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Streamlined Reliability Centered Maintenance Analysis Application Update

Technical Report

Streamlined Reliability Centered Maintenance Analysis Application Update

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EPRI Project Managers
M. Perakis
M. DeCoster

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

N&T Consulting Service, Inc.

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CITATIONS

This report was prepared by

N&T Consulting Service, Inc.
1835 Lynwood Drive
Concord, CA 94519

Principal Investigator
T. Grewis

ERIN Engineering and Research, Inc.
2033 North Main Street, Suite 1000
Walnut Creek, CA 94596

Principal Investigator
G. Toomey

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REPORT SUMMARY

A systematic evaluation of plant equipment and maintenance requirements using Reliability Centered Maintenance (RCM) techniques can help hold down operating costs while maintaining plant availability and reliability. This report describes the application of Streamlined Reliability Centered Maintenance (Streamlined RCM) methodology and software at four utilities.

Background

Historically RCM application costs and data requirements were thought to be prohibitive in fossil plant environment. These problems led to the development of a streamlined version of the methodology that reduces RCM analysis cost, cost for preventative maintenance (PM) task work plan development, and input into a plant's Computerized Maintenance Management System (CMMS). Over 20 utilities have applied Streamlined RCM at some or all of their power plants during the past several years. This report describes the application of Streamlined RCM methodology and software at four utilities with sufficient history to provide significant project results and experience.

Objectives

To improve and further refine the Streamlined RCM analysis method so it can be applied more cost effectively in fossil power plants.

Approach

Between July 1996 and the spring of 2000, investigators worked with core teams of maintenance personnel from four power plants to enhance overall plant economic performance by:

- Defining technically correct levels and types of maintenance to be performed
- Optimizing existing preventive maintenance tasks
- Developing and documenting a sound maintenance program strategy.

The teams typically analyzed 10 systems at coal-fired units and 7 systems at gas fired units. Systems analyzed included: main steam and water, fuel handling, circulating water, ash handling, sootblowing, boiler gas and air, feedwater heater drains/extraction steam, coal handling, feedwater, and condensate.

Results

Utilization of the Streamlined RCM methodology allowed phase-out of costly intrusive inspections on major components while developing or enhancing existing PM programs to monitor and conditionally direct maintenance activities. Cost savings were realized through the elimination of intrusive disassembly and inspections and also by reduction of maintenance

frequency for selected components. Other benefits obtained by using Streamlined RCM methodology included identifying more cost-effective tasks than those in the existing Predictive Maintenance program. Analysis results discovered components with particularly poor performance records ("bad actors"), poor design or application, or simply equipment nearing end-of-life. These findings led to changes in the maintenance performed and identified possible redesign or equipment replacement opportunities. A final benefit from the Streamlined RCM project was the refined prioritization of maintenance tasks and resources utilization. The results provided plant management a clear understanding of why certain maintenance activities have to be performed while others can be eliminated.

EPRI Perspective

Fossil plant application of Streamlined RCM methodology has yielded significant cost reduction in equipment maintenance costs with increased electrical production capability as a result of:

- More aggressive operator involvement in simple maintenance tasks
- Selection of more effective PM tasks to perform
- Extending the interval between maintenance activities
- Increased use and effectiveness of Predictive Maintenance Techniques
- Better focus of maintenance resources on important system equipment

This more effective maintenance approach has allowed power plants to achieve a better balance between Reactive (Unplanned Corrective) Maintenance and Proactive (Preventive) Maintenance while meeting desired production levels.

Streamlined RCM analysis and implementation templates as well as other labor saving activities are being developed to additionally increase the cost effectiveness of applying Streamlined RCM methodology to fossil power plants. Specific plant benefits vary greatly depending upon individual plant circumstances but typical experience indicates that project payback can be anticipated in less that one or at most two years.

Keywords

Reliability centered maintenance (RCM)
Streamlined reliability centered maintenance
Maintenance
Predictive maintenance
Preventative maintenance

ABSTRACT

In order to successfully compete in the electrical generating industry today, plant availability and reliability must be maintained at desired levels while operating costs must be kept as low as reasonably achievable. A key element in this cost reduction is controlling maintenance practices. It has been shown in other industries that a systematic evaluation of plant equipment and maintenance requirements using Reliability Centered Maintenance (RCM) techniques can be an extremely beneficial tool in obtaining this goal. In this project, a Streamlined Reliability Centered Maintenance (Streamlined RCM) methodology was applied to fossil power plants with the expectation that the maintenance programs for the systems analyzed would be improved and made more effective while controlling maintenance cost and maintaining or increasing plant performance.

This report summarizes an evaluation of the applicability of Streamlined RCM methodology to fossil power plants. This report also includes an evaluation of the application process used. The methodology is intended to identify appropriate PM maintenance tasks with suitable performance intervals. EPRI's contractor performed the Streamlined RCM analysis with on-site plant training and plant staff input including analysis review and approval. PM task recommendations reflect input from various sources including industry experience and extensive discussions with plant maintenance, operations and engineering personnel during the review meetings.

Over 20 utilities have applied Streamlined RCM at some or all of their power plants during the past several years. This report describes the application of Streamlined RCM methodology and software at four utilities with sufficient history to provide significant project results and experience. All information contained in this report has been obtained from the following utilities. However, as a result of industry competitiveness, company specific data is not included.

PSE&G – Burlington
Combined Cycle Gas Turbine
8 System Analysis

Salt River Project – Navajo
3 Unit Coal Fired
30 System Analysis

Sierra Pacific – Valmy
2 Unit Coal Fired
10 System Analysis

Salt River Project – Coronado
2 Unit Coal Fired
10 System Analysis

Fossil plant application of Streamlined RCM methodology has yielded significant cost reduction in equipment maintenance costs with increased electrical production capability as a result of:

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This more effective maintenance approach has allowed power plants to achieve a more optimum balance between Reactive (Unplanned Corrective) Maintenance and Proactive (Preventive) Maintenance while meeting desired production levels.

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EXECUTIVE SUMMARY

This report describes the application of Streamlined Reliability Centered Maintenance (Streamlined RCM) methodology and software at four of twenty utilities with sufficient history to provide significant project results and experience. The Streamlined RCM project including PM task implementation by the plants at these four locations was started in July 1996 and completed in the spring of 2000. These Streamlined RCM analysis projects had the explicit intention of determining if Streamlined RCM could cost effectively be used in a fossil power plant environment. The principal project objective was to enhance overall plant economic performance by:

- Defining technically correct levels and types of maintenance to be performed
- Optimizing existing preventive maintenance tasks
- Developing and documenting a sound maintenance program strategy.

Typically 10 systems are analyzed on coal-fired units with 7 systems being sufficient on gas fired units. Systems typically analyzed include: main steam and water, fuel handling, circulating water, ash handling, sootblowing, boiler gas and air, feedwater heater drains/extraction steam, coal handling, feedwater, condensate. The project begins with the selection of 10 systems for analysis. These systems are selected based on operational importance (power production capability), regulatory requirements, importance to availability and reliability, and finally upon existing preventive and corrective maintenance costs. For example, the bottom Ash System is typically a high maintenance system due to the nature of its service. The environmental conditions are often quite harsh and the material being transported is highly erosive subjecting important plant equipment to increased wear. The Flue Gas Scrubbing system is a high profile system, responsible for maintaining stack emissions within legal limits. Similarly, the nature of the service causes a great deal of wear on system equipment. Consequently a plant's primary objective is to develop applicable and cost-effective Preventive Maintenance (PM) programs for these types of systems to increase their reliability and, hence, plant availability and capacity factor while reducing overall maintenance costs if practical.

