
Maintenance Excellence Review

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MAINTENANCE EXCELLENCE REVIEW

By

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Introduction

This course is aimed at individuals who are currently familiar with asset maintenance programs but are uncertain if their program is as effective and efficient as possible. Obviously, a broad range of assets depend on maintenance programs for their on-going health. Chemical plants and refineries, durable good manufacturing plants, paper mills, metals refineries and transportation fleet shops are just a few examples of the industrial and commercial systems of assets dependant on maintenance programs.

In each of those cases, the maintenance being performed can either be highly effective and efficient or it can be marginal. In the latter case, both the cost of maintenance and the products or results of the maintenance program can be a significant burden on the profitability of the business being served.

For individuals working in those industrial and commercial settings described above, they frequently speculate how their own performance fits as compared to their business segment as a whole or the companies who are leaders within their business segment. While benchmarking information that compares various business elements (including maintenance) is available within many industries, that comparative performance information seldom describes the behaviors needed to achieve the performance level consistent with industry leaders.

The maintenance performance level consistent with industry leaders is frequently referred to as **Maintenance Excellence**. Maintenance Excellence is not only performance at a level consistent with the **Key Performance Indicators (KPIs)** of the leading organizations in a given industry; it is a nature of performance that mirrors the behaviors of the best performers in their group.

Rather than focusing on the specific behavior of a specific industry, this course will focus on the various processes that are generally important to all industries. Then within those business processes, the course will define the elements that must be addressed in a manner that will produce “industry best practice” results. For instance, two distinct elements that are consistently required throughout all forms of maintenance are planning and scheduling. Independent of what form

of maintenance is being done or what industry it involves, the work must be well planned and tightly scheduled to effectively use all resources and to complete work in a timely manner. These examples are provided as an introduction to the critical forms of behavior that must be integrated in all business processes or worn management processes to achieve Maintenance Excellence.

Defining Maintenance Excellence

As mentioned in the introduction, the maintenance performance level consistent with industry leaders within a specific industry can be referred to as **Maintenance Excellence**. Obviously some industries have had a more disciplined focus on maintenance for a longer period of time than other industries. As a result, the “best performers” from those industries will be more advanced than the best performers in other industries. Some of the difference will have to do with the level of performance necessary to “function” within that other industry. Some of the difference will have to do with what is necessary to “complete” within an industry. For instance, commercial aircraft must be maintained at a higher level than dump trucks. So, simply to function in the airline industry, all organizations must provide a high level of maintenance. Further, since effective and efficient maintenance determines the “cost of doing business” and determines the reliability and availability of assets, a certain level of maintenance is necessary for all companies in a given industry for them to compete with other companies in the same industry.

As a result, Maintenance Excellence tends to be a characteristic that is somewhat industry-specific. It is important to understand the level of maintenance needed to keep assets functioning and safe. It is also important to manage maintenance spending in a manner and at a level that allows the company to be competitive with other companies in the same industry.

It is possible to identify specific tools that are useful in supporting the effectiveness and efficiency of maintenance. On the other hand, history has shown that companies who simply try to adopt the tools used by industry leaders are not successful in closing the gap between their performance and that of the leaders. Closing the gap between current performance and industry leading performance necessitates changes in behaviors to more closely emulate the leaders.

As an example, the best performers within the refining industry might currently use state-of-the-art diagnostic tools like ultrasonic (UT) sensing devices. Simply

adopting UT devices is unlikely to alter performance. On the other hand, creation of a system that clearly understands the proper role of Predictive Maintenance (PdM) and properly applies UT technology in its proper role is likely to create a situation where significantly improved performance can be achieved.

A widely accepted approach for creating an environment where objectives are clearly defined, followed by activities designed to achieve those objectives, is one that focuses on business processes. The specific business processes that are important to maintenance are **Work Management Processes**.

Work Management Processes

The simplest definition for a Work Management Process is a description of the sequential steps involved in completing a specific form of labor within a specific organization or business. Some organizations focus on a few or a single form of labor and therefore have few or a single process used to manage all their work. Others, like maintenance organizations within a manufacturing plant, must be able to address several forms of labor that occur within the lifecycle of the asset being maintained by that organization. As a result, they must be able to address work in several different ways while remaining effective and efficient in each of them.

A work management process with which most Americans are familiar is the one used in a McDonald's restaurant to order, cook and deliver a hamburger. The apparent process begins with the customer approaching the counter. The process continues with the customer making an order and paying for it. The next step is when the server takes the order and passes it to individuals in the food preparation area. The food preparers either cook the parts of the order from scratch or assemble them from foods that have already been prepared in advance like French fries. The next step is that the parts of the order are packaged and given to the person at the counter to deliver to the customer.

While these steps are the obvious elements of that work process, there are several other elements that are not so apparent but are still important to the efficiency of the process. For instance, the cash register on the counter is set up to take orders only for the products that are served by that McDonald's and the order for each can be completed by pushing a single button. When that button is pushed, a chain of logistics begins to happen in the background that both initiates the immediate food preparation process and initiates the replenishment

process for the raw materials used to fulfill the order, like buns and patties. The data from the transaction is also automatically entered into the accounting system so all important characteristics of the transaction are recorded, including raw material consumption and product sales.

Other elements that are even less apparent are those associated with unspoken expectations. Over the counter there is a sign telling the products that are available and what they cost. There are typically some forms of markings or dividers that maintain the integrity of lines leading up to the servers at the counter. Without having to provide explanations, the customers know what they are allowed to order, what they are expected to pay and how they are expected to queue themselves for ordering. Think of the last time you heard someone in line at McDonalds asking for a BLT sandwich or complaining about the cost of their order. It doesn't happen because those elements are inherent in the design of the process.

