Predictive Maintenance Assessment Guidelines

TR-109241

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Prepared by
Maintenance & Diagnostics, Inc.
1510 Chester Pike
440 Baldwin Towers
Eddystone, PA 19022

Principal Investigator
R. Colsher

Prepared for
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
R. Pflasterer

Generation Group

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ORGANIZATION(S) THAT PREPARED THIS REPORT

Maintenance & Diagnostics, Inc.

ORDERING INFORMATION

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REPORT SUMMARY

This document is the third in a series of guidelines designed to help electric power utilities develop programs that take advantage of diagnostic technologies used to detect problems in machinery. The PDM Assessment Guidelines provide the procedures necessary to plan and implement a plant wide predictive maintenance program.

Background

Over the past few years, the EPRI M&D Center has worked with a number of utility companies to implement a number of machinery diagnostics and monitoring programs. From this experience, the EPRI M&D Center has learned that there are existing technologies that are effective, but they lack program coordination. Alternatively, some programs are well coordinated, but lack the use of effective technologies. The EPRI M&D Center has identified what goes into successful programs and the pitfalls of unsuccessful programs. This project is part of EPRI's Plant Maintenance Optimization development efforts under Target-43-Turbine, Generator, and BOP O & M Cost Reduction (1997) and Target 54, Plant Maintenance Optimization (1998).

Objectives

- To offer a procedure for assessing a plant's current level of technology utilization
- To identify the strengths and weaknesses of existing programs
- To provide new opportunities for the implementation of existing technologies

Approach

The EPRI M&D Center has conducted PDM Assessments of various kinds at over 50 utility sites. The PDM Assessment Guidelines provide the procedures necessary to plan and implement a plant wide predictive maintenance program. The first and second volumes of PDM guidelines (TR-103374: V1,V2) defined predictive maintenance and dealt with basic issues of program goals, procedures, costs, implementation and the challenges of sustaining and optimizing the PDM program. The processes and procedures described in this Guideline are the same as those used for the Assessments at many of the utility sites. All Assessments take the same general form and involve data collection from existing diagnostic systems; interviews of the utility/plant personnel; analysis of the information obtained; and reporting of the findings.

Results

Each Assessment conducted had varying degrees of success, but at a minimum each illustrated the value of Predictive Maintenance to the plant personnel. In most cases, the Assessments provided valuable insights to plant management, and reinforced the usage of condition monitoring data for maintenance decision making. In some cases, the Assessment established a new initiative at the utility for high reliability operation and maintenance through the use of advanced technologies. This initiative can be pursued, along with other cost control methods, to also provide positive control over equipment failures during periods of low plant morale caused by downsizing.

Perspective

Support for plants employing new maintenance strategies will become increasingly important to EPRI Members as they continue to look for ways to reduce costs while maintaining high availability. PDM Assessment was designed to support the growing number of plant reliability programs that have been established throughout the utility industry. The Assessment shows that Predictive Maintenance is a key strategy that allows plant personnel to look for problems with machinery before catastrophic failure can occur. The degree of success in applying PDM is contingent not only on the diagnostics selected, but on the capabilities of the personnel that maintain, monitor, and correct the deficiencies that are found through monitoring. This and other continuing efforts help EPRI member utilities focus on emerging PDM technologies and how these technologies impact plant operations and maintenance. In addition, PDM helps utilities get maximum utilization out of existing machinery installations by eliminating unnecessary tear down inspections.

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Interest Categories

Fossil steam plant performance optimization
Fossil steam plant O&M cost reduction

Key Words

Maintenance optimization
Predictive maintenance
Diagnostic techniques
Rotating equipment
Monitoring systems

ABSTRACT

This document is the third in a series of guidelines designed to help electric power utilities develop programs that take advantage of diagnostic technologies used to detect problems in machinery. The first and second volumes of the PDM Guidelines (TR-103374) defined Predictive Maintenance and dealt with basic issues such as a program goals, procedures, costs, implementation, and the challenges of sustaining and optimizing the PDM program. These PDM Assessment Guidelines provide the procedures necessary to plan and implement a plant-wide Predictive Maintenance program. The PDM Assessment process includes all technical, organizational, and financial aspects of Predictive Maintenance.

Included as Appendix A is a sample Assessment Final Report, developed by an M&D Assessment team, that is the evaluation of the current Predictive Maintenance activities and recommendations for improvement. Integral to this report is a suggested approach for routinely tracking and analyzing the benefits of the Predictive Maintenance program. The report serves as a living document, a handbook for conducting the Predictive Maintenance program; and, as an information resource to help to guide the program for both the short term start-up and long term evaluations and benefits.

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Contributing Authors	EPRI M&D Center
Robert Matusheski, M&D, Inc.	Rich Colsher
William Woyshner, M&D, Inc.	John Niemkiewicz
	Ellie Cherry

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INTRODUCTION AND OVERVIEW

The EPRI M&D Center experience has shown that significant improvements resulting in substantial cost benefits can be achieved through changes to existing processes with small or moderate investments. The degree to which a facility is successful in implementing the PDM program often has more to do with intangibles such as understanding and belief in the technologies, level of personnel enthusiasm, and management support. The PDM Assessment process evaluates these issues, and others, and provides timely and beneficial recommendations to enhance the PDM program.

In an effort to assess existing PDM program efforts, therefore, the Assessment begins by examining existing plant information regarding maintenance, process procedures, and technologies that are already in place. The Assessment then addresses the potential benefits of using the information provided by the PDM Program within the structure of the plant's current organization. This is done by conducting in-depth interviews with the plant personnel, central engineering, and utility management. The final results are recommendations on how best to enhance the PDM process within the utility/plant organization's resources, and future planning and projections.

Why conduct a PDM Plant Assessment?

Predictive Maintenance is part of an overall plant maintenance strategy that applies diagnostic technologies to critical plant equipment in a structured way so as to identify equipment in need of repair prior to catastrophic failure. Plants with advanced maintenance planning systems can take advantage of this information and avoid potential forced outages due to equipment failures.

The Assessment addresses all of the technical, organizational and financial issues surrounding predictive maintenance, gauges current levels of PDM activities and identifies areas for upgrade and improvement. In many cases, a good PDM program exists at the plant, but is disjointed. In these cases the Assessment identifies the existing information and processes that need to be brought together to effectively conduct a plant PDM program.

Key Elements of a Predictive Maintenance Assessment

The PDM Assessment process for the EPRI M&D Center has evolved over 5 years, during which time over 50 Assessments have been conducted. From these experiences, M&D Center engineers have identified 14 key elements that go into a full Predictive Maintenance Assessment. Among these elements are:

1. Full Time PDM Coordinator
2. PDM Program Goals
3. Equipment and Technology Matrices
4. Technology Application Descriptions
5. Organizational Charts
6. Roles and Responsibilities
7. Work Flow Diagrams
8. Program Cost Table
9. Planning and Estimating Guides
10. Schedule
11. Training Matrix
12. Miscellaneous Recommendations
13. Cost Benefit Calculations
14. Communication Format

PDM Assessment Guideline Overview

The following is a brief summary of the overall activities necessary to conduct a successful plant Predictive Maintenance Assessment.

1 - Introduction and Overview

This Guideline is designed to outline the necessary steps to conduct assessments, and to describe the procedures necessary for assessment. The sections are summarized below to indicate the overall structure and organization of the guideline. This section of the guideline also lays the foundation and identifies the business drivers for conducting the assessment.

The word "Assessment" implies that some action will be taken to evaluate the current level of predictive maintenance that exists at the plant. The Assessment activities are:

- Plant personnel assembles preliminary data requested in Section 2 of this Guideline.
- An Assessment team is made up of utility personnel and consultants. The Assessment team reviews the preliminary plant data package prior to conducting the Assessment.
- Typically, one visit is made by the Assessment team to the plant undergoing Assessment to conduct procedures, conduct interviews, and to become familiar with the plant layout and machinery installations.
- Draft and final reports are developed by the Assessment team and are provided to the plant undergoing the Assessment. The draft report is provided to confirm that the information gathered is accurate, the information is made available to all parties concerned, and that the program is progressing in a mutually agreeable positive direction.
- A visit is made by the Assessment team to conduct training seminars based upon the findings and recommendations of the Assessment. The seminar provides an overview of the Assessment findings in the context of formal training courses developed specifically for the plant.
- Developed is a of a database of Assessment information used in PDM Program tracking.

2 - Initial Assessment Data Collection

Pertinent plant information should be provided to the Assessment team prior to the first site visit. The list of documentation needed to conduct the Assessment is provided in Section 2 of this Guideline. Section 4 of this Guideline describes how to analyze this information and combine it with interview data and observations to draw useful conclusions about the existing PDM efforts. Upon receipt of this information, the Assessment team will develop a target interview list and share the list with the Assessment sponsor.

3 - Interview Questions and Site Visit

The initial site visit will extend for approximately one week which will allow the Assessment team to:

- conduct interviews with plant personnel, including supplemental interviews with central engineering and contractors.
- review maintenance records on-site (may require the availability of a maintenance planner).
- research information in the technical library.
- conduct a plant walk down and take photographs.
- have an exit meeting with plant management to provide feedback on the general success of the data gathering mission.

The interviews conducted during the Assessment highlight the effectiveness of the existing program, existing technologies, existing organizational structure, and management support. The interviews also serve as a short training session that helps the person interviewed to understand the basic principles of PDM. This serves to help identify the areas where PDM is applicable and areas where PDM activities may be already existing at the plant. The Table 1-1 gives an idea of the extent of the interview process for the plant personnel involved in the Assessment.

Table 1-1
Target Interviews

Target Interviews
Plant Management
- Plant Manager
- Operations Manager.
- One or more Shift Manager (would like to get someone who would provide a good cross section of operational activities).
- One or more Operators (would like to get someone who would provide a good cross section of operational activities).
Maintenance Manager
- Maintenance Foreman.
- Electrical
- Mechanical
- Planning (Daily)
Engineering Manager
- Plant Engineers
- Planners (Outage)
If Appropriate:
- Local PDM Group Manager
- Contractors supporting any PDM activities.
- Consultants used by the plant for maintenance related activities.
- Central engineering or maintenance group who support the plant.
* Interview list will be developed from existing plant organizational chart

The interview questions are provided in Section 2 of this Guideline. The questions are categorized by position within the organization. Some questions are designed to gather information, while others are designed to gather perceptions. Perceptions are important because they show the level of support and buy-in for the existing efforts which can provide some clues to the future success of any new efforts. During the interviews, Assessment team shares ideas, goals and technology details so that the interview actually takes the form of a mini training session.

4 - Analysis

The Assessment team will work with the personnel of the plant undergoing assessment to evaluate the current efforts in Predictive Maintenance at the plant. Through the actual, hands-on process of interviews, research, evaluations, and analysis, the Assessment team will show the personnel of the plant undergoing assessment the necessary information about the plant; and, provide reporting on the best way to evaluate the plant Predictive Maintenance program, with only a small effort by the plant personnel.

Plant Equipment Survey.

Component information such as nameplate data, equipment manuals, and process and instrumentation diagrams will be gathered and organized so that detailed plans can be developed for diagnostic system implementation on some of the major plant equipment. From this information, detailed guidelines are developed to address the most effective ways to monitor this equipment.