EPRI's contractor with a core team of plant personnel reviewing analysis results and recommendations conducts the Streamlined RCM analyses. EPRI provided project management and guidance along with extensive power plant operating and maintenance experience. The burden of assuring practical analysis results, plant maintenance philosophy, analysis support (reference materials and documentation) was shouldered by the plant Core Team. This Core Team has primary plant responsibility to take the resulting PM tasks and develop suitable job work plans and input them into the plant's Computerized Maintenance Management System (CMMS). Additional personnel for expert system knowledge are made available during review meetings and interviews when necessary.

Analyses are conducted in phases, usually two systems per phase, with each phase lasting approximately two months. A phase consists of data collection, data analysis, reviewing the analysis work products concluding with final document revisions. Core Team member support is minimized to reduce the impact on day-to-day operations. Core Team analysis support not including job work plan development and input into the CMMS averages 10 to 15 days over a 6 to 8 month period for a ten-system project. Work Plan development and CMMS input (implementation of the Streamlined RCM results) begin immediately following each analysis phase (2 systems). Plant labor requirements for the implementation phase vary significantly depending upon the number and quality of existing work plans.

Typical utilization of the Streamlined RCM methodology yields results which phase-out of costly intrusive inspections on major components while developing or enhancing an existing Predictive Maintenance (PdM) program to monitor and conditionally direct maintenance activities. In this way, not only would cost savings be realized in the eventual elimination of intrusive disassembly and inspections, but also in the expected reduction of maintenance frequency for these components thus increasing the ability to generate additional revenue.

Other benefits obtained by using Streamlined RCM methodology included identifying more cost-effective tasks than those in the existing PM program. Analysis results discover components with particularly poor performance records ("bad actors"), poor design or application, or simply equipment nearing end-of-life. When these findings are properly documented the analysis review sessions generate a more thorough discussion by key plant personnel. This leads to potential changes in the maintenance performed or to investigate possible redesign or equipment replacement opportunities.

A final benefit from our Streamlined RCM project was the refined prioritization of maintenance tasks and thus, resources utilization. The results provided plant management a clear understanding of why certain maintenance activities have to be performed while others can be eliminated.

In conclusion, application of the Streamlined RCM methodology has produced significant cost-savings while optimizing the systems' reliability and availability potentially increasing unit generation and revenue production. The risk of unanticipated equipment problems that could result from more intrusive activities are reduced by increasing condition monitoring capabilities, modifying some equipment to facilitate PdM efforts, and installing additional condition monitoring equipment.

Streamlined RCM analysis and implementation templates as well as other labor saving activities are being developed to additionally increase the cost effectiveness of applying Streamlined RCM methodology to fossil power plants. Specific plant benefits vary greatly depending upon individual plant circumstances but typical experience indicates that project payback can be anticipated in less that one or at most two years. Section 3 of this report provides benefit comments (very interesting reading) made by the four plants documented in this report. The report body contains a more complete discussion of the preceding summary including details of the Streamlined RCM methodology used including examples of Streamlined RCM application cost saving tools and activities.

1
INTRODUCTION

In 1995 Electric Power Research Institute (EPRI) began additional fossil plant projects attempting to improve fossil-fueled power plant economic performance. This report describes EPRI's demonstrate projects to determine the feasibility of using Streamlined Reliability Centered Maintenance (Streamlined RCM) methods and templates to aid in optimizing Preventative Maintenance (PM) tasks. Thereby helping power producers reduce the cost of production. To date, approximately 20 utilities have participated in this collaborative TC3889 project to develop an EPRI database on PM maintenance task selection and implementation.

The methodology used is an application of Reliability Centered Maintenance (RCM) principles to fossil plant systems in a streamlined and efficient manner. It is a systematic methodology for identifying applicable and effective maintenance tasks based on system and component functionality. This report describes the application of Streamlined Reliability Centered Maintenance (Streamlined RCM) methodology and software at four Utilities with sufficient history to provide significant project results and experience. The four Utilities described in this report are:

PSE&G – Burlington
Combined Cycle Gas Turbine
8 System Analysis

Salt River Project – Navajo
3 Unit Coal Fired
30 System Analysis

Sierra Pacific – Valmy
2 Unit Coal Fired
10 System Analysis

Salt River Project – Coronado
2 Unit Coal Fired
10 System Analysis

Historically RCM application costs and data requirements were thought to be prohibitive in fossil plant environment. Hence the initial goal was to determine if it was feasible to apply RCM methodology using a streamlined approach at fossil plants. After Streamlined RCM had been successfully applied, the project goals were expanded to include developing additional tools and templates. These further reduced Streamlined RCM analysis cost as well as eliminating, where

ever practical, the subsequent cost for PM task work plan development and input into the plant's Computerized Maintenance Management System (CMMS).

The cost saving tools envisioned included two Templates types:

- Task Selection Templates

These templates provide guidance on selecting the type and frequency of PDM/PM task to be performed while allowing for user customization based upon their technology capabilities and the level of conservatism desired in the maintenance program. A labor saving is obtained from component maintenance templates used in the selection of maintenance tasks (e.g. time-based inspections, condition-based, surveillance tests, run-to-failure). Variations in: equipment functions, maintenance histories and service conditions provide unit specific data input for the templates. The condition assessment (PdM) capability of the plant must also be considered when selecting PdM tasks.

- Task Implementation (work plan) Templates

These templates are designed to simplify and accelerate the process of converting the Streamlined RCM identified PDM/PM tasks into CMMS work requests. The template may include specific direction to maintenance crafts.

An EPRI database on maintenance task selection and PM task implementation work plans was developed and subsequently converted into templates in selection table format to facilitate customization of generic system analysis and maintenance templates. The tables provide typical unit or component customization information to allow an analyst to more rapidly adapt to a specific unit application. Provisions for uncommon modifications will allow special customization at the user's discretion. These two types of templates are being matured by first developing an administrative process to accomplish the analysis and task selection activities, followed by developing software packages to reduce the effort needed to complete the various activities. EPRI plans that participants in this collaborative effort will each have access to the resulting set of generic templates. EPRI's Plant Maintenance Optimization (PMO) and Hydropower Targets are cooperating in developing these Streamlined RCM templates and Living Program process and software.

When applying Streamlined RCM at power plants a cultural change can usually be anticipated. Maintenance tasks would now be selected based on applicability, industry experience and plant history, rather than based solely on recommendations from vendor technical manuals or what had proven to be at least partially effective but was highly reactive in nature with associated high costs. The plants have experienced better personnel allocation assuring that critical maintenance tasks are planned and performed in a timely manner. Initial Unit systems were chosen at the plants for analysis with the goal to effectively focus maintenance in systems, which have historically been maintenance-intensive, and or with poor reliability. Streamlined RCM could also provide other benefits such as reducing materials and spare parts costs and providing guidance for implementing equipment monitoring and diagnostic systems.

