Guideline on Proactive Maintenance

Technical Report

Guideline on Proactive Maintenance

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REPORT SUMMARY

Proactive maintenance (PAM) is the process of learning from past maintenance problems in order to reduce future maintenance work and improve equipment reliability. While most plants practice some form of PAM, this process tends to be underutilized. Many plants rely too heavily on a reactive maintenance practice, which largely involves fixing broken equipment. In response, EPRI has developed effective technologies and processes for power plants to evolve toward a more planned maintenance practice. This report documents PAM elements and presents a method for automating the PAM process via a web-based application.

Background
The daily PAM process of performing review, analysis, and follow-up complements the predictive maintenance (PDM) process and is an important element of a balanced maintenance program in fossil power plants. A balanced maintenance program involves planning and scheduling to complete work efficiently, streamlined reliability centered maintenance (RCM) analysis to determine the most effective maintenance tasks, PDM to monitor equipment condition, and PAM to learn from past problems.

Objective
To describe a disciplined proactive maintenance process as an element of overall plant maintenance optimization.

Approach
EPRI developed this PAM guideline in collaboration with several U.S. and European power producers. To compile the guideline, the authors reviewed best practices and evaluated how they could be incorporated into a PAM program.

Results
This report describes each step of the PAM process in more detail—including the elements of a best-practice PAM process. It also describes how some companies have implemented various aspects of the process, and how to perform cost-effective root cause analysis. Following are some key points:

- Proactive maintenance begins with work close-out, when a maintenance technician resolves an equipment problem then makes recommendations for avoiding that problem in the future. Implementation of recommendations is crucial if a PAM process is to become part of the institutional culture.

- Root cause analysis, which can be expensive and time-consuming, is used on bigger problems. Root cause analysis involves determining the most basic reason for a problem and recommending effective corrective actions.

- For PAM to prove successful, employees must accept the process as an integral part of the corporate culture. Accountability is key to the PAM process and is achieved by assigning specific tasks and measuring progress in achieving them, both at personal and organizational levels.

EPRI Perspective

This guideline is part of EPRI's development efforts under Target 69, Plant Maintenance Optimization (PMO). The PMO mission is to lead the industry by developing and demonstrating products and services that will improve use of power plant maintenance resources and increase profitability for generation businesses. This is the first EPRI guideline addressing proactive maintenance. Quantitative improvements are expected in the areas of commercial availability, maintenance cost, plant efficiency, and inventory cost.

In the day-to-day maintenance processes, PDM can be considered the front-end, and PAM can be considered the back-end. PDM monitors equipment condition using various technologies, always searching for problems before they occur, whereas PAM evaluates past problems to avoid their reoccurrence. Key guidelines in other areas of plant maintenance optimization include: Streamlined Reliability-Centered Maintenance Implementation Guidelines (TR-109795-V3), Best Practice Guideline for Maintenance Planning and Scheduling (1000320), and Predictive Maintenance Guidelines—Volume 4: PDM Best Practices (TR-103374-V4).

Keywords

Proactive maintenance
Plant maintenance optimization
Predictive maintenance
Reliability centered maintenance

EXECUTIVE SUMMARY

Proactive maintenance is a process of learning from past maintenance problems in order to reduce future maintenance work and improve equipment reliability. Root cause analysis is a formal method to determine the most basic reason for a problem and recommend effective corrective actions. Root cause analysis is a natural part of the proactive maintenance process.

This guideline was developed in collaboration with several U.S. and European companies. Best practices at these companies were compiled together in this guideline.

Proactive maintenance is a daily process that complements the maintenance work process, and the predictive maintenance process. Three major steps in proactive maintenance are: review, analysis, and follow-up. The analysis step may or may not include formal root cause analysis. A method to track the proactive process will be described, as well as a way to automate the process with a web-based application.

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1
INTRODUCTION

Proactive Maintenance (PAM) is an important element of a balanced maintenance program in fossil power plants. While most plants practice some proactive maintenance, this process tends to be underutilized. There is constant pressure to reduce costs and maintain reliability of aging equipment in today's power industry. This has resulted in a common situation where most maintenance is reactive, fixing broken equipment. In response, EPRI has developed effective technologies and processes for power plants to evolve toward a more planned maintenance practice. Some elements of that evolution are: work processes with planning and scheduling, streamlined reliability-centered maintenance analysis to determine the most effective maintenance tasks, predictive maintenance to monitor equipment condition, and proactive maintenance to learn from past problems.

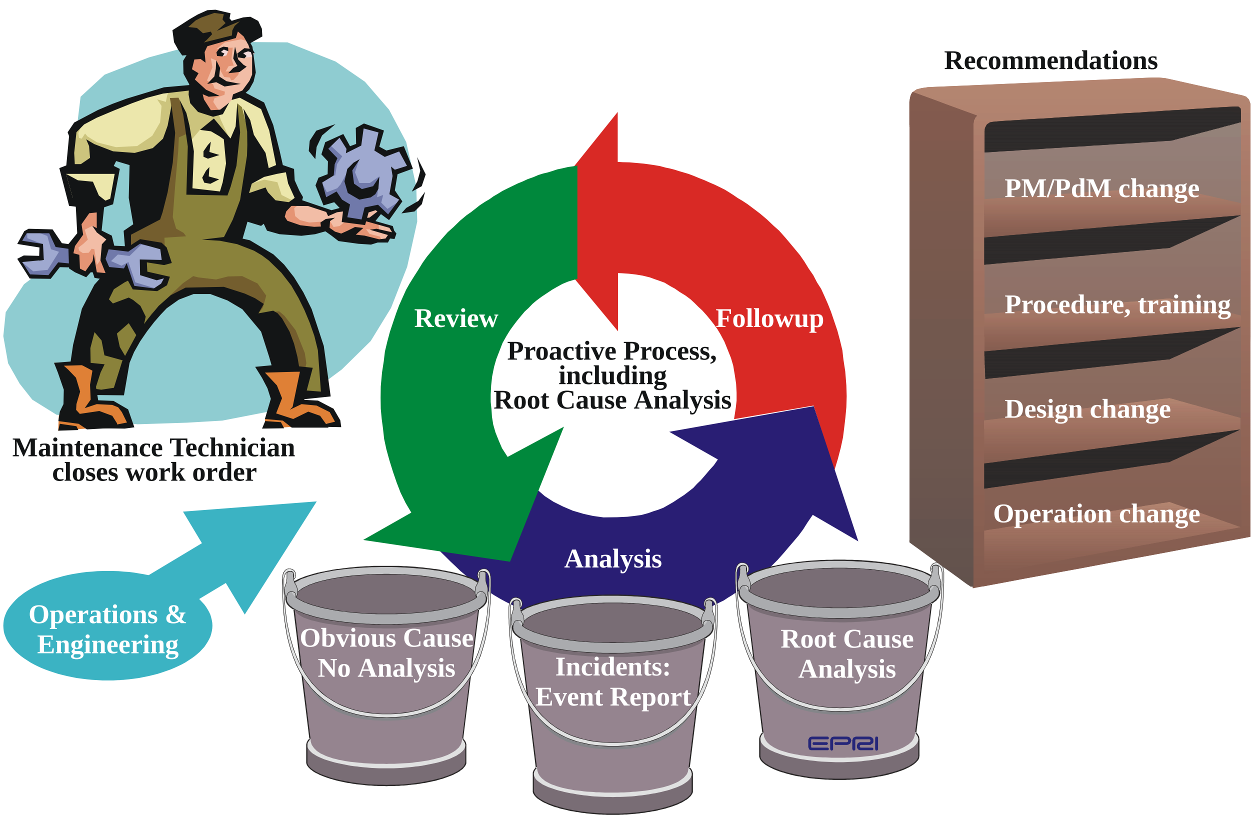


Figure 1-1
Introduction to the Proactive Maintenance Process

As illustrated above, Proactive Maintenance is a continuous daily process of review, analysis, and follow-up. Inputs to the process come from maintenance technicians when they close work orders, as well as from operators and engineers. Outputs from the process are various kinds of changes. Including: PM/PDM change, procedure change, training, design change, or operation change. After work orders are reviewed; some receive no analysis or follow-up, some receive minimal analysis and follow-up, and some are thoroughly analyzed for root causes and follow-up.

Proactive maintenance is both a task type, and a plant process

- Proactive maintenance tasks are also called project tasks. These are maintenance activities associated with equipment improvement or replacement, not just repair or refurbishment.
- The proactive maintenance process is both a daily process and a yearly process. Like other plant processes; it requires people, procedures, and commitment. On a daily basis work is reviewed, analyzed and implemented. On a yearly basis work is summarized and long term factors are revisited.

A proactive process can be more than maintenance, it can also involve operations, engineering, and management. Considering the three proactive steps:

1. Events can be defined and reviewed by maintenance or operations personnel.

2. Events can be analyzed by engineering, or management personnel.

3. And recommendations can apply to maintenance, operations, engineering, or management personnel.

This is the first report by EPRI to address proactive maintenance. It is based on several consulting efforts and surveys at operating power plants. This includes input from the following companies: Enel, Exelon, Progress Energy, Southern Company, and Dairyland Power.

Definitions

Proactive Maintenance Process

A process of learning from past problems, events and maintenance work. Activities that eliminate or reduce future maintenance work.

Root Cause

Root Cause is the most basic reason for a problem, which, if corrected, will prevent recurrence of that problem.

Root Cause Analysis

Root Cause Analysis is the process by which the root cause of a problem or event is determined and corrective actions are recommended.

2
PROACTIVE MAINTENANCE, AN ELEMENT OF PLANT MAINTENANCE OPTIMIZATION

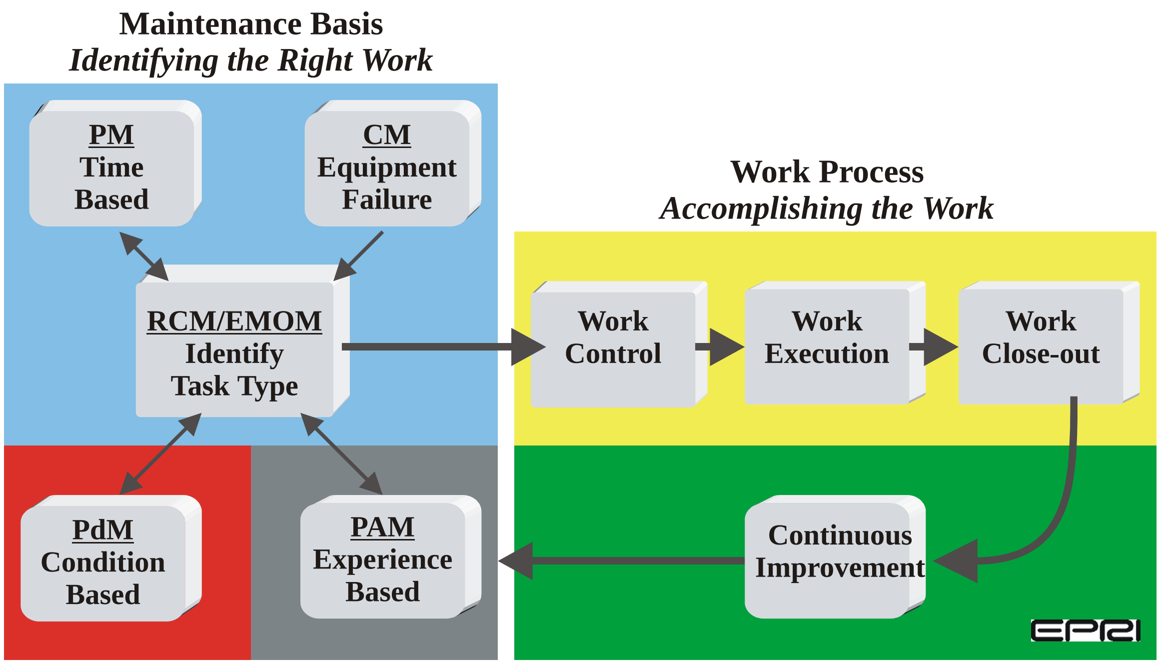


Figure 2-1
EPRI's Plant Maintenance Optimization (PMO) Model

The EPRI Plant Maintenance Optimization Model is illustrated above. One high-level element is the Maintenance Basis, which identifies the right maintenance work to perform. The other high level element is the Work Process, which is how maintenance work is accomplished. The optimum balance between these elements may be different for each power plant, but the process is self-correcting with the Continuous Improvement element.

At the center of the Maintenance Basis is Reliability Centered Maintenance (RCM), this is an analysis technique which identifies the most cost effective maintenance tasks for each component. Another way to identify maintenance tasks is EPRI's Equipment Maintenance Optimization Manuals (EMOM), which may not be as accurate, but it is less costly than RCM. Critical equipment tends to receive an emphasis on Predictive Maintenance (PDM), or condition based maintenance tasks. Corrective Maintenance (CM) tends to be the most expensive, and often needs to be reduced. It is quite common for 80% of all maintenance to be CM, which can be drastically reduced to 10% or 20%. Preventive Maintenance (PM) is often neglected, and it is often not as effective as PDM for critical equipment. Proactive Maintenance (PAM) tasks are typically equipment improvements which are based on operating experience. This report describes a disciplined Proactive Maintenance process which results in a broad range of improvements.

The center of the Work Process element is Work Execution. This is the actual wrench turning work performed by maintenance technicians. Work Control is done to maximize the productivity of Work Execution. Worker utilization can be improved from 25% to over 60% with effective Work Control, which includes Planning and Scheduling. Yet many power plants do not plan their work, or schedule work more than a day in advance. In the worst reactive situations, most of the work can be emergency break-down work. Thorough planning accurately determines job resources, and has them ready before a job starts. Another important element is Work Close-out, where useful information is recorded about each job. This information is needed and used in Continuous Improvement. It is actually this Continuous Improvement element that is the Proactive Maintenance process to be described in detail in this report.

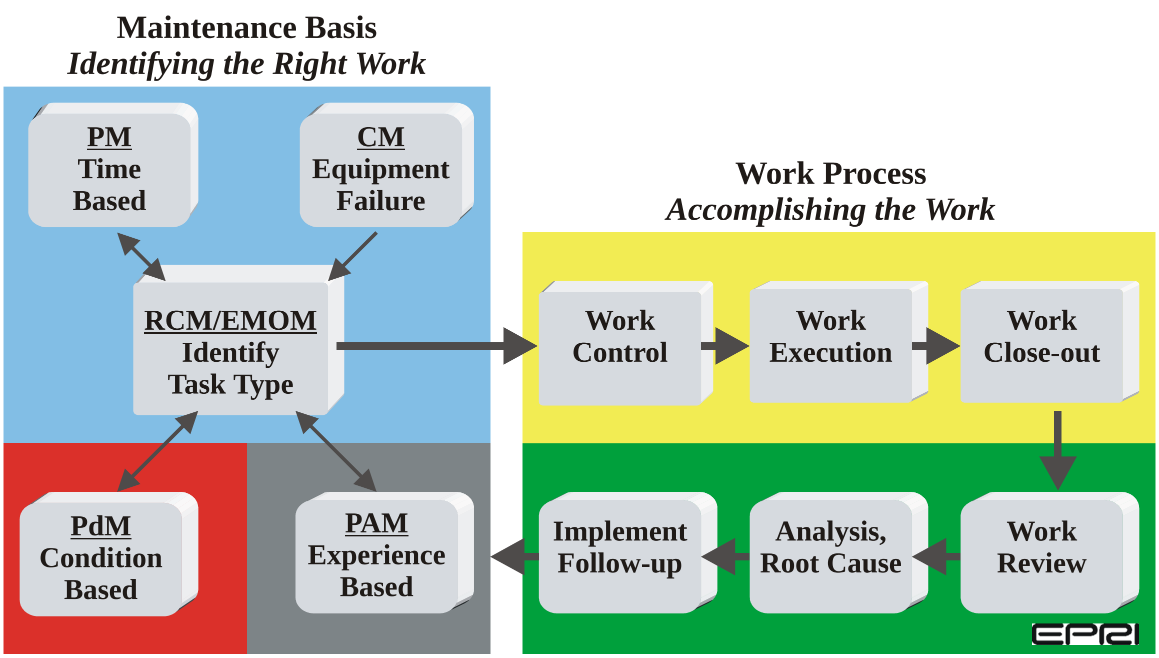


Figure 2-2
The PMO Model expanded to show Proactive Maintenance steps

Maintenance Model above replaces the Continuous Improvement element in the lower right with the three main steps that makeup a Proactive Maintenance process. Those steps are: *Work Review*, *Analysis- Root Cause*, and *Implement Follow-up.* A small, but intentional part of this diagram is the arrow that comes out of the *Implement Follow*-up step. It points at the high-level *Maintenance Basis* element, not just the *PAM Experience Based* element. This is meant to convey that Proactive Maintenance can effect any of those *Maintenance Basis* elements. There may be recommendations to change PM frequency, change the type or frequency of PDM, change the equipment design (PAM tasks), or change the repair procedure (CM tasks).