Current Technology Assessment.

The Assessment team evaluates which information needs to be gathered about the technologies that are currently applied at the plant, shows how to evaluate the effectiveness of the techniques, and suggests ways to improve these procedures as necessary. The Assessment team then organizes this information into what is called the “Equipment and Technology Matrix” and discusses each technology application in detail.

Technology Evaluation.

For the PDM assessment, new technologies will be proposed as appropriate to the utility’s facility. This effort will show the methodology employed in the evaluation, so that in the future the utility’s plant will be able to adapt these technologies to other systems within the plant, and to serve as the Assessment team at other plants within the utility’s organization.

Personal Interviews.

To review current methods and practices at the utility’s plant, the Assessment team conducts a series of interviews with key personnel to identify particular areas of concern. The Assessment team also shows the personnel of the plant undergoing assessment how the Assessment team examines organizational structures and ascertains the level of management required to enhance an existing PDM program or establish a new one.

Organization Analysis.

The technologies used in a PDM program provide valuable information about the plant equipment and their condition; this information is worthless unless the plant organization is structured to accept and use the information. The Assessment training shows how to conduct the work order system analysis. This analysis identifies how plant information is currently used and how it should be modified by the PDM program. This analysis also identifies the optimum organizational level at which the program operates.

Plant-wide Predictive Maintenance Program.

One of the most valuable features of the assessment is the identification of an overall maintenance strategy, that identifies goals for the plant and the program. The goal for all of these activities is to help the utility's plant use the appropriate maintenance strategy for all installed equipment. M&D's concept of a plant-wide predictive strategy involves doing the appropriate maintenance activities using as many existing plant personnel and equipment resources as possible.

5 - Reporting

Draft Report.

Report elements, developed by the Assessment team , will be reviewed by the plant personnel, in a draft report. Upon complete review of all report elements, the Assessment team assembles and submits the final report.

Final Report.

Elements that will be included in the final report will be provided to the plant undergoing assessment. The contents of this final report will range from general topics to specific information relative to Predictive Maintenance. This report consists of a table of contents, an executive summary, five major sections and appendices. These sections form the report structure and they are as follows:

- The **First Section** will include an introduction to Predictive Maintenance with an emphasis on the existing plant financial situation, and how PDM implementation or enhancement will be expected to impact that situation.
- The **Second Section** will include a detailed implementation plan that pays particular attention to the existing resources and needs of the utility's plant.
- The **Third Section** discusses the plant's equipment, the technologies that are being applied, and those that should be applied.
- The **Fourth Section** examines the plant's organizational structure and how PDM information will impact their decision making.
- The **Fifth Section** identifies all costs that will be incurred as a result of recommended actions and potential benefits from the program.
- **Appendices** are added to include any plant data, procedures, analyses or other pertinent documentation. Section 5 illustrates the type of information that will be developed during the Assessment, and what information will be included in the report.

The Assessment report serves as a 'PlayBook' for the implementation of PDM at the plant. The final report reflects the conditions at the plant and summarizes the current technology utilization. Review periods should ensue after the plant Assessment has been completed to ensure that recommendations are carried out. Once the Assessment has been completed, the Assessment team conducts periodic progress reviews and makes necessary changes to the final report. The final report should be periodically re-issued. This process has several purposes:

- Provides instruction into the goals, mission and general philosophy of PDM.
- Demonstrates the potential effectiveness of technologies, using examples from the plant's equipment or from similar equipment at other plants.
- Shows the need for new lines of communication and organizational changes brought about by PDM Program implementation.
- Illustrates roles and responsibilities.
- Shows PDM Program Costs and Return on Investment (ROI).
- Provides closure to the assessment activities.

2

PRE-ASSESSMENT DOCUMENTATION

Assessment Preliminary Data Request

Some or all of this data is requested prior to the beginning of the Assessment effort. Existing data reports and other readily available plant documentation is requested to support this effort. No special writing or research is required by plant personnel. Any data not provided in the preliminary package can be supplemented during the on-site period.

General and Performance Data

- Number of Units

- Information Needed for each Unit:
  - » Age of Unit
  - » Maximum Rated Load
  - » Capacity Factor (annual average, past 3 years, goal for next 2 years)
  - » EAF - Equivalent Availability Factor (annual average, past 3 years, goal for next 2 years)
  - » EFOR - Equivalent Forced Outage Rate (annual average, past 3 years, goal for next 2 years)
  - » Forced Outage List (Duration and Reason)
  - » Heat Cycle Diagram (with design heat rate at full load)
  - » Heat Balances at Multiple Load points
  - » Thermal Kit/Correction Curves for both gas turbines and steam turbines
  - » Historical Performance Test reports
    - - Tests within last 12 months
    - - Acceptance test report
  - » Sample Operator's Log
  - » Performance/Operators Report (DCS or Manual)

- » Plant Operating Procedures manual(s)
- » Plant Performance Testing manual
- » P&ID Diagrams for major plant systems
- » Design Specification sheet on the HRSG(s)
- » Description of and pertinent information on any performance monitoring package used with a current input/output summary
- » Current, typical fuel analysis report

Technical Information

- Any Existing Diagnostic Reports
    - » Vibration
    - » Lubrication Oil
- List of Major Plant Equipment
    - » Critical equipment (with % de-rate)
    - » List of Equipment Common between Units
    - » Other Diagnostic Technologies, applied to each piece of equipment
    - » Nameplate Data
    - » DCS or PLC Process point list
    - » Bearing type for each machine
        - - Journal
        - - Rolling Element
        - - Lubrication type
- List of troubled equipment (top 10 or 12 with highest maintenance costs)
- Plant Computer Network
    - » Parts ordering system
    - » Spare parts inventory
- Maintenance Management System
    - » Vendor, version
    - » Reports
    - » Data input screens
    - » List of available applications
    - » Number of workstations
    - » Connectivity diagram
- Furnace Type and Configuration
    - » Single or dual furnace
    - » Single or double reheat

» Fuel type(s)
» Burners (number and type)
» Performance (design and actual)

- Ash Handling System Type
  » Description with type and number of components
- Fuel handling system
  » Delivery system
  - Rail, Barge, Truck, Pipeline
  - List of fuel handling equipment
  - Conveyors, crushers
- Electrical Distribution System
  » List of Critical Electrical Equipment
  » Number of Transformers and rating
  » High Voltage Circuit Breakers
  » Switch yard Line Drawing
- Motor Control Center Equipment (Number of cubicles)

Organizational Information

- Organizational Chart
  » Plant
  » Central Office
  » Description of any recent changes
  » Number of employees
  - By department
  » Central Support offices
- Contractors used for Diagnostic Testing
  » Point of Contact, Phone
- Work Request Procedure (step by step)
- Work Rules (with respect to new technologies)
- Special Technologies conducted or available by Central Support offices
- Special programs underway at the plant
  » Safety
  » Quality Improvement
  » Root Cause Analysis
  » Reliability Analysis (RCM)
  » Others

Financial Information

- Plant Budget
- Total for plant (Actual and Goals)
  - » O&M Labor
  - » O&M Non Labor
  - » Other available breakdowns
- Fuel costs
  - » Total annual expenditures (by unit for last three years)
  - » per MWHR (gross and net)
  - » per million BTUs
- Plant Capital Improvement Plan
  - » Previous 2 years
  - » Next 3 or 5 years
- Percent of O&M Budget directed to Fuel and Ash Handling
- Replacement Power Costs ($/MWHR)
  - » Average Peak (8am to 6pm)
  - » Average Off Peak (6pm to 8am)

3

INTERVIEW QUESTIONS

The information needed to assess the current level of activity in PDM at a particular plant is typically not directly available. If it were, then an assessment would not be necessary. Often, the necessary information exists in the knowledge, attitudes, and perceptions of the management and O&M personnel at the plant.

The questions are categorized by position within the organization. Some questions are designed to gather information, while others are designed to gather perceptions. Perceptions are important because they show the level of support and buy-in for the existing efforts, which can provide some clues to the future success of any new efforts.

Why conduct interviews?

The interview process is the most efficient way to gather the necessary assessment information when trying to obtain information about the knowledge, attitudes, and perception of plant personnel. Some people have suggested that written questionnaires be used to develop assessment information. This method is very inefficient because of the level of detail necessary to achieve the level of information necessary. Also, not all information is needed from all persons interviewed. Interviewers can selectively ask questions when conducting interviews, gathering only the necessary information. Table 3-1 illustrates the savings in labor hours.

Table 3-1
Labor Hours per Method

Method	Labor hours/person interviewed	Total hours/Assessment (based on 30 targets)	Advantages of method	Disadvantages of method
Interviews	2 (1 interviewer and 1 target)	60 hours	more flexibility	Scheduling interviews
Questionnaires	8 (estimated hours to fill out questionnaire)	240 hours	More data, more details	more burden on plant, data is less candid

Predictive Maintenance Assessment - General Interview Questions

Personal Questions

1. What is your current function in the organization?

2. How long have you held this position?

3. What is your background? (Emphasize your work with this company)
   (*This helps us to understand where he or she came from and gives us good perspective of what the interviewee feels is important. People tend to believe in things they do, or did in the past.)*

Plant Operations and Maintenance Questions

1. Who sets the priority for work requests? Who should?

2. Are there any existing procedures or processes that you consider to be highly efficient and cost effective? (i.e. quality program, heat recovery, etc.)

3. Are there any old processes or procedures that should be brought back?

4. In your opinion, are current resources (personnel and materials) adequate for operating and maintaining the plant?

5. Is your company planning to reorganize or down-size anytime soon?
   (A*sk the following questions only if the response to this question is positive.)*

   a) Will personnel reduction resulting from down-sizing cause problems maintaining or operating in the future?

   b) What steps should be taken to relieve some of these difficulties?

   c) Are you aware of any other programs for cost reductions, either at the plant level or at the corporate level?

   d) What are the risks involved with reducing these costs?

6. How do seasonal variations affect plant maintenance workload.

7. Does management support you when requesting investments for maintenance?

Preventive Maintenance General Questions

1. What types of preventive activities are carried out on a regular basis?
2. On which equipment?
3. Do the maintenance crews capture the "as found" condition of the components that were repaired or replaced during these preventive procedures?
4. Are there any written schedules for performing these activities?

Predictive Maintenance Specific Questions

1. What is your definition of Predictive Maintenance?
   (*Ask for a definition as the interviewee understands it. This is important to know what the person perceives as the definition. Take time here to encourage the person interviewed. It may help to show the definition of PDM, CM, PM, PAM, and RCM in the Guidelines.)*
2. What are the most troublesome pieces of equipment or components in the plant? and Why?
   (*Is their perception the same as their colleagues and does it match the maintenance records? If it does not, then that means they may be solving the wrong problems. Information gathered here can be used to develop equipment and technology matrixes and set priorities.)*
3. What, if any, monitoring or diagnostics have been applied to these systems?
   (*Does the culture at the plant support monitoring as a solution for equipment problems? This will give clues as to the reception and "buy- in" of monitoring solutions.)*
4. What diagnostic technologies are used in your plant's maintenance program?

   a) What diagnostic technologies are used by your maintenance craft personnel?

   b) Are there any technologies used by operations?

   c) Are any technologies conducted by the plant technical staff or by outside organizations?
   (*If applicable)*

   d) Are there any contracted services that have been conducted in the past or present that were effective?
   (If applicable)

   e) What condition monitoring diagnostic technologies do you know of that your company is not using?

f) To what equipment problems would you apply them?