Actual work at the Plant site had plant personnel assigned as Core Teams to coordinate with EPRI's contractor personnel (ERIN Engineering & Research, Inc.) for interviews, various intermediate product reviews and final approval of the analysis results. ERIN personnel would perform the actual analyses, submitting reports to the Teams at key points in each analysis for plant review and approval. The Core Teams were comprised of personnel representing the Operations, Maintenance, and Engineering disciplines, and having extensive experience in all facets of plant operations. The Team was empowered to make all necessary decisions to establish applicable plant maintenance strategies thus enabling the analysis to proceed.

The Streamlined RCM TC project work scope included:

- Considering the economic effects of equipment failures using Streamlined RCM methods.
- Documenting Streamlined RCM maintenance optimization evaluations in view of current industry experience.
- Developing equipment PM task selection and work plan templates.
- EPRI's contractor ERIN Engineering and Research Inc. assists with planning the implementation of Streamlined RCM recommendations for preventive maintenance (PM) tasks into CMMS work order format.
- Helping the plant implementation teams to properly understand each Streamlined RCM recommendation.
- Provision for ERIN to provide a Living Program process and procedure in which the results of ongoing future maintenance activities (e.g. time intervals, causes, and significance of equipment failures) are used to update and improve the Streamlined RCM analysis and the recommended maintenance tasks. The procedure specifies data requirements and organizational roles and responsibilities.
- Training workshops in addition to participation throughout the project assure a complete understanding of the Streamlined RCM process and its application.
- Technology transfer and training at plant sites in all aspects of Streamlined RCM maintenance optimization including cost/benefit analysis results.

The contractor support did not include performing any implementation activities but rather provide consultation on various Streamlined RCM analysis recommendations as required by the plant teams. In some instances, following completion of the PM task implementation by the individual plants ERIN has performed a partial review of the information placed in the CMMS.

The plant is responsible for implementing Streamlined RCM analysis recommendations by developing work plans and loading the plant CMMS with the appropriate PDM/PM tasks at the desired frequency for all components analyzed during the Streamlined RCM analysis. Information to be presented on the CMMS generated work order is determined by the plant considering the capabilities of its CMMS. Observation and comments by ERIN and EPRI provide insights on what other Utilities have included in their work plans. Strong management support is required to successfully implement any recommended changes in current processes or concepts.

EPRI's existing library of templates, already developed with other PMO Target member Utilities participating in this TC project, are made available for each new application of the Streamlined RCM process to expand the template data base.

The analysis phase of the work is designed to provide a maintenance program:

1. Focused on critical equipment with documented failure modes.

2. Strategy emphasizing condition-based tasks.

3. Identifying actions that help preclude costly unplanned corrective maintenance.

4. Identifying and removing unnecessary routine PM tasks.

This report offers a description of the methodology, application, and achieved results. Section 2 provides a summary of the details involved in performing an Streamlined RCM analysis and developing work plans for the PM tasks identified by the analysis, Section 3 summarizes the results achieved (including plant results comments), and Section 4 lists insights and lessons learned.

2
OVERVIEW OF THE STREAMLINED RCM PROCESS

The Streamlined Reliability Centered Maintenance (Streamlined RCM) Process evolved from Reliability Centered Maintenance (RCM) techniques currently used on nuclear plant safety systems. Streamlined RCM provides the same benefits as RCM, but without some of the excess detail and redundant documentation that are necessary in the nuclear environment. The Streamlined RCM analysis process combines a reliability analysis with a review of plant maintenance history to develop a recommended maintenance plan. A review of each analysis step by the plant staff, as well as interviews with maintenance and operations personnel are combined with ERIN's analysis experience to produce unit specific PM tasks.

Streamlined RCM methodology is designed to ensure the reliability of every important plant function. The resulting system component (equipment) maintenance plan is prioritized based on system functionality and importance. The plan is optimized based on a combination of analyst experienced and postulated component failures as well as the need to contain expenses by reducing intrusive maintenance and observation inspections as appropriate. Maintenance tasks are developed within reasonable economic bounds to monitor or maintain only those components whose failure would interrupt an important plant function. All other components are run to failure when it is safe and economical to do so. In addition to a documented basis for the resulting "optimum" maintenance tasks, the Streamlined RCM process can identify a set of recommended PM task changes to the existing plant maintenance program.

The goals of Streamlined RCM can be summarized as follows:

- Concentrate maintenance resources where they will do the most good.
- Eliminate unnecessary and ineffective maintenance.
- Devise the simplest and most cost-effective means of maintaining equipment, or testing for degradation
- Focus PM tasks on predictive or condition monitoring activities where applicable.
- Develop a documented basis and history for the maintenance program.
- Maximize plant employee and contractor (analyst) experience when determining equipment PM tasks with appropriate frequencies.

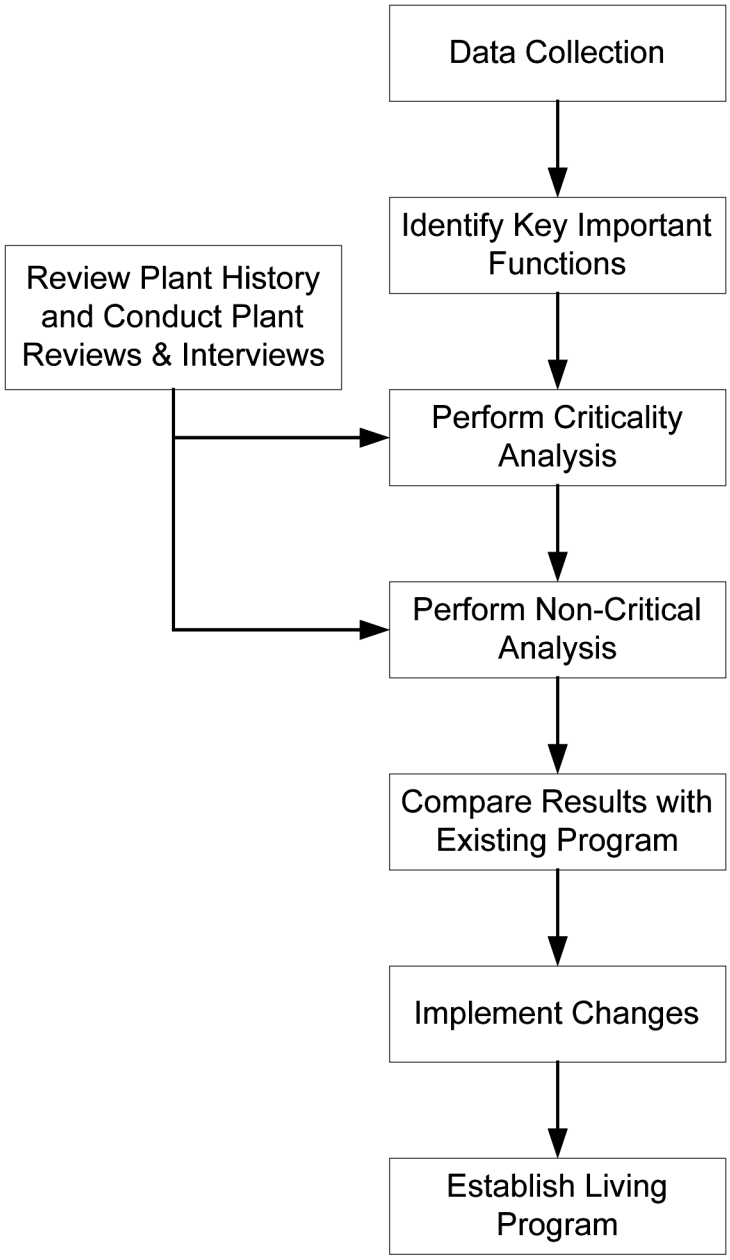


Figure 2-1
Streamlined RCM Process

Data Collection

The documents collected during the "Data Collection" step include system descriptions, Piping and Instrument Diagrams (P&IDs), Functional Diagrams, Plant Operating and Alarm Response Procedures, Work Procedures, Routine Surveillance Tests, Vendor Information, Corrective and Preventive Maintenance History and Component Lists.