3
PROACTIVE MAINTENANCE STARTS WITH WORK CLOSE-OUT

Work is closed-out by the maintenance technician. They know the equipment, how it works, and what went wrong. An accurate description of the problem and what was done to fix it is important. This is also the first, and sometimes best, opportunity to capture recommendations for avoiding the problem in the future. After a work order is closed-out, it is reviewed, typically by a Proactive Maintenance (PAM) coordinator. This reinforces the Work Close-out effort because the maintenance technician knows his information is being used. Then the PAM coordinator performs analysis, assigns it to someone else to perform analysis, or assigns it to a Root Cause Analysis (RCA) coordinator to perform detailed analysis. Root Cause Analysis is an expensive effort that is only applied to the most costly problems, where the effort is justified. The end result of any of these analysis activities is **RECOMMENDATIONS**. Now the final step is needed, *Implement and Follow-up.* Obviously! Recommendations are implemented, typically by the PAM coordinator working with others in charge of the various equipment and departments. The follow-up can include feedback to the maintenance technician or RCA coordinator on whether the recommendation was completed, and how to improve recommendations in the future.

That's it, relatively simple! The rest of this report describes each step in more detail, what makes up a best practice Proactive Maintenance process, and describes how some companies have implemented various aspects of the process, and how to perform Root Cause Analysis. This is the first Proactive Maintenance guideline from EPRI. There is an intention to refine and demonstrate this process at power plants through EPRI Tailored Collaboration projects. EPRI will publish those results in Case Study reports, and may change the recommended process based on experience. At which time, a new guideline will be published.

Details of the PAM Process

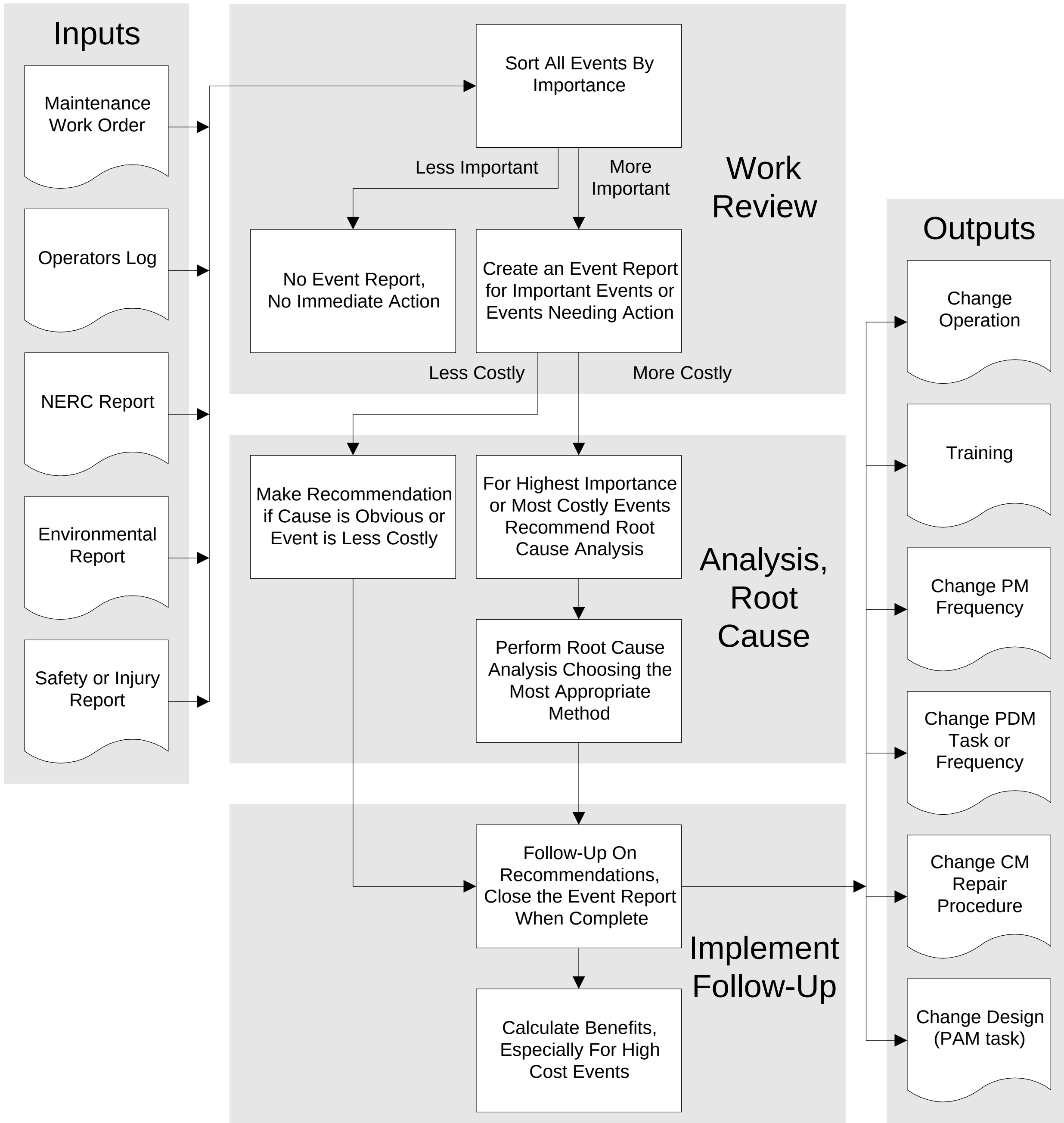


Figure 3-1
Detailed Model of the complete Proactive Maintenance Process

The illustration above shows a detailed model of the Proactive Maintenance process. The three major steps are shown with sub-steps. Several steps will be described.

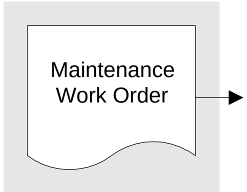


Figure 3-2
Proactive Maintenance starts with work order close-out

Proactive maintenance starts with work order close-out. It should be easy for a Maintenance Technician to close a work order, as well as provide useful information to the proactive coordinator. The Proactive Coordinator needs to review work orders for importance, so they can be put into one of three categories (also called buckets in the introduction section). Those categories are:

- Low importance problems which deserve no further attention.
- Important problems which deserve some follow-up.
- Important and costly problems which deserve root cause analysis.

What information should a Maintenance Technician enter on a work order for later use by the Proactive Coordinator? Three pieces of information will be discussed. First, work order type, which often separates the type of work that should be reduced from acceptable work. Second, equipment condition code, which can identify excessive or too little preventive maintenance. And third, comments about the cause and long term fix for the problem.

EPRI promotes a standard set of maintenance work order types. Which are:

CM - Corrective Maintenance

CM-RTF: Run To Failure, acceptable work

CM-CDM: Condition Based work from PM, PdM, PAM

CM-CDM-P1&P2: Priority emergency or urgent work (bad)

CM-U: Unexpected (bad)

CM-S: Sponsored Work (bad)

PM - Preventive Maintenance

PM-PdM: Predictive Maintenance data collection tasks

PM: all other PM work

Unexpected corrective maintenance (CM-U) is important enough to deserve some follow-up, and perhaps root cause analysis. Depending on the maturity of your predictive maintenance program, high priority condition directed maintenance (CM-CDM-P1&P2) may also deserve some follow-up. While sponsored work is often undesireable, it probably is not important to deserve proactive follow-up.

Another useful piece of information the maintenance technician can provide is the as-found condition of the equipment. A standard set of condition codes makes it easy to enter this information such as:

C1 - Unexpected Failure, root cause analysis	(bad)
C2 - Failure, Not normal wear, consider root cause analysis	(bad)
C3 - Failure, Normal wear, consider changing PM	(too little PM)
C4 - Outside of Tolerance, no failure, consider changing PM	(too little PM)
C5 - Reliability Degraded, no failure, consider changing PM	(too little PM)
C6 - Within Tolerance, adjustment required, no changes	
C7 - Satisfactory, no adjustment, no changes	
C8 - Superior / Like New, less wear, consider changing PM	(too much PM)

This list was adapted from the nuclear industry, and it has been instrumental in the success of proactive maintenance programs at some power plants. These codes probably can be entered in the CMMS along with work order types. Condition code C1 overlaps with work order category CM-U, however, the other condition codes provide additional information about work order importance. In addition, these condition codes, provide information directed toward PM and PDM frequency. In addition, condition codes C6 and C7 identify work orders which can receive no further attention.

Other pieces of information that will be used later are the comments describing as-found and as-left conditions, and recommendations from the maintenance technician. To the extent feasible, this should include the problem cause and recommended solutions. Some other information associated with work closeout is:

Close-out Feedback to Initiator

Close-out Approval

House Keeping

Post Maintenance Testing

Identify Unplanned Work

Orders for PAM Review

Continuous Improvement Metrics

Measure Work Order Initiators Satisfaction

Measure PAM Review Team Satisfaction (Maintenance Histories)

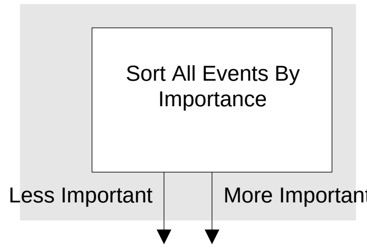


Figure 3-3
The first part of Review is to sort events by importance

The primary measure of importance is the importance of the equipment. Most power plants have a top-ten list of equipment. If Reliability Centered Maintenance (RCM) analysis has been performed, the critical equipment is more important than non-critical equipment. There are other scales of importance, such as EPRI's rating scale called SERP (System and Equipment Rating Process). That is described later, in Appendix C. It is really only necessary to separate two categories: problems that are important enough to deserve some follow-up, and those that do not deserve some follow-up. The more important events will be tracked with an event report.

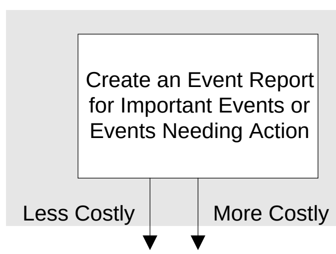
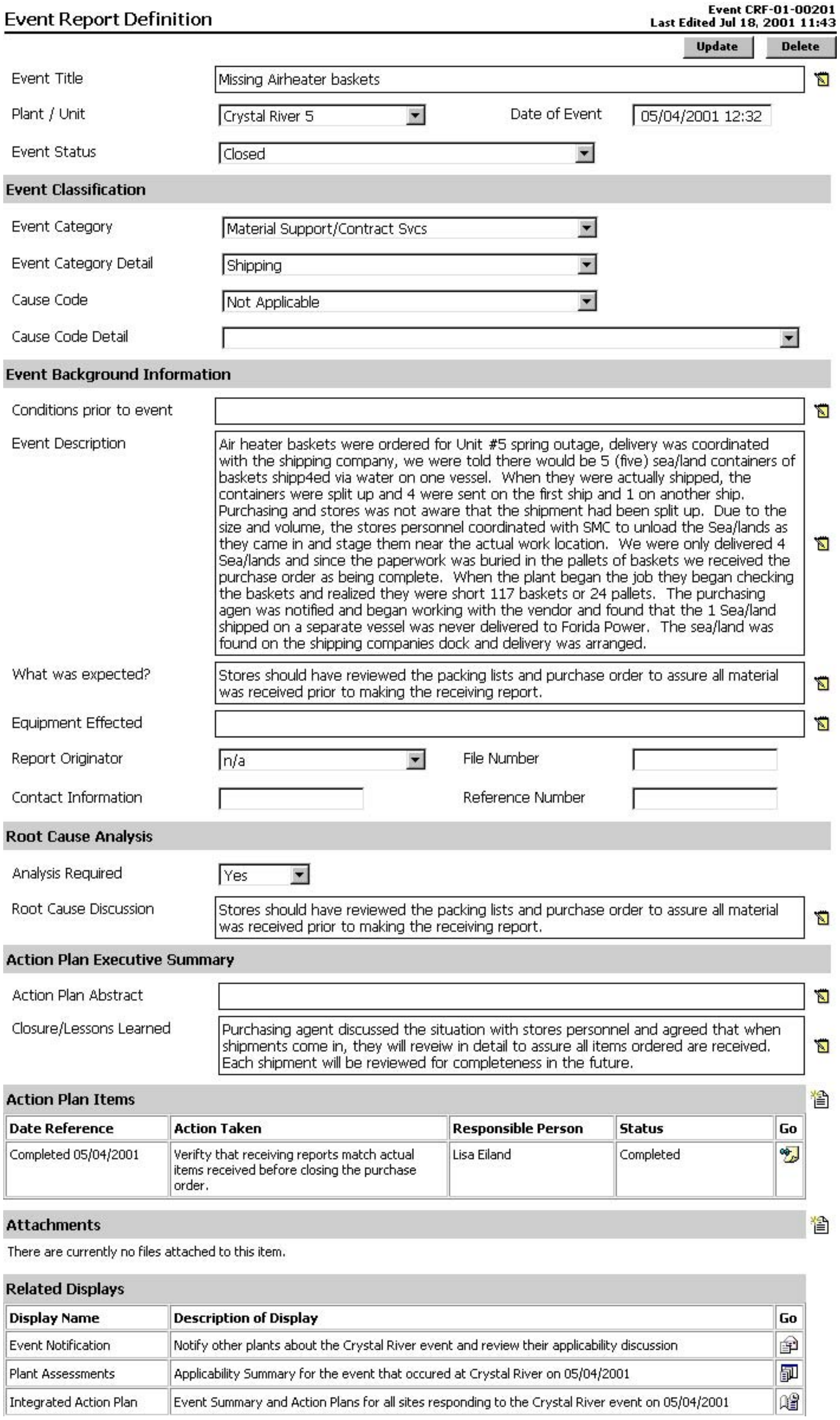


Figure 3-4
The second part of Review is to create an Event Report

An event report may be a new concept, or you may have something similar. It can be a paper form, a computerized form associated with your CMMS, or another stand-alone system. EPRI has developed a PlantView module called Event Reporting for this purpose. So the name Event Report will be used here. The purpose of the form is to track and document steps and actions associated with the proactive process. There are fields to capture the results of work review, root cause analysis, and implementation & follow-up. The following table compares two examples of an Event Report form. Details of the form will be described later. It is important to have some way to track the proactive process, and an event report form is one way. Relying on procedures or informal email messages probably will not work.

Proactive Step	**Region in Form**	**PlantView Event Report**	**Plant Incident Report**
Work Review	Definition	Event Number (meaningful) Event Title (text) Plant/Unit (menu) Date of Event (date & time) Event Status (menu)	Report # (yr-num) W/O # (work order) (text) Incident Subject (text) Plant(Unit?) (menu) Beginning date/time Ending date/time Preliminary/Final (menu)
Work Review	Classification	Event Category (23, menu) Event Category Detail Cause Code (19, menu) Cause Code Detail (menu)	Category (boiler etc.) (6) (Cause Codes, entered?) (24)
Work Review	Background	Conditions prior to event Event Description (text) What was expected? (text) Equipment Effected (text) Report Originator (menu) File Number (?) Contact Information (?) Reference Number (?)	Oper. Condit. Prior to Incid. Generator Output (text) Changes Caused by Incident Description of Incident (text) Prepared By (text) Date (prepared) (text)
Analysis, Root Cause	Root Cause Analysis	Analysis Required (yes/no) Root Cause Discussion (text)	Immediate Evaluation (text) Perm. Correct. Action (text) Root Cause of Incident (text)
Implement Follow-up	Action Plan	Action Plan Abstract (text) Lessons Learned (text) Action Plan Items (multiple) Date Reference Action Taken Responsible Person Status, Go	 Attached Crew Discussion: Date returned Crew A, B, C, D Shift Leaders
	Attachments	(files stored in server) Related Displays (3) Event Notification Plant Assessments Integrated Action Plan	(see above)

Figure 3-5
Contents of an Event Report



Event Report Definition

Event CRF-01-00201
Last Edited Jul 18, 2001 11:43

Update | Delete

Event Title: Missing Airheater baskets

Plant / Unit: Crystal River 5 — Date of Event: 05/04/2001 12:32

Event Status: Closed

Event Classification

Event Category: Material Support/Contract Svcs

Event Category Detail: Shipping

Cause Code: Not Applicable

Cause Code Detail:

Event Background Information

Conditions prior to event:

Event Description: Air heater baskets were ordered for Unit #5 spring outage, delivery was coordinated with the shipping company, we were told there would be 5 (five) sea/land containers of baskets shipp4ed via water on one vessel. When they were actually shipped, the containers were split up and 4 were sent on the first ship and 1 on another ship. Purchasing and stores was not aware that the shipment had been split up. Due to the size and volume, the stores personnel coordinated with SMC to unload the Sea/lands as they came in and stage them near the actual work location. We were only delivered 4 Sea/lands and since the paperwork was buried in the pallets of baskets we received the purchase order as being complete. When the plant began the job they began checking the baskets and realized they were short 117 baskets or 24 pallets. The purchasing agen was notified and began working with the vendor and found that the 1 Sea/land shipped on a separate vessel was never delivered to Forida Power. The sea/land was found on the shipping companies dock and delivery was arranged.