5. Do recommended repairs reflect the actual "as found" problem?

Communications Questions

1. On a scale of 1 to 10 (10 being perfect) how well does your utility, within the plant and also with any central support group, communicate information regarding diagnostic testing or special testing related to a specific equipment problem? (This is asked to establish how well the personnel communicates and uses operation, maintenance, and engineering to help diagnose problems.)

2. Explain how the conversion of data to information and corrective action works. (Use the Data, Information, Corrective Action presentation slide.)

   On a scale of 1 to 10 -

   ____DATA____INFORMATION______ACTION
   (Explain any reasons for low scores.)

3. Is your department involved in the process of evaluating component conditions?

   a) If yes, how is this information transferred to other parts of the organization?

Training Questions

1. Is the current training program adequate to the needs of plant operations and maintenance? What other courses should be offered?

2. Do you feel you need training? If so, in what areas?
   (Either program training or special condition monitoring technology training)

3. Do you have any experience using personal computers? Would training in this area be helpful?

4. Do you feel confident in crafts that you have had some previous training, or would some refreshers help?
   (*Craft personnel only)*

Computerized Maintenance Management System Questions

1. Does your facility have a Computerized Maintenance Management System?

2. Do you use this system? If not, Who Does?

3. Do you know your plant's production costs?
   (It is important to know their level of awareness of this business issue.)

4. Are you aware of any sort of equipment trouble list? If so, Who keeps it?

Predictive Maintenance Plant Assessment - PDM Coordinator Interview Questions

Ask all the general questions from the previous section, Predictive Maintenance Assessment - General Interview Questions, then become more specific by asking the following questions.

Diagnostic Tools Questions

1. Which diagnostic systems, on-line or periodic, are utilized in the PDM program?

2. Do you have reporting responsibility to a specific plant person or group?

3. Are there any existing procedures for condition based testing which you perform for the plant?(i.e. lube oil sampling, vibration, etc.) If so, Can we get a copy?

Reporting Questions

1. How do you make other plant personnel aware of diagnostic results?

2. Is there a standard procedure for reporting anomalies?

   a) Is the report by exception only or on all equipment tested?

   b) Are there any hard copy reporting requirements?

Management Support Questions

1. Does plant management support the Predictive Maintenance philosophy?
2. Who prioritizes work associated with the PDM program findings?
3. Do you perform cost benefit analyses?
4. At your plant, has PDM affected the following:
   ___Component or plant availability?
   ___O&M cost reductions?

___Capital Expenses?
___Plant heat rate reductions?
___Safety or regulatory compliance?

5. How much extra cost does your company incur which your plant is not available to produce.

Communications Questions

1. Are PDM capabilities and procedures well known among:
   (y/n) plant management
   (y/n) engineering staff
   (y/n) maintenance craft
   (y/n) operators

2. Are operators or maintenance supervisors and craft ever consulted before work orders are issued on PDM program findings?

Predictive Maintenance Assessment - Maintenance Manager and Supervisors Interview Questions

Ask all the general questions from the previous section, Predictive Maintenance Assessment - General Interview Questions, then become more specific by asking the following questions.

Maintenance Strategy Questions

1. What is your overall maintenance strategy?
   (Do they do mostly CM, PM, CBM, PAM? What is the current mix?)

2. How do you categorize repair activities?

3. Do you distinguish between corrective, preventive, and condition-based work orders?

4. How much of your plant maintenance is done on overtime? If any, Do you track this by employee? By component?

5. Are root cause failure analyses ever conducted on equipment? Is maintenance involved when the analyses are conducted on failed equipment?

Maintenance Management System Questions

1. Does the plant use a Computerized Maintenance Management System (CMMS)? If so, Is it linked corporate-wide?

2. Is there a training program in place for the use of the CMMS?

3. What are the most frequently recurring problems faced by your maintenance department? and Does your system flag these recurring problems automatically?

4. Describe, step-by-step, how a maintenance work order is initiated, reviewed, processed and closed out.

1. Who sets the priority for work requests/work orders? Who should?

    a) What percentage of work orders are planned? and How far in advance?

    b) Are there existing work packages or are they developed as needed?

    c) How much does it cost to process a work order?

    d) On the average, how many maintenance orders do you receive per year?

2. Who assigns resources (people and materials)?

3. Do you track costs on individual pieces of equipment? If not, Can you? and Would this be useful?

4. Do you track individual availability on major components? If not, Can you? and Would this be useful?

Maintenance Backlog Questions

1. What is the current maintenance order backlog? (in worker-weeks) and Is this normal?

2. Is the backlog increasing, decreasing, or staying the same?

3. Do you periodically purge the backlog for duplicates or outdated work requests?

4. Do you keep a running list of the top 10 or 12 problems?

    a) Could we get a copy of the list?

Post Maintenance Testing Questions

1. Is post maintenance testing done? If so, By whom? What tests are done? and On which machines?

2. As a result of post maintenance testing, how is any rework justified? and Do you track rework?

Spare Parts Questions

1. What is your spare parts policy?

2. What is the basis for the policy?

3. Where are spare parts kept?

4. Has your storeroom been recently purged for overstocked or obsolete parts?

5. Who orders spare parts?

6. Is parts control in the CMMS or is it a separate system? and Is it manual or computerized?

Predictive Maintenance Assessment - Operations Manager or Shift Supervisor Interview Questions

Ask all the general questions from the previous section, Predictive Maintenance Assessment - General Interview Questions, then become more specific by asking the following questions.

Normal Plant Operations

1. How many shifts per week do the operators work.

2. How many operators per shift?
   Control Room___
   Roving___

3. What are operations managers/shift supervisors currently responsible for?

   a) Has this always been the same?

4. Does the plant have any problems with the electrostatic precipitators?

5. Are there any active programs for reducing or conserving auxiliary power consumption in the plant?

6. Are you aware of any heat conservation programs?

7. Have any of these types of programs existed before?

Operations Involvement in PDM Questions

1. Are operators involved in evaluating the equipment condition? and, If not should they be, and how?

2. Describe the plant control system DCS or analog? Year installed? Are there plans for upgrading?

3. What key process data points are used for plant control?

4. Are there any process data points that are often used for identifying equipment problems or troubleshooting?

5. What portable diagnostic tools are regularly used by operators?

6. Is the plant adequately covered with monitoring systems?

   a) If not, What monitoring technologies would you like to see applied and to which equipment?

7. Do you think PDM could be or has been effective in reducing O&M cost, increasing availability, or decreasing plant heat rate?

8. Do you track running hours on individual pieces of major equipment? If not, Is it possible?

Predictive Maintenance Assessment - Upper Management Interview Questions

Utility General Questions

1. Does the company have the installed capacity to meet current and future demands from a generation capacity standpoint in its operating area?

2. Could you explain the importance of each production facility in your overall corporate structure?
   (This question is asked to determine life expectancy of each plant and how much each will

run. This directly affects "payback" for dollars spent on the PDM program and on condition monitoring technologies.)

3. On the average, what percentage of power is supplied by the company versus purchased from other utilities?

4. Are there plans for any new generation in the near future?

5. Are there any published plans for the sale of any generating plants to other utilities or Independent Power Producers?

6. Are there any existing corporate-wide initiatives for:
   ___quality improvement
   ___safety
   ___reliability improvements
   ___problem solving
   ___cost reduction
   ___other personnel development

Performance Indicators Questions

1. How do you define a forced outage?
   (Forced outage means different things to different utilities. Some people are very fuzzy on the definition.)

2. What is your average forced outage average rate?
   (All units)

3. What is the goal for average availability for the plant as a whole, or by unit?
   (If they have charts ask for a copy.)

4. Is the plant meeting goals for production? and How much room is there for improvement?

Life Extension Questions

1. Are there any plans for life extension of the plants? Rebuild or replace?
   (This is asked to determine if there is a program for plant life extension, or if they are nursing old units along until retirement.)

2. Have there been any major capital investments for plant equipment? If not, Are any planned?

Predictive Maintenance Questions

1. What is your definition of Predictive Maintenance?
   (Give your definition as you understand it. It is important to know what the interviewee perceives as the definition. Take time here to encourage the interviewee. It may help to show the definition of PDM, CM, PM, PAM, and RCM in the Guidelines.)

2. As you understand PDM, why do you think you can control O&M costs?
   (Wanted to learn here is whether or not the VP or PM is a true believer and what that person bases this belief on. If there is not true belief, then some effort needs to be spent to convince the individual that PDM will help.)

   a) On what are you basing your belief?
      (Articles on PDM in industry, practical experience at this utility or in prior occupations, etc.)

Financial Performance Question

1. What are the costs per kwhr, peak and off peak (bus bar or customer costs)? and Where do you see them going in the near future? Higher or lower?

Leadership Questions

1. Are there incentives for plant managers who meet their goals for generation, cost control, personnel caps, others?

2. How did your current organization evolve, and do you see any changes in the near future?

3. Where does the PDM Group effort exist in your organization?
   (PDM is a philosophy that is lived by all plant personnel if it is successful. It is also a block on the organization chart because someone has to manage the effort early on. It does not matter where (engineering, maintenance, operations) the responsibility is placed so it is normal to go with the general consensus. If a PDM group is in existence efforts should be made to try to support how it could improve effectiveness where it is currently located.)

Goals Questions

1. For the plant under study, prioritize the following
   ___Availability Improvement
   ___Safety
   ___Equipment Life
   ___Operations Management

___Reduction of Maintenance Costs
(It is important to clearly define the goals for this utility in the PDM implementation plan. It is also important that emphasizes is placed on what is important to them as long as it is mutually agreed that these goals are correct for PDM.)

2. What is the plant history?
   Operating Profile
   Remaining Life - Any plans for life extension?
   Availability
   Forced outage rate
   Heat rate
   (Ask only if this information has not already been obtained.)

3. Has the plant readily met goals for production, availability, forced outage, heat rate, and budget in the past?

Budget Questions

1. What is your current total plant budget? Fuel? O&M Labor? Expenses?
   (If they have any charts available showing a few prior years, ask if it is possible to get a copy. This also helps with determining "pay back".)

2. Is there a line item in the budget for PDM?
   (Here it is necessary to try to establish their level of commitment to the PDM approach Note: the Guidelines state that if you do not have management commitment, then stop! Get the commitment and continue with PDM. If you don't, your program may get cut and frustrate craft personnel who have already put their efforts into the program.)

Capital Expenditures Questions

1. What is your typical expected payback period for investment in capital equipment?
   (This is needed to know in order to apply cost payback for on-line systems, if applicable.)

2. How are capital expenditures justified?

3. Is there a written procedure?
   (Can a copy be obtained?)

Accountability Questions

1. What meetings are held regularly to address plant equipment problems or other O&M issues?

2. Who attends these meetings?

3. What reports are you aware of (paper, electronic, voice mail) and are currently available to you? and Who produces these reports?