Identify Key Important Functions

The identification of key important functions involves specifying those functions that are *essential* to plant operation and safety. Only the important functions are evaluated in the Critical Analysis. All the components that support the non-essential system functions are evaluated in the Non-Critical Analysis.

Perform Criticality Analysis

The "Critical Analysis" in the Streamlined RCM Process combines the standard Failure Modes and Effects Analysis (FMEA) and the maintenance task selection Logic Tree Analysis (LTA) into one record. This process allows the analyst to list multiple failure modes for a specific component and only identify the *dominant* plant effects. If the component is determined to be critical, the analyst identifies the appropriate failure causes and recommends the applicable PM tasks to prevent or detect the identified failures. Components that are initially analyzed in the Critical Analysis but are identified as non-critical will get evaluated again during the Non-Critical Analysis to determine if there are cost effective PM tasks that should be performed. The Streamlined RCM technique, with minor documentation loss, can significantly reduce the amount of time required to perform both the FMEA and LTA portions of the analysis compared with the standard RCM process by combining failure modes and plant effects. Most standard RCM processes have individual entries for each component failure mode with local, system, and plant effects identified. This traditional RCM approach requires significant addition analysis labor cost not to mention many more maintenance tasks to be performed. It is doubtful that fossil plant can justify these additional costs considering their impact on unit profits.

Perform Non-Critical Analysis

The "Non-Critical Analysis" provides an evaluation using economic criteria listed below for those components that were identified as functionally non-critical in the Critical Analysis. In the Non-Critical Analysis, several questions are used to determine the cost effectiveness of providing some level of preventive maintenance versus allowing the component to run to failure. The questions used in the non-critical evaluation are as follows:

1. Is there a high repair/replacement cost if the component is run to failure
2. Is there currently excessive corrective maintenance performed on this component
3. Is there a simple cost-effective task that can be performed to prevent component degradation
4. Can failure of this component induce other failures
5. Is there an increased personnel or environmental hazard if the component is run to failure
6. Is this component required to perform or in support of other recommended maintenance activities

During the critical and non-critical analysis steps, corrective maintenance data from the plant is reviewed. Interviews are held with plant operations, engineering and maintenance personnel to obtain additional information regarding current component performance and maintenance. This analysis data appears in the form of assumptions, which are verified during the plant review meetings. Plant reviews and interviews are also used to:

1. Verify the classification of a component as critical or non-critical
2. The existence and performance of existing PMs.
3. The potential for design changes are considered if such changes could reduce the critically of a component and eliminate the need of a PM or if the change will improve the ability to perform a PM.

Compare Results with Existing Program

Comparison of the Streamlined RCM analysis identified PM tasks (for each component) as they appear in the Criticality Analysis, the Non-Critical analysis with the existing plant maintenance program will potentially identify any of the following:

- "Add" - A new task from the Critical or Non-Critical analysis when there is no existing task
- "Retain" - The existing task in the plant's current PM program as it is identical to the Streamlined RCM identified task
- "Modify" - The existing task in the plant's current PM program has similar requirements to the Streamlined RCM identified task but need modification either in work scope or changing the interval when task is performed (frequency)
- "Delete" – The existing task is redundant to another task or is no longer considered applicable or effective

Task Selection Templates

Figure 2-2 is an example of a task selection templates used during the task selection phase of the Streamlined RCM analysis. These templates identify typical condition monitoring, time directed and surveillance tasks for various equipment types based upon criticality and service. The recommended time interval between task execution is also available.

The templates are being developed as part of the EPRI's Streamlined RCM TC projects. Information contained in the template reflects related industry experience, other historical plant practices as well as ERIN's experience. The template data is expanded and modified during the Streamlined RCM process by the plant to "personalize" the maintenance practices and reflect the amount of conservatism desired. Fifty three task selection templates have been developed to date under this TC. They were contained in EPRI Report TR-109795-V3, Streamlined Reliability-Centered Maintenance Implementation Guidelines.

Component type:											
Component Classification Category:											
Critical	YES	✓	✓	✓	✓						
	NO					✓	✓	✓	✓		
Environment	Harsh	✓	✓			✓	✓				
	Non-Harsh			✓	✓			✓	✓		
Usage	Frequently	✓		✓		✓		✓			
	Seldom		✓		✓		✓		✓		
		Frequency								Failure Cause	COMMENTS
Condition Monitoring Tasks:											
Perform full spectrum vibration monitoring. Establish baseline and action levels. Trend results.		3M	6M	3M	6M	6M	12M	6M	12M	BS; GW; LC; SC	
Perform lube oil analysis. Establish action levels. Trend results.		3M	6M	3M	6M	12M	12M	12M	12M	BS; SC; SL; DL	*Sampling and analysis of lube oil to include water, sediment, viscosity. A qualitative and quantitative analysis of metal and impurity content to be performed for diagnostics only.*
Perform component performance test over full range of operation. Establish baseline and action levels. Trend results.		18M	18M	18M	18M	NN	NN	NN	NN	IW; SC	*This test should include pressures, temperatures, flows, leaf-offs, etc.*
Time Directed Tasks:											
Perform detailed clean and inspect. Include inspection for erosion/corrosion.		CD /54M	CD /54M	CD /54M	CD /54M	CD /90M note 2	CD /90M note 2	CD /90M note 2	CD /90M note 2	BS; DL; IW; LC; PL; SC; SL; UD	*Use these frequencies only if NOT implementing ALL the Condition-Monitoring and Surveillance Tasks, otherwise, condition direct this task.*
Perform overhaul of component		CD /60M	CD /90M	CD /60M	CD /90M	NN	NN	NN	NN	BS; DL; IW; SC; UD; GW; AG; PL	*Use these frequencies only if NOT implementing ALL the Condition-Monitoring and Surveillance Tasks, otherwise, condition direct this task.*
Perform visual/pump seal inspection		OR	OR	OR	OR	OR	Note 1	OR	Note 1	DL; LC; PL; SL; UD	*The qualitative observation of a component's condition or performance.*
Perform check of lubricant, add or change oil when needed		OR	OR	OR	OR	OR	Note 1	OR	Note 1	BS; DL; SC; SL	*Use lube oil analysis to condition direct the oil change when possible.*
Lubricate (Greased bearings and coupling)		18M	18M	18M	18M	24M	24M	24M	24M	BS; DL; SC; SL	
Perform changeout of lubricant		CD /18M	CD /18M	CD /18M	CD /18M	CD /24M	CD /24M	CD /36M	CD /36M	BS; DL; SC; SL	Use these frequencies if not performing lube oil sampling.
Surveillance Tasks:											
Monitor vibration and temperatures, and performance.		1D	1D	1D	1D	1W	1W	1W	1W	BS, LC, SC	*Data log and trend either daily or weekly.*
Verify proper operation		OR	OR	OR	OR	OR	OR	OR	OR	DA; LC; MB; MS; SC; SH	*The qualitative observation of a component's condition or performance. [Look, Listen, Touch]*
Economic Considerations:											
Run until corrective maintenance is required		NA	NA	NA	NA	ü	ü	ü	ü		