What was expected?: Stores should have reviewed the packing lists and purchase order to assure all material was received prior to making the receiving report.

Equipment Effected:

Report Originator: n/a — File Number:

Contact Information: — Reference Number:

Root Cause Analysis

Analysis Required: Yes

Root Cause Discussion: Stores should have reviewed the packing lists and purchase order to assure all material was received prior to making the receiving report.

Action Plan Executive Summary

Action Plan Abstract:

Closure/Lessons Learned: Purchasing agent discussed the situation with stores personnel and agreed that when shipments come in, they will reveiw in detail to assure all items ordered are received. Each shipment will be reviewed for completeness in the future.

Action Plan Items

Date Reference	Action Taken	Responsible Person	Status	Go
Completed 05/04/2001	Verifty that receiving reports match actual items received before closing the purchase order.	Lisa Eiland	Completed	

Attachments

There are currently no files attached to this item.

Related Displays

Display Name	Description of Display	Go
Event Notification	Notify other plants about the Crystal River event and review their applicability discussion	
Plant Assessments	Applicability Summary for the event that occured at Crystal River on 05/04/2001	
Integrated Action Plan	Event Summary and Action Plans for all sites responding to the Crystal River event on 05/04/2001	

Figure 3-6
Event Report Example From PlantView/Event Reporting Module

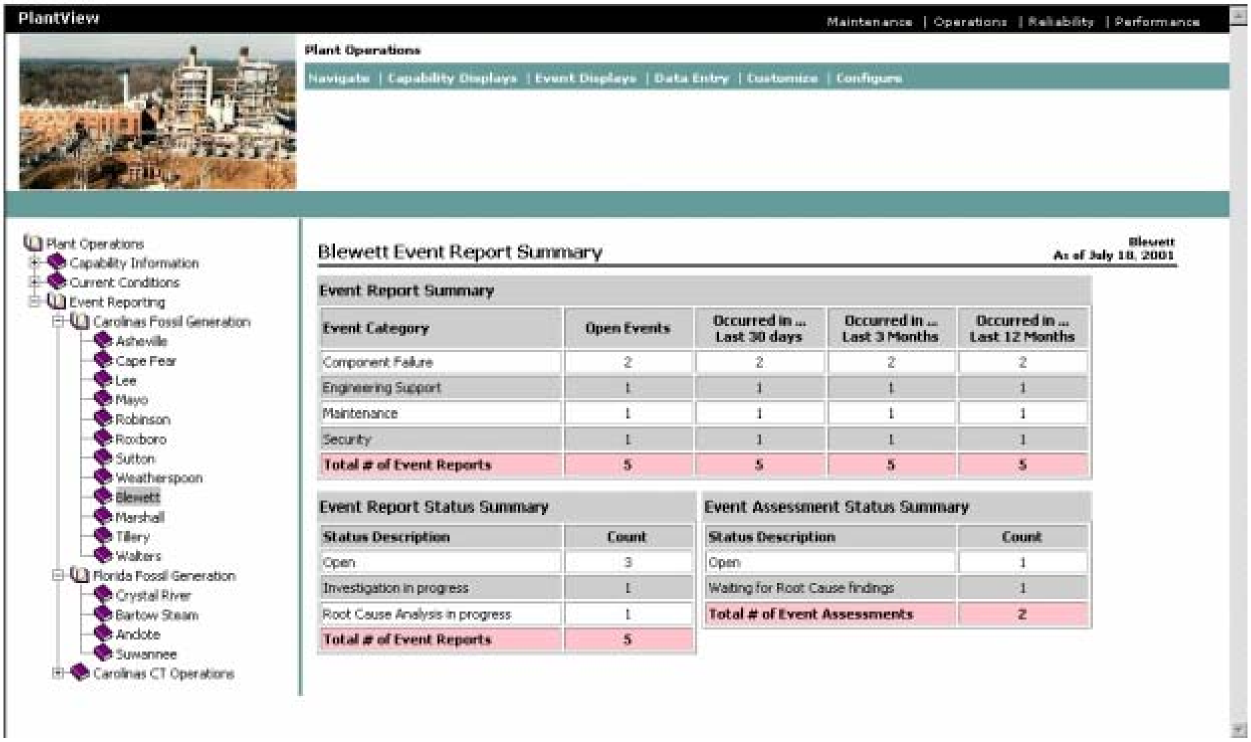


Figure 3-7
Event Report Summary Example From PlantView/Event Reporting Module

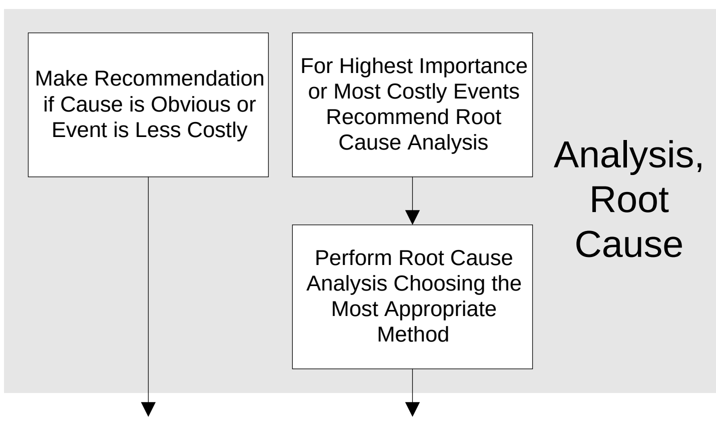


Figure 3-8
Analysis can include Root Cause Analysis

The next step in the Review is to determine if the event is costly enough to deserve Root Cause Analysis. What is costly depends on the plant mission, and company goals. Costly events can include: lost generation opportunities (forced outage or reduced output), injuries, or environmental events.

Some reasons **not** to perform root cause analysis are:

- The root cause and corrective action are obvious.
- The root cause and corrective action were entered on the work order.
- The same problem was already analyzed, but recommendations have not been implemented.

Sometimes a specific type of analysis, other than Root Cause Analysis, is appropriate such as:

- A confirmatory test such as microscopic fatigue analysis, or oil analysis.
- An engineering analysis of chemistry, vibration, or stress.
- A sequence of events review of process data.

Then, even if Root Cause Analysis is appropriate, there are many different root cause analysis methods to choose from. It takes sufficient training and experience in Root Cause Analysis to discover the true root cause, and recommend effective corrective actions. So if you only know one or two methods, those are the ones you should use. If you want to learn more, there are several books, courses, and software tools on the subject. In addition, EPRI offers a course on Root Cause Analysis.

Some power plants only perform root cause analysis when the problem is big enough to get the attention of the plant manager and it causes a major forced outage. This practice limits the proactive process, and misses some potential benefits, but it is valid. Most plants with effective proactive processes perform root cause analysis more often than that.

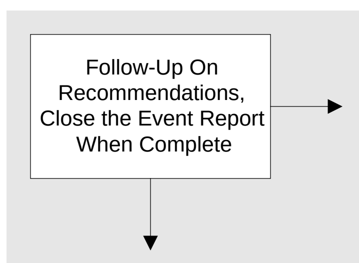


Figure 3-9
Follow-up is needed to implement recommendations

A key element of a proactive process are the **recommendations**. These are the fuel for the fire, good recommendations are needed for proactive process to be effective. Recommendations can come from the maintenance technician on the work order, a proactive coordinator on the event report, or a root cause analysis team on their report.

After recommendations are made, the next step is to **implement and follow-up**, without this the recommendations may not be implemented, probably will not be noticed, and certainly won't be remembered. Follow-up should also include reporting results back to the people who made the recommendations, reporting to management, and recording results for future reference. This can include calculation of cost benefits. An important lesson from other EPRI projects is that cost benefits help management understand the value of the program and supports its continuation.

It is valuable to share follow-up information with other power plants. This can go as far as requiring other plants to review event reports. PlantView supports a method to notify other plants via email to review particular event reports, and track completion of those reviews.

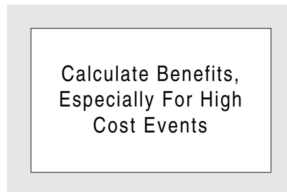


Figure 3-10
Benefit Calculation

Since proactive maintenance avoids future maintenance costs, the benefits will not be immediate cash in the budget or profit. It will be revenue next month or next year when equipment is running instead of breaking down. Management and stockholders, will forget the investment made last year, or many years ago on proactive improvements. The time to take credit for proactive improvements is when they are implemented.

EPRI developed a technique to calculate cost benefits for predictive maintenance (PDM) programs. Details of the EPRI PDM cost benefit calculation is be described in Appendix B. This method calculates how much a failure would have cost, minus the cost of the actual work done. A big difference between proactive and predictive maintenance is that proactive benefits go on for the life of the improvement, whereas predictive maintenance benefits are for a one-time save. Therefore proactive cost benefits should include a factor for long term, or continuing benefits. Therefore, failure probabilities in the PDM method should be replaced with a factor representing the probability of future cost avoidance over the life of the improvement.

Two important success factors for any cost benefit calculation technique are:

- Review the technique with management, so they understand and agree with it.
- Be conservative, so the numbers are not questioned.

If proactive maintenance is as effective as predictive maintenance, benefits could approach a million dollars per year for a medium size power plant. In the short term, PAM should avoid costs by improving commercial availability and reducing forced shutdowns. In the long term, PAM should reduce outage costs and reduce capital expenditures.

4
ROOT CAUSE ANALYSIS

All Root Cause Analysis methods used in the marketplace have one thing in common; they are based on cause-and-effect relationships. It is this thinking that makes finding root cause possible.

In the proactive maintenance work flow process, continuous improvement is enhanced by ongoing evaluations.   As a result of these evaluations root cause analysis, in one form or another, is often requested, the results of which lead to corrective actions. These are then fed back into the maintenance process for implementation.

This chapter defines what Root Cause is, other causes that are necessary to understand, and the benefits of doing Root Cause Analysis.

The rest of the chapter covers topics concerning creating the right environment for a Root Cause Program to succeed, the steps in the Root Cause Analysis process and also a variety of techniques that can be used to analyze problems. The final portion of the chapter explains one of the major techniques in depth and shows an example of how it is applied.

Root Cause Analysis Background

Root Cause is the most basic cause(s) of a problem, that can reasonably be identified, that can be fixed, and when fixed, will prevent (or significantly reduce the likelihood or consequences of) the problem's recurrence.

If the Root Cause of a problem is not uncovered, one is fixing symptoms or apparent causes of the problem. This will lead to the fix/correct behavior mode and the problem is likely to recur. When Root Cause is uncovered, the behavior mode is prevention and the problem will be prevented from recurring, or the likelihood thereof reduced. See diagram below.

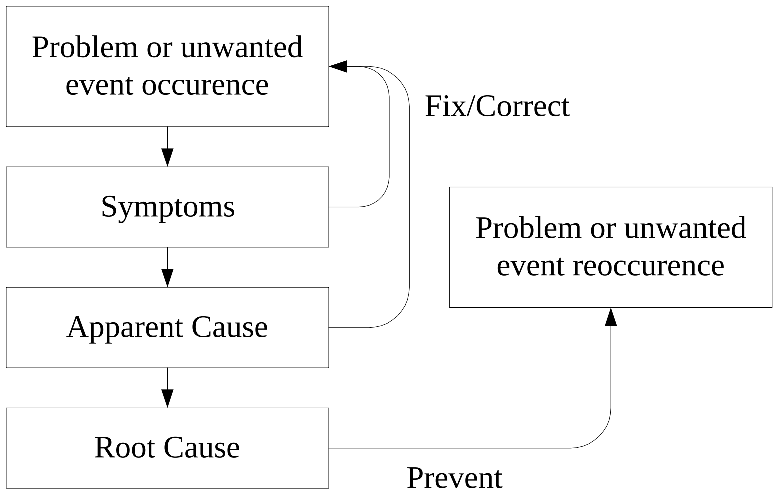


Figure 4-1
Apparent and Root Causes

Causal Factors

A causal factor is a human error, component failures or unsafe conditions that had a direct impact on the event. Elimination of the causal factors will prevent recurrence of the event or mitigate its consequences. Many investigations and root cause analyses simply identify these causal factors and make recommendations to correct them. This may prevent the same event from recurring, but if the root causes are not addressed, similar events are likely to happen in the future. The root causes of these causal factors must be identified and corrected.

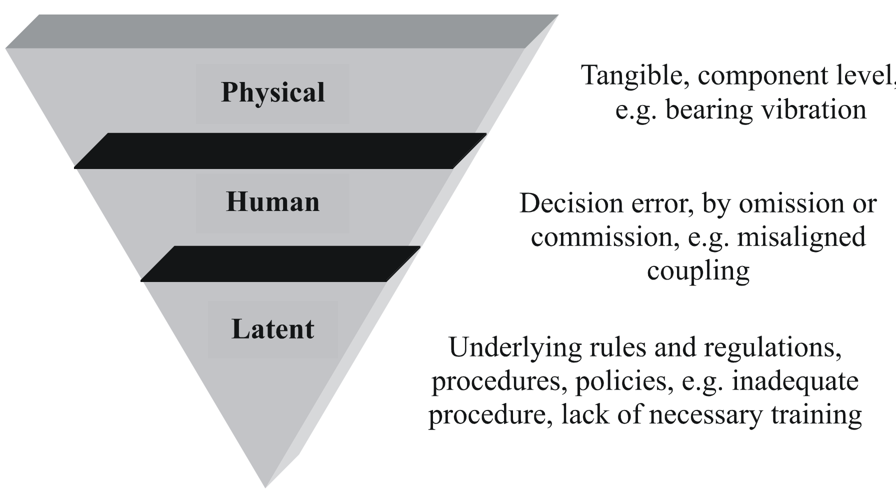


Figure 4-2
Levels of Causes

Root Cause is the underlying (latent) cause of a problem and these are often left unresolved, causing recurrence of that problem.

Very often one deals with the **physical causes** of a problem (this is the tangible or component level) and considers the problem resolved. If one takes an example of a plant experiencing recurring pump failure - this is an event about which the plant cares and needs to take action, hence a root cause analysis would be done. If it is found that the reason for the pump failure is excessive vibration on the bearing, some analysts may stop the analysis there and just replace the bearing. Have the root causes of the event been resolved? Not likely as the part was just replaced and the analyst did not considered how the excessive vibration developed.

The next level of causes relates to the **human causes**. These are usually decision errors, either of omission (missing a step in a procedure for example) or commission (where someone intends to do something correctly, but errs). Continuing with the example of the pump failures and excessive vibration, delving further into what happened, the analyst discovers that a mechanic misaligned the motor/pump coupling. He intended to align it, but didn't. Some analysts would stop here in their search for root cause, but we still haven't reached the underlying reason for this occurrence.

The next level, which is the true root cause level, is the **latent causes** (underlying). It is only when these are uncovered that appropriate understanding of the problem and accurate corrective actions will occur to prevent recurrence. These underlying causes are dormant and hidden in the daily business routine. They are policies, procedures, purchasing practices, etc., which are put in place to assist us with decision making. Often they are not used, not modified when changes are made, or not used correctly (the culture of the organization often dictates how strictly these are followed). When trying to uncover latent causes we are getting into the minds of the people who made decision errors. The mechanic that misaligned the pump in our example above, didn't decide to come to work to deliberately do this. Perhaps he does not possess the correct tools, is not properly trained, or there was no procedure in place for this function. These are examples latent causes.

What Is Root Cause Analysis?

Root Cause Analysis is a process used to systematically detect and analyze the possible causes (why) of a problem so that the appropriate corrective action can be planned and implemented.

During Root Cause Analysis, the analyst relies heavily on internal logic and reasoning skills (thinking) to reach conclusions. By making that thinking visible, by using tools like lists, worksheets and charts, information to show assumptions and test conclusions is easy to see and understand.

What Is the Purpose of Determining Root Cause?

