



ELEMENTS OF AN EFFECTIVE
MAINTENANCE PROCESS
Understanding the
Requirements of a World Class
Maintenance Organization

Whitepaper

Written by:
Ron Thomas
Senior Reliability Practitioner
and Project Manager,
Dofasco

IVARA CORPORATION
935 Sheldon Court,
Burlington Ontario, Canada. L7L 5K6

Elements of an Effective Maintenance Process, Version 2

Copyright © 2006 Ivara Corporation. All rights reserved.

Information in this document is confidential.

No part of this document may be reproduced, stored in a retrieval system or transmitted in any form or any means electronic or mechanical, including photocopying for any purpose other as agreed without permission of Ivara Corporation.

Ivara Corporation
935 Sheldon Court
Burlington, Ontario
Canada. L7L 5K6
Toll free: 1-877-746-3787
Tel: 905-632-8000
Fax: 905-632-5129
www.ivara.com

Physical Asset Management

The purpose of most equipment in a production process is to support the production of product destined to downstream customers. Ultimately our focus is on meeting customer needs. This is illustrated in **Figure 1**. Customer expectations are normally defined in terms of product quality, on-time delivery and competitive pricing. By reviewing the composite requirements of all current customers and potential customers in those markets we wish to penetrate, the performance requirements of our physical assets can be defined. Equipment performance parameters can be associated with quality, availability, cost/unit, safety and environmental integrity. To achieve this performance there are three inputs to be managed.

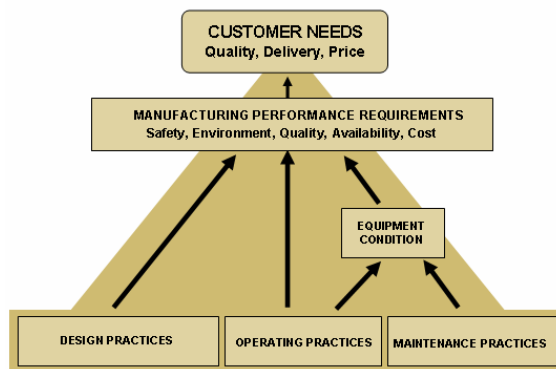


Figure 1: Managing physical asset performance to meet customer needs

The first requirement is **Process Technology**. Process Technology provides capable equipment "by design" (inherent capability), to meet the equipment performance requirements.

The second requirement is **Operating Practices** that make use of the inherent capability of process equipment. The documentation of standard operating practices assures the consistent and correct operation of equipment to maximize performance.

The third requirement is **Maintenance Practices** that maintain the inherent capability of the equipment. Deterioration begins to take place as

soon as equipment is commissioned. In addition to normal wear and deterioration, other failures may also occur. This happens when equipment is pushed beyond the limitations of its design or operational errors occur. Degradation in equipment condition results in reduced equipment capability. Equipment downtime, quality problems or the potential for accidents and/or environmental excursions are the visible outcome. All of these can negatively impact operating cost.

The Asset Reliability Process

The management of physical asset performance is integral to business success. What we manage are the business processes required to produce results. One of these business processes is responsible for the maintenance of physical asset reliability. The Asset Reliability Process is shown in **Figure 2**. It is an integral part of a much larger business process responsible for managing the total enterprise.

The Asset Reliability Process focuses the maintenance of physical asset reliability on the business goals of the company. The potential contribution of the equipment asset base to these goals is evaluated. The largest contributors are recognized as critical assets and specific performance targets identified.

The Maintenance Process, represented by the series of six (6) elements on the right of the model aims to deliver the performance required by the enterprise to meet all of its corporate objectives. Each element within the Maintenance process is in itself a sub-process. A brief description of each element follows:

Work Identification, as a process, produces technically based Asset Reliability Programs. Program activities identify and control failure modes impacting on the equipment's ability to perform the intended function at the required performance level. Activities are evaluated to judge if they are worth doing based on the consequences of failure.