Note 1: Daily when operated
Note 2: Performed ONLY on expensive/large pumps

Figure 2-2
Task Selection Template Example

Streamlined RCM Identified PM Task Implementation Process

Once the PM tasks have been determined considerable effort is required to plan and develop Work Plans for loading into the CMMS. This important step must be completed before the new unit maintenance plan can be effectively performed and resultant saving realized.

As mentioned previously the analysis process develops a list of PM tasks requiring deletion, modification or retention to convert from the old to the new maintenance plan. Tasks being retained do not require any special implementation other than to ensure proper work plans are in place. PM tasks no longer considered necessary simply have to be deleted from the CMMS to stop future execution by maintenance craft personnel.

New or modified tasks should consider several factors when deciding which tasks should be implemented first. Primary consideration should be given for the need to meet code, insurance, or regulatory requirements. Next determine if significant time is needed or if special approval is necessary before the new task can be effectively executed. Finally consider the tasks impact on:

- Plant availability and reliability
- Task execution frequency
- Ability to perform as part of operator rounds
- The impact on maintenance cost reduction
- Lead-time while the craft expertise is learned i.e. tasks requiring a new PdM knowledge

Full implementation is achieved when an executable PM program is contained within the CMMS using the Streamlined RCM analysis as its basis. Figure 2-3 depicts the steps usually applied to a successful PM task implementation process. Note the need to integrate emergent unplanned corrective maintenance activities with normal preventative maintenance work in step 4. In addition prioritization of all work tasks to be performed is essential to assure timely execution of all maintenance activities (planned and unplanned, secluded and nonscheduled, breakdown and preventative). Figure 2-4 illustrates a maintenance task priority determination process used during the Streamlined RCM analysis. Results can be included as part of the information loaded into the CMMS work plans. The Living Program, step 6, discussion follows the work plan information portion of this report.

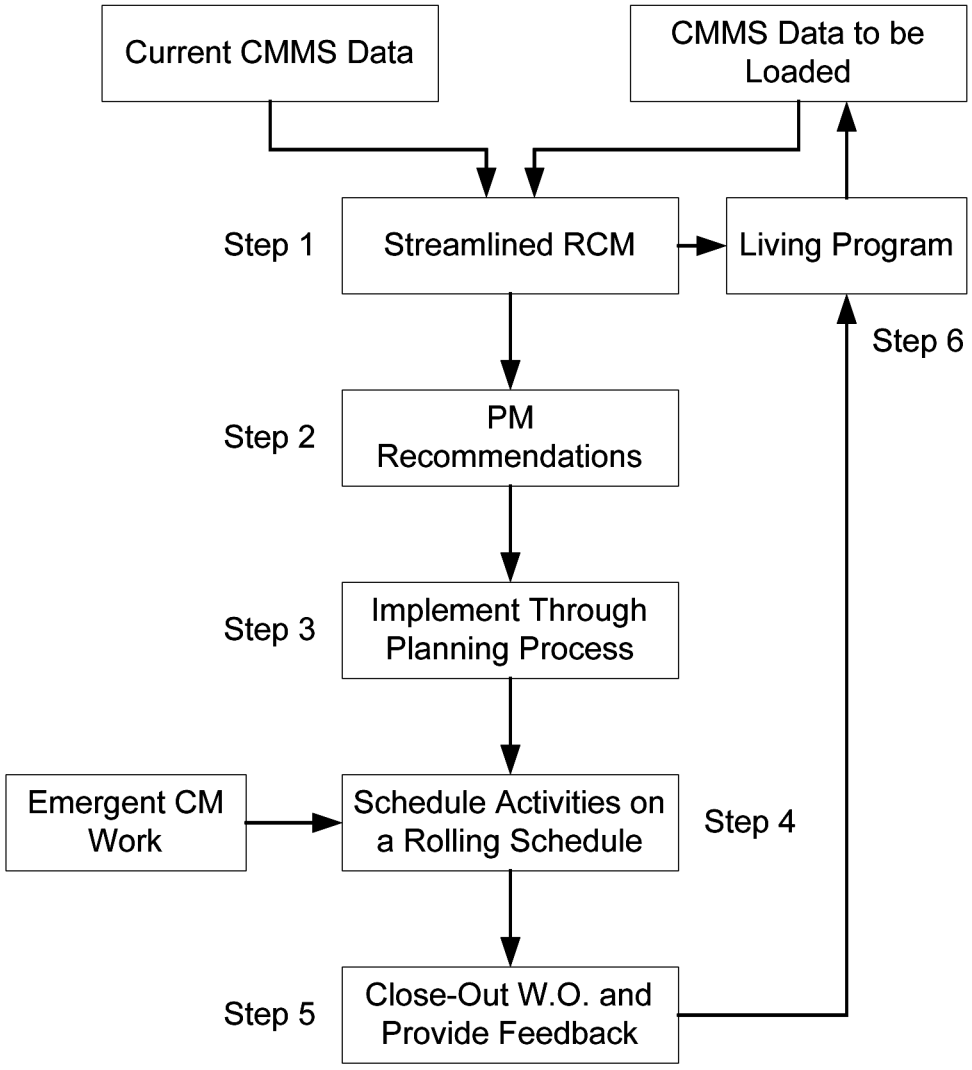


Figure 2-3
Steps for Successful Implementation

Priority	Type of Work
1	Unplanned CM resulting in trip, derate, etc.
2	PM on FC with FE results in trip, derate, etc.
3	CM on FC not resulting in trip, derate, etc. CM on FNC due to redundancy PM on other FC PM on FNC where Q1-3 is yes
4	PM on FNC where Q4-5 is yes CM on FNC where Q1-3 is yes
5	CM on FNC where Q4-5 is yes Other

Where:
CM means Corrective Maintenance
PM means Preventive Maintenance
FNC means Functionally Non-Critical
FC means Functionally Critical
FE means Failure Effect
Q are non-critical evaluation Questions
Q1: Is there a high repair cost after failure?
Q2: Are there simple tasks to prevent failure?
Q3: Induce other failures or prevent critical PM?
Q4: Is there a potential personnel hazard?
Q5: Is there a costly CM history to eliminate?