By understanding how the process is completed, it is possible to both streamline it and to optimize the results. Think for a moment, if you were to begin making and selling hamburgers out of your kitchen at home, how the process would be conducted? While it might be possible to approach the effectiveness and efficiency of the process used by McDonalds in a number of years, it is likely things would be pretty ragged for quite some time.

The objective of understanding the various work processes used at your place of work is to move them from being as ragged as they might be in your kitchen at home to being as effective and efficient as the McDonalds example. It is desirable to make that transition in a short period of time. It is also desirable to integrate state-of-the-art tools for optimizing the performance as was described for the register on the counter described above. Computers and software automate many of the activities that would otherwise have to be done in a manual manner that distracts attention from the primary objective of performing maintenance (or selling hamburgers).

Operating in Different Timeframes

As a part of the effort to achieve Maintenance Excellence by optimizing work management processes at your place of work, it is critical to keep in mind that people tend to respond to stimuli that makes their activities seem urgent more than they respond to importance. An example of this characteristic can be shown by our response to a ringing phone. Say for instance, you are working on

a critical project that requires your intense concentration to complete when a phone rings. Now let's further assume that the person on the phone is a salesperson hoping have you agree to receive a new credit card. The activity you are performing is important, but the ringing phone seems urgent.

The same problem exists if you mix the activities a person performs with some requiring immediate response and other needing to be completed over an extended period. The short term need always seems urgent and the long-term activity always seems to get lost. As a result, it is important to avoid organizing in a manner that mixes short term demands with long term requirements. Doing so will cause the long term activity to get pushed off. An important characteristic of many long term activities is that, while completion occurs long into the future, the current activities needed to support timely completion of the entire chain of the critical path requires that some amount of work be done now.

The Routine Maintenance Process (RMP)

The Routine Maintenance Process (RMP) is the process by which most of the day-to-day maintenance work is accomplished. The day-to-day work in a refinery or process plant typically includes some amount of proactive work (Predictive and Preventive Maintenance) and some amount of reactive work (repair). While it is possible to include program (like insulation or painting) or project work, combining the different types of work results in some difficulties.

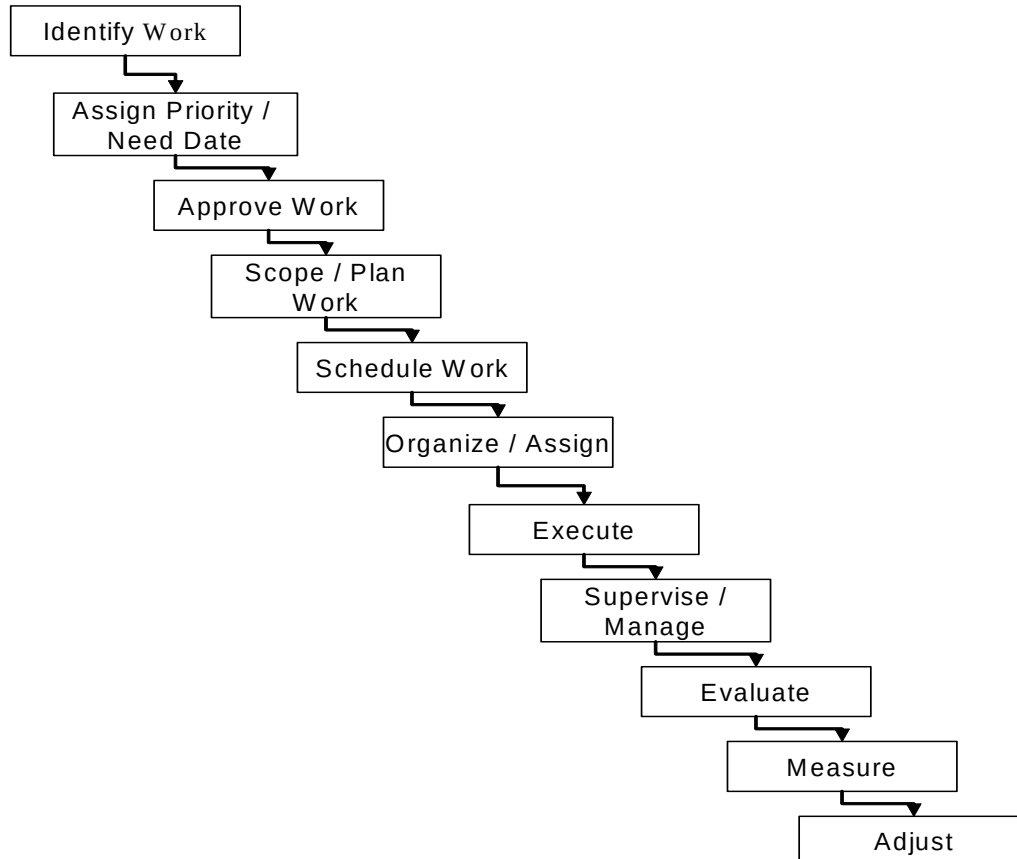
If program work like painting that can be done only during warm and dry weather is combined with routine maintenance work, the quantity of work in the backlog will be distorted. The routine maintenance backlog should include only work that can be addressed immediately. For instance, if the backlog is used to justify the size of the work crew and the backlog includes work that is unavailable, the crew will be sized too large. Combining important project work with urgent routine maintenance work may result in the project work always taking a back seat and never being completed.

Managing backlog and managing the size of the workforce are just two of the elements that must be closely managed in order to achieve "excellent" performance for Routine Maintenance work. Despite that fact, workforce size determines efficiency and costs. And backlog (or the timing of your response to work requests) determines customer satisfaction. Ultimately cost performance and customer satisfaction are two of the elements seen as most important in deciding if excellent performance has been achieved.

The RMP is a process that ensures all day-to-day work is planned in a thorough manner and tightly scheduled into a work plan.