4. Do you think the plant benefits from the current PDM efforts?
   (Does the VP or plant manager respond in terms of O&M reduction (saving money)? If not, this is a good time to review management issues regarding PDM.)

Asset Management Questions

1. What is your current maintenance strategy for the plant?
   (Get perception, distribution of dollars spent on CM, PM, PDM, PAM - give percentages.)

2. Are root cause analyses ever conducted on failed components?

Technology Utilization Questions

1. What is your understanding of your utility's Predictive Maintenance efforts?
   (It is important to note the level of communication that exists between the plant manager and others in the utility.)

2. Are there any technologies that you believe to be particularly effective in determining machine condition?

3. Are there any additional technologies that would be beneficial to the plant that should be or will be implemented in the near future?

4. What are the risks involved with beginning or expanding a PDM approach?
   (Depending on what they perceive as risks, it is important to try to address how to avoid or alleviate these risks when the report is assembled. Also, a probability of the success of each of the technologies recommended will be applied to the proposed benefit numbers. This risk may influence that probability.)

Outage Planning Questions

1. How is outage scope derived?

2. Are diagnostic results used to direct outage maintenance?

Central Support Question

1. What services does the plant use on a regular basis from central corporate or contractor support?
   ____Diagnostic Testing (including NDT Inspections)
   ____Laboratory
   ____Engineering Design
   ____Troubleshooting
   ____Outage Maintenance
   (*Check all that apply)*

4

ANALYSIS OF ASSESSMENT DATA

General Overview

From the Assessment data, answer the following questions about Predictive Maintenance programs, technologies and procedures.

1. Which technologies are broadly and regularly applied at the facility?

	Yes	No
Periodic vibration measurements	_________	_________
Infrared thermography	_________	_________
Lube oil analysis	_________	_________
Motor current analysis	_________	_________
Valve leak detection	_________	_________
Performance analysis	_________	_________
Chemistry monitoring	_________	_________
Ultrasonic thickness testing	_________	_________
On-line vibration monitoring	_________	_________
Electrical testing	_________	_________

9. Which of the following statements is true for your plant? (Circle one)

   a) Most personnel at my plant understand the fundamentals of these technologies and are willing and eager to react to the results of diagnostic tests.

   b) Some people at the plant understand and support regular diagnostic testing.

   c) Some diagnostic testing is conducted at the plant, but only for troubleshooting.

   d) Only outside contractors are used for diagnostic testing and the plant personnel are not made aware of the findings.

e) No diagnostic testing is accomplished at the plant.

10. Which statement best describes your plant's use of information gathered in a Predictive Maintenance program to plan and schedule outage work? (circle one)

a) All plant critical components are evaluated for condition prior to outage.

b) Some plant equipment, showing signs of wear through diagnostic tests, is scheduled for overhaul.

c) Outage scope is set based only on known problems. No attempt is made to evaluate the condition of other pieces of equipment prior to the outage.

d) Outage scope is set based only on equipment time in service.

e) Equipment, known to be in good condition, is scheduled for overhaul regardless of diagnostic test results.

11. Which statement best describes your plant personnel? (circle one)

a) There is a clear and well understood relationship between plant equipment function and the impact on production by all plant personnel.

b) The plant personnel know the general function of each plant critical system, but details about these components or systems that impact production are kept within individual groups.

c) Only selected individuals know how the reliability of the plant's equipment affects production.

12. Are plant management performance indicators well known and understood throughout the work-force? (check one for each type of goal)

Plant Goals	All Plant Personnel	Some Personnel	Management Only
Production	________	________	________
Reliability	________	________	________
Production Costs	________	________	________
Capital Budget	________	________	________
Productivity	________	________	________

6. Which statements describes plant personnel support of the Predictive Maintenance program? (check all that apply)

______ Predictive Maintenance has the support of top management.

______ The activities under Predictive Maintenance have a separate line item in the budget

______ Maintenance supervisors support Predictive Maintenance activities.

______ Operators support Predictive Maintenance.

______ Maintenance craft support Predictive Maintenance activities.

9. Which statement best describes the situation at your plant? (circle one)

   a) Management keeps a list of the top 10 or 12 equipment problems and has a plan for the elimination of each problem. Most corrective and preventive activities are conducted on time and backlog is low and constant.

   b) Current resources are adequate for conducting critical repairs. Backlog fluctuates but is under control.

   c) Work backlog is large and keeps growing.

   d) Budget constraints do not allow work-force to completely repair existing problems.

   e) Most work is not planned and conducted every day in an emergency mode. Backlog is not tracked.

10. Select the statements which best describe computerized Maintenance Management System usage. (check all that apply)

______ The plant has a Computerized Maintenance Management System that allows for easy identification of recurrent work orders.

______ Computerized Maintenance Management System is capable of tracking costs of maintenance on individual major components.

______ Components are checked for other condition related problems prior to issuing work orders.

______ "As found, as left" are accurately captured and documented prior to work order close out.

______ Work orders for post maintenance diagnostic testing are issued upon completion of all repairs.

9. For the Predictive Maintenance program, select the statement that best describes your PDM reporting system. (circle one)

a) Predictive Maintenance reporting captures all pertinent information that can be used to describe the condition of the equipment: all diagnostic tests, process data, maintenance histories and operations logs, batch testing, maintenance cost, and component availability data.

b) The Predictive Maintenance report captures all diagnostic (vibration, lube oil, thermography) data in a single report.

c) The Predictive Maintenance program consists mainly of two separate reports, vibration and oil data.

d) The PDM program consists of a monthly exception report of vibration data.

e) No regular reporting is conducted. Unacceptable test results are reported on a case-by-case basis.

10. Which statement best describes your plant's PDM Program? (circle one)

a) Management indicators for PDM program success (such as average cost per work order and maintenance cost per component) are established and tracked regularly.

b) The benefit to cost ratios for Predictive Maintenance are tracked and widely published.

c) Procedures exist for calculations of benefits and are based on individual occurrences or events. Benefits are calculated on a periodic basis and reported to management.

d) No standard procedure exists for calculating benefits, but individual events are captured and estimated.

e) No form of benefit estimating procedures exist for the plant.

Analysis of Interview Data

From all the responses gathered during the interview processes, read the notes from all respondent interviews. Note any comments that gave particular insight, or that the respondent felt strongly about.

Predictive Maintenance Assessment - General Interview Questions

- Personal
- Plant Operations and Maintenance
- Preventive Maintenance
- Predictive Maintenance
- Communications
- Training
- Computerized Maintenance Management System

Predictive Maintenance Plant Assessment - PDM Coordinator Interview Questions

- Diagnostic Tools
- Reporting
- Management Support
- Communications

Predictive Maintenance Assessment - Maintenance Manager and Supervisors Interview Questions

- Maintenance Strategy
- Maintenance Management System
- Maintenance Backlog
- Post Maintenance Testing
- Spare Parts

Predictive Maintenance Assessment - Operations Manager or Shift Supervisor Interview Questions

- Normal Plant Operations
- Operations Involvement in PDM

Predictive Maintenance Assessment - Upper Management Interview Questions

- Utility General
- Performance Indicators
- Life Extension
- Predictive Maintenance
- Financial Performance
- Leadership
- Goals
- Budget
- Capital Expenditures
- Accountability
- Asset Management
- Technology Utilization
- Outage Planning
- Central support

Analysis of Assessment Data

Analysis Procedures

1. Assemble all existing plant performance indicators and financial information and calculate the following:

    - Controllable Expenses

        » Materials

        » Supplies

        » Contracted services

    - Controllable O&M Labor Costs

        » Overtime

    - Controllable Fuel Cost

        » Auxiliary power consumption tracking

        » Difference between design heat rate and actual

        » Hot and cold restart costs

    - Controllable capital

        » Compare overhaul schedule with available PDM data

    - Estimate savings from outage scope reduction due to elimination of unnecessary work

2. Develop Equipment and Technology Matrix

- Identify all critical plant equipment.
- Identify equipment with high maintenance costs.
- Identify all technologies and other information resources that are available for the equipment listed.

3. Conduct Organizational Analysis

- Review plant organization chart for optimum organizational level for PDM Coordinator
(Note: PDM Coordinator's supervisor must have PDM program buy-in.)

- Work Flow analysis

  » Chart how work orders are accomplished

  » Identify how existing data resources are used

  » Identify who makes major decisions

  » Understand how rework is accomplished

  - Is a second work order issued?

  » Overlay how equipment condition information will be taken into account in future decision making

  » Show connections between unused information resources and decision making personnel

- Roles and responsibilities

  » For each preliminary recommendation, assign tasks to the plant department that will accomplish the task.

  » Show all parties concerned, especially maintenance craft functions

  » Include contractors and off-site corporate personnel

4. Conduct Financial Analysis

- Planning and estimating guides should be developed for each technology to be newly implemented or upgraded
- Capture all Material and Labor Start-up Costs
- Capture all recurring costs
- Estimate Annual Benefits

- Develop PDM Program Cost table

5. Develop preliminary recommendations based on interview data and known best practices *(Be sure to address all issues raised during the interviews, especially by management.)*

6. Assemble any supporting documentation and include it in the appendices.

5

REFERENCES

1. *Predictive Maintenance Guidelines*, Volume I, Electric Power Research Institute, TR-103374, August 1994.

2. *Predictive Maintenance Guidelines*, Volume II, Electric Power Research Institute, TR-103374, December 1997

3. *Predictive Maintenance Program: Development and Implementation*, EPRI M&D Center, Training Course Notes, Eddystone, PA,

4. *Predictive Maintenance Advisory Group*, Meeting Minutes, Indianapolis, IN, December 1995.

5. *Benefits of Predictive Maintenance Program in a Power Plant Environment*, Colsher et al., EPRI 5th Predictive Maintenance Conference, Knoxville, TN, July 1992.

6. *Development of a Predictive Maintenance Implementation Plan*, Matusheski et al., EPRI 6th Predictive Maintenance Conference, Philadelphia, PA, July 1994

7. *Condition Monitoring as a Maintenance Management Tool: A Case History*, Blane, BP Oil Company, Marcus Hook, PA.

A

SAMPLE REPORT

The final report, developed by the Assessment team, is the evaluation of the current predictive maintenance activities and recommendations for improvement. Integral to this report is a suggested approach for routinely tracking and analyzing the benefits of the predictive maintenance program. The report serves as a living document, a handbook for conducting the predictive maintenance program; and, an information resource to help to guide the program for both the short term start-up and long term evaluation.

Appendix A

Predictive Maintenance Assessment

Final Report

for

Utility Power Company

Plant Station

by

Electric Power Research Institute
and
Maintenance & Diagnostics
440 Baldwin Tower
Eddystone, PA 19022

December, 1997

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1.0 INTRODUCTION and OVERVIEW

The EPRI Maintenance & Diagnostics Center (M&D Center) has conducted a Predictive Maintenance (PDM) Assessment workshop for the ***Plant*** of the ***Utility***. This report contains the findings from work started during this workshop, with strong emphasis on recommended steps to be taken to develop a meaningful and beneficial PDM Program.