The purpose of this step in the Proactive Maintenance Process is to collect and analyze data to determine why the problem occurred - root cause - so that the appropriate action can be planned and implemented. Root Cause is determined by analyzing the data that you have collected.

Goals:

- To determine presumptive causes of the performance problem - equipment, procedures, personnel and work processes.
- To eliminate apparent causes that data do not support
- To select causes that need verification
- To determine root causes and enable the implementation of appropriate corrective actions
- To predict future problems and/or determine how to improve a process already in place

Benefits:

- Providing enhanced utilization of available resources
- Avoiding unnecessary disruptions
- Ensuring objective problem solving
- Facilitating development of a comprehensive set of solutions
- Predicting other problems
- Identifying, assembling, and integrating contributory circumstances
- Focusing on preventing recurrence, as well as providing immediate corrective action
- Identifying improvement opportunities

Achieving these goals will provide the focus for corrective actions.

Creating an Environment in which Root Cause Analysis Will Succeed

An investigation needs to get off to a smooth, quick start once it is reported that one is necessary. To do this, a facility must already be committed to performing incident investigations as a means of problem solving, or as a means of improving performance - continuous improvement. Such a commitment means having trained investigators on staff and having resources available for the investigation. Having an incident investigation program in place will give the investigator the tools and administrative support necessary to help control the pre- and post-investigation activities as well as help ensure the consistency of investigations in an organization.

Why should an organization investigate incidents? In the United States, regulations require it, and industry initiatives encourage it. It is good business practice - if we prevent recurrence and reduce the likelihood/impact of other incidents with the same root causes, we can eliminate the costs (human, equipment, and product) associated with incidents of all types.

Before discussing the development and implementation of a root cause program, it is interesting to look at two aspects of reliability, as reliability is the driver of maintenance programs. Reliability can be program based or behavior based (work culture), and is important to explain in relation to Root Cause Analysis:

Reliability Program Development - The program should produce written management policies that provide a broad base for institutionalizing any or all of the key elements of effective reliability management programs, of which Root Cause Analysis is one. The program should define roles and responsibilities within an organization for implementing aspects of the program, and should outline the plan and schedule for implementation of the program.

Behavior-based Reliability - This is an issue that relates to changing the workplace culture. It is necessary to assess the strengths and weaknesses of the current culture, from management down, highlighting characteristics that may keep reliability improvement programs from becoming part of the organization's culture. These assessments will produce recommendations for nurturing staff behavior that is necessary to reap the benefits of good reliability programs.

For a Root Cause Analysis program to succeed there are some building blocks that need to be in place. These are the foundation of a solid program and need to be put in place as the program develops. Some ideas on what is needed to be in place for a complete program:

- Management Support
- Root Cause Champion/sponsor
- Root Cause Driver owner on the floor
- Resources
- Administrative procedures
- Consistent reporting and analysis
- Rewards and Nurturing

Management Support

Management support is necessary to ensure that adequate resources are devoted to the improvement program. Some pertinent points to consider are:

- Management must be seen to rubber-stamp the RCA effort.
- Management needs to provide the financial resources for the program to succeed a most important sign of approval and support.
- Senior Management should have themselves educated in RCA, if only an overview of the process in use - sends a clear message to staff on their support of the process.
- The benefit the RCA program affords the organization and the work life of each employee should be clearly outlined.
- Management needs to outline how the RCA process is going to be implemented to accomplish the organization's objectives, and how they will support such actions.

- A policy or procedure to institutionalize the RCA process should be developed, as this provides continuity and staying power for the overall process should there be a change in management.
- Management, if they wish the effort to succeed, should designate someone in middle management to be the root cause owner/champion.

Root Cause Champion/sponsor

This role should be allocated to a mid-level manager (like a maintenance manager in a power utility); who would provide the conduit to ensure that the message from the top to the floor is communicated correctly and effectively. There is often miscommunication, otherwise, and the best intentions come to nothing and the process fails. This person should have authority to defend the users of the process if they uncover causes that are politically sensitive. The best champion/sponsor is a previous driver. The major responsibilities of the champion are:

- Selecting RCA owners who will lead teams and investigations, and providing skills-based training for them.
- Developing root cause analysis performance criteria like expected financial returns, time frames for delivery, etc.
- Ensuring that time is provided for designated employees to work on RCA processes.
- Processing the corrective actions and ensuring that they are handled in the current reactive work system - getting proactive work done.
- Providing support to the owners of the RCA program to ensure that they can use the process in place effectively, e.g. obtaining extra interview time with personnel involved in incidents, obtaining sensitive information when it is essential, etc.
- Controlling all the necessary resources for the program to succeed.
- Developing and setting up a system of recognition for RCA successes, whether it be a letter from senior management or a financial incentive, like tickets to a match.

Root Cause Owner

No matter how good the root cause analysis process and tools are, for the program to succeed, there has to be a human element, the owner (a supervisor in a power utility). One of this person's major functions is to ensure that all the building blocks of this process are in use and being used properly, as in all come together cohesively. The roles of the owner are shown below.

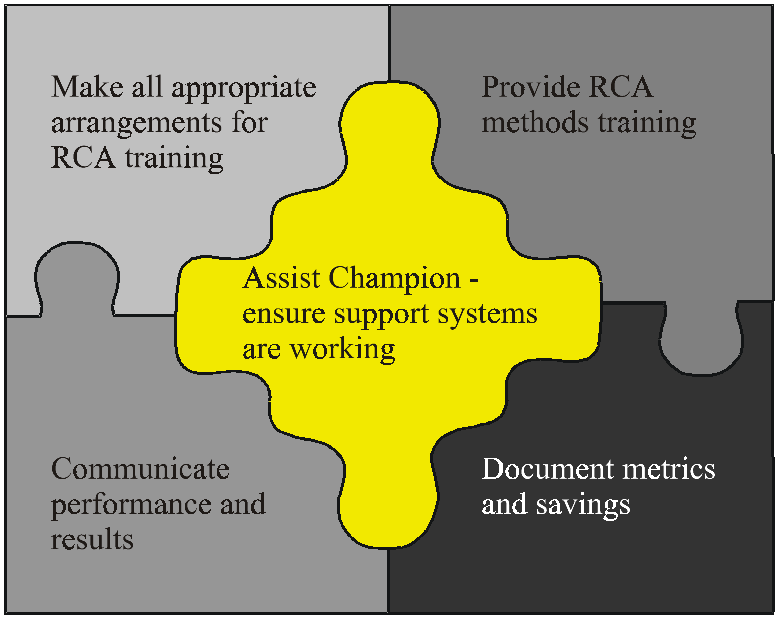


Figure 4-3
RCA Owner Roles

This person has to have the vision of improved performance and must see people as part of the solution, not as the focus of the problem.

Resources

Resources will be easier to obtain if the RCA program has management support. On a continuing basis the RCA champion should track resources used and the return achieved - to continually show the value of the improvement program's efforts. If they are not showing acceptable returns on investment, they should be scaled back for a while. Resources should be continually justified, as management is more likely to supply them if this is the understanding from the beginning.

- Types of resources needed for a Root Cause Analysis program:
- An owner - someone whose time is committed to the program
- Trained analysts who can perform investigations when needed
- Continued training for these investigators
- Time to adequately perform investigations and track the effectiveness of corrective actions
- Access to experts and further training if needed
- Allocation of time for regular feedback and support meetings
- The personnel and money to implement corrective actions

Administrative procedure

This is to ensure consistency in the application of the RCA program. This procedure should provide guidance on how the program works, and how it is to be administered within the organization. When an analyst has to undertake a root cause analysis, there should be standardized procedure that can be accessed and followed. What is included in this procedure will depend on the program and organizational preferences. Items that can be included in a procedure:

- Purpose
- Objective
- Scope
- Responsibilities
- Terms and Definitions
- Problem Reporting Requirements
- Near-Miss Reporting
- Investigation and Reporting Matrix
- Definition of Incident Types
- Corrective Action Development
- Guidance on Corrective Action Review and Approval
- Prioritization of Corrective Actions
- Corrective Action Assignment and Tracking
- Corrective Action Verification and Effectiveness Assessment
- ROI Calculation, Tracking and Reporting
- Data Entry and Database Maintenance
- Improvement/Incident Statistics and Reporting

Consistent reporting and analysis

Consistency is often under estimated in the "toolbox" of building blocks of a RCA program, but it is an essential for the program to succeed. Areas where consistency is needed:

- Reporting of problems and near-misses

This is enabled by well-defined and understood problem reporting categories, as well as acknowledgement/reward for reporting. When a staff member reports a problem and has the reward of having it fixed promptly, this will encourage consistent reporting. Reporting of near-misses needs to be handled sensitively, without 'punishing' the messenger or assigning blame to someone who might have erred.

- Root cause analysis

Root cause analysis has to be done consistently, which revolved around having trained investigators and standardized techniques in use. Refresher training of investigators also ensures consistency as sometimes investigators become over familiar techniques they use; often leads to minor, inadvertent, slips in their application.

- Peer reviews and management reviews

Feedback from peers, in a peer review setting, helps investigators hone their skills and helps improve RCA consistency. Peer review settings are a less threatening forum for feedback. The management review should focus on consistency in judging corrective actions and how effective they will be in performance improvement.

Rewards/Nurturing

Acknowledgement is one of the most powerful motivators of human performance. A heartfelt 'thank you' by supervisors to staff involved in solving a problem and implementing appropriate corrective actions, certainly goes a long way to ensuring their continued buy-in and support of a program. Other types of rewards to consider, small gifts, gift certificates, dinners to celebrate jobs well done, plus bonus incentives are a few suggestions. Morale is improved and staff will look for ways to get involved in a root cause analysis program. To keep this attitude alive in the long term requires hard work. Ultimately, once the program is functioning well, rewarding everyone in the organization/group for sustained excellence should become a replacement for rewarding people for targeted improvement.

Root Cause Analysis Process

It is important to remember that we talk about a process of root cause analysis as opposed to a program. The word program has a finite meaning, having a beginning and end, whereas a process is constantly evolving, which is what should happen with root cause analysis in an organization. As people work with, and become more experienced in, the techniques that are available to them, they will hone the process to suit the organization's particular needs. The following steps outline the process in its logical sequence:

Define the problem

"A problem not properly defined, may result in a failure to reach a proper solution"

When it comes to problem definition, we have to think about a number of issues before we start, to ensure that the problem/issue is defined properly. When an investigator first starts an evaluation, gathering all available initial information is essential to be able to define a problem. Data is gathered throughout the investigation to ensure that the 'picture' of what happened is complete.

Once an incident is reported, it is first necessary to define then classify the incident according to its impact, regulatory exposure, complexity, etc. Classification is important for many reasons, including the need to match the skill level of the investigator(s) and the investigation resources with the incident to be investigated.

The first step in this process is to clearly and specifically identify and describe the problem, in an effort to focus the root cause analysis and corrective action efforts. When defining a problem it is essential to answer the following questions:

- **What is the problem?** Not, what happened? A problem is something like Equipment failure, production loss, lost customer sales, job delays, safety issues.
- **When did it happen?** Be specific when putting down the time and add in information like if it was at the end of a shift, early in the morning, during a storm, after an overhaul, etc. Often the time can lead you to an understanding of why something inappropriate happened.
- **Where did it happen?** Again precision in pinpointing the exact location is essential to avoid confusion during an investigation. The exact distance that something occurs in relation to something else, could tell the investigator something.
- **Why is it significant?** It is important to assess the significance of the problem to the organization - it is the answer to the question "Why are we doing this?" Examples of items that one can examine under significance are Safety Aspect (someone injured, how badly, etc.), Number of times this has happened before, Maintenance costs involved, Cost of lost production, Environmental aspects and Customer satisfaction. If one assess some of these items in financial terms, it will become obvious why this event is significant.

When defining the problem, do not ask the question "who?" or 'why?" The purpose of problem definition is to focus on prevention, not blame, so therefore no "who". "Why" in a problem definition shows that the analyst has already decided on why this has happened, before starting the analysis? These questions will be answered during the investigation.

Collecting information

Collect and preserve all the necessary information relating to the incident. It is essential that data is preserved and recorded accurately, whatever means is used. Ways to collect data could include:

- Conduct interviews with personnel involved in the event.
- Conduct interviews with subject experts, specifically regarding possible consequences of corrective actions.
- Review logs, records, OEM specifications, etc.
- Collect written statements from staff that cannot be interviewed.
- Personally observe the scene of the incident.
- Request or perform laboratory testing.
- Perform the task under investigation yourself or ask do a walk-through task analysis.
- Take photographs, use a video probe or sketch the scene.

Below is a diagram that will assist in the collection of the relevant information, by answering the questions the are down the middle of the page. These questions are common questions that analysts need to answer in a root cause analysis. The points on the left-hand side of the page are to guide and remind the analyst on what to do. The points on the right-hand side of the page are specifically to guide the interview process, e.g. what happened? The use of this type of document is of real value to an analyst, as it keeps the focus on getting pertinent questions answered.

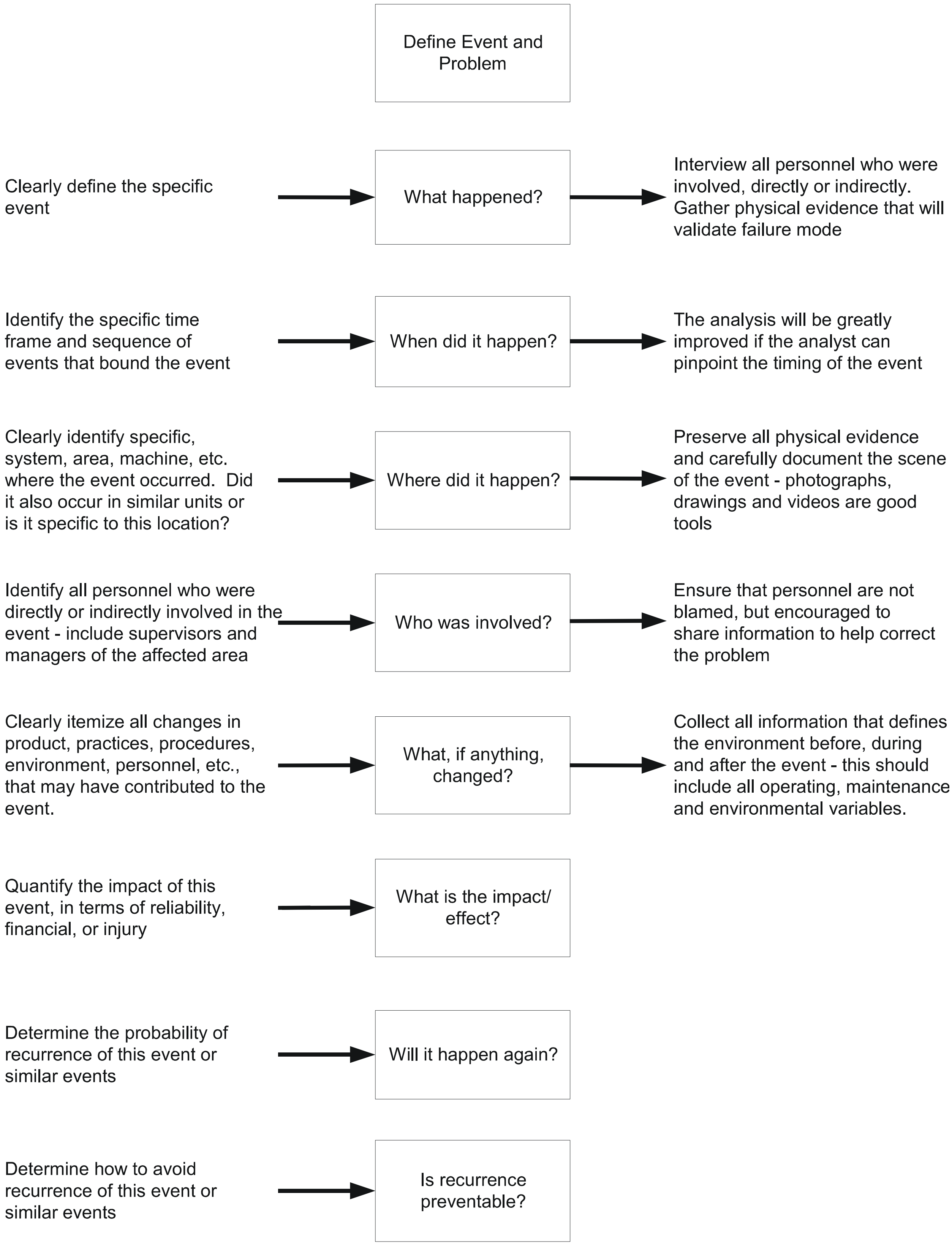


Figure 4-4
Collecting Relevant Information

Develop a sequence of events

It is important to organize the events, identifying as precisely as possible when each of them happened. It is important to note times for each event, plus attach the source of that information, e.g. eye witness account, computer printout, logs, OEM records, etc. Arranging events chronologically

The analyst will be confronted with a report/notification of the incident, giving the available relevant information relating to the incident that occurred. This information should be used to organize into a sequence of events, the steps of which can be noted down as they are identified. Accurate identification of the steps in this event can often assist the analyst, when viewing them logically, to see gaps in this sequence, actions performed out of sequence, actions that were not performed at all, etc. This can lead to early detection of causes of a problem.