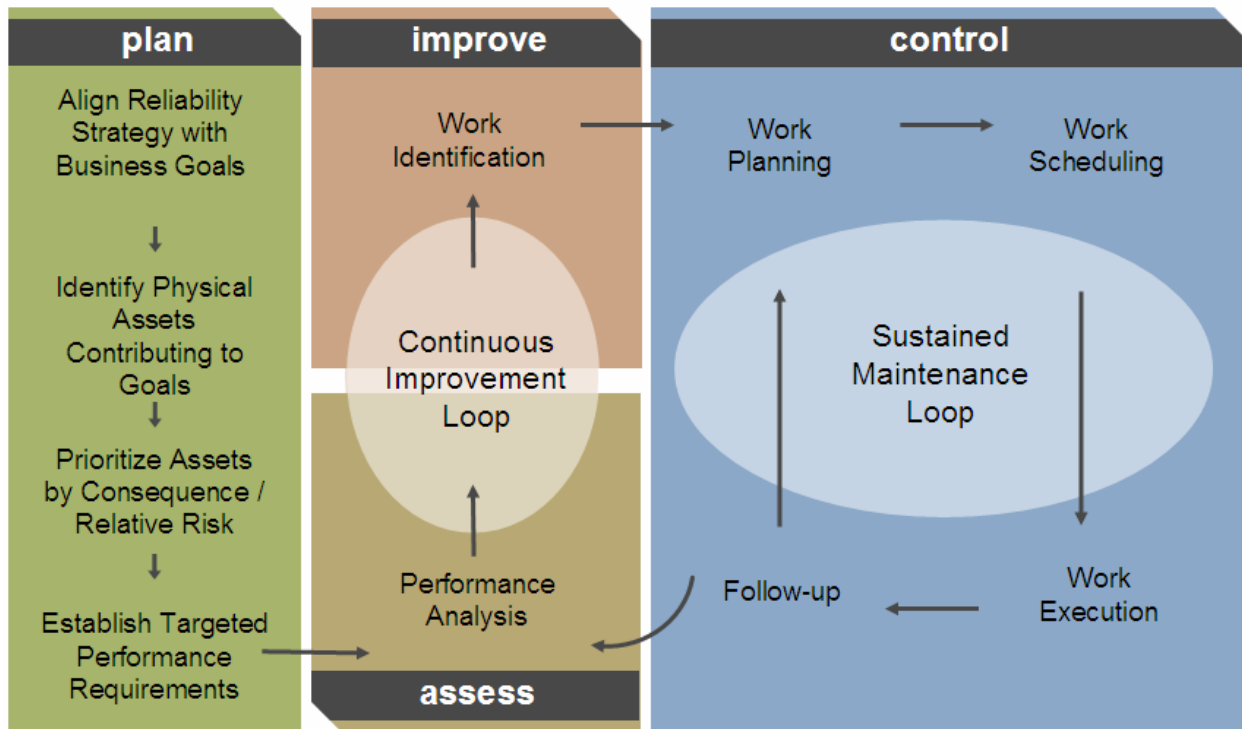


Figure 2: Asset Reliability Business Process Model

Planning develops procedures and work orders for these work activities. The procedures identify resource requirements, safety precautions and special work instructions required to execute the work.

Scheduling evaluates the availability of all resources required for work "due" in a specified time frame. Often this work requires the equipment to be shut down. A review of production schedules is required. Resources are attached to a specific work schedule. The use of resources is balanced out.

In the **Execution** process, trained, competent personnel carry out the required work.

The **Follow-up** process responds to information collected in the execution process. Work order completion comments outline what was done and what was found. Actual time and manpower, to complete the job, is documented. Job status is updated as complete or incomplete. Corrective work requests, resulting from the analysis of

inspection data, are created. Requests are made for changes to drawings and procedures.

The process of **Performance Analysis** evaluates maintenance program effectiveness. Gaps between actual process performance and the required performance are identified. Historical maintenance data is compared to the current process performance. Maintenance activity costs are reviewed. Significant performance gaps are addressed by revisiting the Work Identification function.

Each element is important to provide an effective maintenance strategy. Omitting any element will result in poor equipment performance, increased maintenance costs or both.