Figure 2-4
Task Priority Determination Process

Deciding the appropriate level of information to include in work plans entered into the CMMS is extremely important. Consideration must be given to the fact that more information usually takes longer to acquire and demands more resources. However work execution is normally improved with more specific information and planning that is included in the work plans. The plant has to decide what's appropriate for each unit where Streamlined RCM is applied. Work plan information contained in the CMMS may include specific direction to maintenance craft on what maintenance actions are required as well as what maintenance history is needed. Emphasis is placed on what actions are required not on how to perform the actions. Before and after maintenance equipment performance testing requirements should also be included as information entered into the CMMS work plans. A Task Implementation Template example is shown in Figure 2-5 and a sample maintenance feedback form is shown in Figure 2-6. One hundred and one task implementation templates have been developed to date under this TC. They were contained in EPRI Report TR-109795-V3, Streamlined Reliability-Centered Maintenance Implementation Guidelines.

SAMPLE CONVEYOR

Recommendation: PERFORM CLEAN, INSPECT & LUBRICATE.

Seq. Number	Detailed Instructions	Responsible Organization	Man hrs	Materials	Materials Description	Qty.	Cost	Total Man Hours
10	Verify lockout/tagout	MECHANICAL	20.00					20
20	Visually inspect components	MECHANICAL				0		20
30	Clean all components	MECHANICAL				0		20
40	Check belt scrapper for excessive wear	MECHANICAL				0		20
41	Check tip of scrapper for excessive wear	MECHANICAL				0		20
50	Check belt wear	MECHANICAL		81-1947	Belt Conv. #3	0		20
51	Look for grooves, exposed cords, rips, holes,	MECHANICAL				0		20
	and excessive wear							
60	Check Troughing Idler	MECHANICAL		80-8513	Troughing Idler	0		20
					35 deg.			
61	Check for cleanliness, lubrication, and rusty holes	MECHANICAL				0		20
70	Check Return Idlers	MECHANICAL		80-11053	Return Idlers	0		20
80	Check for cleanliness, lubrication, and rusty holes	MECHANICAL				0		20
90	Sound gear box; Listen for grinding, clinking, and	MECHANICAL				0		20
	vibration sounds							
100	Make minor adjustments and repairs	MECHANICAL				0		20

Figure 2-5
Task Implementation Template Example

WO/PM #: _____ Component ID: _____

Corrective Maintenance Feedback COMP TYPE: _____

1. ____ The failure resulted in a significant production loss.
2. ____ The failure should have been prevented by an existing PM job(s).
3. ____ Something can be done to extend the time between failures which should cost less than the failure itself.
4. ____ The failure was caused by improper:

   ____ Maintenance ____ Operation ____ Design

Preventive Maintenance Feedback

1. ____ The PM is being unsuccessful (scope or frequency) at preventing equipment degradation/failure.
2. ____ Other degradation/failure was discovered during the PM which should be addressed.
3. ____ The PM could be done less frequently or with less scope and still effectively prevent degradation/failure.

Additional Details

_____

_____

_____

Name: _____ Date: _____

Figure 2-6
Sample Maintenance Feedback Form

Living Program Portion of the PM Task Implementation Process, Step 6

The Living Program's function is designed to manage the change process when updating the Streamlined RCM analysis. Its objectives are to:

- Ensure design and operational changes are reflected in the current PM program
- Ensure new maintenance technologies are optimally used in the PM program
- Track maintenance experience to confirm that the bases for PM tasks remain valid and are still effective (accomplished by monitoring and trending maintenance history)
- Keep the Streamlined RCM decision basis current
- Review and approve PM change requests for components having Streamlined RCM analysis

Administratively, the living program will require that no changes to the maintenance program (e.g. time-directed, condition-directed and equipment performance testing) can be made unless the potential change has been reviewed and considered against the current basis (Streamlined RCM analysis). This will ensure the analysis will always reflect the actual maintenance being performed and conform to the Streamlined RCM maintenance plan philosophy. Procedures are developed to manage the Streamlined RCM program and provide guidance on how to implement the analysis.

Typical analysis examples were provided in EPRI Report TR-109795-V2, Streamlined Reliability-Centered Maintenance Implementation Guidelines, This included Functional Failure Analysis, Criticality Analysis, Critical and Non-Critical Task Selection, and Task Comparison.

Project Organization and Management

Project origination must focus on three major aspects namely:

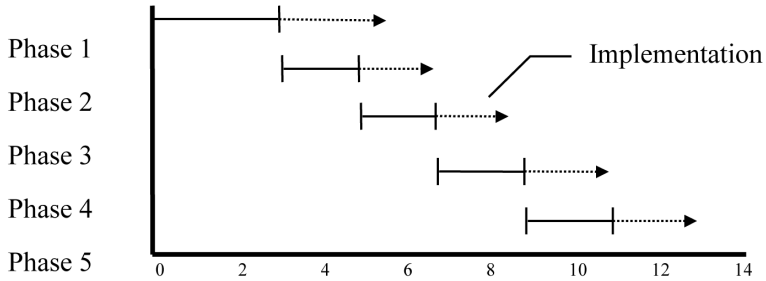
- Streamlined RCM Analysis
- PM task implementation (work plan preparation and CMMS input)
- Living program development with application.

Performance of Streamlined RCM analysis on any plant system entails a coordinated effort between plant personnel and the analyst. Several plant departments are required to participate in the effort. The involved plant personnel include crafts: maintenance (all disciplines: mechanical, electrical and instrument), engineering and operations, as well as those directly responsible for the project (Core Team). In order to obtain the most thorough and accurate information about the system under analysis, the analyst must solicit input from these various organizations. For this to happen, the project lead/manager must coordinate schedules such that the personnel most knowledgeable are available for analysis reviews (Criticality, Task selection and Task Comparison) and Maintenance interviews. This can, at times, be a substantial investment of manpower into the Streamlined RCM analysis, therefore, it is vital that the reviews and interviews be conducted efficiently, without sacrificing quality for speed.

Typically, the Core Team make-up consists of personnel from engineering, operations, planning and maintenance (includes supervisors, foremen and craft personnel). These personnel are empowered to make decisions and implement the PM task changes in the maintenance program (change existing PM tasks, add new tasks, purchase PdM technology/equipment, etc.). This core team requires a leader responsible for all aspect of engineering analysis product quality, schedule and budget. The Core Team will also know which personnel are "expert" on a particular system, and will ensure that these experts are available to participate in the analysis. Most often, the analyst (outside contractor) will perform the analysis with predetermined steps identified as review points. Usually, these points are the Criticality Analysis, Task Selection and Task Comparison. The reviews are lead by the analyst with the Core Team and all other appropriate technical "experts". On occasion, the analyst reviews the Criticality Analysis with only a representative from Operations. This is acceptable, as Criticality is functional determination based on the effects of failure on the operation of the plant. However, the criticality review and determination should involve all members of the Core Team, as this will ensure that all members of the group understand the reasoning behind a component's criticality. Effective utilization of the Streamlined RCM methodology requires a broad understanding of the Streamlined RCM process by a many people as practicable. Task Selection and Task Comparison require full Core Team participation in the review meetings.

As part of the Task Selection process, it is necessary for the analyst to conduct interviews with the system "experts" to identify problems, design deficiencies, ineffective maintenance tasks and practices, as well as suggestions for improvement of the maintenance performed. These experts are usually senior craft personnel or foremen/supervisors from the mechanical, electrical and instrumentation disciplines with additional input from operations and engineering. The interviews are conducted individually or collectively, depending on personnel availability. It is usually most effective to obtain the information during the analysis review meetings. The interviews are designed to collect information about equipment performance and find insights as to what maintenance is felt necessary.