Decide on which technique to use

Which technique to use? There are a variety of structured techniques that can be applied to root cause analysis, e.g. Task Analysis, Change Analysis, Barrier Analysis, Logic Trees/Root Cause Trees, Events and Causal Factors Charting, to name a few. There are also some unstructured approaches that can be used and can be extremely effective in problem solving. It is outside of the scope of this guideline to provide detailed information on the many techniques that can possibly used.

Deciding on which technique to use as part of the overall Root Cause Analysis process will continue to be refined as experience is accumulated. The positive aspect of having structured techniques to use is that they will work for almost any problem. Certain techniques, however, will tend to be easier to use than others on a particular part of a problem. Change Analysis, for example, is the easiest to understand and apply, and therefore extremely useful in finding a starting point for the analysis. It is, however, difficult to use if you cannot determine what has changed or is different, so its use can be limited. Barrier Analysis is a solid starting point for an investigation and is one of the simplest techniques to use, which will identify causes of a problem. Most analysts very quickly learn which techniques are best suited to which problems.

There is some danger in suggesting which analysis technique is most appropriate to solve a particular problem, except in a general sense. *The specific problem to be analyzed remains the major determinant and accumulated experience of the analyst the best guide in technique selection.*

Techniques that can be used fall into structured and less structured approaches. The less structured approaches that are commonly used are:

- Brainstorming
- Networking
- Experience
- "What If?" type questioning

- Flowcharts or process charts
- Checklist analysis
- Trend Analysis
- Process control charts

Structured techniques which will be discussed further later in this guideline include:

- Task Analysis
- Change Analysis
- Barrier Analysis
- Logic Tree
- Events and Causal Factors Charting

The following Table shows some structured analysis techniques that seem to work better in specific situations.

Nature of problem	Change Analysis	Barrier Analysis	Events and Causal Factors Charting	Logic Tree Diagrams
Organisational	Good	**Best**		
Activity or Process	Good	**Best**	Good	Better
New or Changed Activity	**Best**	Better		Good
Personnel	Good	**Best**	Better	
Accident or Incident	Good	Better	**Best**	Better
Equipment failure	Good		Better	**Best**

Figure 4-5
Which Analysis Method To Use

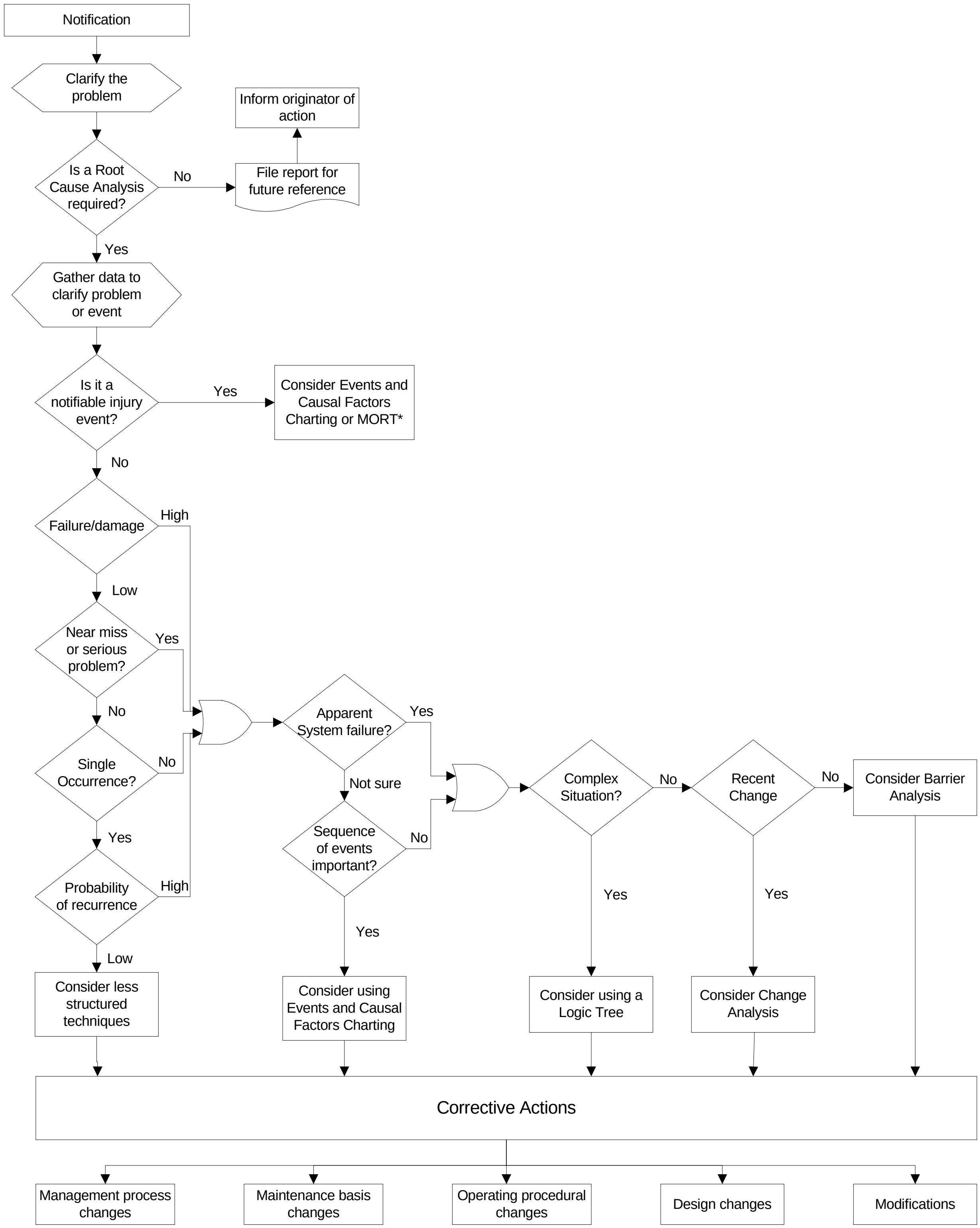


Figure 4-6
Root Cause Analysis Technique Selection Guide

Analyze the problem and draw conclusions

Identify what the causes of the problem are, using the technique selected, ensuring that objectivity is maintained by adhering to structured problem solving. Once the problem has been analyzed completely and correctly, the analyst can conclude what the causal factors and root causes are. Depending on the risk or potential consequence of recurrence of a problem, many organizations will use two different techniques to analyze a problem, then correlate the results to validate them. This will be done rather than rechecking the results of one method to attempt to validate them, or having someone else use the same technique to validate them.

Develop corrective actions

The Root Cause Analysis process will culminate in the development of Corrective Actions/Recommendations to prevent recurrence of the incident/event under investigation, or minimize its impact in future.

Potential corrective actions then have to be scrutinized, and the possibilities analyzed. These possibilities might range from doing nothing to replacing equipment or a system. Which corrective actions should be implemented? Not all of them are financially viable or justifiable and, in some cases, the impact of the incident is lower than the cost of the corrective action. In these cases the Root Cause Analyst should document the incident for future reference and recommend that no corrective action be taken. The most important aspect of this is that it is noted for future records.

Cost-benefit analysis - A full cost-benefit is one of the final steps before recommending a course of action. It is needed to compare costs with the benefits derived from corrective actions that are being considered. *Cost-benefit analysis is simply a direct comparison of the actual total costs associated with an activity,* e.g. replacing a pump, with the benefits derived from the change.

Types of corrective actions/solutions

When developing solutions, it is helpful to consider the solutions to be either long- vs. short-term and targeted vs. generic. The distinction is important in framing the solution or corrective action, as well as in considering whether or not all options have been explored.

- **Long - vs. Short-term**

The time frame and expected results of implementing proposed solutions are important aspects to consider. For example, personnel's training is often listed as a potential fix for a problem. Indeed it might be a solution, except that the effects of training tend to wear off. This makes its value as a long-term solution suspect. If the needed training is not implemented on a continual basis, the problem of personnel turnover and replacement will negatively impact this solution. Conversely, if the training is to be repeated, will the training program design include refresher sessions, with needed updates, after the initial training is conducted? In other words, "provide the necessary training" is only a partial corrective action. The short- and long-term aspects must also be addressed as part of the solution for it to be considered complete.

- **Targeted vs. Generic**

The solution provided should be examined in terms of its specificity. Is the proposed fix targeted and specific to the problem at hand, or does it represent a broader, more generic solution? This does not suggest targeted approaches are necessarily inadequate, but that the intended scope of the proposed action should be understood and clearly stated.

Using the same example of training, it is important to examine whether the proposed training is specifically targeted toward the problem or intended to include the problem with larger, more generic issues that might be involved. For example, you might want to provide toolbox or on the job training for craftsmen on the proper way to lock out and tag equipment that has been removed from service for maintenance or repair. This represents a targeted approach to a fairly specific problem. If on the other hand you want to use a more generic approach, you might include this specific topic with others as part of overall training on the subject of safety. This latter approach might be considered more proactive in those cases where the surfaced problem is considered indicative of a general lack of understanding regarding safety issues or less-than-adequate work practices on the part of maintenance personnel. If the problem is determined to be more random, or particular information that was missed (not supplied), or new practice, then the targeted approach, training on the specific issue of locking out and tagging equipment, is far more appropriate. In fact, it might be considered wasteful to over-react by putting into place a more elaborate training program than necessary.

Process of developing Corrective Actions/solutions

- Become familiar with all aspects of the problem and cause
- Derive a number of tentative solutions
- Assemble as much detail as is needed to clearly define what it will require to implement these solutions
- Evaluate the suggested solutions
- Objectively test and revise the solutions
- Develop a final list of potential solutions

Considerations when developing corrective actions

Will the corrective action/s prevent recurrence of this type of incident?

Is the company capable of implementing the corrective action?

Does the corrective action allow us to meet our primary organizational objective?

Have assumed risks been clearly stated?

Is the corrective action compatible with other commitments?

Will the corrective action have any adverse effects on the man-machine interface?

Other considerations:

Affect on Resources	• What is the cost (Capital and O & M) of implementing the corrective actions? • What resources are required for successful development of corrective actions? • What resources are required for successful implementation and continued effectiveness of the corrective action?
Affect on Schedule	• In what time frame can the corrective actions reasonably be implemented? • Will training be required as part of the implementation, and will training affect schedule?
Affect on Regulatory Commitments	• Will the implementation of corrective action negate a commitment to the regulator? • Will corrective action create a new regulatory commitment?

Are your corrective actions effective and feasible?

- Do your corrective actions address all the root causes?
- Will the corrective actions cause detrimental effects?
- What are the consequences of implementing the corrective actions?
- What are the consequences of not implementing the corrective actions?

Once a number of corrective actions are developed, it is necessary to prioritize them, using some means of objectivity. Otherwise the analyst can unwittingly become subjective in judgement of which are the best. It is suggested that the analyst completes the matrix below to assess the feasibility and effectiveness of each appropriate corrective action. Someone else in the investigation team, a supervisor, subject expert, etc., could then do the same exercise, independently. The results of both studies could then be correlated. The way that this matrix is completed is as follows:

- Enter the corrective actions in the first column - not in any specific order
- Rate each one for feasibility and effectiveness - using a score out of 5, with 5 being the top score.
- Multiply these two figures together to get a total.
- Any corrective action that scores >12 points is considered to be worth acting upon.
- Tick the 'Action' box next to these scores above 12, making it easier to see which ones one is now working with. This 'Action' column could be divided further to include the name of the person/group responsible for the actions and action dates.
- Assign a priority rating to the corrective actions, according to their individual scores.

Corrective Actions	**Feasibility**	**Effectiveness**	**Total**	**Action?**	**Priority**
1.					
2.					
3.					
4.					
5.					

This matrix works similarly to the one above, except that one assigns the value, also out of 5, for a series of criteria relevant to the problem resolution. The headings of these columns can change according to organizational needs.

Corrective Action	Financial	Labor	Time	Resources	Legal	**Total**
1.						
2.						
3.						
4.						
5.						

Follow up/feedback/tracking

Once a root cause analysis has been completed, information gained from it must be fed back into the maintenance loop, as depicted in the diagram at the beginning of this chapter. The recommendations that emerge from a Root Cause Analysis need to be implemented, thus closing the loop from a request for an analysis to its end, back in the work order system. One means would be to have a simplified, standard report (as shown below) on the root cause analysis that could be attached to the initiating incident report. Follow up should be strictly enforced and become part of the routine

Root Cause Analysis Investigation Report

Investigation Team/Member		
Name	**Division/Organization**	**Role**
Event Description		

Root Causes	Recommendations
1. 2. 3.	

Approved and Accepted			
Name	**Designation**	**Signature**	**Date**

It is essential to focus on following up and measuring the effects of the implemented recommendations/corrective actions.

Measuring Success

What is the accurate definition of a successful RCA? Is it the accurate determination of root causes? Is developing pertinent recommendations the answer? Gaining approval for recommendations? Is it getting the recommendations implemented? The answer to all of these questions should be 'no'. The best definition of success is that some bottom-line performance measurement has improved as a result of recommendations implemented from the RCA. The clearest way to measure this is to look back to what alerted us that a problem existed, e.g. too many reworks, recurrence of problems, escalating maintenance costs, MNBF unacceptable, etc.

Organizations work with key performance indicators that one can examine to determine the success of the root cause analysis efforts. The purpose, always, of root cause analysis is to improve the ROI; therefore the results have to justify the continued allocation of resources to the program. There is a vast range of performance indicators that an organization has at its disposal, but it would select the ones that suit their requirements.

Some examples of performance indicators that should improve as a result of RCA in proactive maintenance include:

Tactical and Functional Performance Indicators (expressed as percentages)

Number of Breakdowns that should have been prevented
Total number of Breakdowns

Number of repetitive equipment failures
Total number of equipment failures

Number of equipment breakdowns
Total hours in time period

Number of failures where RCA was performed
Total number of equipment failures

Efficiency and Effectiveness performance

Equipment uptime
Equipment capacity
Maintenance Labor

OSHA Citations: Notices per inspection (current year)
OSHA Citations: Notices per inspection (previous year)

EPA Citations: Notices per inspection (current year)
EPA Citations: Notices per inspection (previous year)

ISO-9000: Notices per inspection (current year)
ISO-9000: Notices per inspection (previous year)

Structured/Formal Root Cause Analysis Techniques

Technique Task Analysis

Definition	When to consider using it	How to apply it - steps
Task Analysis focuses on the steps in a task and how they are performed – it is a method of dividing or breaking down a task into its steps and/or sub-steps, by identifying the sequence of actions, instructions, conditions, tools and materials associated with performing a particular task.	• As the first tool in an analysis • When you are first notified that you are expected to identify and solve a problem • When you need to know what was supposed to happen in an incident/event • When you need a performance baseline – it identifies when human or equipment performance was not to standard/when equipment failure or inappropriate human action contributed to or caused a problem	Paper and Pencil: 1. Obtain preliminary information on what the person was doing when error occurred, other conditions like time of day, etc. 2. Determine the analysis scope – which task will be of interest to our analysis? 3. Gather information on task requirements – us interviews and review documents, e.g. procedures, drawings, manuals, etc. 4. Split the task that you wish to analyse into action steps and write the name of the action step in order of occurrence on a worksheet (Task Analysis Worksheet). 5. For each of these action steps, identify who performs it and the equipment component and tools used – write on worksheet. 6. Review this analysis information and use to formulate your questions when needing to collect further data

Technique Change Analysis

Definition	When to consider using it	How to apply it - steps
Change analysis is the comparison of an activity that has been successfully performed to the same activity when has been performed unsuccessfully – the process by which you compare and analyze what you expected would happen to what actually happened, paying particular attention to changes over time.	• When you don't know where to start. • When the causes of an inappropriate action or equipment failure are obscure. • When you suspect that change may have contributed to the inappropriate action of equipment failure. • When you have started an evaluation and don't know what else to do – you are stumped.	1. Study a situation when an inappropriate action or equipment failure occurred – write down steps and actions taken during task performance (what actually happened). 2. Consider the same situation where there was no inappropriate action or equipment failure – write down steps and actions taken during task performance (what should have happened). 3. Compare these two. 4. Write down the differences between the two – use a change analysis worksheet. 5. Analyse the differences to see how they affected the situation – formulate questions to ask to clarify when interviewing. 6. Integrate the data gathered. It can be useful to place the results of change analysis on an Events and Causal Factors Chart.