For example, Work Identification systematically identifies the Right Work to be performed at the Right Time. Without proper Work Identification, maintenance resources may be wasted. Unnecessary or incorrect work will be planned. Once

executed, this work may not achieve the desired performance results, despite significant maintenance costs. Without Planning the correct and efficient execution of the work is left to chance. The Planned Maintenance Process is a cycle. Maintenance work is targeted to achieve required asset performance. Its effectiveness is reviewed and improvement opportunities identified. This guarantees continuous improvement in process performance impacted by Maintenance. Within the Planned Maintenance Process two internal loops exist. Planning, Scheduling, Execution and Follow Up make up the first loop. Once maintenance activities are initially identified, an Asset Reliability Program, based on current knowledge and requirements, is initiated. The selected maintenance activities will be enacted upon at the designed frequency and maintenance tolerance limits. The process is self-sustaining. The second loop consists of the Work Identification and Analysis elements. This is the continuous improvement loop. Actual Process Performance is monitored relative to the demands placed on the process (driven by Facility Goals). Performance gaps are identified. The 'cause' of these gaps is established and corrective action recommended. The criteria for defining the maintenance activities, established in the Work Identification process, are revisited using updated information. The Asset Reliability Program is revised to optimize its effectiveness.

Parallel Strategies for Asset Reliability Program Development

Work Identification is the cornerstone of the Asset Reliability Process. Careful attention to the practices associated with the sustained maintenance loop impacts the efficiency of the maintenance effort. However, as noted earlier, if the right work at the right time is not identified, the desired performance of the asset will not be achieved.

Different strategies can be used to define or refine the maintenance program for equipment. These may include the

application of Reliability-centred Maintenance (RCM), Maintenance Task Analysis, the application of Predictive Maintenance Needs Assessments, as well as the use of preventive maintenance optimization techniques and failure analysis techniques. There are many other hybrid approaches available in the market combining elements of the above that can be applied in pursuit of maintenance program development efficiency. The user of these methodologies almost always is looking for the solution with the lowest resource intensity promising to deliver the highest equipment reliability performance.

Our experience has demonstrated that a business case can be developed for the use of parallel strategies for asset reliability program development. This is because the operating performance of different assets varies and what is currently being done to secure that performance varies significantly from asset to asset. In some cases mature, well-documented maintenance programs are yielding excellent performance while in other cases little evidence of any proactive maintenance exists. Quantifying these variables on other assets across the organization provides a spectrum of everything in between. This can be further complicated by new equipment being commissioned on tight time schedules with minimum resource availability for maintenance program development.

Reliability-centred Maintenance (RCM), the most robust of the Work Identification approaches provided the highest assurance that all reasonably likely causes of failure will be addressed. However, it is intuitively obvious that it isn't practical to wait to upgrade the maintenance programs on assets not initially targeted for the application of RCM. As a result, several alternative approaches can be implemented. Each of these approaches uses RCM thinking but is much less rigorous in approach, increasing the risk of equipment failure on the equipment where it is applied. The challenge is to educate the user on the appropriate selection of these maintenance program development approaches.

This paper describes an approach to select the appropriate maintenance program development methodology for individual assets. When applied across an enterprise this rational normally requires the adoption of several approaches simultaneously.

Classifying Maintenance Work

Maintenance work is defined as the collection of work done on the equipment with the intent of predicting, preventing or correcting equipment failure. It excludes all work done to modify the initial capability of the asset and improve its performance.

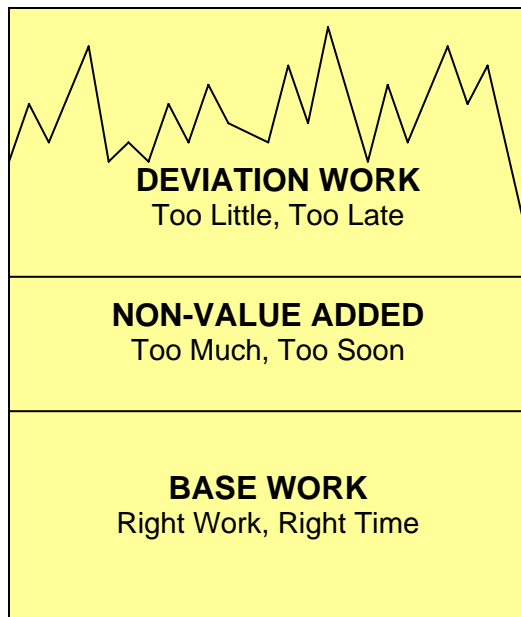


Figure 3: Classifying Maintenance Work

The illustration in Figure 3 shows a hypothetical breakdown of all 'Maintenance Work'. The work is classified into three types.

