step 1 - Task Compilation

PM Optimisation starts by collecting or documenting the existing formal and informal maintenance program (Figure 2). 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 PM program is done on 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 2:

Sources of Preventive Maintenance



Step 2 - Failure Mode Analysis

This involves people from shop floor normally working in cross-functional teams identifying what failure mode(s) each maintenance task (or inspection) is meant to address.

Step 3 - Rationalisation and Failure Mode Review

Through grouping the data by failure mode, task duplication may be easily identified. Task duplication is where the same failure mode is managed by PM conducted by more than one section or task, 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 or the experience of the team.

Step 4 - Functional Analysis

The functions lost owing to each failure mode may 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 maintenance program. For less critical items, or simple systems, identifying all of the functions of an equipment item adds cost and time, but yields few benefits.

Step 5 - Consequence Evaluation

In Step 5, each failure mode is analysed to determine whether the failure is hidden or evident. For evident failures a further determination of hazard or operational consequence is made.

Step 6 - Maintenance Policy Determination

In this step, each failure mode is analysed using Reliability Centred Maintenance (RCM) decision logic principles. This step establishes new or revised maintenance policies.

Step 7 - Grouping and Review

Once task analysis has been completed, the team establishes the most efficient and effective method for managing 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

Here the analysis is communicated to stakeholders for review and comment. Following approval, the most important aspect of PMO 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.

Step 9 - Living Program

Through Steps 1 to 8, 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 accelerates as resources are freed to focus on plant design defects or inherent operational limitations.

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. A key part of this part of the program is Failure Reporting and Analysis. Our preferred approach to this is discussed below.

11 Failure Reporting and Analysis

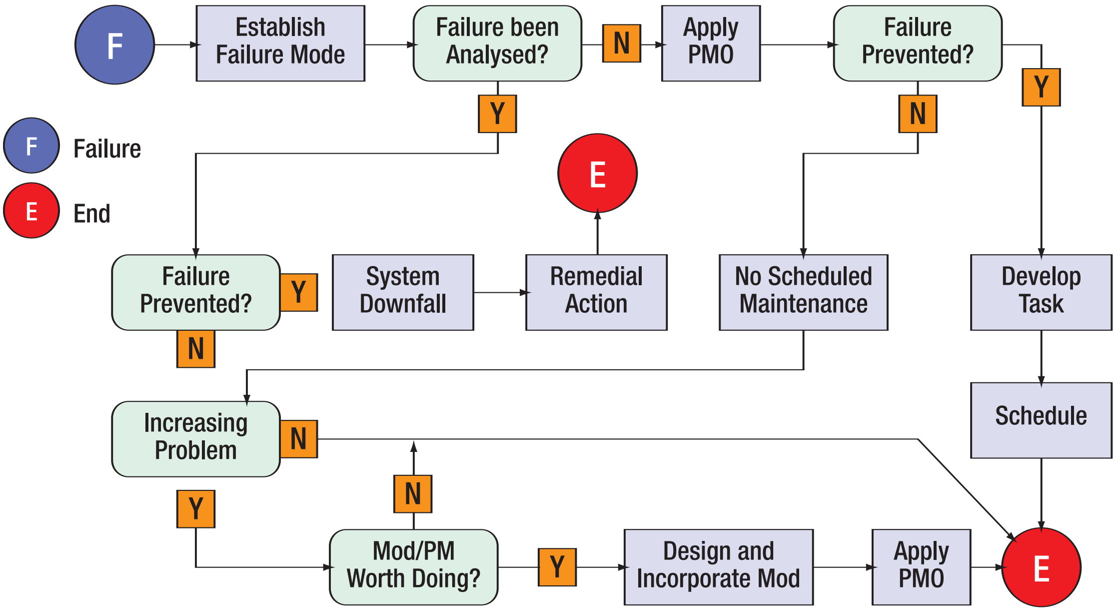
The best way to review a maintenance program is to analyse failures as they occur. A typical flow chart for Failure Reporting and Analysis is shown in Figure 3. Despite the best efforts of organisations, this process becomes almost impossible to conduct without efficient software to first search for the failure mode on the equipment, determine whether or not this failure mode has been analysed, what the current maintenance strategy is, and to communicate and track progress. The unfortunate reality is that there is no CMMS known to the author that can do this.

In most instances, the CMMS systems lack the data structure to create the link between equipment, failure mode and strategy, and also the ability to control investigations efficiently. For this reason, OMCS International has created software to execute these activities easily.