The key to success for multi-system Streamlined RCM analysis projects is to allow a continuous flow of PM tasks that can be reasonably implemented. The timetable below depicts the schedule for a typical unit.



Note: 2 systems/ phase.

Figure 2-7
PM Tasks Schedule for Typical Unit

Phase I is longer due to training. Gas fired units have only 3 phases.

The following table lists the typical man-hour requirements for performing an Streamlined RCM system analysis.

Required Staff Resources

Table 2-1
Man-Hours Required for a Typical System Study

ACTIVITY	HOURS	
	Contractor	**Plant**
Data Collection	24	8
Critical Analysis and Task Selection	80	20
Non-Critical Evaluation and Task Selection	16	8
Analysis Reviews	16	16
Task Comparison and Review	24	12
Implementation	–	20-200[1]
Totals	160	84-264[1]

[1] The number of hours required for implementation is plant-specific and driven by a variety of factors. The scope of changes to the PM program, purchase and installation of new PDM equipment with training in it's use, upkeep and interpretation of PDM data and the interface between the Streamlined RCM software and the plant's maintenance management software, etc.

3
RESULTS AND COST BENEFIT

The Streamlined RCM TC project generated maintenance plans including PM task implementation has been in operation at four Utilities with sufficient time to allow project results analysis. General project goals achieved to date include a thoroughly documented, applicable and effective maintenance program. This new maintenance plan uses existing and new Predictive Maintenance (PdM) technologies to conditionally direct equipment maintenance activities. Now Plant personnel more effectively perform the desired maintenance focusing on equipment essential to critical plant functions. Maintenance task priority has been redefined such that all of the plant staff understands the difference between

- Have to do maintenance
- Like to do maintenance
- Don't have to do maintenance

Appropriate changes are observed in reliability, availability and capacity factor. Plant resources are refocused with significantly improved integration and optimization of individual craft functions. Immediate cost savings are obtained when the currently executed PM program is excessive while a somewhat longer payback is experienced when the existing PM program is inadequate. The latter payback is obtained through reliability improvements and reduced corrective maintenance task execution.

The next report section is included because most accurate project result findings are most likely found in statements and observations made by plant staff members from the reporting locations. Individual plant observations are not identified to protect the sensitive and possibly competitive information. In some instances detailed cost data could not be made available.

Plant Observations - Streamlined RCM Project

What is the status and schedule to complete implementation?

The Streamlined RCM process has been completed on all systems. 90 critical component (identified by the Streamlined RCM analysis) PM tasks were input into SAP computer system with work scopes and bill of materials. The non-critical components PM task list implementation was completed 9/15/2000.

Implementation was started in August 1999 and completed in January 2000. We spent approximately 2500 man-hours reviewing and suspending existing PM work orders that existed in our Maintenance Management System. Approximately 280 PM work orders were reviewed

and rewritten to better describe the work needed on the PM. The man-hour estimates were also reviewed and adjusted to a more "real" number on these remaining PM's.

Implementation completed spring of 2000.

What are the actual and anticipated benefits of the Streamlined RCM effort?

The benefits of this process are that we are doing the right things on the right equipment elimination unnecessary work and saving resources for other activities. We can again schedule work following the transition from our old CMMS, the old system was system turned off before new PM tasks were determined and input into SAP. Our Equivalent Forced Outage Rate improved by 2%.

From the standpoint of a reduction in preventative maintenance activities, approximately 400 work orders have been suspended. These PM's involved approximately 23,000 man-hours of labor annually to perform. Theoretically freeing up some 11 people per year to do other things. This can be seen as over a half a million dollars of labor costs that can be spent on other things.

The change in the wholesale market this summer has changed the dynamics on when it is profitable to run a component to failure. As a result we are doing a great deal more condition based monitoring, checking weekly or daily on some components in order to stay in the market at the high power prices. There are several pieces of equipment that we would have normally taken a derate to fix that we are running and watching until failure is just a heart beat away. The cost of down time is much higher than it has ever been for us. I think that our outages this year were much more successful in keeping us available this summer than in the past, this is with a reduced O&M and Capital budget over past years. We have been under several "no touch day" situations and have had very good luck with both units. We are at maximum capacity at all times, they get mad when we blow soot on day shift as it causes us to loose a couple of MWs.

We cut out maintenance that wasn't buying us anything. Run-to-failure became an option, where it never was before. We had a 15% reduction in maintenance expenditures. Maintenance is performed in some areas where it never was in the past.

We have saved $1,500,000 to date in avoided costs by not purchasing MW because our plant was more available now.

What effect has the PM task changes had on your available plant labor?

Our PM work has increased while our corrective maintenance (CM) work has decreased.
We expect to see additional plant performance savings during the summer load season.
The plant labor force effectiveness has improved particularly on back shifts where the majority of the PM work is accomplished. We reduced our Non-Station workforce by 6 people; this saving is about $100,000 per year.

We have not had to add people to our PDM staff. We have four individuals doing our PDM work and they have been able to pick up the additional work without help. The predictive maintenance

group will monitor some 620 pieces of equipment throughout the plant. This effort will require four full-time employees to do oil analysis, vibration and thermal monitoring.

Changes in soot blower maintenance alone have saved 8 man-days per maintenance cycle a 66% reduction. There was an 8% decrease in actual total maintenance labor requirements.

Are the maintenance people looking at their responsibilities differently?

Yes in that they have more information on the jobs that they are working. Work is completed with less supervision and the people can assume more responsibility having good procedures available. The Planning Department now pre-stages more work. Maintenance also was a part of the Streamlined RCM analysis Process and is excited that it is working.

I see people looking more at the performance of the equipment and calling in the predictive group to look at things when there is a problem (reduced equipment performance, vibration increases, lubrication problems). This may be on something that is not regularly monitored but people now see the value in being able to plan for their work more effectively.

Currently we are allowing equipment to run to failure as identified during the analysis with good employee acceptance and maintenance savings.

Streamlined RCM maintenance has crafts working smarter helping us maintain plant performance even with a cut back on personnel.

Have you had any success correction one-time design and reliability issues identified during the analysis?

We were able to justify and procure funding to purchase new equipment. We have corrected issues on the vacuum pump system ($150,000 saving) as well as the UPS feeding the environmental compliance monitoring systems ($40,000 saving). Vibration analysis software replacement has resulted in a $30,000 saving.

A review committee has handled this issue for many years. This committee meets once a week to discuss and approve any changes to any plant systems regarding design and reliability. The “run to Failure” idea, may bring to light issues not previously identified.

Experiencing great success correcting one-time design and reliability issues identified during the analysis. Examples include:

1. Soot blower blowing schedule changes and more effective PM’s have allowed the operators to maintain a more constant throttle temperature resulting in higher MW output.

2. Philosophy change brought about by Streamlined RCM increased turbine performance monitoring to increase MW capacity.

3. Change in pulverizer maintenance frequency helped unit capacity factor immensely.

4. Training on limit torque MOV calibration.

5. Changing the type of grease on some equipment has contributed to the current level of plant performance improvement.

6. We have also stepped up our Root Cause Failure analysis.

7. Boiler shut off valves are being retrofitted to knife gates on unit two. This allows us to cut maintenance and improve start up time and load response.