The maintenance strategies currently in place at ***Utility*** include a very well-developed Preventive Maintenance (PM) Program, which is time-based, and Corrective-Maintenance (CM). The maintenance personnel respond well to CM as they are very aggressive problem solvers when troubles arise on major pieces of equipment. However, some unexpected catastrophic failures have occurred on more obscure critical equipment which have raised safety concerns. In addition, there are doubts as to whether PM alone provides the appropriate level of protection for critical plant components.

Many of the Predictive Maintenance technologies, or tools, have existed at ***Utility*** for many years; but, the applications and capabilities of these technologies were not well defined and programmatic issues were not addressed. A formalized Predictive Maintenance approach based on the integration of all of the available data necessary to make timely decisions regarding the equipment maintenance definitely applies. Some interview comments which indicate that a formalized application of PDM is appropriate are:

- "Safety is why PDM is being considered." PDM can provide early indications of equipment problems that can, over time, develop into catastrophic events.
- We want to take care of our equipment, not maintain an abundant amount of spare equipment.
- "The Utility wants lowest-cost electrical production." PDM plays a vital role in optimizing balance of an overall maintenance strategy to provide least-cost electrical production.
- "The Utility's goal is to keep EFOR at $\leq$ 4%, system wide, and $\leq$ 2 % at strategic facilities as equipment ages and system capacity factors increase." This is directed at the deferral of new unit construction as load and competition grows. Effective PDM Programs reduce EFOR.

- "Communications between the plants and corporate could improve." To be successful, PDM requires network communications and teamwork from all involved! The plant, Corporate Engineering, Operational Services, and Power Generation Engineers, all have integral roles in PDM at ***Utility***.

- "Budget goals for the next five years are to stay flat (no increases) except for inflation and salaries." PDM offers the highest benefit-to-cost ratio of all maintenance strategies.

- "***Utility*** is focused on improving the design heat rates on its units". To enable fuel optimization in a competitive environment, PDM enables effective and timely equipment information evaluation and exchange.

- "Continue to evaluate ways to extend planned outage frequency beyond the current 20 - 24 months and reduce the duration to 8 - 12 weeks." "Use PDM to better define work scopes." "Break away from PM mind set." PDM provides the earliest warning of incipient equipment problems enabling control and careful planning of maintenance tasks to suit the energy dispatcher.

- "We want to do a better job of what we are doing, and how often we do it."

1.1 PDM Assessment Purpose

Utility is preparing to meet the challenges of a rapidly changing electric Utility environment. ***Utility*** has added Predictive Maintenance (PDM) as a maintenance strategy to improve personnel safety, equipment reliability, unit availability, and process work-flow, all to emerge as "The World's Premier Supplier of Electricity and Related Services." The main objectives of the Assessment were focused on the short and long term. The short term focus would be on formalizing the PDM strategy at ***Plant,*** with a long term focus on developing internal ***Utility*** support functions to support PDM system-wide.

- To evaluate existing PDM activities and plant information resources for applicability in a program that guides maintenance based on plant equipment condition.

- To investigate new technologies, not currently in use at ***Plant***, that could be used cost effectively in a Predictive Maintenance program.

- To re-engineer the plant and support organizations to optimize the integration of maintenance strategies, with a focus on Predictive Maintenance.

- To assess and recommend means to improve organizational communication of condition-based equipment information.

- To develop sound economic models that assure the most cost-effective selection, and strategic organizational placement of predictive technologies within ***Utility's*** system.

- To develop a detailed plan and schedule for the development, implementation, and coordination of a Predictive Maintenance program at ***Plant*** and all applicable support organizations.

- To investigate the computer-based operation, maintenance, and predictive maintenance tools at the plant, corporate, and regional offices for application and integration in EPRI's Operations and Maintenance Workstation that automates the PDM process.

1.2 PDM Assessment Methodology

The Assessment workshop consisted of several M&D Center staff personnel working along with a number of ***Utility*** employees from ***Plant***, Corporate Engineering, Plant Services Department, and Operation Services Group. The team assembled and reviewed plant and departmental records, performed plant equipment surveys, and conducted interviews with plant and staff personnel in order to investigate current PDM activities and develop recommendations for PDM program implementation.

2.0 Key Findings And Recommendations

Recommendation #1

Plant should initiate a formal Predictive Maintenance Program implementation. The Predictive Maintenance engineers are the energy behind this effort. They are responsible for the internal and external communication channel that ensure data-to-information-to-corrective action conversion. They coordinate the plant PDM program financial, technical, and organizational, as well as root cause (proactive maintenance), analysis. The PDM engineers are responsible for publishing as well as coordinating formal reviews of the periodic equipment health reports. The PDM engineers share results with Corporate Engineering, Plant Services, and Generation Engineering personnel to make sure they compliment plant and corporate performance goals. The PDM engineers must establish and communicate clear expectations for the PDM Program and for all of the people involved. Their efforts must be received by a plant and corporate culture that supports learning for continuous program improvement.

Recommendation #2

Plant should provide internal craft resources to support the PDM effort. The M&D Center recommends that a trained, experienced mechanic, supervised by the PDM engineers, provide periodic vibration monitoring, alignment, and machine balancing services to the plant. In addition, the M&D Center recommends that a trained, experienced electrician, supervised by the PDM engineers, perform thermography surveys and coordinate/perform all electrical and broken rotor bar tests on critical plant motors to support the EMPM program. The M&D Center recommends that acoustic leak detection surveys, coordinated with infrared thermography surveys, be performed by ***Plant*** team operations personnel. Data should be analyzed and corrective action initiated by the PDM engineers. M&D recommends that equipment testing, more cost-effectively handled within ***Plant***, be performed by plant engineering.

Lube oil monitoring should be managed by the ***Plant*** chemist and the laboratory technicians. All testing should be conducted by a suitable laboratory specializing in used-oil and wear particle analysis. The samples should be collected and screened by the plant laboratory technicians, obvious action initiated, then mailed off. Upon receipt, the analysis results should be reviewed by the ***Plant*** chemist, (eventually Corporate Engineering, if responsible for periodic vibration monitoring), and the ***Plant*** PDM engineers, and action should be initiated.

Recommendation #3

The PDM engineers, working with plant superintendents, supervisors and engineers should develop plant performance metrics/indicators to measure the effectiveness of the PDM program. Since maintenance costs and availability for individual components will be tracked in this program, performance indicators should be modeled against design or benchmark values. (Refer to Figures 3-4 through 3-6).

Recommendation #4

Corporate Engineering should focus on developing expertise in PDM technologies (periodic vibration monitoring, infrared thermography, major component performance tests, etc.) to support ***Utility's*** Predictive Maintenance program in the short term; and, organizing primary PDM technology support at smaller plants and secondary support at the larger plants in the long-term. M&D's short-term recommendation stems from ***Utility's*** goal to have PDM programs underway system-wide before the end of 1996. The long-term recommendation is based upon an economic model that compares the cost of PDM services supplied by Corporate Engineering versus the individual plant or contract resources. If properly staffed, trained, and equipped, Corporate Engineering will provide a "best value" for ***Utility*** as a whole because of wide-spread equipment standardization. This cannot be added by using plant or outside resources. M&D also recommends, as PDM evolves at ***Utility***, that Corporate Engineering help manage the lube oil and EMPM databases to take advantage of the overlap between these and other technologies.

Recommendation #5

Utility should consider creating the position of System PDM Coordinator. The position should operate from the Power Services Department, Operations Services Group. In that the long-term company goals should include the development of expertise and self-sufficiency in the area of PDM technologies, the Coordinator would develop and sponsor cohesion and consistency in all of ***Utility's*** PDM information exchange and root-cause analysis efforts. The System PDM Coordinator ensures that maximum economic gain is realized from ***Utility's*** inherent strength; i.e. economies of scale for utilization of support services, extensive equipment standardization, computer networking, etc. He/she would interface between and ensure support from management and equipment experts at Operations Services and Power Generation Engineering, to allow PDM engineers at the plants to dispatch complex or recurring problems, track resolutions to closure, and document and distribute findings.

Recommendation #6

A mature PDM program provides valuable long-range planning information to both daily and outage maintenance planning personnel, as well as near-term troubleshooting assistance. The ***Plant*** PDM engineers and the Planners need to incorporate PDM information into the routine planning and scheduling work process flow. The Planners must understand and make use of the PDM information to properly cost-effectively plan and schedule overhauls and adjust PM activities.

Recommendation #7

In order for a PDM program to be successful, all plant personnel should accept the philosophy of maintenance based on condition. This philosophy needs to be carried to the field by individuals selected by the Craft. In order to gain buy-in at the worker level, ***Plant*** should initiate a Plant Maintenance Review Panel. This panel consists of knowledgeable individuals from each plant discipline (Mechanical, Electrical, Instrumentation, Operations, etc.), that meet regularly with Planners, Supervisors, and Engineering (PDM included) to discuss the maintenance needs of the plant equipment. They should be informed of the status and disposition of outstanding critical job orders. Panel members should also understand the decision-making process that surrounds job order prioritization. By understanding the process, they can convey that understanding to other plant workers. The functions of this panel should be preserved and supported by management.

Recommendation #8

Utility must provide various levels of training to the plant and support group personnel involved in the PDM effort. The training needs should be evaluated based on the role of the individual in question. For example, M&D recommends that basic PDM training be given plant-wide, particularly to the plant engineers, operators, and planners. This training emphasizes the programmatic (organizational and communication) aspects of Predictive Maintenance, as well as a fundamental understanding of how technologies are applied to detect equipment problems. Refer to Section 4.5 of this report for specific recommendations on training.

Recommendation #9

Plant, in conjunction with electrical operations, should investigate the applicability of a Switchyard and Substation Predictive Maintenance program to guide maintenance activities. The plant should take the responsibility for the development and implementation of PDM on the plant primary and secondary electrical distribution systems. This recommendation is key to satisfying plant safety goals and concerns.

Recommendation #10

Plant should formalize and publish a component-level, multi-discipline, user-friendly maintenance labor and material tracking information system. J-File and the existing Job Order form may be configurable to satisfy this important need. In order to optimize the mix of maintenance strategies in use at the plant, the Maintenance Manager, PDM engineers, Supervisors, Planners and Craft should be able to perform simple inquiries in order to determine equipment maintenance costs. Maintenance management should be able to evaluate the distribution of maintenance funding by discipline, and by maintenance strategies (O&M, PM, PDM, indirect maintenance projects, etc.) for maintenance program performance monitoring. The plant should encourage the use of this information as part of its day-to-day tasks.

Recommendation #11

Plant should work with the EPRI M&D and N.D.E. Centers, and ***Utility*** Corporate resources to optimize the application and integration of nondestructive examination techniques into the PDM program. Special attention should be paid to the steam generator, its accessories, and plant heat exchangers. ***Plant*** is doing a good job of applying technologies for directing PM efforts in the steam generators. If that effort was formalized, applied to other components, and the information integrated into the PDM program "Web", a plant-wide condition-based maintenance program would be born that would serve as the model for ***Utility*** and the industry.