- A useful measure to determine if work has been thoroughly planned is if workers ever need to leave the workplace once work is started. If work has been thoroughly planned, workers will have all tools, materials, instructions, permits, drawings, etc. before arriving at the work site. If the worker needs to leave the worksite for any reason that could have been foreseen, the work was not adequately planned.
- A useful way of describing a tight schedule is by thinking of a wall made up from a number of bricks of different sizes. If the wall has been assembled in a manner where all the different sized bricks fit together without gaps it would emulate a tightly scheduled schedule. Gaps between the different sized bricks would be analogous to openings between jobs that allow for wasted workforce time.

The RMP is typically viewed as consisting of the following steps:



These steps are the process that a specific item of work follows from inception through completion. While the RMP is typically designed to manage each of the steps shown above in an effective and efficient manner, success in performing the RMP can only be achieved by teaching members of your maintenance to behave in a manner that ensures the RMP is accomplished properly. Said another way, you need to focus on the activities of people. If people act in an appropriate manner, the work will take care of itself.

A good example of that point can be made by discussing the concept of scheduling. Clearly, without the flow of the RMP, work cannot be scheduled until after it has been approved and planned. On the other hand, in a plant, the day-to-day scheduling process is something that happens each and every day at a specific time. At say 2:00 pm each day, a group of people get together to schedule the following day's work. All jobs for which planning is complete can be scheduled during that meeting.

While the above protocol describes how the RMP will be carried out, there are several "behavioral" issues that determine the success or failure of the RMP. First, the scheduling meeting must be held early enough each day to allow final preparation and assignment to be accomplished that day. Second, there must be a "discipline" that prevents other work (other than a dire emergency) from being pushed into the schedule at any time after the 2:00 scheduling meeting. Third, there must be an agreement that only fully planned work will be scheduled for all other than dire emergency work.

These simple protocols allow the vast majority of all work to be thoroughly planned. They also allow the individuals assigned to perform Routine Maintenance to "plan their work and work their plan". (People frequently confuse the terms "planning" and "scheduling" as was done in this commonly used saying. Properly stated it should have been stated as "schedule your work and work your schedule".)

Another critical element of the RMP is the feature that allows proper sizing of the workforce and timely responses to changes in workforce demand. As was mentioned above, it is not unusual to use backlog or amount of incomplete work as a basis for the workforce size. It is not uncommon to use backlog durations of two to three weeks as reasonable. This would mean that when the total amount of workable (completely planned and ready to schedule) work is divided by the number of work-hours capable of the current crew in each week, the resulting number of weeks of backlog would be two or three. While

this method is widely used, it is a bit cumbersome and unresponsive to changes. Using this method as a basis for adjusting the workforce size often results in the workforce size never being adjusted. Either the workforce remains too large resulting in higher costs than necessary, or the workforce is unresponsive to increased demands and needed work is addressed too slowly.

A better approach is to monitor the Work Input Rate (WIP) in man-hours each day and compare the number of input hours to the number of man-hours the current crew should be capable of completing each day. When more work has been identified than the crew can handle the crew size should be adjusted upward and when the crew is sized to complete more hours than is being identified, the crew should be adjusted downward.

This approach helps address two important elements of RMP-excellence on a real time basis:

1. It ensures optimum efficiency by ensuring the crew size is being adjusted in real-time.
2. It ensures the appropriate amount of work is being accomplished each day, thus helping to ensure customer satisfaction and currency of predictive and preventive work.

The Turnaround Process (TAP)

The Turnaround Process or TAP is the work process designed to prepare and manage major maintenance activities like those associated with overhauls, outages, turnarounds or shutdowns. The kind of events mentioned are significant maintenance events that occur on a regular while infrequent routine. There are two inherent problems with performing turnarounds in a manner that can be viewed as excellent. First, many organizations do not have separate groups assigned to prepare and execute turnarounds. Second, even for those organizations that have separate turnaround groups; much of preparatory work involves individuals assigned to the groups who are also assigned to perform day-to-day operations and routine maintenance. With either or both of those problems, the issue once again becomes one of competing urgency versus importance. While it may take twelve to eighteen months to adequately prepare for a turnaround, it is difficult to justify spending time on an event that will occur that far in the future when there are immediate problems to address today.

The most important element of achieving excellence in performing the TAP is advanced planning and scheduling. A good way to measure the adequacy of time being spent in the preparation for these major events is by seeing if schedule optimization has had an opportunity to be done. In many large turnarounds, there are hundreds or thousands of distinct jobs to be thoroughly planned. Once the individual jobs have been planned, a comprehensive schedule containing thousands or tens of thousands of individual tasks is assembled. Typically the draft schedule contains a number of critical path or near-critical path strings of activities. Schedule optimization entails reviewing the entire critical path and near-critical path strings of activities to see if the overall schedule can be reduced.

Typically a critical path or near-critical path string of activities can be reduced in one or more of several ways:

1. It might be possible to increase the crew size assigned to that work. Frequently, increasing the crew size will entail additional job staging to prevent workers from interfering with one another.
2. It might be possible to increase the number of hours being worked on those jobs. Most turnarounds have some periods when work is not being done during off-shifts, periods between shifts or weekends. With special arrangements, it might be possible to use these periods to make progress and decrease the duration of the overall turnaround. In order to benefit from this activity, it will be important to see that there is plenty of supervision and progress is actually being made.
3. Apart from focusing on the schedule, it might be possible to decrease the duration by focusing on the plan for those jobs. For instance if the work plan entails performing a significant amount of repair work during the turnaround, it might be possible to shift that work outside of the turnaround duration. In some instances, it is a good idea to purchase spares for components that require lots of time and resources to repair during the outage. The work done during the outage includes only installation of the fresh spare. Rejuvenation activities can then be accomplished at leisure outside of the turnaround duration. This approach saves both money and time.
4. Another approach focusing on the individual steps within the repair plans associated with critical path or near-critical path activities is to get very

creative. For instance, if large, bound bolts take a long time to remove, simply cut them out. While it may seem wasteful to discard some components like this, the cost of running the entire outage for a longer period of time can be more costly.