The first type of maintenance work is called 'Base Work'. 'Base Work' is defined, as the minimum work required by the asset to deliver its targeted performance requirements.

Simply put it is the collection of *'The Right Work at the Right Time'*.

The second type of maintenance work is defined as 'Non-Value Added Work'. Included in this category are any activities done in the name of preventing or predicting failure that are not necessary to achieve the targeted performance requirements. This includes unnecessary inspections and scheduled overhauls. It also includes the execution of any predictive or preventive task more frequently than required.

In other words, this work can be described as *'Too Much / Too Soon'*.

The third type of maintenance work is 'Deviation Work'. This work results from equipment failure. The absence of base work and the presence of non-value added work, disrupting otherwise stable systems contributes to the number of failures that occur and increases the volume of 'deviation work'. Failures that are non-maintenance preventable and failures that are not worth preventing are also included.

This work can be categorized, for the most part, as *'Too Little / Too Late'*.

Asset Reliability Program Development Strategies

Reliability programs for equipment can be identified using different strategies with differing levels of rigor and resource intensity. Program completeness and program accuracy are traded for speed and resources. With less rigorous approaches comes increased risk of equipment failure. However, substantial performance improvements in equipment reliability may be achieved quickly with minimum resource effort in 'some' applications. These different strategies are briefly described here.

Maintenance Task Analysis

A common way to develop an asset reliability program is to 'implement the obvious' proactive tasks recommended by various sources of knowledge about the equipment. These knowledge sources include manufacturer recommendations, tasks done on similar equipment and the

input of skilled trade personnel and specialists. Over time, templates summarizing failure modes and maintenance action plans by type of equipment are developed to speed up the review process. In all cases, these templates need to be carefully reviewed to ensure that the recommended tasks are applicable and effective in the context of the equipment being reviewed.

Maintenance Task Analyses are intended to define 'base work'. In the absence of a proactive asset reliability program, this approach can be effective in reducing maintenance preventable failures.

However, they are not conducted following a rigorous process. The potential exists to miss required tasks, specify tasks that are not required and incorrectly specify task intervals. This can result in the creation of 'non-value added' work or 'deviation' work resulting when unnecessary intrusive maintenance interferes with an otherwise stable system.

Predictive Maintenance Needs Assessment

In recent years, tremendous advances have been made in the area of condition monitoring and predictive maintenance. When properly applied this form of maintenance is highly desirable allowing the user to leave the equipment in service until its condition deteriorates to the point that failure is imminent. The useful life of equipment is maximized. Personnel with knowledge of these technologies are able to quickly identify opportunities to apply the technology based on their experience with other equipment and systems. The Predictive Maintenance Needs Assessment combines predictive maintenance expertise and process expertise to make recommendations for the application of condition monitoring techniques. This includes, but is not limited to, the application of vibration monitoring, thermography, lubrication serviceability and wear and contamination testing, traditional non-destructive testing techniques and electrical

equipment monitoring techniques. The objective is to realize the benefits of applying predictive maintenance technology in the shortest time with minimum resource intensity.

The Predictive Maintenance Needs Assessment attempts to define the predictive maintenance component of 'base work'. This could include displacing some intrusive maintenance tasks.

Reliability-centred Maintenance (RCM)

Reliability-centred Maintenance (RCM) is a rigorous, highly structured approach to work identification. RCM can go beyond maintenance program development by including failure modes addressing causes of human error and design deficiencies. When these are included RCM produces the following outcomes:

- ◆ Maintenance Programs evaluated on technical feasibility and worth doing.
- ◆ Recommendations addressing changes to standard operating practices.
- ◆ Operational and Maintenance training recommendations.
- ◆ Physical redesign recommendations.