Technique Barrier or Safeguard Analysis

Definition	When to consider using it	How to apply it - steps
Barrier/Safeguard Analysis is a technique used to analyze an activity or process, which pays particular attention to where physical or administrative barriers are needed to prevent events/unwanted actions – locates where barriers were either missing or ineffective.	• As a first tool in identifying causes of an event – some simple events need only barrier analysis for the whole evaluation. Do it early in the evaluation. • Whatever situation you analyse, use control barrier analysis – either on its own or integrated into an Event and Causal Factors Chart. • As soon as you are familiar with the task, its procedures and documentation – observe the actual scene and interview subject matter experts. • Some advocates believe that there is no 'right' time to consider using Barrier Analysis – it is a very useful tool and can be used at varying stages of an evaluation. • ***Control Barrier Analysis can be used proactively as well as reactively. In the proactive mode, one can take existing procedures, processes, etc. These are examined to identify existing barriers and their effectiveness, as well as pinpointing areas of weakness that need better barriers to prevent incidents from occurring***.	1. Identify all existing control barriers/safeguards relating to the problematic situation. Use a Barrier Analysis worksheet and show them on an Events and Causal Factors chart if doing one. 2. Evaluate effectiveness of these existing barriers and identify barriers that apparently failed, allowing this event to progress. 3. Determine **how** the barrier failed – was there a procedure (barrier) but it was not used? 4. Determine **why** the barrier failed – the operator might not have used the procedure because nobody really bothers or checks whether it is done. 5. Identify places where barriers, if they had existed, would have prevented this event's occurrence. 6. Validate your results and formulate questions for interviews – subject experts can be of great use in validation.

Technique Logic Tree

Definition	**When to consider using it**	**How to apply it - steps**
This is a means of organizing information gathered, and putting it into an understandable and logical format for comprehension. It is a combination of the decision flowchart thinking and fault tree thinking. One step will lead you further down the path of logic to another. **The Logic Tree starts with factual information**, not a hypothesis.	• Any analysis can be done using this process as it is easy to follow and produces pertinent results. • It is especially powerful when working with events relating to equipment/component failure. • Accident/Incident investigations can be thoroughly examined using this method. It uncovers all three levels of causes, physical, human and latent.	1. Start at the top with an event block that states a brief description of the undesirable outcome being analysed. This information must be fact. 2. Underneath that place the modes, which are a further factual description of how the event has occurred in the past. 3. Ask the question “How could this event have occurred?” Write down, in boxes, broad and inclusive answers (hypotheses). 4. Verify which of these hypotheses are facts. Cross out the ones that are not, because the ones that are become the fact line(s), moving down the tree. 5. Following the fact line, ask the question “How can?” to find the Physical Roots of this fact – tangible, component level. Select the ones that apply to this event – fact line continues. 6. Ask the question “Why?”. This is to understand how the person was thinking when an error occurred. This is the Human Root. 7. Ask the question “Why?” We are trying to uncover what allowed the person to err. Latent Roots are procedures, policies, organisational culture, etc.

Events and Causal Factors Charting

Events and Causal Factors Charting has evolved and there are programs on the market today, including EPRI's Root Cause Analysis program, which use this charting to define causal factors. These causal factors are then analyzed individually to define root causes. This is done using standard root cause categories, e.g. communication, procedures, etc., which are broken down further into their own sub-parts, e.g. communication - lack of; unclear; etc. So, when ECFC is used in this guideline it is with this understanding of its meaning.

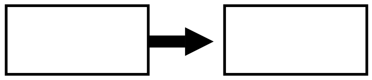
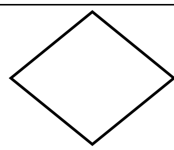
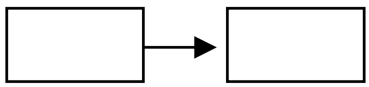
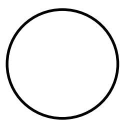
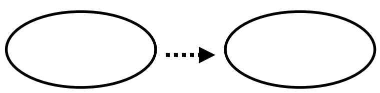
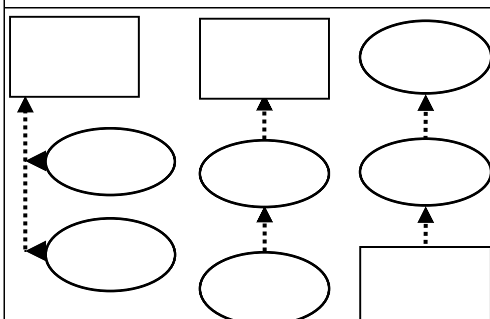
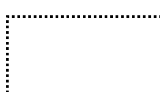
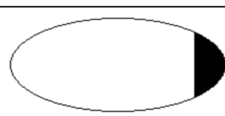
This is an analysis tool that enables the analyst to collect information and display it in a sequence of events, as it happened. This tool is the most effective tool to use as it shows the sequence in which something occurs/occurred, including times/dates and verification means. You can begin constructing this chart as soon as you know what happened. Then you can collect information and place it in this chart as you go along, moving events around until the correct and clear picture of what happened is displayed. Many analysts use PostIt notes to write events onto, then paste them on a surface, like a white board, as they collect them. It is very easy, then, to detach them and move them to where they should be in the sequence. You will find that things will sometimes change, the more information you collect and the clearer your understanding of the problem becomes. For example, as you 'read' the sequence, you might pick up obvious 'missing' pieces in this time line, or events that just seem to not fit where you have been told they happened, etc. This is often an indicator of where to start looking for information to clarify what you already have been told.

This type of charting is effective because it captures the whole situation in one integrated format and many causal factors readily become evident. Equipment failure, conditions and inappropriate human actions are usually associated with a set of successive events e.g. when barriers are ineffective or non-existent, causing an event to progress.

Benefits of constructing and Event and Causal Factors chart:

- It organizes the situation and all the information that is involved in this analysis
- It shows the exact sequence in which events happened - from beginning to end.
- It encourages the development of primary events, secondary events, conditions, causal factors, control barriers and also shows when information is an assumption, not fact.
- It presents the gathered information as one picture, at a single glance.
- It helps ensure objectivity.
- It provides a cause-orientated explanation for the event you are analyzing.
- It organizes quantitative information like time, temperature, distance, etc.
- It provides a basis for developing beneficial changes that will prevent future similar problems.

Symbols used in this charting and definitions thereof

	**Event** – Action or happening that occurs during an activity.
	**Primary Event** – Action or happening directly leading up to or following the incident. Heavy arrow joins events in sequence.
	**Primary Event** – Undesirable – equipment failure/condition or inappropriate action that was critical for the event being analysed to occur.
	**Secondary Event** – Action or happening that affects the primary event, but not directly involved. Light Arrows join events.
	**Trigger Event/Incident** – The end of the sequence of events being analysed – shown at end of primary event line. The event that initiates the investigation/analysis – the reason 'why'.
	**Conditions** – Circumstances that a pertinent/relevant to an event. Joined to one another and/or the events by dotted lines.
	**Conditions and Events** – various ways of showing their relationship. Whether the analyst prefers to use the primary event line as a base and show the conditions above it, as in the right-hand drawing of these three, or with the event line and the conditions below – that is purely a matter of choice. Events that are directly linked to one another are joined together with arrows. A group of individual conditions linked to one event are shown attached to a single line, as in the left-hand drawing.
	**Presumed event** – an action or happening that has not been verified, so is left as assumed. It can also be assumed because it appears to be logical in the sequence.
	**Causal Factor** – A factor that shaped the outcome

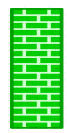
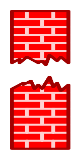
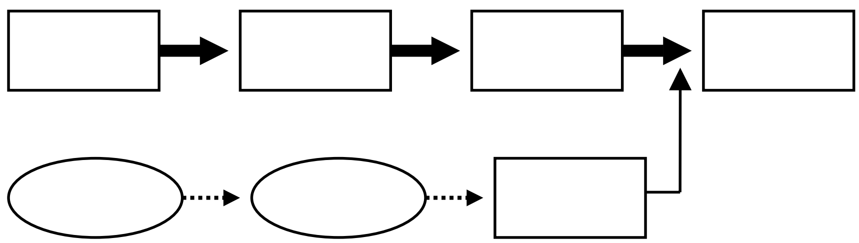
	**Presumed Causal Factor** – A causal factor that is presumed because is cannot be verified, but is thought to logically affect the outcome.
	**Barrier/Safeguard** – A physical or administrative means to prevent threats reaching their targets. They are shown where they exist and have worked, plus where one should implement them to prevent recurrence of an event.
	**Broken Barrier/Safeguard** – This is to indicate where a barrier/safeguard existed but did not perform its intended function.
 **Secondary Event line –** This secondary event line can be shown below the primary event line if the analyst is placing conditions above the line, or above the primary event line if placing them below. Note the light arrows of secondary event line.	

Figure 4-7
Symbols used in Events and Causal Factors Charting

Constructing an Events and Causal Factors Chart

- Define the scope for the chart - identify the beginning point of that specific investigation as well as the terminal event/trigger event. Anything that occurs outside of these two points would fall into a separate investigation. Investigations are often led off course because the analyst is working with more than one event at a time and is unaware of it at the time. One can put down all events in a sequence, as you collect them, but at some stage a decision must be made on which are applicable/pertinent to this investigation. Figure 3-8 is an example of the way one could enter a sequence of events, decide whether pertinent by answering 'yes', 'no', 'not sure'. Once all information is collected, the 'no' steps will be deleted and a final decision made on 'not sure' ones.
- Assess the initial documentation and information to uncover what happened, when, how did it occur, what were the consequences, etc.
- Begin by constructing the primary event line - start early, putting in primary events on the primary event line, use PostIt notes on which to record your information and move them around as the 'picture' changes. When defining an event, some points to consider:

- An event is a happening/occurrence, not a condition, state, circumstance, e.g. "there were no trucks to carry the materials", not "the supply of trucks was inadequate"
- An event is shown in a rectangle and should contain one subject and one verb.
- State the event precisely, be as exact as you can - what happened, exactly?
- If possible quantify each event - how long, how far, how many?
- Include dates/times/sources of your events - include them with your description on the chart.
- Events must be shown in their actual sequence, from left to right on the page - makes for easier checking against what is normal and logical.
- Gather new facts by whichever means are applicable, and classify conditions as Initial -such as time of day, number of workers; Leading to unwanted event - such as problems with tools and equipment, communications, frequent repairs/rework, procedures that are outdated; After the unwanted event - such as responses to the problem, actions taken that could have compounded the problem or could be improved.
- Add conditions and identify unwanted actions/events - Also add the results of other techniques, like barrier analysis and/change analysis if you have used them.
- Identify Causal Factors that led directly to this event occurring.
- Causal factors should then be analyzed, individually, using a Tree Diagram to uncover Root Causes - This will help pinpoint the exact root causes of each causal factor. The tree diagram that is used can be tailored to suit the organization using it.
- Identify corrective actions that need to be taken - these will then be put forward as recommendations to prevent recurrence of this type of event, or to minimize its effect if it does recur.
- Report these resulting corrective actions - The recommendations that arise from this analysis have to be reported and presented to management, who will make the final decisions on implementation. Feeding the results back into the work order system is essential. Ensure that the prioritized corrective actions are recorded and followed up. One example of a form for recording them is given below. The previous forms shown in point 9.6.5, for assessing effectiveness and feasibility of corrective actions, could also be adapted to include the details shown below.

Causal Factor	Root Cause	Corrective Actions	Rank	By Whom?	By When?	Review Date

What follows below is an example of an Events and Causal Factors Chart, showing how the events are depicted, with their relevant conditions attached. Causal Factors are indicated as shown in the table of symbols, but it is important to know that the analyst and/or organization can decide on using some other means of indicating them. In certain root cause programs a tiny triangle is placed on the condition to show that it is a causal factor, others use colored ovals. As long as the means of indicating this is consistent in the organization so that everyone recognizes them and can therefore read the charts easily.

From the chart below, two of the causal factors will be used to show how further analysis is done to get to true root causes. The reason for not analyzing all causal factors in the example is that the purpose of the guideline is to illustrate how the technique works, not to provide a teaching tool. If one needs a complete technique and how it works, an EPRI Root Cause Analysis course can be attended or arranged in-house.

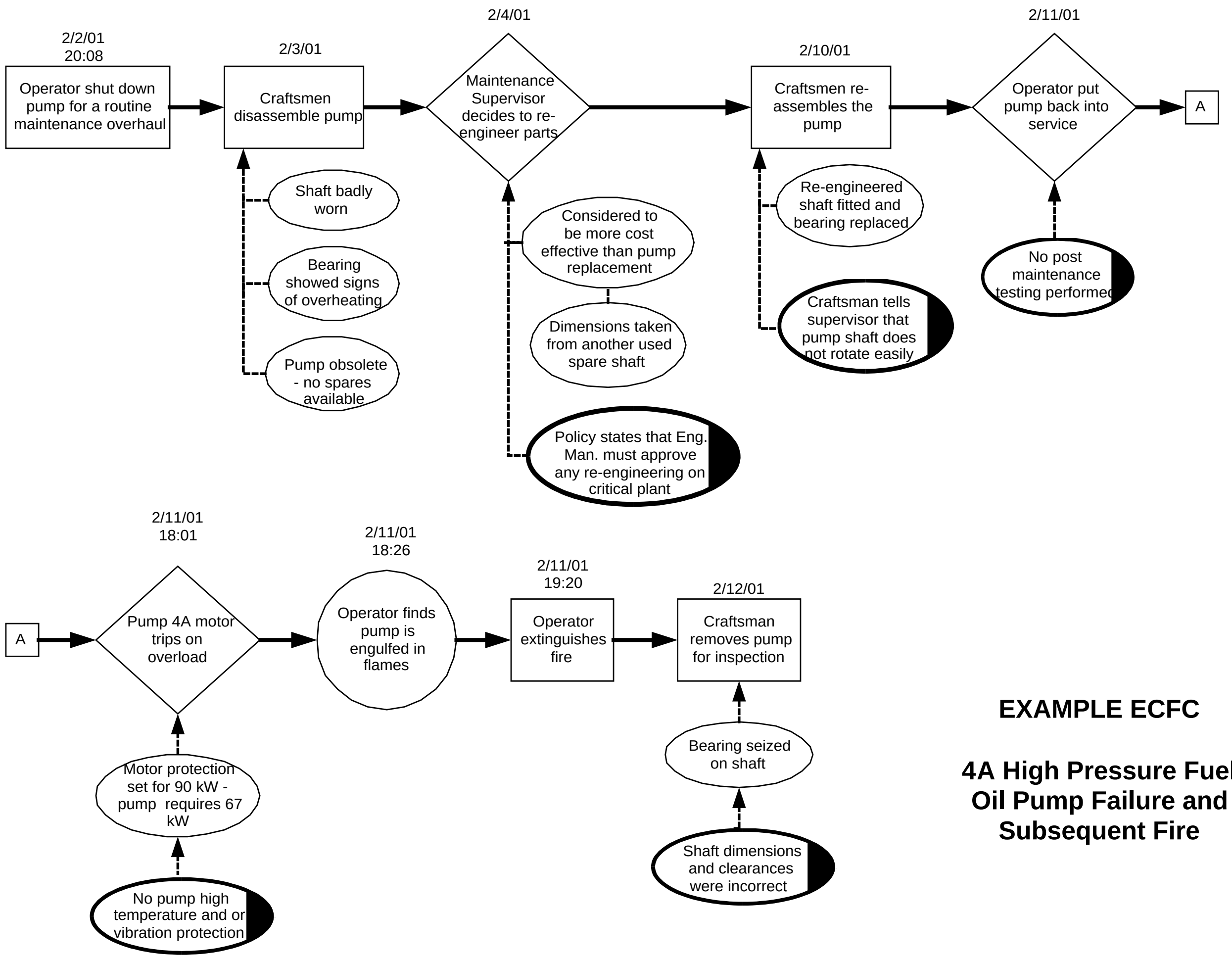


Figure 4-8
Event and Causal Factor Chart

Causal Factor Analysis

Having identified the causal factors on the chart above, two will be used to show how they are analyzed further, using a tree diagram for root causes, to uncover root causes.