Plant outages are critical activities for a number of reasons including:

- They stop the production capacity of money-making assets.
- They detract the attention of the entire organization while they are being done.
- They consume lots of key resources.
- They cost lots of money.

Another key element of achieving excellence in the TAP process is accurately managing the scope of work during these events. In many cases, the number of people and the amount of skilled resource needed to conduct a major outage will go well beyond the amount of resource readily available in the area where the turnaround is being conducted. As a result, the last 10% or 20% of the human resource brought in to conduct the turnaround is of dubious quality. Clearly, the fewer number of marginal resources the better.

The best way to reduce the number of marginal resources being used is to reduce the total amount of work being done during the turnaround. Any work that can be done outside the duration of the turnaround should be done outside the duration of the turnaround. This includes:

- Maintenance of spared equipment
- Painting and insulation
- Scaffold installation and removal
- Job staging
- Non-critical activities in other parts of the plant

The following is a list of the key steps involved in planning and executing a turnaround. These TAP steps will need to begin well in advance of the turnaround. The length of the preparatory period will depend on how large the turnaround will be and how similar the work will be to prior turnarounds. If new

work is involved and the delivery time of significant components are unknown, the work should be started well enough in advance to preclude large expediting fees.

- Identify Turnaround Manager
- Assemble Turnaround Team
- Adapt TA Calendar and Control Document
- Develop TA Premises
- Assemble TA Worklist
- Close TA Worklist
- Initiate Cost Tracking/Forecasting System
- Conduct Worklist Review
- Order Long-Lead Materials
- Conduct Detailed Planning
- Develop/Release Bid Packages
- Integrate Capital Projects
- Develop SD and SU Plans
- Develop Final Cost Estimate
- Create Comprehensive Schedule
- Assemble Work Packages
- Conduct Management Review
- Optimize Schedule and Job Plans
- Release Purchase Orders and Rentals
- Assemble Execution Team
- Complete Field Staging
- Initiate Work Add System
- Begin Tracking Schedule/Costs
- Begin Tracking Key Measures
- Complete Turnaround
- Critique Turnaround

TAP excellence can ultimately be measured by several important comparisons:

1. Is your turnaround being completed in the same amount or less time than equivalent sized assets being maintained by other companies in the same business?
2. Is your turnaround being completed at the same amount or less cost than equivalent sized assets being maintained by other companies in the same business?

3. Is your turnaround completing all the work needed to allow the asset to run for the maximum possible interval before the next outage?
4. Is your turnaround completing all the work needed to allow the asset to function at peak production, peak efficiency and effectiveness, and peak reliability for the entire interval of the upcoming run?

The Project Management Process (PMP)

While many organizations have separate groups assigned to handle major projects, most maintenance organizations find themselves handling small projects from time to time and some handle all projects associated with the assets they maintain.

Generally speaking most Project Managers pay most attention to managing:

- Scope
- Schedule
- Cost

Scope refers to the complete description of all tangible or specified elements of a project. The most common cause of project failures is poor definition of scope at the start or scope-creep during the execution of a project. Clearly, neither schedule nor cost can be determined until the scope has been decided. Also, if the schedule and scope has been set and scope changes, the current schedule and cost estimates are valueless. While many Project Managers are viewed as focusing exclusively on scope, schedule and costs, there is good reason. The individuals driving changes in scope are typically unwilling to share the blame when schedule or costs run over.

Schedule is far more complex than just the completion date, but the completion date is the issue that is most visible and the one most people remember. The actual project schedule is typically represented by a Gantt Chart with a series of sequential bars representing each of the major activities needed to complete the overall project. While the end product of a project schedule may appear relatively simple, the Gantt Chart is a device intended to communicate a relatively complex concept in a simple and easily understood manner. While it appears simple, it is the end product of a significant amount of work.

As with all of the other processes that are parts of Maintenance Excellence, the principal elements necessary to achieve Maintenance Excellence in the PMP are planning and scheduling. As with the TAP, it is critical to identify the individual jobs or, in the case of the PMP, the individual steps needing discrete plans. Once all the discrete plans are complete, they are assembled in the proper sequence to produce a comprehensive and accurate schedule. While the term “planning and scheduling” slips off the tongue as if it were a single activity, planning is one thing and scheduling is something else entirely.

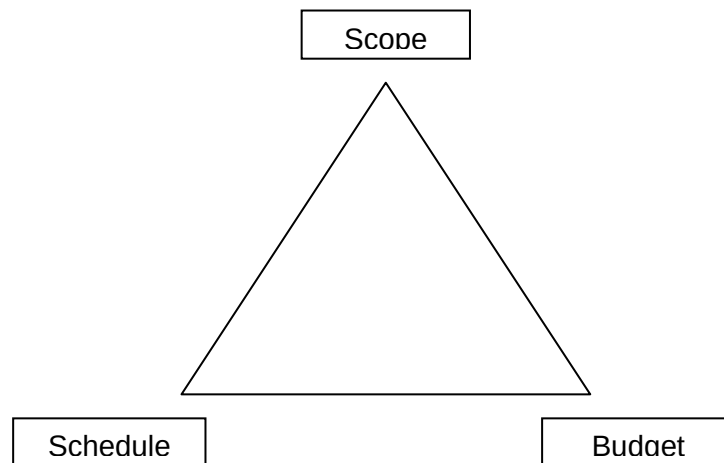
Unlike many of the other work processes that are part of Maintenance Excellence, the PMP typically involves the creation of a completely new product. As a result, much more emphasis needs to be placed on understanding precisely what that product will be. Having never been done before (at least in the specific manner the project is currently being requested), it is important to clearly understand the final product and the scope of work needed to create that product. Once the scope of work is understood, the cost estimate can be created and the schedule assembled. As mentioned earlier, the measures by which a Project Manager is typically judged are:

1. Completion of the project on schedule or earlier.
2. Completion of the project on or under budget.

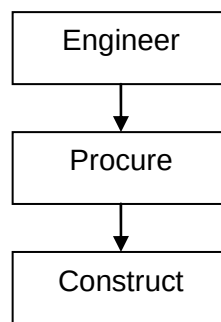
While those are the typical measures of success for typical projects, many Project Managers who are part of maintenance organizations are evaluated by several other measures including:

- Completion of the entire scope of work and not leaving unfinished work for others to complete.
- Completing the project safely with no major injuries and an injury incident rate less than some established target.
- Creation of a product that performs all the intended functions including environmental performance and quality performance.
- Creation of a product that meets or exceeds some desired level of reliability and availability.

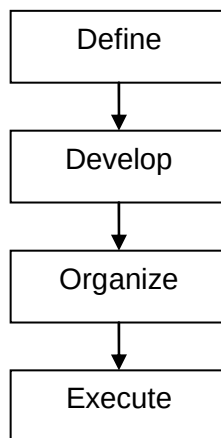
While in the past, the accountability triangle for project managers typically took the form of the following graphic:



And the work process for a typical project could be described by the following simplified flow chart:



Things have changed and successful Project Managers have assumed broader roles as not only project drivers but also project executives as shown in the following flow chart:



The roles of definer, developer, organizer and executer for a Project Manager within the maintenance organization typically require that the Project Manager depend more on his ability to “influence” others who are not part of his organization than “control” those who are.

The Program Management Process (PrMP)

Apart from turnarounds (covered in an earlier section) and projects (to be covered in the last section) another form of activity typically conducted by organizations tasked with maintaining assets are programs. Programs can be major or minor. Programs can be seasonal or repetitive. They can be of a critical nature or they can be mundane.

The key point to keep in mind about programs is that they are a necessity of life and they can be accomplished in an efficient and effective manner that reflects well on the maintenance organization. Alternatively, they can be done in a manner that consumes an inordinate amount of resources, if completed in an untimely manner.

The following list is a few of the various kinds of programs that are conducted by the maintenance organization:

- Painting
- Insulation
- Paving
- Infrastructure

- Training
- Clean up
- Unused parts and materials recovery
- Recovery of tools that were not returned to the tool crib
- Implementation of new processes
- Implementation of new software systems
- Etc.

The important thing to keep in mind is that, no matter how big or small, each of these programs should be addressed in much of the same way as a project. Each of them has three characteristics that should be managed:

1. Scope
2. Schedule
3. Cost

Failure to manage the scope can allow poorly defined and structured programs to get out of hand. Unfortunately the costs associated with many programs end up being charged to maintenance overhead. In turn, the maintenance overheads end up being transferred back to the customer's accounts in one way or another. This is just another way that the maintenance function can begin to appear inefficient.

At minimum, each and every program to which resources are assigned and for which money is spent should be clearly defined using the following dimensions:

- Why – Describe the reason the program is being undertaken.
- What – Describe the product expected at the conclusion of the program.
- How – Are there boundaries in terms of how the program should be done or methods that must be avoided.
- Who – Who is in charge? Who will provide support? Who is the customer? Who are the stakeholders?

- When – When must it start? When must it be complete? Are there other time related limitations?
- Where – Are there any geographic considerations?

Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance is a form of Failure Mode and Effect Analysis (FMEA) that is specifically designed to identify the Predictive Maintenance and Preventive Maintenance needed to maintain the Inherent Reliability of an asset over its entire useful life. The Inherent Reliability of an asset is the greatest level of reliability performance an asset can achieve as limited only by the asset configuration and component selection. For instance, if the asset configuration includes redundancy in areas where needed, the configuration of the asset will support good reliability. Also, if the components are selected in a manner that takes into account the loading, severity of service, failure mechanisms that are present and possible failure modes, it is more likely that the asset will be reliable.

If an asset has been designed to deliver an acceptable level of reliability, it is still necessary to perform the appropriate Predictive and Preventive Maintenance to ensure the Inherent Reliability is maintained over the life of the asset. RCM is the analytical tool specifically designed to identify the predictive and preventive maintenance.

The term Failure Modes and Effects Analysis (FMEA) is very useful in understanding how an RCM analysis is performed.

- The Effects of a failure are typically exhibited in the loss of functionality. Each and every asset is intended to perform one or more functions and a failure of that asset results in the impairment or complete loss of one or more functions. In performing an RCM analysis, the first step is to determine what functions the asset performs and how those functions can fail or be impaired in a manner that is viewed as an asset failure. Many forms of RCM call for each form of asset loss or impairment to be quantified in terms of the cost per hour or cost per day. This information is useful later in the analysis when determining the impact of various failure modes based on the amount of time needed to repair and restore functionality.
- Failure Modes are best described by identifying each specific component that is part of an asset and the specific conditions associated with typical

failures of that component. Taking a simple wire as a component, the wire can fail by parting in two or by loss of insulation. While there may be other conditions associated with a wire failure, they would be fairly unusual. Say in the RCM, we assume the Failure Mode Wire XYZ – Broken (or parted), there are several Failure Mechanisms that might have led to this Failure Mode. Corrosion is one and fatigue is another. A way to prevent corrosion would be to keep the wire from being exposed to moisture or corrosive substances. A form of Predictive Maintenance that could be used to prevent failures of this wire would be routine inspections looking for signs of corrosion. A typical Preventive task that could be used to prevent Wire XYZ – Broken would be to renew the seal on the protective enclosure housing Wire XYZ on some regular basis.