The RCM process requires answers to the following seven questions:

1. What are the functions of the asset in its present operating context?
2. In what ways can it fail?
3. What causes it to fail?
4. What happens when it fails?
5. Does it matter if it fails?
6. What can be done to predict or prevent the failure?
7. What can be done if you can't predict or prevent the failure?

Why RCM?

It is not the intent of this paper to describe how to do RCM but to help the reader better understand the validity of its application. To this end, what is described is some thinking that helps justify why each of the seven steps in RCM is required to rigorously define a comprehensive maintenance program.

Deviation from these steps requires the user to make assumptions about the steps that have been simplified or missed. More assumptions substantially increase the risk that the desired outcome of reliable asset performance will not be achieved.

An Asset Reliability Program is designed by selecting maintenance tasks directed at failure causes or failure modes. Tasks are defined to predict, prevent or detect failure and provide opportunity to take action to minimize the failure consequence.

In defining a maintenance program, each task needs to be rationalized against the cause of failure it is meant to address. If a task does not address a known cause of failure, it should be excluded from the maintenance program.

Therefore, a task included in the maintenance program must successfully address a specific cause of failure and the effort associated with doing the task should be considered worth doing when compared to the consequence of the failure that it is meant to prevent.

The RCM process includes a detailed failure mode and effect analysis. All failure modes, considered reasonably likely to occur are identified. This is done to ensure that the failure management strategy is comprehensive, addressing all reasonably likely causes of failure. Recommendations must be made to deal with each cause of failure. Failure effect descriptions provide sufficient information to evaluate the consequences of failure. The RCM decision logic provides criteria for 'technical feasibility', determining if a task can successfully manage the failure consequence and criteria for establishing whether the task is 'worth doing'.

This explains the rationale for including detailed failure mode and effect analysis and task selection criteria in a maintenance program development methodology accounting for questions 3 to 6 in the RCM process.

The inclusion of question 7 in the RCM methodology deals with those instances when the failure mode cannot be addressed by performing a scheduled maintenance task or it is not worth doing. Sometimes, the default decision in RCM could be a conscious decision to allow the equipment to run-to-failure because the failure consequences are tolerable and preventing the failure may not be technically feasible or worth doing. Also, human error causes and design deficiencies can account for a surprisingly high number of failure modes in an RCM analyses. Other default decisions covered by question 7 provide the ability to define recommendations to modify operating procedures, train maintainers and operators and to redesign the equipment. The technical basis for each recommendation is provided. All reasonably likely failure modes are addressed by recommending the best failure management strategy whether it is proactive maintenance or not.

The above discussion illustrates that maintenance program development deals with identifying and successfully managing failure causes. In order to develop a maintenance program, persons charged with this responsibility must ensure that they identify all reasonably likely causes of failure. At this point in the process, one 'huge' assumption has been made. We assume that everyone understands what constitutes failure. Why is this important?

Most people associate failure with complete loss of use. A car that doesn't start certainly has failed by any driver's standards. To prevent one cause of this failure, we routinely check the fuel gauge and refill the fuel tank as required. It is straight-forward to decide when the intervention is required. When the tank is empty, the car stops.

However, there may be other performance expectations. For example, the owner/user of an automobile might have an expectation around fuel efficiency. Over time, system deterioration and wear causes the car to consume more fuel and increases operating costs. At some point, the performance of the car is deemed unacceptable to the owner/user and the car is scheduled for a tune-up. Failure, in this case, is related to lack of performance. The definition of acceptable performance is defined by the owner/user. In the extreme case, if the owner/user has a high tolerance for fuel inefficiency they might not care as long as the car is running. The decision to intervene and when to intervene is related to the performance standard that has been set. If a 'failed state' is not recognized the 'failure causes' leading to the failed state may be overlooked. When defining a maintenance program it is imperative to understand the performance expectations of the owner/user so that all failures can be defined. Once the failure is identified all failure modes resulting in that failure can also be identified.

In RCM, failure is defined as the inability to meet a performance standard. Functional failures are defined for each performance standard that can be breached. These functional failures are summarized in Question 2 of the RCM process.