The two causal factors chosen are:

- Policy states that Engineering Manager must approve any re-engineering on critical plant
- Shaft dimensions and clearances were incorrect

By asking a series of troubleshooting questions, it is decided to examine certain categories of root causes in more depth. An example of a root cause category and its 'roots', is shown below.

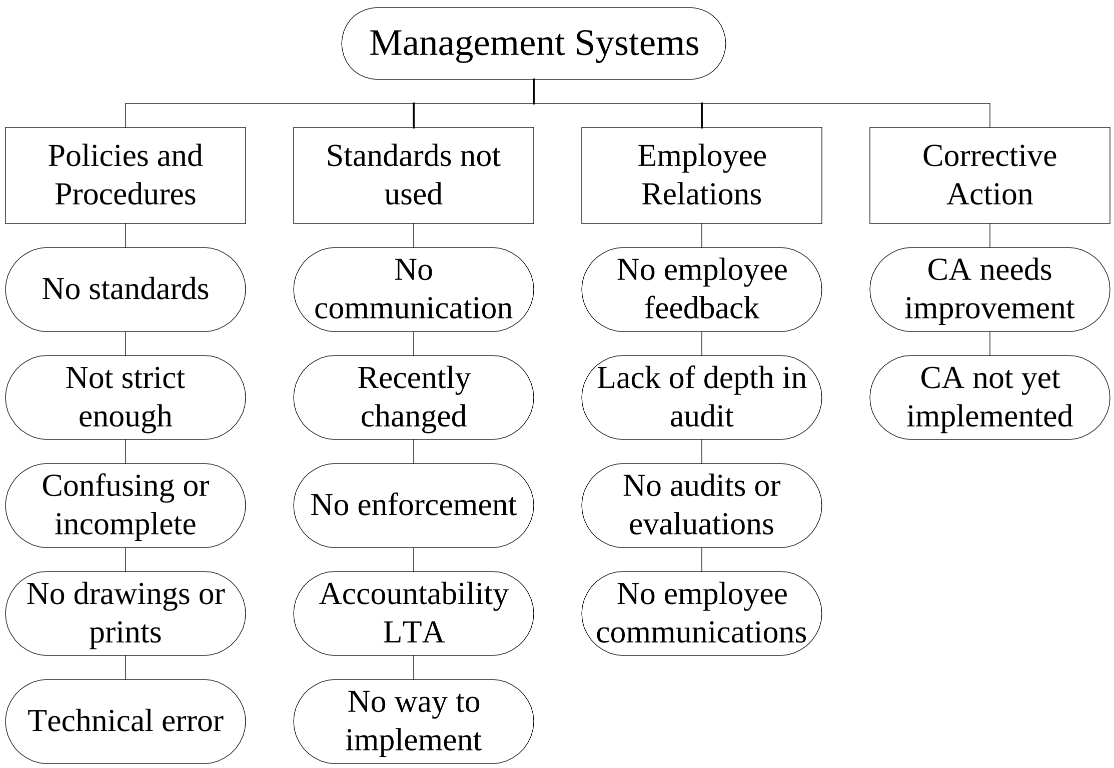


Figure 4-9
Root Cause Categories

Having worked through a variety of tree diagrams for different categories of root causes, by a process of elimination it was decided on the root causes for the two causal factors in our example that we selected.

- Policy states that Engineering Manager must approve any re-engineering on critical plant - root cause was in the category of Management Systems and the cause pinpointed was Standards not used, and the pertinent answer to why? was 'no enforcement'.

- Shaft dimensions and clearances were incorrect - Root causes were in three different categories, Procedures, Supervision and Quality Control. In the category of Procedures, the cause pinpointed was not used, and answer to why? - because of 'no procedure'. In the category of Supervision, the cause pinpointed was Preparation, because of 'work package LTD' and also Supervision during work, because of 'no supervision'. In the category of Quality Control the pertinent cause was No Inspection, because 'inspection not done'.

5
HOW TO GET STARTED

The change process at a personal level starts with someone in an organization gaining Knowledge about a new way of doing things, in this case Proactive Maintenance. The next step is Application, or trying it out. Since Proactive Maintenance requires people dedicated to the process, management must sponsor an initial trial. Preferably this sponsorship will be by the Plant Manager. Then, if the initial trial is Successful, people will start to Believe in the new way of doing things. And eventually this will become part of people's Behavior, until it spreads throughout the organization and becomes part of the work Culture. The point is that an initial trial is not enough to make a new process like Proactive Maintenance stick. It has to become part of people's belief, their behavior, and be accepted into the work culture. This takes time, encouragement, reinforcement; and probably most importantly it needs accountability. Accountability is achieved by assigning responsibility and measuring progress, both at a personal and organizational level.

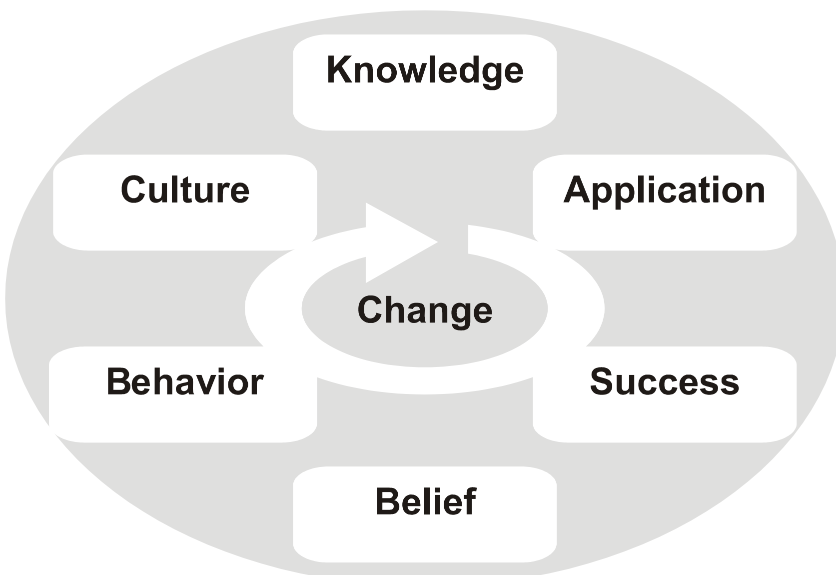


Figure 5-1
The Change process: on a personal level

Continuous improvement is a way of life in the competitive business environment. It is required in order to maintain market position; whether it is plants vying for dispatch order, or companies competing for customers. Proactive maintenance is an element of a balanced maintenance strategy that will provide the lowest cost, and most reliable electrical generation.

EPRI promotes a step-by-step approach to continuous improvement. The first step is to Introduce an organization to a new way of doing things, in this case Proactive Maintenance. The next step is to Assess where an organization is in order to plan for the next step, Implementation. After an initial implementation, the process can be Extended to the full intended scope. In the case of Proactive Maintenance, this may mean to automate the process with a software tool, or assign more people to the process to realize its full value. Measuring the process is important, as well as reinforcing the people responsible for the process. Even if people have to be pulled off Proactive Maintenance duties for emergencies or outage work, they must be replaced or re-assigned when the interruption is over.

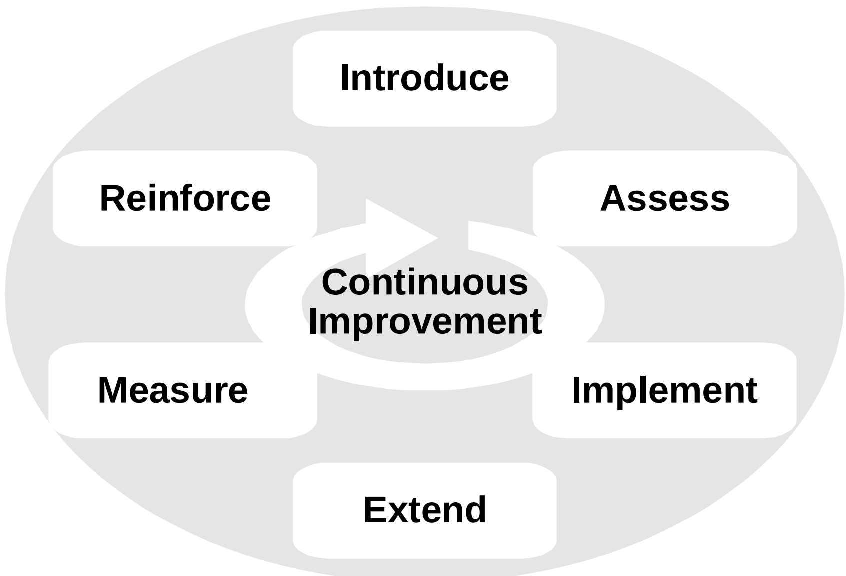


Figure 5-2
Continuous Improvement: for an organization

The assessment phase of continuous improvement should include the following:

- Develop objectives related to business goals
- Map the current process
- Measure key elements of current process
- Determine issues and plan improvements
- Commit resources

Assessment also involves evaluating your organization. The following key elements can evaluated for Proactive Maintenance and Root Cause Analysis.

Key Elements of PAM

- Work order codes
- Person/coordinator
- Roles/responsibilities
- Management support
- Process/procedure
- Criteria for action
- Multiple levels of action
- Reporting tools
- Automate/computerize
- Communication
- Feedback
- Action tracking
- All plants review actions
- Effectiveness review
- Change control/approval
- Metrics
- Training
- Financial benefits

Key Elements of RCA

- Person/expert
- Team resources
- Management support
- Process/procedure
- Address “P” causes: plant, people & process
- Ask “W” questions: what, who, when & why
- Go deep enough
- Recent results
- Report/computerize
- Action tracking
- All plants review actions
- Effectiveness review
- Change control/approval
- Metrics
- Training
- Financial benefits
- Standard technique

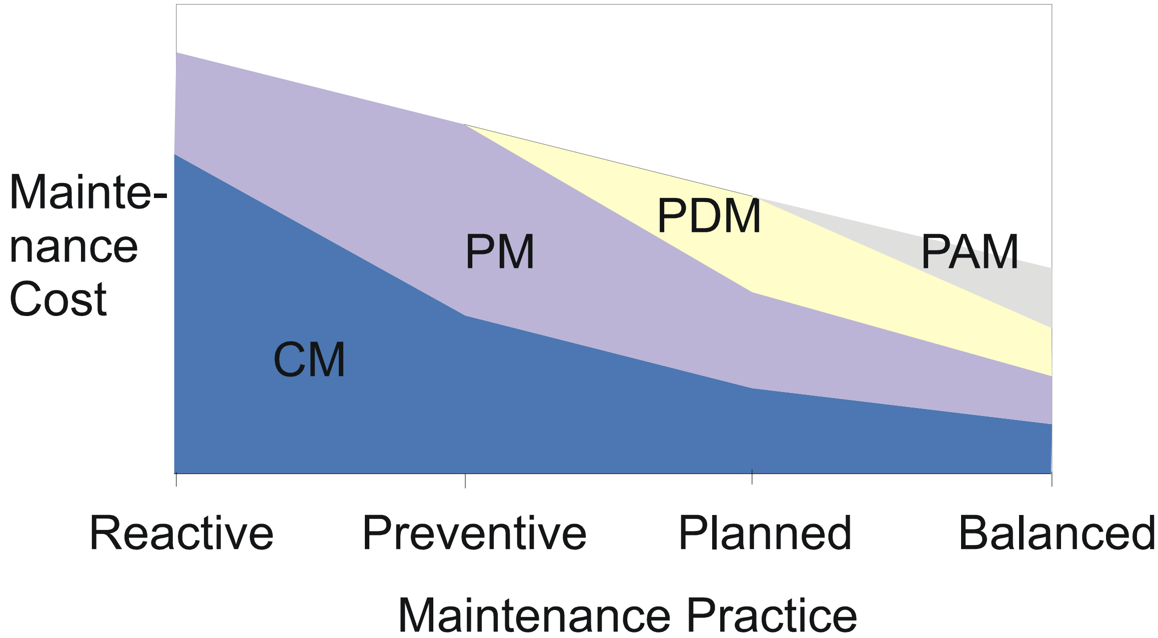


Figure 5-3
Long term goal for Plant Maintenance Optimization

A long term goal for Plant Maintenance Optimization is to reduce total maintenance costs. An organization will change their maintenance practice, or strategy, as they continually improve and optimize maintenance processes. The chart above shows an organization going from a Reactive practice, to a lower cost Balanced practice. Organizations tend to slip into a Reactive maintenance practice when resources are cut and management doesn't enforce efficient work processes. A Reactive maintenance practice is where a majority of the work is corrective. The first step of improvement is to establish efficient work processes including planning and scheduling. Then an organization can be considered having a preventive maintenance practice, where there is as much preventive work as corrective work. The third improvement shown is to establish predictive maintenance by assessing equipment condition. Then an organization can be considered having a planned maintenance practice, where there are similar levels of preventive, predictive and corrective maintenance. Then finally, a truly Balance maintenance practice is achieved when proactive maintenance is established. This is where there are similar levels of preventive, predictive, proactive and corrective maintenance.

6
METRICS AND CONTINUOUS IMPROVEMENT

Like other complex functions, proactive maintenance effectiveness require a package of measures to represent it accurately; no single measure will do, and single measures should not be taken out of the context of the package lest the information cause misunderstandings and possibly be used inappropriately. However, it is possible to select too many indicators, which dilutes the importance of a few key measures and fragments the attention of the management staff and planners responsible for the process.

For proactive maintenance effectiveness indicators, as with all indicator packages, it is not enough simply for them to exist. They must be used. The indicators should be reported frequently with little lag time between the period or event and its report, in order to reinforce good results and give early warning of bad results. Reports should be widely distributed, posted and discussed. In addition, indicators must be effective in supporting strategic decision-making and maintaining the health of the work management process.

The data of which reports are comprised must be collected in as easy and automatic a way as possible, so that data collection won't be sacrificed to day-to-day urgency and short-term priority. Data should have the following characteristics:

- Data collection: easy, automatic, timely
- Data integrity: resists manipulation, objective
- Reporting: fast, frequent, organized for comprehension, graphic
- Communication: distributed widely, posted, discussed formally
- Effectiveness: improving trends

The following metrics are leading indicators, they describe the health of the Proactive Maintenance Process and Root Cause Analysis Process. They are sensitive indicators that can be used to improve processes before the results show-up in lagging metrics. Lagging metrics are the typical accounting bottom-line results of the process. Examples of lagging metrics are: availability, forced outage rate, capacity factor, total generation, heat rate, emissions, budget, total manpower, overtime, contractor non-outage hours, and hours on blanket Work Orders.

Leading Indicators

Number of work orders reviewed
Number of events analyzed for root cause
Number of suggested changes (PM's)
Number of suggestions completed
Number of suggestions rejected

Number of increased PM frequency
Number of decreased PM frequency
Number of requests with system owner, with age of request distribution
Number of requests with PDM coordinator, with age of request distribution
Number of requests with PAM coordinator, with age of request distribution
Number of requests with RCA coordinator, with age of request distribution
Number of requests with Planning, with age of request distribution
Cost Benefits

7
SUMMARY

In the day-to-day maintenance processes, PDM can be considered the front-end, and PAM can be considered the back-end. PDM monitors equipment condition using various data, always looking for problems before they occur. PAM looks at past problems to avoid their reoccurrence.