As part of the RCM analysis, the likelihood of each Failure Mode is determined and the associated risk can be calculated using the following equation:

$$\text{Risk} = \text{Impact} \times \text{Likelihood}$$

The Impact of each Failure Mode is determined by multiplying the repair time for each Failure Mode by the hourly cost of the asset function that was impaired or lost as a result of the Failure Mode. The likelihood of each Failure Mode is either calculated based on historic records of similar failures or by using tables containing failure rates for similar components in similar services.

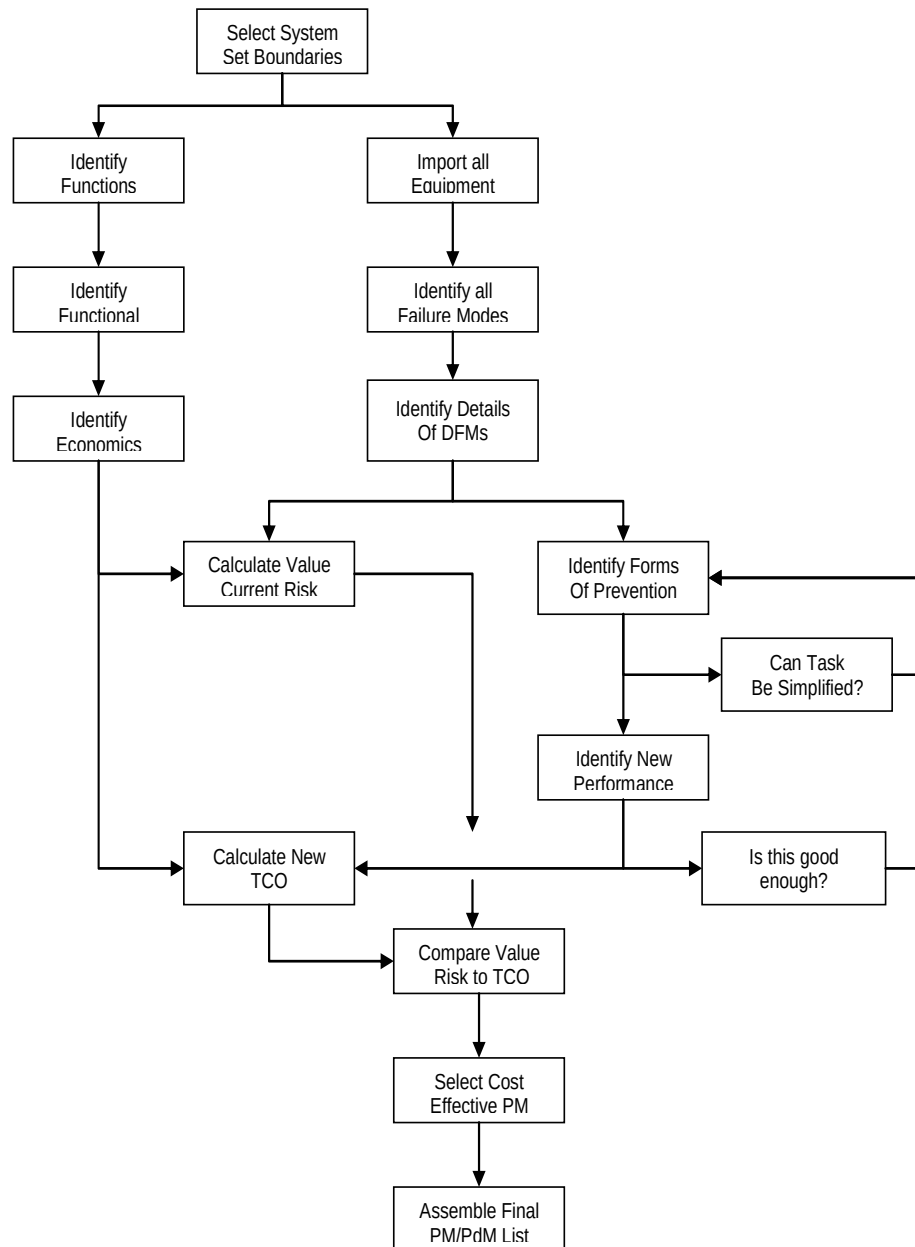
Once the value of the annual risk has been calculated, it is possible to compare that cost to the cost of predictive or preventive maintenance intended to reduce or eliminate the risk.

Say, that a specific Failure Mode has an annual risk of \$50,000.00 associated with the effect it can trigger. Also say that a specific program of Predictive and Preventive Maintenance will cost \$10,000.00 per year and that it will cut the annual failure risk in half. (It can do so either by reducing the likelihood of the failure or by mitigating the impact.) Comparing the cost of Predictive and Preventive Maintenance to the reduced cost of risk shows the following.

$$\$10,000.00 < \$50,000.00 / 2$$

In other words, the cost of proactive maintenance is less than the cost of the risk of failure. So in this case, the program of Predictive and Preventive Maintenance would be cost justified.

In performing RCM there are also cases when the cost of Predictive and Preventive Maintenance is not justified by the reduction in risk that will result. In this case, one can choose either to identify a less costly program of Predictive and Preventive Maintenance or to “run to failure”. The following is a useful flow chart of the RCM process:



While the apparent objective of performing RCM analysis is to improve reliability and eliminate failures by identifying an effective program of Predictive and Preventive Maintenance, the overall objective is more significant. A significant part of Maintenance Excellence is the transformation from being highly reactive

to being highly proactive. Typical reactive organizations have a mix of 80% reactive work and 20% proactive work. Typical proactive organizations have a mix of 80% proactive work and 20% reactive work. While both reactive work and proactive work are simply ways to “buy” additional life of an asset, proactive work can typically be completed using significantly less assets than reactive work. It also avoids the cost associated with service interruptions.