The starting point [S] is any unexpected failure [Failure] that has occurred in the plant. The first check that needs to be conducted [Failure Analysed?] is an assessment of whether or not that failure mode has been analysed previously using RCM logic. If it has not [N], then it should be put through an RCM analysis [Apply RCM]. If it has been reviewed [Y], then the validity of the previous review needs to be assessed against the fact that the failure has now occurred unexpectedly [Failure Prevented?]. The previous analysis may have recommended a "No Scheduled Maintenance" policy in which case, the outcome was expected and no further action need be taken unless the failure has now become more of a problem than originally thought [Increasing problem?]. Then modifications and a revision of the RCM should be undertaken based on the decreased reliability. If, however, the recommendation was for PM and the PM has failed [System Downfall], then the source of the problem needs to be identified and corrective action taken.

Figure 3:

Failure Reporting and Corrective Action System



Typically, the following could have gone wrong:

- The original analysis could have errors of judgement such as the task being set at too long an interval,
- The task is not capable of detecting the potential for failure, or
- The PM was not done.

The findings of this analysis are the means by which the Optimised PM program is assessed.

13 Comparing PMO2000™ with RCM

Review of the RCM Approach

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 dose 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)?

Functional Differences

RCM and PMO are both methods used to define the complete maintenance requirements of physical assets.

Nowlan and Heap (1978) coined the term Reliability Centred Maintenance (RCM) as a process to be used to draw up maintenance programs for aircraft before they entered service (Moubray, 1997). Thus it was a zero-based tool developed for use in the design phase of an asset's life cycle.

In the absence of better methods, since Nowlan and Heap, RCM has been applied retrospectively to plants well into their life cycle. In over 20 years 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 suggesting that there need to be alternate paths to the creation of maintenance policies rather than starting from scratch.

In response to this need, PMO was developed as a process of review for assets that have an established maintenance program (formal or informal) but where that maintenance program was inefficient or misaligned with business needs.

Methodology Differences

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

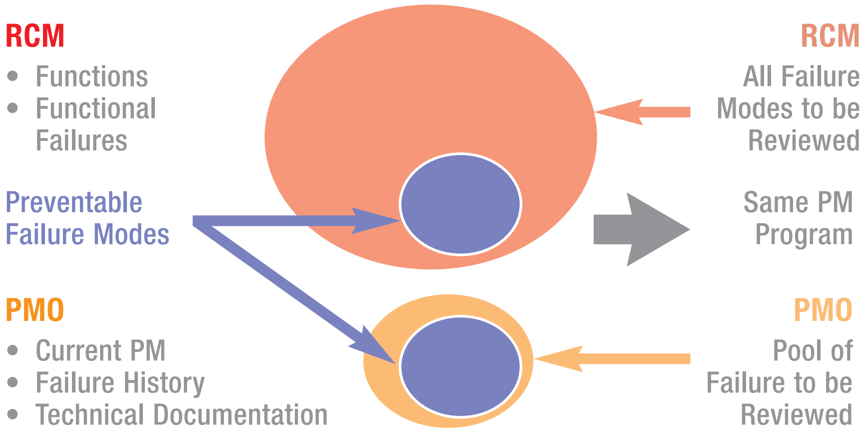


Figure 4:
Illustration of how RCM and PMO produce the same result.

- RCM seeks to analyse every reasonably likely failure mode on every piece of equipment within the system being analysed.
- PMO generates a list of failure modes from the current maintenance program, an assessment of known failures and by hazard analysis of technical documentation - primarily Process 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. PMO's selective coverage means that the maintenance program that results will be the same regardless of whether PMO or RCM is used (figure 3). Other differences are discussed in the following paragraphs.

Failure Mode Analysis

The focus of good equipment design is to ensure high levels of reliability, maintainability and operability over the equipment life cycle. At the design stage, this means attempting to eliminate all 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, either:

- Their likelihood is very low. Therefore the cost of a preventive or predictive task is likely to be more than the cost of failure, or
- There is no technically feasible predictive or preventive maintenance task known to manage them.

In the author's experience, rigorous RCM analysis of equipment in accordance with the standard shows that, on average, about 80% of failure modes result with the policy of No Scheduled Maintenance.

This number rises with electronic equipment such as a PLC and falls with equipment that has a high number of moving parts such as a conveyor.

Rolling up of Failure Mode Analysis where Logical

RCM treats each failure mode independently. This results in the same analysis being documented many times but resulting in only one task being recommended for all the failure modes listed. Using RCM this is unavoidable no matter how experienced the analysis team may be.

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 Tables 2 and 3.

It can be seen from Table 2 that providing vibration analysis was a technically feasible and cost effective task to prevent all these failure modes from occurring unexpectedly, PMO would consider the failure modes as a group.

Conversely at Table 3, RCM can be seen to have created a lengthy analysis process compared with PMO. Accepting that the resulting maintenance program will be the same the route to this result covered four times the administration and probably double the analysis time.

Furthermore, with decomposed failure modes, there is additional administrative effort required to roll them back up and link the four failure modes to the one task.