What does management think about the project?

Local plant management likes the process, and we are trying to roll it out to other stations in the system.

Management has promoted and supported this project and its philosophy of maintaining equipment.

We intended Streamlined RCM to increase unit capacity factor as a means to improve plant performance. This goal has been accomplished. Cost reduction was not seen as a viable alternative at this time. Operations department is focusing on unit availability while the maintenance department tried to improve capacity factor.

They are satisfied with the outcome. In today's competitive environment, high maintenance costs can eat you alive. I believe that an Streamlined RCM based program was what the plant needed to position itself for upcoming deregulation in a fiercely competitive environment. Although we have not fully implemented Streamlined RCM we know enough about the process to project a six figure savings in preventative maintenance labor alone.

Any capacity factor improvement?

We increased our Capacity Factor by 3%.

Our capacity factor increase has resulted in a $1,370,000 reduction in power purchase cost this year.

We had a pretty good one to start with, so I would say not necessarily.

Any reduction in maintenance backlog?

As a result of better overall maintenance we have not had any lost MW do to undetected equipment problems since the program started. All identified problems were repaired on Reserve Shutdown.

The fact that a significant amount of PM activity has been suspended will tend to reduce the backlogs. It is important to establish a baseline of your backlog at the time of implementation so

that you will be better able to identify any changes later on. We have not been able to quantify a backlog reduction but it appears to be substantial.

We have experienced a 25% reduction in maintenance backlog as a result of:

1. Reduced corrective equipment maintenance requirements.

2. Improved PdM program and letting certain equipment run to failure before repair.

3. Plant implementation of Streamlined RCM analysis results caused improved integration and coordination of individual craft functions saving as much as two days of equipment outage time.

4. There was a reduction in the maintenance backlog because many tasks were cut out.

How are the plant employees accepting the Streamlined RCM approach?

When a station employee is doing a job and finds the scope of work needs to be changed, he brings that to the planners and has it changed ASAP. This shows that it is a living program accepted by the people.

It is generally well accepted. There has not been any feedback regarding the reduction in PM activities. The observation is that the work force has in general accepted the Streamlined RCM philosophy. This change has only had nine months to impact the condition of the equipment, and may yet cause some long-term concern. A key to success is having people in the PDM group that really get joy from being able to predict what is going on with the equipment. They write work requests after discussing what they find with maintenance supervision and carry a lot weight with their decisions on a solution to the problem.

Plant employees are accepting the Streamlined RCM approach (a real culture shift) because they see it is working for them and making their plant a more valuable asset.

I believe that they accept it in general, but say that, there still isn't enough time to get all the maintenance done.

How could EPRI improve the project?

The project went very well for the plant.

Establish pre-implementation measures to monitor your costs and other management variables up front before implementation to better identify your changes after implementation.

I don’t think that you could have done anything to improve what was done. I am satisfied with the services that EPR I /ERIN Engineering provided, and would personally recommend Streamlined RCM to any organization that desires to get the most for their maintenance dollar.

What do you consider as the major project benefit?

Dollars saved in lost MW (being able to generate more now) and having all site employees doing the right thing at the right time.

The change in philosophy and way of doing maintenance is the most important benefit of Streamlined RCM. The emphasis on more of a predictive maintenance program rather than the traditional periodic inspection of equipment regardless of the current performance of the equipment.

At this time I would say that we are placing more emphases on the condition based monitoring component of Streamlined RCM than anyone would ever have believed. In the past work orders that were generated as a result of the monitoring would receive a priority 4, six to eight weeks to get it fixed, now they are receiving a 2, less than 8 working days to be checked.

That we cut out non-payback maintenance, and are concentrating on the things that will take us off-line.

Have you seen any culture change?

The employees are more independent and they are working to keep the Streamlined RCM program going.

The fact that we held meetings explaining what Streamlined RCM is and getting everyone's input in the beginning, has helped greatly in making the program acceptable to both maintenance and operations.

I think the crafts are slowly coming around to the Streamlined RCM method of performing maintenance, but the change has not been an easy one, or a willing one in some cases.

Are you using the PM tasks, what is your experience?

The first nine months have not revealed any real problems with the suspended PM activities.

Using all of the tasks that are input to SAP. Jobs are now being scheduled 52 weeks in advance. We have changed the cycle for pulverizer work and the corresponding work process. This has added reliability and some capacity.

Any other things that we should put in the report?

With our plant performing the Streamlined RCM process we feel that the station life will be extended. We are going to roll it out to all other stations.

Since increasing the use of Predictive Maintenance, the plant has decided to perform pump and motor overhauls on an "as required" frequency based on results of condition monitoring activities such as vibration and lube oil analysis. We focus particularly on vital equipment such

as the recycle pumps and motors, the induced draft fans and motors, and the scrubber agitators, motors and gearboxes. Consideration is also being given to utilize thermography in diverse applications (breakers, motor control centers, load centers, motors, gearboxes and heat exchangers).

Recommendations were made to better monitor fluid chemistry and investigate new metallurgy materials for the scrubber liners and the reheat panels. Also, a recommendation was made to investigate better methods of reheater panel leak detection.

Expected O&M savings include reductions in craft man-hours for unplanned corrective maintenance, reduction in duplication of efforts and reductions in materials use. The plant intends to make more optimal use of its personnel by allowing operations to play a larger role in the maintenance of equipment (performing simple tasks such as lubrications and inspections, and condition monitoring activities.), allowing maintenance craft labor to be expended on activities requiring specific expertise.

4
INSIGHTS AND LESSONS LEARNED

Hindsight always provides an opportunity to increase value and usually with reduced resources. A major learning discovered late in the project was the lack of good initial performance data (base line) from which to measure change. Good initial project goals are developed but their values were not always determined at project onset. Measure identification including methods for obtaining the measured values must be the first project step before meaningful quantitative change can be determined.

It is important to involve key personnel in every phase of the analysis process including the analysis reviews (Criticality Analysis, Task Selection and Task Comparison). Their participation demonstrates overwhelming support and commitment to the project and instilled confidence in the decisions made and results obtained.

In most instances implementation began immediately upon completion of an analysis phase following approval of the recommended PM tasks. Responsibility designation for different implementation actions was also clearly identified at this time. Overall responsibility for the project must remain with the initial project lead to assure continuity.

At the outset, the core team needs to understand that prioritizing maintenance tasks based on equipment functionality will improve the plants ability to “work smarter” and maximize project value. Work re-prioritization helps establish a more optimized balance between reactive and proactive maintenance in line with unit specific objectives.

An added benefit of the process was the identification of current PM tasks, which were truly redundant. These tasks were identical to each other in all aspects, save the identification number.

It is important to note that the mechanism used to review analysis results worked extremely well. Active participation of personnel was an indicator of the commitment to the project and most definitely had a positive impact. Team make-up ensured that all maintenance disciplines were represented, in addition to operations, engineering and plant management. This, in turn, helped secured the buy-in of plant personnel necessary for project success.

Targets:

Maintenance Task Selection Guidelines and Technologies

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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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com