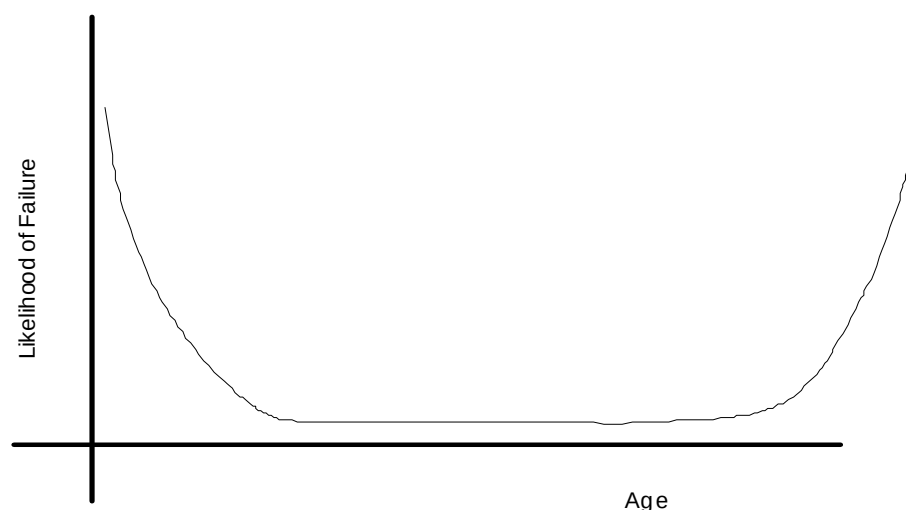
The shift from being a reactive organization to being a proactive organization is a characteristic most commonly associated with Maintenance Excellence.

Predictive Maintenance (PdM)

This section and the next section will describe Predictive Maintenance and Preventive Maintenance. While these two are closely associated and frequently confused, they are different activities.

As the name implies, Predictive Maintenance is a form of maintenance that is used to predict when additional, more complex and more invasive steps are justified.

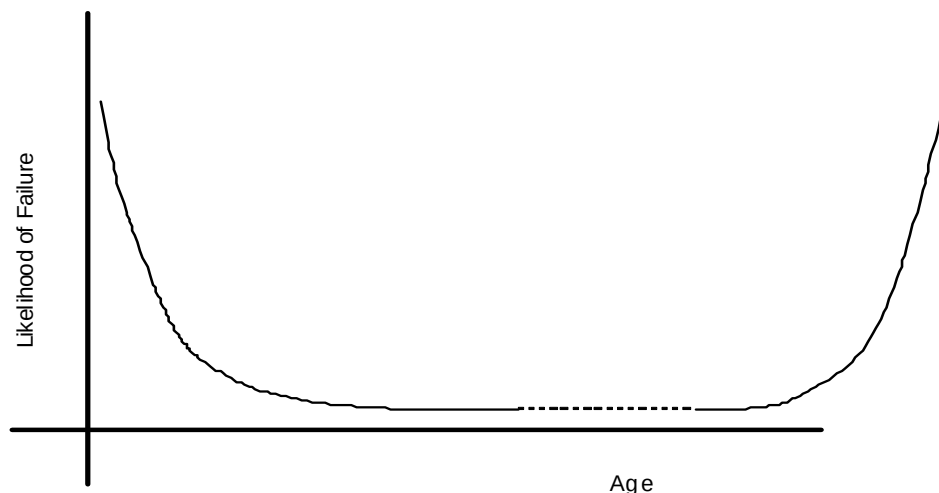
A good way to think of Predictive Maintenance is by using the typical bathtub curve. The bathtub curve is a graph of the likelihood of failure over the entire life of an asset. The likelihood of failure is high at the start of life when all infantile failure modes are present. After surviving the infantile period, most assets experience a long period of low but constant likelihood of failure. As the end of the useful life approaches, the likelihood of failure again increases. The following is an example of a typical bathtub curve.



Bathtub Curve

If the concept portrayed by the bathtub curve was completely accurate, there would be no need for Predictive Maintenance. The most logical and cost effective thing to do would be to perform Preventive Maintenance and simply replace the component introducing the increased risk of failure as soon as the likelihood of failure began to increase. Unfortunately that is not often the case. As portrayed by the dotted line in the modified bathtub curve below, there is a period of uncertainty. Since it is uncertain when the likelihood of failure will begin to increase, it is best to use some form of inspection activity like Predictive Maintenance to identify the actual point when the likelihood of failure is actually increasing.

When dealing with a large population, it is often reasonable to actually endure a small number of failures as proof that the likelihood of failure is increasing. In cases of small populations or single components, it is preferable to use some other form of PdM like vibration testing or Ultrasonic sensing to identify the point in time when the component has experienced deterioration and is on the way toward failure.



Bathtub Curve – Unknown End-of-Life

Increasing forms of PdM have been made available as the result of electronics. In addition, the low cost of microprocessor technology and digital memory have provided PdM devices that can both detect and process information. Despite the increase in technology, the philosophy remains the same. The objective of PdM is to use a non-invasive technique to identify when end-of-life conditions

are approaching and to eliminate failures in a proactive and cost effective manner.

Preventive Maintenance (PM)

Preventive maintenance is different from Predictive Maintenance. At the conclusion of performing Predictive Maintenance, the asset is still “good as old”. At the conclusion of performing Preventive Maintenance, the asset should be “good as new”. In other words, the Inherent Reliability of the asset should be restored.

Preventive Maintenance is an invasive activity that carries with it several negative aspects:

1. Preventive Maintenance typically replaces a component and is therefore more expensive than PdM.
2. Preventive Maintenance typically removes and replaces a component that is viewed as being defective. From the viewpoint of reliability analysis this is either a failure or suspension and can therefore influence future replacements to be made at this interval.
3. During any form of invasive activity, there is always the risk of introducing defects into the asset while it is apart.
4. When installing a new component, if the component has any forms of infantile failure mode, the asset will need to survive this period of increased likelihood of failure before once again reaching a stable situation.