The need to define standards of performance in creating a maintenance program now seems clear. But a performance standard must apply to something. For example, a performance standard on speed means nothing unless it is clear that it applies to a person, a car, a train or an airplane. In fact, performance standards are associated with things and more precisely they apply to 'what things must do'. Physical assets exist in the first place because we want them to perform specific 'functions' at or above a minimum level of performance. Most assets have more than one function with related performance standards. To ensure that all 'functional failures' are considered and all failure causes are identified the maintenance program development strategy must start by considering all the functions

and performance levels required by the owner/user.

In fact, the definition of functions precisely defines the objectives of maintenance. Question 1 in the RCM methodology defines the functions of the asset.

Each step in the RCM process is logical and necessary. A properly applied RCM analysis minimizes the risk that significant causes of failure are overlooked. All reasonably likely causes of failure are considered and addressed by recommending the optimum failure management strategy. One of these outcomes is a technically based Asset Reliability Program designed to deliver the targeted performance requirements of the owner/user. This is by definition, the 'base work' for the asset being analyzed. Existing routine tasks not validated by RCM are the 'non-value added' component of work and should be eliminated. The complete identification of the 'base work' will also result in the minimum 'deviation work'.

Failure Analysis

Different approaches are available to investigate the cause of failures and identify what should be done to prevent them from re-occurring. Like Reliability-centred Maintenance, failure analysis methodologies seek to identify the failure modes responsible for equipment failure. Failure analysis is conducted in reaction to a specific failure. It seeks to identify the cause of that failure and what should be done to prevent the specific failure cause in the future. Often the focus of failure analysis is on the component (s) that have failed.

RCM is proactively applied at the system level, identifying functions, functional failures and considering all the failure modes reasonably likely to occur and their proper disposition. One possible way of conducting a failure analysis review is to conduct a partial RCM analysis. When a failure occurs, identify the functional failure that has been breached not just the component failure. Complete the RCM process for the single functional failure. Identify all reasonably likely causes of failure including the (root) cause of the failure this time. Apply the RCM

decision logic to define the appropriate failure management strategies for all the causes of the functional failure. Failure analysis techniques are aimed at eliminating 'deviation work'.

Reliability Program Optimization

Many RCM like approaches have been developed focusing on the optimization of current maintenance programs. Statistics are available that claim when RCM is applied to a mature, well-defined maintenance program 40% to 60% of the maintenance can be eliminated. This generally occurs because maintenance programs evolve over time through the combination of best practice reviews, applying generic standards and by 'just in case / never again' additions reacting to previous failures. Individual tasks are added with no formalized review criteria. This statistic illustrates one downside of unstructured maintenance program development; that being the magnitude of non-value added work that can result.

The technical feasibility and worth doing criteria used in RCM can be applied to existing maintenance programs if it is easy to identify the failure mode that the task is meant to address. This may seem straightforward but experience shows that many mature well-defined maintenance programs include statements like "inspect the gearbox" with no qualifications. Once the failure mode is determined, the task is evaluated against the defined criteria to decide whether it stays or goes. It is possible for a different task to emerge as the preferred task.

Maintenance program optimization techniques draw heavily on the logic within RCM but generally shortcut the first part of the process where functions and functional failures are defined. As we have seen, it is through the definition of functions and functional failures that we are able to establish maintenance objectives. Functional failure defines the threshold of failure impacting both the need for tasks and the timing of those tasks. In the absence of this review, more assumptions must be made in the decision making process. Maintenance program optimization

techniques focus on the elimination of 'non-value added' work.

A Rational Approach to Applying Parallel Strategies

In **Figure 4**, a matrix has been produced to aid in selecting the initial maintenance program development approach for an individual asset.

The horizontal axis is titled, "Maintenance Program Definition". The position along the horizontal axis refers to the degree that the required proactive maintenance for the selected asset is both known and documented. A position to the far left of the axis represents a situation where the proactive maintenance program is neither known nor documented. The extreme right would represent the existence of a detailed, documented maintenance program.

The vertical axis represents how well the

Figure 5: RCM identifies Base Work, eliminates Non-Value Added Work minimizing Deviations.

selected asset is currently performing. A low position on the vertical axis represents an asset whose performance is poor while a high position on the vertical axis represents an asset whose performance is very good.

Let us now examine several scenarios using the resulting matrix.