Recommendation #12

Utility's plants should coordinate with each other to standardize on diagnostic tools, software, and training. ***Utility*** plants share common designs and therefore strengths and problems throughout many of the generating units. This commonality of generating equipment design, and the utilization of the Corporate Engineering as consultants and back-up resources for the plants, offers benefits not often available in the utility industry. Standardization of tools, software, and training extends this strength by providing personnel familiarity, the ability to share data electronically, and back-up tools in the event of diagnostic equipment failure. This synergism maximizes the benefit from the PDM program.

3.0 "Utility Plant" PDM Program Goals and Expected Benefits

During the Assessment process, various goals for implementation of the PDM program were discussed, and the following goals have been identified:

- Support the extension of time between major outage intervals to 20 - 24 months and beyond. Reduce the duration of outages to less than 8 - 12 weeks.
- Maintain high levels of equipment reliability. The proof of the success of these objectives will be evidenced by measuring O&M cost performance and plant availability performance.
- Ensure a high standard of personnel safety by minimizing unexpected equipment failures through early detection of equipment anomalies. The proof of success here would be evidenced by lower OSHA rates at the plant.

Specific goals would be to:

- Reduce plant O&M costs by ***"number"*** percent. A factor influencing this measurement is the plant's response to available budgets.
- Reduce plant EFOR (Equivalent Forced Outage Rate (%) average for the plant by ***"number"*** percent.
- Increase weighted average plant availability by ***"number"*** percent.
- Reduce plant heat rate by ***"number"*** percent.

The average net cost effect of achieving these goals would be on the order of ***"number"*** percent in improved performance at the plant.

Non-Fuel O&M

The non-fuel O&M budget has been **"number"** each year for the past seven years. The budget forecast is estimated at **"number"**. The PDM program should allow for cost performance at **"number"** for the forecast years, representing a **"number"** percent in non-fuel O&M costs or a **"number"** percent in maintenance costs. A typical plot showing these trends over the seven year period is shown in Figure 3-1.

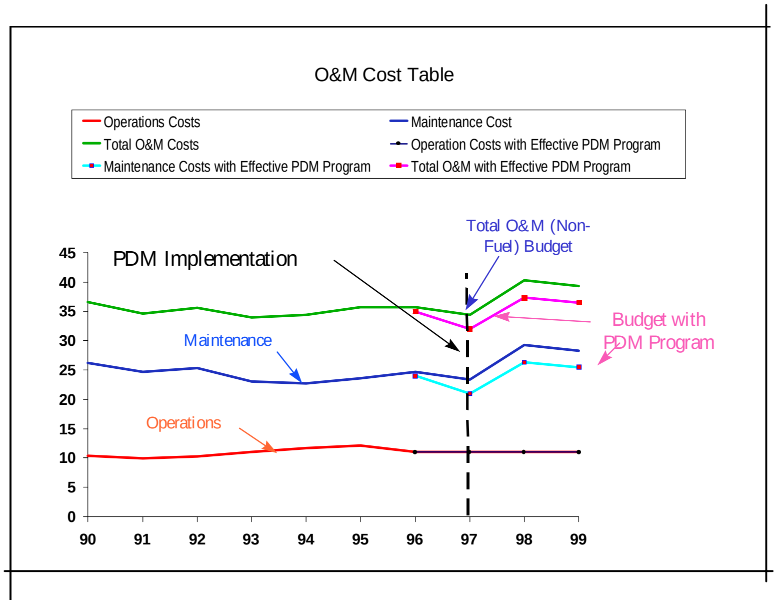


Figure 3-1: O&M Cost Table

EFOR

The EFOR rate for a single unit varies greatly from year to year. Measuring the average EFOR smoothes the curve and permits establishing a meaningful goal. For years 1994 and 1995, as shown in Figure 3-2, the average EFOR was **"number"** and **"number"**, respectively. The target goal for EFOR with the PDM program in place is **"number**." Successful achievement of this goal will result in over **"number"** of increased net revenue generated by the plant.

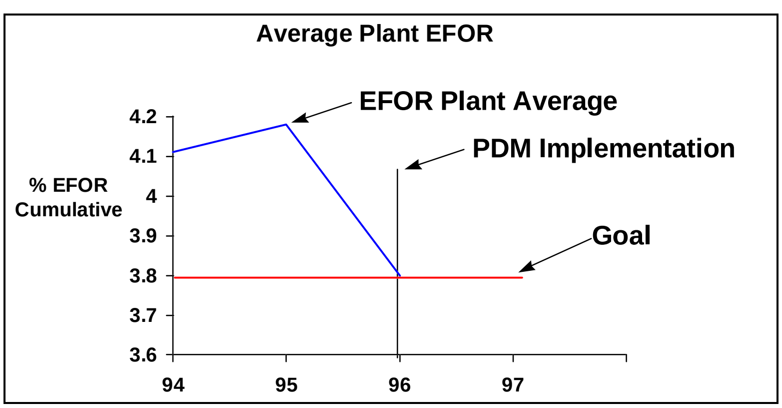


Figure 3-2: Average Plant EFOR

Availability

The weighted average for availability for all three units at the plant has been fluctuating between **"number"** over the past five years, as indicated in Figure 3-3. The PDM program goal is to increase that availability by **"number"**.

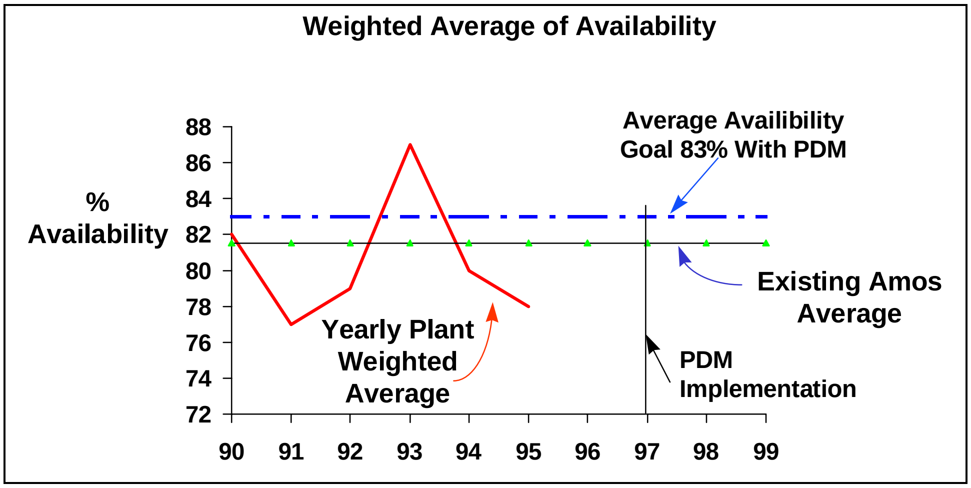


Figure 3-3: Weighted Average of Availability

Other Indicators

Figures 3-4 through 3-6 show the verification and tracking of other indicators of the results and benefits of the program over shorter near-term time frames, 2 to 4 years.

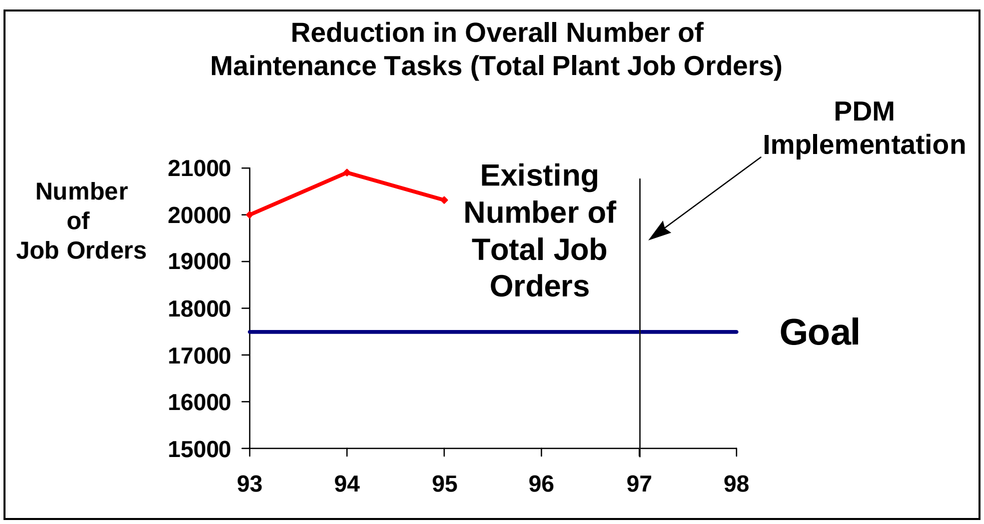


Figure 3-4: Recommended Performance Indicators to put in place in PDM program

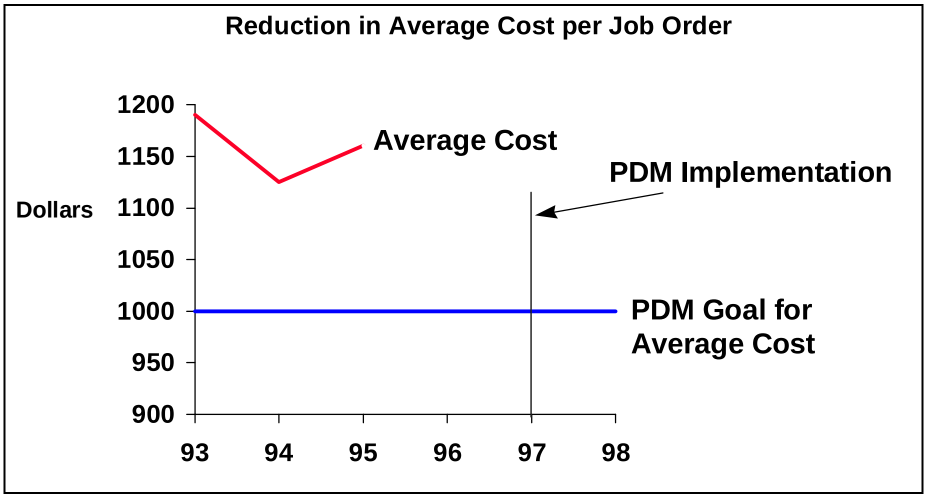


Figure 3-5: Reduction in Average Cost per Job Order

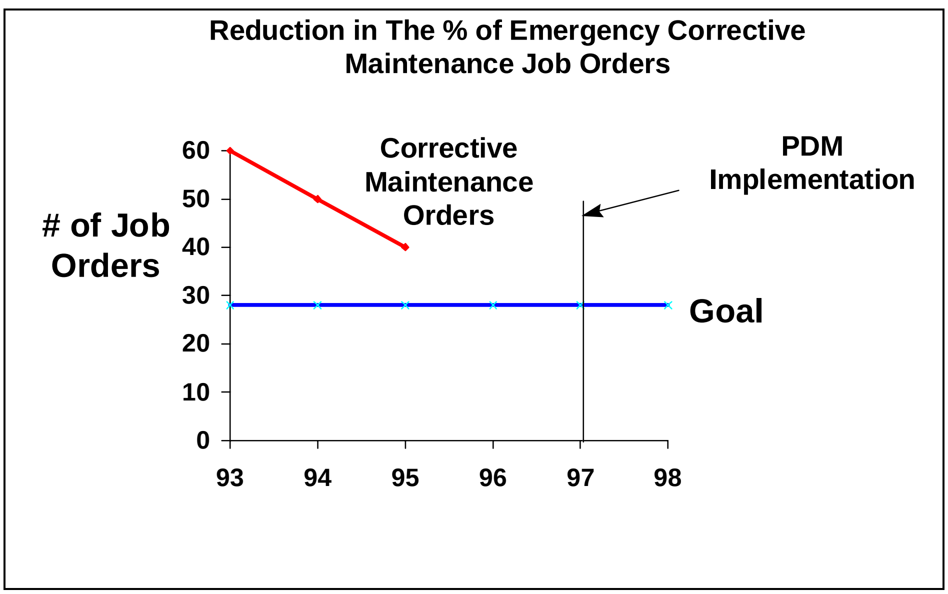


Figure 3-6: Reduction in % of Emergency Corrective Maintenance Job Orders

Comparison Charts

Figures 3-7 and 3-8 are pie-charts that illustrate the comparison of controllable costs with and without PDM Implementation.