As a result, it is always best to use some form of PdM before resorting to PM. Lacking a valid form of PdM, it is best to use a simplified form of troubleshooting that confirms the component being removed is in fact defective before removing it. For instance, a sensor might exhibit a normal resistance across its leads when good. If the device resistance is either zero or infinity, there is a good likelihood the sensor is defective.

Precision Maintenance (PrcM)

Precision Maintenance is a term used to describe a form of maintenance that incorporates the following steps:

- Determination and recording of As-Found conditions when being disassembled for repair or renewal. (These As-Found conditions are measures of critical tolerances, fits and clearances.)
- Determination and recording of As-Left conditions when being reassembled.
- Determination of deterioration by subtracting As-Found measures from As-Left measures for successive assemblies and disassemblies.
- Determination of Deterioration Rate by dividing the Deterioration by the amount of time between prior assembly and current disassembly.
- Determination of the “deterioration allowance” by subtracting the minimum allowable measurement (for each critical tolerance, fit or clearance) from the current actual condition.
- Determine the number expected run-length by dividing the deterioration allowance by the deterioration rate.
- Compare the calculated expected run-length to the desired run-length. If the desired run-length is not likely to be achieved, replace components with ones having greater deterioration allowance.

Following the steps described above is a way of ensuring the assets are maintained in a way that is sensitive to various forms of deterioration and of “forcing” the asset to achieve the desired lifespan.

This level of sensitivity to the condition of components being used during repair or renewal activities is likely to identify either reused or new parts with inherent defects. All too often, rebuilders take for granted that new parts are good. After close scrutiny, they find that the new parts are no better than the ones being removed.

The objective of PrcM is to use precision measures and heightened sensitivity to component condition to achieve significantly enhanced life of equipment and complete assets. Experience shows that application of PrcM can increase the MTBF by three to five times current levels.

The Operators Role in Maintenance (ORM)

Plant Operators can play a significant role in increasing asset reliability and therefore reducing the cost of maintenance. There are two simple objectives associated with ORM:

1. Do no harm.
2. Do some good.

When operators understand the way the equipment under their control functions and the things they do that can cause damage and deterioration, it is possible to change their behavior so they “do no harm”. A common example of a situation in which an operator can control a pump in a way that causes harm is cavitation. By either maintaining the suction temperature too warm or the level of the suction drum too low, it is possible for an operator to allow cavitation to occur. Over time, cavitation will deteriorate the pump impeller and cause the pump to be removed and rebuilt.

If the operator understands the physics of this situation, he can either raise the suction temperature or raise the level in the suction drum to avoid cavitation and damage. If an operator is sensitive to the sounds being produced by the pump, he can identify the presence of cavitation and take steps to halt it.

Using a typical process as an example, there are a variety of simple steps an operator can take to do some good. If the operator touches the bearing housing on each pump in his area during each round, he can do several things:

- He can determine if the pump is experiencing any unusual vibrations.
- He can determine if the pump case is unusually warm.
- He can see if the oil in the oiler has turned color.
- He can see if the shim pack in the coupling has begun to deteriorate.
- He can hear cavitation.

By taking this simple step during each round, the operator can catch a pump early during the process of deteriorating. Often discolored oil can be changed before a pump needs to be removed. At the very least, identification or early deterioration can prevent additional damage or catastrophic failure. This is a way an operator can do some good.

While the above examples are confined to pumps, there are similar steps that can be applied to all forms of equipment to implement ORM.

Key Performance Indicators (KPIs)

Key Performance Indicators are a critical and on-going tool for ensuring that performance retains a consistently high standard. Over the years hundreds of KPIs have been invented and some organizations measure and publish many of them. Use of too many KPIs tends to dilute the focus on the important ones. It is important to gather and publish only those KPIs for which one plans to respond with action.

Obviously, safety performance is an important KPI. While few organizations fail to measure and report their safety performance, fewer have specific action levels and have identified specific actions that will be taken when specific unacceptable levels are met.

Another excellent KPI is a number that compares the current hourly workforce level to the current Work Identification rate. For instance if the current crew size is 110 men and work is being identified at the rate of 100 man-days per day, this KPI would be 1.10. In this case there would be 10% more workers that are required by the amount of work being identified in the work order system. While one day at 1.10 would be acceptable, at the end of several weeks, if there haven't been as many .90 days as there are 1.10 days, there are too many crafts and the crew size should be reduced. This may not immediately mean a lay-off, but some members of the crew should be assigned to project or program work.

Several other useful KPI's are:

- Percentage of proactive work.
- Percentage of break-in (unplanned) work.
- Percent schedule attainment. (Portion of work completed on the day it was scheduled to be completed.)
- Percent Schedule adherence. (Portion of first-start jobs started by 9:00 am on the day they were scheduled.)
- Estimating accuracy (Actual hours spent on jobs divided by the estimated number of hours.)

Conclusion

Maintenance Excellence means a lot of different things to different people. One characteristic that seems to be consistent is that Maintenance Excellence suggests the application of organized and scientific methods. Those methods ensure the maintenance function is under control and the tools exist to provide tighter control as time moves forward.

Two of the elements that permeate most every work management process that are parts of Maintenance Excellence are planning and scheduling. Thorough and accurate work plans prevent the need for workers to leave the job site once they arrive. Tight schedules result in effective use of the entire available workforce without gaps or unnecessary breaks.

Another important element of Maintenance Excellence is the shift from reactive work to proactive work. Historic blends of 80% reactive work and 20% proactive work are being replaced with blends of 80% proactive work and 20% reactive work.

Effectiveness and efficiency are key elements of Maintenance Excellence. KPIs are used to track measures that drive real-time changes. The size of the workforce is determined by current need rather than historic levels.

In an organization exhibiting Maintenance Excellence, surprises are the exception rather than the norm.