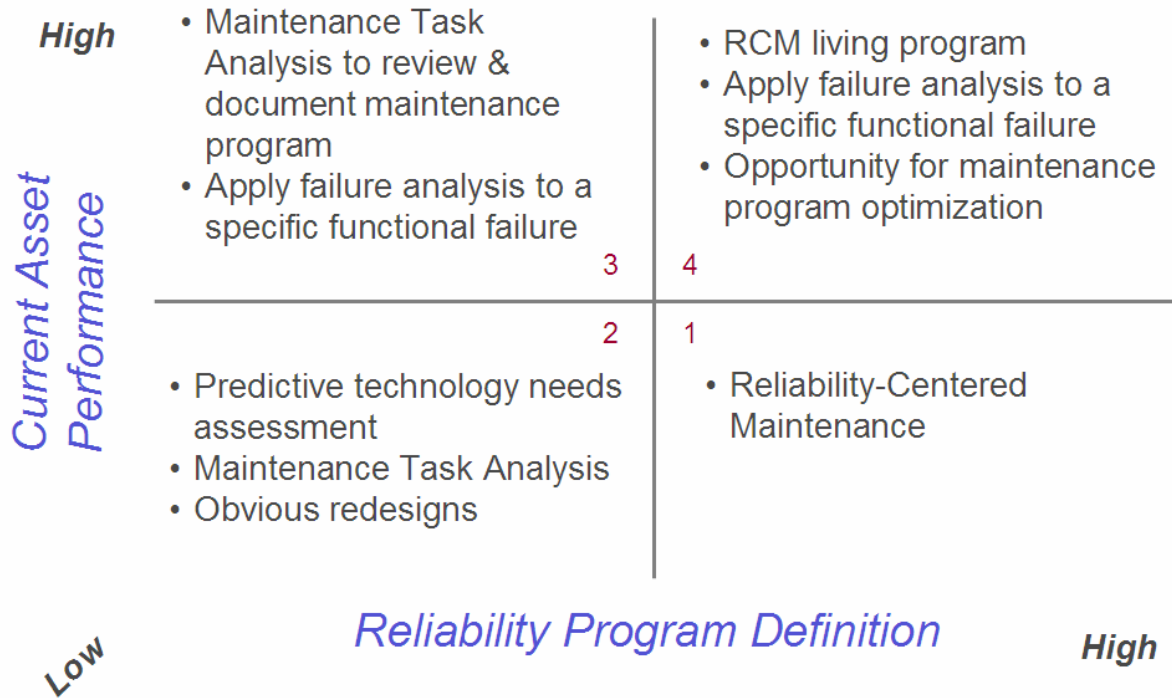


Figure 4: Maintenance Program Development Approach Selection Matrix

Quadrant 1:

Analysis: In quadrant 1, the selected asset has a low level of maintenance program definition and asset performance is poor. The asset experiences many failures and the maintenance effort is highly reactive. Minimum proactive maintenance is being executed.

Suggested Approach: Opportunity exists to use Best Practice Reviews and Predictive Maintenance Needs Assessments to establish the maintenance program. Changing the emphasis to proactive maintenance will help to stabilize the situation. Resource intensity in developing the program should be low and emphasis placed on speed to implement.

Pitfalls: A major pitfall is spending too much resource time to identify the program. Resources are likely a constraint because of the volume of reactive maintenance. The initial maintenance program may include non-value added work (unnecessary tasks or tasks done at incorrect frequencies) or exclude base work resulting in failures.

Quadrant 2:

Analysis: In quadrant 2, the selected asset has a low level of maintenance program definition but asset performance is good. It can be inferred that much of the right maintenance is currently being performed but the lack of maintenance program definition is the result of the absence of documentation describing the proactive maintenance being executed. This is often the case where a mature work force has a history working with the equipment. They know what to do and they are doing it.

Suggested Approach: Document the proactive maintenance being executed by conducting Best Practice Reviews with the equipment specialists. This needs to be done to capture the knowledge base and ensure that performance can be sustained if resources move or retire. There is also opportunity to use a more structured failure

analysis approach to focus on the failures that do occur and refine the maintenance program.