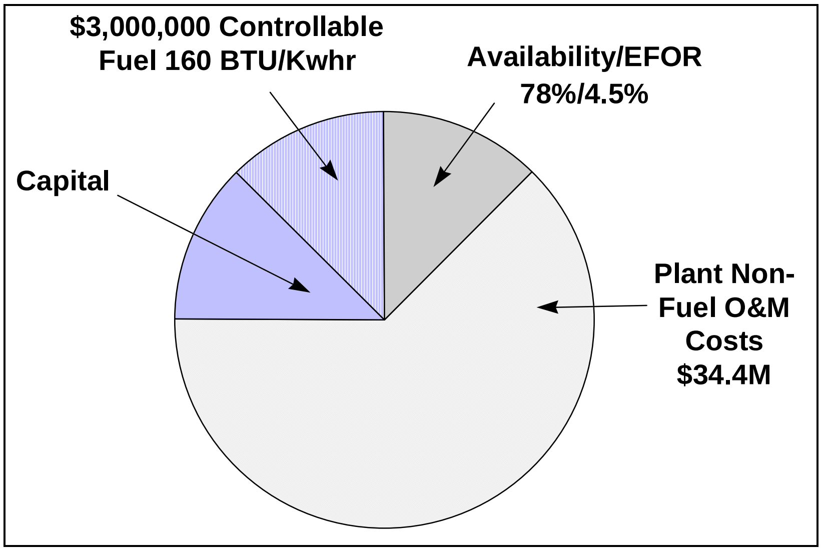


Figure 3-7: Plan Controllable Costs without PDM Implementation

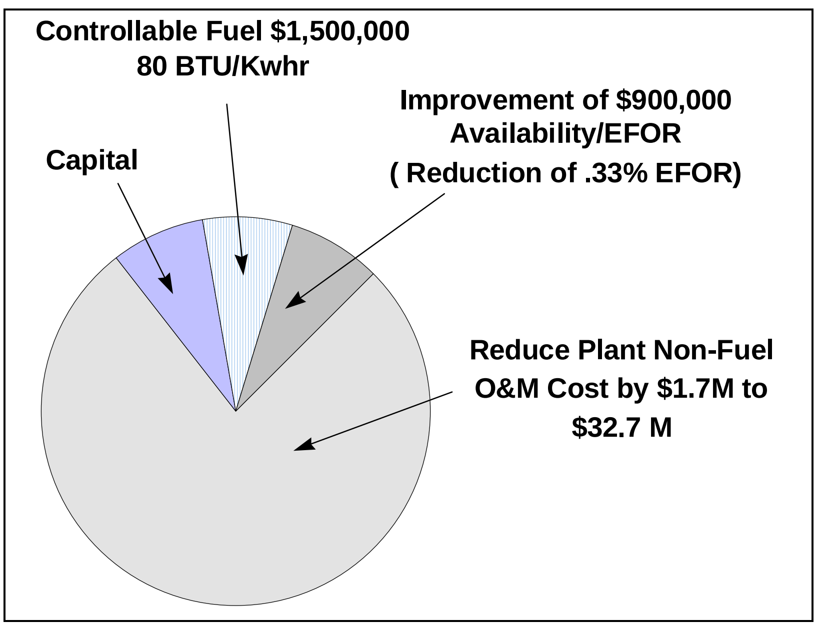


Figure 3-8: Plan Controllable Costs with PDM Implementation

4.0 Implementation Plan

4.1 Overview

PDM implementation is a step-by-step process that yields a fully integrated program with maximum potential impact. The action steps for the recommended PDM program are listed below:

1. Define program goals.
2. Confirm management support.
3. Provide programmatic and technical training.
4. Select the plant equipment to be monitored.
5. Allocate support from departments with a role in the PDM program.
6. Purchase any additional cost-justified technologies.
7. Establish a reporting mechanism on the plant LAN and corporate WAN.
8. Conduct repairs based on PDM recommendations.
9. Advertise early successes.
10. Reevaluate the PDM program periodically.

Action Step Summary Comments:

1. ***Utility*** should establish overall performance plant goals for the generating facilities. ***Plant*** should have specific goals identified for the PDM program. Those goals should be clearly communicated to everyone. The M&D Center suggested some goals for consideration in Section 3 “Program Goals and Expected Benefits” of this report.

2. ***Utility*** has demonstrated good management support for the development of a PDM effort system-wide. Positions to support the efforts have been established at the plants and at regional service organizations. Technical support dispatching, communications and action items exist to support a PDM program at the Corporate level. The pilot effort at ***Plant*** is fully

funded through EPRI Core funding and Tailored Collaboration dollars. The associated ***Utility*** task groups are evaluating other PDM opportunities; and, the plants are in agreement that PDM could be of value in the competitive environment. Once the pilot is complete, the most applicable facets of PDM evaluated at ***Plant*** will be shared throughout the ***Utility*** system. Recognizing that there will be funding issues, management support should continue through the program implementation phase. Section 4.4 "Financial" of this report summarizes these issues for the EPRI/***Utility*** program at ***Plant***.

3. Personnel from many organizations, both inside and outside ***Plant***, will be involved in the PDM program. In order to function properly in their new rolls and responsibilities, training will be required. Training requirements are detailed in Section 4.5 "Training".

4. PDM is one of a number of maintenance strategies in place in a plant maintenance program. The use of PDM to augment the mix provides a least-cost approach to equipment maintenance expense. However, to achieve plant performance goals utilizing these strategies, maintenance must be focused to the right degree on the right equipment. A component-level guideline for optimizing the use of PDM on critical plant equipment at ***Plant*** is found in Section 4.2.1. Logistical details for applying each technology are found in the accompanying Section 4.2.2.

5. As mentioned previously, many plant and support departments cooperate in EPRI's recommended PDM program. Department managers must evaluate the roles and responsibilities and allocate their support for the program. Interdepartmental "Roles and Responsibilities" are defined in Section 4.3.2.

6. Many technologies and communication networks, beneficial to PDM, were found to already exist throughout ***Utility***. One purpose of the Predictive Plant Assessment was to evaluate what exists versus what is required in these areas for maximum benefit from PDM. The EPRI M&D Center recommends that a few additional diagnostic technologies be implemented. The benefit-to-cost worksheets that justify these technologies can be found in Section 4.4.2 "Planning and Estimating Guides". Also, P&E Guides justifying the fully integrated PDM program and automating Predictive Maintenance utilizing the Operations and Maintenance Workstation are included.

7. 70% of an effective PDM program is the communication of equipment condition information. A major role of the plant PDM engineers and the

PDM Coordinator, in Operations Services and Corporate Engineering, is the establishment and maintenance of PDM communication channels throughout the plant and ***Utility's*** system. The plant PDM engineers have an advantage in that computer LANs and WANs are in place and available. EPRI M&D recommends that the plant LAN be used to establish a manual equipment condition reporting system, until the Operations & Maintenance Workstation can be commissioned plant-wide.

8. The PDM process now joins the plant maintenance program strategies at this point. PDM program goals and expectations should be defined and communicated, all of the resources should be in place, roles and responsibilities clarified, and communication channels established. At this point, efforts should be focused on: (1) evaluating maintenance backlogs; and, (2) screening of incoming new job orders for the application of more cost-effective solutions to equipment repair.

9. The PDM program will be carefully scrutinized to begin with. It is important to continually enlist buy-in to the program by advertising successes to ensure longevity. The plant equipment health report, plant newsletters, word-of-mouth communication via the Plant Maintenance Review Panel and the Plant and Operations Service's periodic PDM meetings are all valuable communication networks for PDM information exchange and program advertising. If proper tools are installed to report successes (and failures, with reasons why) at the plant and Corporate level, then program justification is reduced to a series of benefit-to-cost calculations and periodic program goal assessments.

4.2 Equipment and Technologies

This section outlines which PDM technologies should be applied or enhanced at the plant. This Plant Assessment Report should answer these four important questions:

- What am I attempting to accomplish?
- Why is this technology applicable?
- How will I go about these efforts?
- When do I achieve my goals (recognize return on investment)?

The Planning and Estimating (P&E) Guides (in the Financial Analysis section of this report) address each proven technology individually, and provide specific cost and task information to implement the technology. The Guides included are for the following technologies:

- The Integrated PDM Program Implementation
- Periodic Vibration Monitoring
- Periodic Lube Oil Monitoring
- Periodic Thermography
- Electric Motor PDM Program
- Ultrasonic Leak Detection
- Operations and Maintenance Workstation

Equipment and Technologies (E&T) matrices are included in Section 4.2.1 as a guide for ***Plant***. The matrices, in conjunction with the applicable Planning and Estimating Guides, will provide the plant with technologies that are appropriate and cost-justified.

Note: When planning a PDM program, begin surveillance on the most critical and costly plant process components.

- *What are the most troublesome pieces of equipment at the plant?*

  The "Top 10" most troublesome pieces of equipment are listed below:
  (in descending order)

  1. Ash Handling Pumps *
  2. Fans *
  3. Coal Pulverizers *
  4. Precipitator *
  5. Boiler Tube Leaks
  6. Sootblowers
  7. Electric Motors *
  8. Pumps (General) *

9. Coal Handling (Misc.) *

10. Compressors *

Note (1) The asterisk (*) indicates areas where the PDM program described in this report will have an impact. The PDM Program will also help to control costs in other areas of the plant so that resources are available to address these high cost areas.

Note (2) The Equipment and Technology matrices were developed to show existing monitoring activities, as well as new technologies to be added under the PDM program.

Note (3) Equipment 5 and 6 are addressed if an NDE program is formalized and integrated into the plant PDM Program.

- *Is there a flag in the maintenance request process to indicate recurring problems prior to job order issuance?*

  There is no automated process; however, J-File may house this capability. If so, it should be enabled.

4.2.1 Equipment and Technology (E&T) Matrices

The following matrices (Figures 4-1 and 4-2) outline the existing technologies and new technologies recommended for the PDM Program. At the intersection of each technology/plant component, a letter will appear if that technology is to be applied to the component. An "E" indicates an existing technology; "N" indicates a new technology; and, "R" indicates that research is needed. The number next to the letter is the frequency of surveillance in months. If no number follows the letter, monitoring is more frequent than once a month.