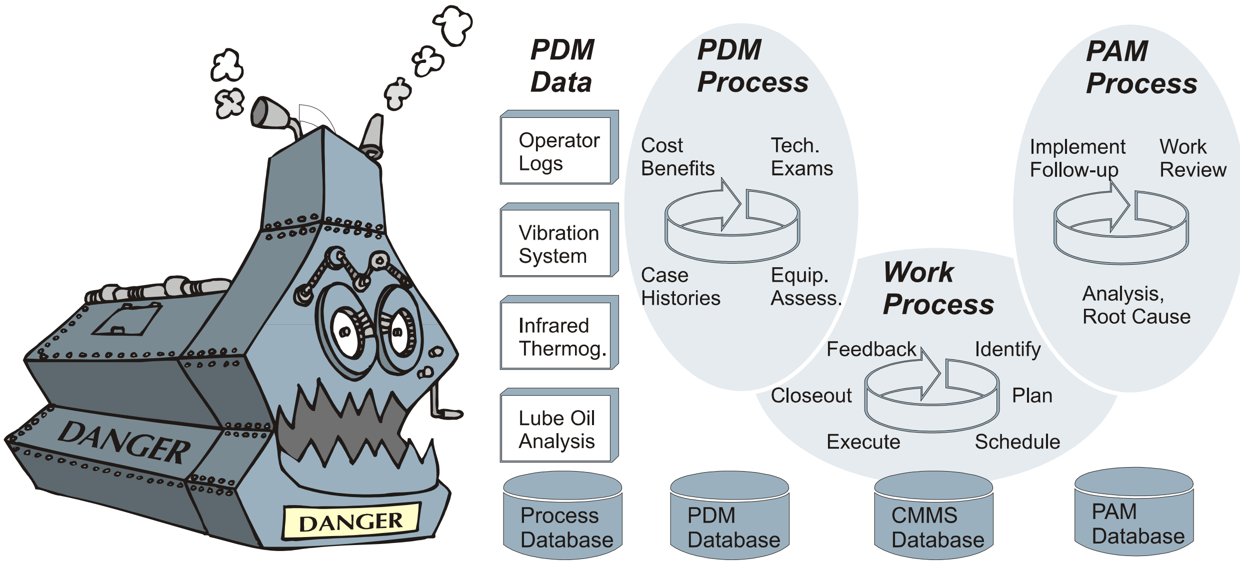


Figure 7-1
Summary of the Proactive Maintenance Process

As illustrated above, there are various maintenance processes associated with plant equipment. On the left, various PDM data sources are shown, including operator logs, vibration systems, infrared thermography, lube oil analysis, and process data. The PDM process uses all of this information to determine equipment condition. As shown, the PDM process includes technology exams, equipment assessments, case histories, and cost benefits. All of these PDM results are stored in a PDM database. The maintenance work process is shown in the center. This includes work identification, work planning, work scheduling, work execution, work closeout, and work feedback. Results of the work process are stored in the Computerized Maintenance Management System (CMMS) database. The proactive maintenance process is shown on the right. This includes work review, analysis & root cause analysis, and implementation & follow-up. Results of the PAM process are stored in the PAM database.

A
DEFINITIONS

Acronyms

- CBM Condition Based Maintenance
- CM Corrective Maintenance (Work Order)
- CMMS Computerized Maintenance Management System
- EFOR Equivalent Forced Outage Rate
- PAM Project or Proactive Maintenance (Work Order)
- PCM Profit Centered Maintenance
- PDM Predictive Maintenance (Work Order)
- PM Preventive Maintenance (Work Order)
- PM Basis Basis documentation for required PM’s
- PMO Plant Maintenance Optimization – EPRI Target Name
- PMT Post Maintenance Testing
- RCA Root Cause Analysis
- RCM Reliability Centered Maintenance
- P&S Planning & Scheduling

Definition of Terms

- Backlog - Backlog is all assigned* work orders that include CM's, PDM's, PAM's, all due PM's, and all overdue PM's. Backlog is described in terms of hours, gross weeks to execute, and projected schedule duration - for both online and offline work.
- CBM or PDM - Condition Based Maintenance or Predictive Maintenance: A process which requires technologies and people skills, while combining and using all available diagnostic and performance data, maintenance histories, operator logs, and design data to make timely decisions about maintenance requirements of major / critical equipment.
- CM - Corrective Maintenance: Corrective repair tasks on equipment that has failed and lost its functionality. CM's will also include failures on designated "run to failure".
- CMMS - Computerized Maintenance Management System: A software application designed to assist in managing the maintenance function.

- EFOR - Equivalent Forced Outage Rate: An industry metric for measuring reliability taking into account total and reduced load events. Forced is undesirable, emergency and unplanned events.
- Equipment Owner - Equipment Owner refers to a component specialist, whose components may extend through several systems. The owner would be so designated as the "go to" person for that component. An example would be the valve specialist, or motor specialist, or pump specialist.
- Latent Cause - the underlying causes to human and physical causes of problems. They are hidden in the daily business routine.
- Net Available Man-hours - Total Manpower less non direct work time such as sickness, vacation, training, & meetings
- PAM - A process of learning from past problems, events and maintenance work.
- PAM task - A task that is initiated for the purpose of eliminating or reducing future maintenance activities.
- PDM task -Condition directed tasks (Planned Maintenance) on equipment where degradation has been detected and action is warranted to prevent functional failure.
- PM - Preventive Maintenance: Maintenance tasks carried out at predetermined intervals, including PDM routes, and intended to reduce the likelihood of a functional failure.
- PMT - Post Maintenance Testing: Equipment tests performed following maintenance tasks and prior to returning the equipment to service for the purpose of gathering quality and base line information.
- Priority: - A rating system to establish precedence by order of importance or urgency.
- PMO - Plant Maintenance Optimization achieves the appropriate investment balance of Corrective (CM), Preventive (PM), Predictive (PDM), and Pro-Active (PAM) techniques for maintenance, integrating all diagnostic, maintenance, financial, and process data into the decision making process.
- Root Cause - is the most basic reason for a problem, which, if corrected, will prevent recurrence of that problem.
- RCA - Root Cause Analysis: is a process to systematically detect and analyze the possible causes of a problem so that appropriate corrective action can be planned and implemented.
- RCM - Reliability Centered Maintenance: RCM reviews the design of each system and postulates a set of failure modes based upon an assumed failure of each component (and sub component) in the system. Based on the assumption, all possible outcomes are postulated and a maintenance program formulated.
- Streamlined RCM - EPRI's streamlined approach to traditional Reliability Centered Maintenance analysis.
- Work Order Categories - the acronyms above are combined to identify categories of work on work orders. A typical set of work order categories and sub-categories are:

CM, Corrective Maintenance

- CM-RTF, Run To Failure (acceptable work)
- CM-CBM, Condition Based Maint. (acceptable work from PM, PDM or PAM)
  - CM-CBM-P1&P2, Priority 1&2 (undesirable work)
- CM-U, Unplanned (undesirable work)

PM, Preventive Maintenance

- PM-PDM, Predictive Maintenance data collection tasks
- PM, all other PM work

Maintenance Strategies: A number of maintenance strategies are being utilized in industry today and these fit into the following categories:

- Corrective/Reactive Maintenance (CM) - Corrective maintenance (a.k.a. Fire Fighting, Breakdown Maintenance) is failure based. Often times this strategy, when applied to critical equipment, leads to catastrophic failure causing a loss of production. Most Power Producers today relay heavily on this strategy. Although it is important to move beyond the reliance on Corrective Maintenance, there still exists a place for this strategy in the overall maintenance plan. Certain systems and assets simply lack the criticality to justify Preventive, Predictive, or Proactive action. A sensible approach helps to identify when this is the case, which prevents squandering resources on these lower priority assets.
- Preventive Maintenance (PM) - Performing a task on a time or interval basis in an effort to avoid catastrophic failure is referred to as Preventive Maintenance. This strategy offers the efficiency of performing maintenance tasks on a planned rather than reactive basis, thus avoiding the losses associated with unplanned downtime. However, the penalty of PM is that many times maintenance is performed that is unnecessary and costly.
- Predictive Maintenance (PDM) - Basing maintenance of assets on equipment condition represents yet another step improvement in effectiveness. A weakness of Preventive Maintenance is that most assets are either over maintained or under maintained - rarely is action taken at exactly the optimal time. Alternatively, PDM relies on employing technologies to understand the current condition of assets so that only required maintenance is performed, and it is done on a planned basis.
- Proactive Maintenance (PAM) - Any asset, whether being maintained using PM, PDM, or CM, that continues to demonstrate unacceptable reliability should be considered a candidate for a PAM investigation. PAM is a study that determines the root cause of the problem. Chronic problems warrant the application of advanced technologies, additional resources, and time to fix the problem "once and for all". The problem could be the result of poor design, maintenance, or operating procedures.
- Reliability Centered Maintenance (RCM) - This conceptual exercise identifies the most effective and applicable maintenance tasks for each piece of equipment. This task selection defines the Maintenance Basis (optimum mix of CM, PM, PDM, PAM). A full classical RCM study involves an exhaustive investigation of all failure modes and their effects. This approach, however, has now been streamlined by EPRI for the utility industry. This

streamlined RCM includes the investigation of common, known failure modes and the analysis of the resultant effects, as well as the determination of effective and applicable maintenance tasks to address those modes.

- Equipment Maintenance Optimization Manuals (EMOMs) - This strategy works in conjunction with the RCM approach. In addition to the RCM task selection , EMOMs include task cost justification, equipment work packages and maintenance procedures.

B

COST BENEFIT CALCULATION

Occurrence Assumption Worksheet

Plant Name:	Waukegan Sta. 16	Unit Number:	7	
Definition of detected fault:	#7 Main Transformer, B phase bushing significantly hotter than adjacent phases			
Occurrence No.:	WAK-008	Max. Rated Load:	353	
Occurence Assumption:	**(a)Catastr.**	**(b)Moderate**	**(c)Loss of Perf.**	**(d)Actual**
Occurrence Description	Transformer destroyed, forced	Bushing failure, transformer		Bushing replaced.
Loss of Generating Revenue				
Power Reduction (MW)	353	353	0	353
Hours	3456	100	0	48
Capacity Factor (%)	60	60	0	
Forced Outage (Yes =1 No =0)	1	1	0	0
Maintenance Costs				
Cost of Parts ($)	$1,250,000	$20,000	0	2000
Labor Hours (Hrs)	2160	1008	0	72
Percent Probability of Fault Occurrence	10	90		

Definitions:

OCCURRENCE - any detected or diagnosed fault which the station takes action, whether the action was proactive or reactive.
When the station schedules repairs or modifies plant operation to minimize the fault's impact, a cost benefit analysis will be conducted.
If maintenance is deferred based on a PDM technology, the CBA, based on the deferral, will be calculated on the time-value of $$$ saved.

CATASTROPHIC - Total equipment failure requiring full repalcement.
MODERATE - System failure resulting in some repairable equipment damage.
LOSS OF PERFORMANCE - Reduction of operating capacity due to fault.
ACTUAL - Actual cost of outage.

	Calculated Values			Input Data
Total Cost Benefit - This Occurrence	$855,637		Average Replacement Power Costs ($/MWH)=	9
Maintenance Costs Savings ($):	$177,792			
Impact on EFOR (%):	4.97			
			Average Labor Rate ($/HR) =	35

Figure B-1
Cost benefit calculation example

Use of the Cost Benefit Analysis Worksheet

A Cost Benefit Analysis (CBA) worksheet should be filled out whenever a predictive maintenance technology has been used to identify a potential problem with a piece of equipment, and a corrective action was initiated.

This process will be performed by the Process Specialists, Team members, with support from the PDM Specialist.

The following section outlines the steps involved in preparing a CBA Worksheet:

(Only the first sheet of the CBA worksheet will have any information added to it. All calculations are performed on the second page of the worksheet, based on entries on the first page.)

Starting at the top of the page, the unit-specific fields must be filled in, including Occurrence number. It is recommended that a standard numbering system be used, including a station designator, such as CRA for Crawford, J29 for Joliet 29, etc. plus an Occurrence number as shown on the sample worksheet. Crawford's first Occurrence for 1996 would be shown as CRA96-001.

The worksheet is based on assumptions of losses in two major categories: lost generating revenues and expenses associated with repairs made. The levels of failures are also separated into three potential categories: 1) catastrophic, which would indicate damage severe enough to require total replacement, 2) moderate, which would indicate some damage requiring repairs, and 3)loss of performance, which would include possible deratings and also minor equipment damage. Actual costs also need to be entered, in order to yield a net benefit for the Occurrence.

Loss of Generating Revenue

This section of the CBA will need to be filled out on a Unit by Unit and Occurrence by occurrence basis. Enter the potential de-rating caused by loss of or failure of this piece of equipment in the field marked "Power Reduction", enter the expected number of hours the de-rating would last, and indicate (with a 1=yes and 0=no) if it will be a forced outage. This will figure into the EFOR calculation later.

Maintenance Costs

The section relating to Maintenance Costs will require some research, usually through the Maintenance Management Program, (TJM or EWCS). Costs associated with past maintenance repairs, including both parts and labor can be found in both TJM and EWCS and should be used as the basis for the "Cost of Parts" and "Labor Hours" fields on the worksheet.

Percent Probability of Fault Occurrence

This section will require a consensus from a cross-section of personnel from your site. People familiar with the equipment should be brought together for a brief meeting to discuss the finds, the actions required and, based on a wide range of operating and maintenance experience, an agreement on the probability of each scenario actually occurring should be reached. The combination of probability for all possible scenarios must equal 100%.

Total Cost Benefit for this Occurrence

This section of the worksheet shows the values which have been calculated based on the numbers you enter on the worksheet. The Total Cost Benefit for this Occurrence, Maintenance Cost Savings, and impact on EFOR will change as the numbers above are added or modified.

Input Data

The box labeled "Input Data" contains two numbers that the calculations are based upon, and should not be modified. Any change to the Average Replacement Power Costs or the Average Labor Rate will change the resulting figures for the CBA and will hamper efforts to accumulate total saving for the Fossil Division

C

EQUIPMENT RANKING BY SERP (SYSTEM AND EQUIPMENT RANKING PROCESS)

This process starts by calculating an Asset Criticality Rating (ACR) which is the product of the System Criticality Ranking (SCR) and the Equipment Criticality (ECR). The ACR is independent of the current equipment status. Typically this number ranges from 10 to 100.

Then the process calculates a Maintenance Priority Index (MPI) which is the product of the ACR and a current status factor. This number typically ranges from 10 to 200.

SCR (System Criticality Ranking), RMS (Root Mean Square) combination of 5 factors

SCR = SQRT (S^2 + E^2 +C^2 + CA^2 + EFF^2)

ECR (Equipment Criticality Ranking), RMS combination of 5 factors

ECR = SQRT (S^2 + E^2 +C^2 + CA^2 + EFF^2)

ACR (Asset Criticality Rating) = SCR * ECR

MPI (Maintenance Priority Index) = ACR * RMS(Condition-Status and Repair-Status)

Where:

Repair Status is:

1 if minimal maintenance is required

2 if moderate maintenance is required

3 if frequent maintenance is required

Condition Status is:

1 if acceptable (green) or watch list (blue)

2 if marginal (yellow)

3 if unacceptable (red)

System Critically Ranking Criteria (SCR)

Safety

10	High Safety Concern, possible fatality, injuries occur to personnel
8	High Safety Concern - injuries occur to personnel, lost time.
5	Safety concerns - Possible doctor attended injuries.
3	Low Safety Concern - Action taken to secure area.
1	No Safety Concern

Environmental

10	Shut Down
8	Fine
5	Notice of Violation
3	Close Call (Non-Reportable)
1	No Effect

Cost

10	Major O&M Cost > $100,000
6	Medium O&M Cost $100,000 > X >$50,000
4	Minor O&M Cost < $50,000
1	No Effect

Commercial Availability

10	Plant Shutdown
9	Long Term Unit Shutdown (> 1 week)
8	Short Term Unit Shutdown (< 1 week)
7	Long Term Boiler Shutdown (> 1week)
6	Short Term Boiler Shutdown (< 1week)
5	Long Term Load Reduction (> 1 week)
4	Short Term Load Reduction (< 1 week)
3	Future Potential Loss of MW’s
1	No Effect

Efficiency

10	> 100 BTU’s
8	> 75 BTU’s
6	> 50 BTU’s
4	> 25 BTU’s
1	< 25 BTU’s

Equipment Critically Ranking Criteria (ECR)

Safety

10	High safety concern - Possible fatality - Injuries to personnel
8	High safety concern - Injuries occur to personnel - lost time
5	Safety concern - Possible doctor attended injury5
3	Low safety concern - Action taken to secure area
1	No safety concern

Environmental

10	Shut down
8	Fine
5	Notice of Violation (NOV)
3	Close call
1	No effect

Cost

10	> $1,000,000
9	$500,000 - $1,000,000
8	$250,000 - $500,000
7	$100,000 - $250,000
6	$75,000 - $100,000
5	$50,000 - $75,000
4	$25,000 - $50,000
3	$5,000 - $25,000
2	$1,000 - $5,000
1	< $1,000

Commercial Availability / Reliability

10	Plant shut down	
9	Long term unit shutdown	> 1 week
8	Short term unit shutdown	< 1 week
7	Long term boiler shutdown	> 1 week
6	Short term boiler shutdown	< 1 week
5	Long term load reduction	> 1 week
4	Short term load reduction	< 1 week
3	Future potential loss of MWs	
1	No effect	

Efficiency

10	>100 BTUs/ nKWH
9	81 - 90 BTUs / nKWH
8	71 - 80 BTUs / nKWH
7	61 - 70 BTUs / nKWH
6	51 - 60 BTUs / nKWH
5	41 - 50 BTUs / nKWH
4	31 - 40 BTUs / nKWH
3	21 - 30 BTUs / nKWH
2	11 - 20 BTUs / nKWH
1	< 10 BTUs / nKWH

Reference: TR-103374-V3, Predictive Maintenance Guideline, PDM Implementation Plan

Targets:

Work Process Improvement Guidelines and Techniques

Plant Maintenance Optimization

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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