Pitfalls: A major pitfall is spending too much resource time to document the program. The maintenance program may include non-value added work (unnecessary tasks or tasks done at incorrect frequencies).

Quadrant 3:

Analysis: In quadrant 3, the selected asset has a high level of maintenance program definition but asset performance is poor. The high level of maintenance program definition indicates that the poor performance is not due to lack of attention. Consideration has likely been given to all the Best Practices and the solution to the problem is not that obvious or accepted. If it were, it would have been already done.

Suggested Approach: Apply a rigorous, structured approach like Reliability-centred Maintenance. By applying RCM, the base work will be defined; non-value added work eliminated and deviation work minimized. Review the RCM analysis if and when a failure occurs or whenever there is a change in the operating context for the asset.

Pitfalls: Applying RCM to assets that have not been properly prioritized against business objectives. The business case for performing the RCM analysis should be communicated and understood.

Quadrant 4:

Analysis: In quadrant 4, the selected asset has a high level of maintenance program definition and asset performance is good. This indicates that much of the maintenance being done is effective at managing failure. If the maintenance program wasn't created using a rigorous approach like RCM, potential exists for the presence of non-value added work (unnecessary tasks or tasks done at incorrect frequencies).

Suggested Approach: Opportunity exists to apply maintenance optimization techniques to screen the existing maintenance program and eliminate non-value-added work. Use

failure analysis to focus on the failures that do occur and refine the maintenance program.

Pitfalls: If too much time is spent applying a partial RCM approach yielding only partial results, one should consider why RCM is not done. Maintenance optimization techniques provide the means to review current tasks. However, in the absence of complete function and functional failure development there is no mechanism to ensure that all reasonably likely causes of failure are explored and that missing tasks are addressed. Often a best practice review is combined with maintenance program optimization to ensure required tasks are not missed. This increases the resource requirements but adds no formal structure.

The bigger danger is over-estimating current asset performance. This is particularly true in the assessment of current risk performance.

Operational performance indicators and the total number of failures associated with an asset may be acceptable. However, the risk of a failure with severe safety, environmental or economic impact may be many orders of magnitude higher than desirable and not recognized. The implication of this is that the organization will experience a catastrophic failure sometime in the future and more probably the near future.

The Case for Parallel Strategies

The matrix described above provides a means for deciding the initial rigor required in addressing an asset maintenance program. Within most organizations assets will be found at all levels of performance, with varying degrees of maintenance program definition.

It follows that no one strategy for maintenance program development will satisfy all applications. The plan addressing the maintenance programs in an organization could include parallel strategies. Low performing assets in the company, where minimal proactive maintenance has been applied, become candidates for the rapid deployment of

Maintenance Task Analysis incorporating Predictive Maintenance Needs assessments.

Other equipment may initially warrant a combination of Predictive Maintenance Needs Assessment and Maintenance Program Optimization techniques. Still other equipment may require that current programs simply be documented to sustain them.

In parallel with these strategies there should be a plan to apply a rigorous review process such as RCM. RCM application should be prioritized based on potential impact to the business.

In many cases RCM analyses identify failure modes directly impacting safety and environmental integrity, in addition to their operational impact. As such, the owner/user has a legal obligation to reduce the risk associated with these causes of failure to a level tolerable to society as a whole. It is not abnormal for the presence of these failure modes or their potential consequences to be a surprise to the RCM review team conducting the RCM analysis. Less rigorous strategies should be applied with the knowledge that the technical basis and completeness of the outcome is sacrificed. If failure modes with Safety or Environmental outcomes are missed the potential for very serious consequences indeed exists.

In theory, non-rigorous strategies should be applied quickly, with low resource intensity moving through the organization quickly. Once all the low hanging fruit is eliminated, all that will be left will be problems requiring a more rigorous approach to find a solution. As the organization progresses more of the effort expended on the work identification function will be directed to applying rigorous approaches. Eventually, Reliability-centred Maintenance will become the primary tool of choice to hone the maintenance program and minimize risk.

ACKNOWLEDGMENTS

The description of RCM in this paper refers to the application of the RCM2 process. A detailed explanation of RCM2 can be found in the following reference: Moubray, John. Reliability-centred Maintenance. Industrial Press, New York. 1997.