Table 2:
Illustration of Failure Mode Analysis using PMO

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

Table 3:
Illustration of Failure Mode Analysis using RCM

Function	Function 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	Gearbox fails due to wear
	No power whatsoever	Gearbox bearings fails due to wear

Optional Function Analysis

RCM begins with a complete functional analysis of the equipment whereas with PMO this is done as a short discussion at the start of the workshop. Further effort expended on functional analysis is discretionary. This is primarily because consequence evaluation is performed at Question 5 of PMO. As consequence evaluation implicitly involves understanding what loss of function is incurred, additional functional assessment is a duplication[5] of effort.

Completed according to the standard (Moubray 1997), functional analysis consumes 30% of the total RCM analysis time. In our experience this is the lowest value adding activity of the process in most cases. One of the arguments against PMO is that by making functional analysis discretionary the workshop team can miss the occasions when the equipment is near incapable of meeting site expectations. Using PMO, this fact will become evident during the workshop preparation without compiling a comprehensive functional assessment.

Flexibility Comparisons

Filtering of Failure Modes by Trade

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. With PMO it is possible to review the activities of a particular trade on a particular piece of equipment or site. This is because PMO begins with maintenance tasks that can be filtered by trade. This is particularly useful when the activities of one trade are ineffective or inefficient and need to be reviewed in isolation from other trades.

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 many hours 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. Conversely, PMO would require only the operators as electronic failure modes would not form part of the pool of failure modes that are currently addressed by PM nor part of the failure history to any great extent.

PMO 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.

[5] 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.

Benefits of Speed

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 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 valuable and scarce on site. The less resource intensive the program (for the same results) the less the organisation will suffer from the loss of its most valuable people.
- Efficient analysis allows the organisation to be implementation intensive rather than analysis intensive.
- Maintenance analysis is subject to diminishing returns. PMO is cost effective on all items of the plant whereas it is difficult to justify RCM on any other than critical assets because of the high fixed cost and the inflexibility of the process.
- Where the maintenance of failure modes that have safety or environmental consequences is considered suspect, the use of PMO will allow these issues to be dealt with much faster than by using RCM as they will be eradicated plant wide six times faster.
- First line supervisors who invest in the program get rewarded with labour productivity improvements six times greater. PMO targets a return on analysis time of 5 to 1. That is for every man-hour invested in analysis, five man-hours will be returned to the department every year. At this rate, line supervision is prepared to invest their resources. At a rate six times less, they often become uncooperative.

Typical Results

For organisations which are in a reactive maintenance cycle, the proper application of all PMO steps typically results in the total downtime for the plant being halved within 12 to 18 months.

In addition, the labour productivity aspects of the program usually result in releasing maintenance labour for work on further reliability improvement projects. This additional work typically provides further improvements coming through in the following years.

19 Conclusion

There are numbers of factors contributing to the difficulties faced by asset managers in the current business environment. Many maintenance organisations are caught in a vicious cycle of reactive maintenance which leaves them exposed to unknown risks of safety, environmental or commercial disasters (hazards), low plant performance, high maintenance costs and a workforce with low morale and motivation.

- To break the vicious cycle of reactive maintenance, experience has shown that an effective approach is to focus on both machine and labour productivity whilst reducing hazard risk.
- RCM is a process that was originally developed for use in the design phase of equipment life cycle. It is an inefficient process when used to review an existing maintenance program.
- PMO is a process of analysis developed to meet industry needs of an efficient analysis process for companies with in-service equipment.
- Both RCM and PMO generate the same results when used in mature plants. Neither provides defensible protection against catastrophic failure as neither considers the effects of multiple evident failures which evidence shows to be the lethal cocktail.
- Asset managers should recognise that PMO and RCM are quite different tools and should apply each where they are appropriate. PMO is far more efficient for in-service equipment than RCM, therefore a PMO program should be considered ahead of an RCM program in these circumstances.

OMCS Asia-Pacific Sdn. Bhd.
Suite 4005 4th Floor President House
Jalan Sultan Ismail
Kuala Lumpur Malaysia 50250
Telephone: +6 03 2144 6455
Facsimile: +6 03 2164 3944
Agust Tan
Mobile: +6 019 382 7699
agust@omcsap.com

Malaysia
Mark Jones
Mobile: +6 019 664 7699
mark@omcsap.com

Australia
Steve Turner
Mobile: +614 1939 7035
steve@omcsap.com

Indonesia
Tony Hartono
Mobile: +628 1115 3159
tony@omcsap.com

Singapore
Jeffrey Huan
Mobile: +65 9690 1968
jeffrey@omcsap.com

www.reliabilityassurance.com

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A significant amount of further information is available from PMOptimisation web site at www.pmoptimisation.com