NOTES:

1. Please note that coal handling equipment received a limited appraisal in this Assessment, but should be evaluated and added to the program as deemed appropriate by the PDM, and Production Support engineers.
2. The PDM engineers should review which points are available and include these points in the equipment health report, as appropriate.
3. The EPRI M&D Center can assist ***Utility*** if it wishes to implement a Predictive Maintenance program for switchyard and substation components. That effort is beyond the scope of this Assessment.

Component Description	Vibration (Periodic)	On-Line Vibration	Infrared Thermography	Lube Oil Analysis	Process Data	Water Chemistry	Ultrasonics	Acoustic Leak Detection	Mill Fineness Test	Electrical Motor Testing	Motor Current Monitoring	Non-Destructive Testing	Visual Inspection	Performance
Rotating Equipment														
Circulating Water Pump 1-1,2,3,4	N3												N24	R
Circulating Water Pump Motor 1-1,2	N3		N3	N3						N12	N12			
Service Water Pump 1-1,2	N3													
Service Water Pump Motor 1-1,2	N3		N6							N24				
Hotwell Pump 1-1,2,3	N3			N3										
Hotwell Pump Motor 1-1,2,3	N3		N3	N3						N12	N12			
Auxiliary Hotwell Pump 1-1,2	N3													
Auxiliary Hotwell Pump Motor 1-1,2	N3		N6							N24				
Condensate Booster Pump 1-1,2,3	N3			N3										
Condensate Booster Pump Motor 1-1,2,3	N3		N3	N3						N12	N12			
Boiler Feed Pump 1-1	N3	E		N3	E									E
Boiler Feed Pump Turbine 1-1	N3	E	N3	N3	E									E
Auxiliary Boiler Feed Pump 1-1,2	N3			N3										
Auxiliary Boiler Feed Pump Motor 1-1,2	N3		N6							N24				
Auxiliary Drain Pump 1-1	N3			N3										
Auxiliary Drain Pump Motor 1-1	N3		N6							N24				
Condensate Reclaim Pump 1-1	N3			N3										
Condensate Reclaim Pump Motor 1-1	N3		N6							N24				
Condensate Clean-Up Pump 1-1,2,3	N3													
Condensate Clean-Up Pump Motor 1-1,2,3	N3		N6							N24				
Filter Coating Pump 1-1,2,3,4	N3													
Filter Coating Pump Motor 1-1,2,3,4	N3		N6							N24				
Condenser Vacuum Pump 1-1,2	N3		N6											
Condenser Vacuum Pump Motor 1-1,2	N3		N6							N24				
Nash Condenser Vacuum Pump 1-3,4	N3		N6											
Nash Condenser Vacuum Pump Mtr. 1-3,4	N3		N6							N24				
Forced Draft Fan 1-1,2	N3	E		N3	E							N24	N24	
Forced Draft Fan Motor 1-1,2	N3		N3	N3	E					N12	N12			
Primary Air Fan 1-1,2	N3	E		N3	E							N24	N24	
Primary Air Fan Motor 1-1,2	N3		N3	N3	E					N12	N12			
Coal Mill 1-1,2,3,4,5,6				R	E				E			N24	E	E
Coal Mill Motor 1-1,2,3,4,5,6	N3		N3	N3	E					N12	N12			
Coal Mill Gearbox 1-1,2,3,4,5,6	N3			EM			N3						E	
Dry Flyash Vacuum Pump 1a,b, 2a,b	N3		N3	N3			N3							
Dry Flyash Vacuum Pump Motor 1a,b, 2a,b	N3		N6							N24				
Bottom Ash Water Pump 1-1,2	N3			N3	E									
Bottom Ash Water Pump Motor 1-1,2	N3		N3	N3						N12	N12			
Fly Ash Water Pump 1-1,2,3	N3			N3	E									
Fly Ash Water Pump Motor 1-1,2,3	N3		N3	N3						N12	N12			
Fly Ash Slurry Pump 1-1,2,3,4,5,6	N3													
Fly Ash Slurry Pump Mtr. 1-1,2,3,4,5,6	N3		N3							N12	N24			
High Demand Fire Pump 1-1	N3		N3											
High Demand Fire Pump Mtr. 1-1	N3		N3								N12			
Low Demand Fire Pump 1-1	N3		N3											
Low Demand Fire Pump Mtr. 1-1	N3		N3								N12			
Engine Driven Fire Pump 1-1	N3		N3											
Engine Driven Fire Pump Diesel 1-1				N3										
Air Heater Rotor Bearings 1-1,2				N3	E									
Air Heater Drive Gearbox 1-1,2	N3			N3			N3							

Figure 4-1: Equipment and Technology Matrix

Component Description	Vibration (Periodic)	On-Line Vibration	Infrared Thermography	Lube Oil Analysis	Process Data	Water Chemistry	Ultrasonics	Acoustic Leak Detection	Mill Fineness Test	Electrical Motor Testing	Motor Current Monitoring	Non-Destructive Testing	Visual Inspection	Performance
Mechanical Equipment														
Condenser					E	E		N				N24		E
Auxiliary Condenser					E	E		N				N24		E
Process & Oil Heat Exchangers			N3		E							N24	N24	R
Circulating Water System					E	E								R
Cooling Tower					E	E								E
Boiler Safety Valves			N3					N3				E		R
Boiler/Turbine Drain Valves			E					N3						
Furnace Water Walls and Conv. Pass					E	E		E				EM	E	E
Boiler Primary and Secondary Supht.					E	E						EM	E	E
Boiler 1st. and 2nd. Reheater					E	E						EM	E	E
Boiler Economizer					E	E						EM	E	E
Boiler Air Heater 1-1,2			N24		E							EM	E	E
Boiler Casing			E										E	
Auxiliary Boiler			N24		E	E						E	E	
Condensate System					E	E								
Condensate Clean-up System					E	E								
Feedwater Heater 1-1					E	E		N				EM		E
Feedwater Heater 1-2					E	E		N				EM		E
Feedwater Heater 1-3					E	E		N				EM		E
Feedwater Heater 1-4					E	E		N				EM		E
Deaerating Heater					E	E						EM		E
Feedwater System					E	E		N						E
Feedwater Heater 1-7A, B					E	E		N				EM		E
Feedwater Heater 1-8A, B					E	E		N				EM		E
Steam Traps and Drip-Leg Drain Valves			N3		E			N3						
Reheater and Superheater Attemporators					E			R						
Electrical Equipment														
Main Transformer Ph. 1,2,3, & Iso.	R		N3	R			R						R	
Air Blast Circuit Breaker S,S-1,S-2			N3				R	N12					R	
Auxiliary Transformer 1A,B,C,D	R		N3	R			R						R	
Reserve Auxiliary Transformer 101	R		N3	R			R						R	
4160 V Circuit Breaker			N3				R						ER	
600V Transformer and Circuit Breaker			N3				R						ER	
Primary and Secondary Buss Sections			N3							N24				
Station Batteries and Inverter			N3										N12	
Precipitator	R		N3		E		R	N3				N24	N24	E

Figure 4-2: Equipment and Technology Matrix

4.2.2 Technology Applications and Descriptions

4.2.2.1 Periodic Vibration

- Monitoring services should be provided on critical rotating equipment without on-line monitoring protection on three-month intervals, once baselines and problems are defined and short term critical indications are addressed.
- Monitoring services should be provided on critical equipment with on-line monitoring protection when established overall vibration action levels are reached. Periodic vibration provides mechanical and hydraulic condition monitoring of equipment.
- ***Plant*** is to provide technical support and data collection resources for this service. As the program matures, ***Plant*** and Corporate Engineering should provide these services. However, service capabilities provided by Corporate Engineering must include <u>fast response</u> to special problem diagnostic testing and analysis.
- This program must be based on standard software, agreed upon by the plant, for maximum service value. No software has been recommended at the plant for use with data-collectors.
- Technical direction is to be provided by the ***Plant*** PDM engineers.
- ***Plant*** PDM engineers are responsible for coordinating data, assigning problem severity, initiating action, coordinating post maintenance follow-up testing, documentation distribution, and case closure.
- Training recommendations are provided in Section 4.5 of this report.
- Coordination of vibration monitoring data and lube oil analysis data is important. One technology serves as an important backup to the other. With careful coordination, significant increases in value will result.

4.2.2.2 Infrared Thermography Technical Application Descriptions

- Perform routine monitoring service on 3-month intervals, once baselines and problems are defined and short term critical indications are addressed.
- For use on rotating or static electrical, mechanical, and substation/switchyard equipment for trending condition and performance.
- M&D recommends that a common software (IR-SIP or equivalent) be utilized system-wide.

- ***Plant*** is to provide technical support and data collection resources for this routine service. ***Plant*** may consider using Corporate Engineering for special needs that may arise between routing surveys. Routine thermography performed by Corporate Engineering is recommended for smaller facilities.
- Technical direction provided by the ***Plant*** PDM engineers.
- ***Plant*** PDM engineers are responsible for coordinating data, assigning problem severity, initiating action, coordinating post maintenance follow-up testing, documentation distribution, and case closure.
- Training recommendations are provided in Section 4.5 of this report.
- This technology should be coordinated with plant operations personnel charged with performing acoustic leak detection surveys. The two technologies when combined provide qualitative and quantitative data to guide maintenance on plant valves and heat exchange tubes.

> ***Note:*** These are initial program recommendations. As the PDM program grows at ***Utility***, consideration may be given to technical application of thermography directly at plants with more than two units and/or installed capacity of greater than 1000 MW. Corporate Engineering provides primary support to smaller plants and secondary support to the larger facilities.

4.2.2.3 Electric Motor Predictive Maintenance

- Static electrical testing on 30 critical plant motors is to be performed annually by a ***Plant*** electrician under the guidance of the EPRI M&D Center, and the Guidelines established for the EPRI EMPM program.
- Periodic vibration, thermography, and oil analysis are to be performed every three months on the same 30 critical plant motors as above, under the guidance of the EPRI M&D Center and the Guidelines established for the EMPM project.
- ***Plant*** should perform the recommended quarterly vibration and thermography surveys. Data should be provided to the ***Plant*** PDM engineers for review, disposition, and archiving in the EMPM database.
- The ***Plant*** chemist and laboratory technicians should extract and screen the lube oil samples. The resulting data should be reviewed by ***Plant*** chemist, then by the ***Plant*** PDM engineers who are responsible for disposition and archiving at Corporate Engineering in the EMPM database.
- Technical direction is to be provided by the EPRI M&D Center.

- The ***Plant*** PDM engineers are EPRI's focal point on issues regarding the EMPM program.
- The ***Plant*** PDM engineers are responsible for coordinating data, assigning problem severity, initiating action, coordinating post-maintenance follow-up testing, documentation distribution, and case closure.
- Training recommendations are provided in Section 4.5 of this report.

  Note: Corporate Engineering should be responsible for motor location tracking and the maintenance of the EMPM database.

4.2.2.4 Ultrasonics and Acoustic Leak Detection

- Ultrasonic and acoustic leak detection surveys should be performed on critical plant valving, gearboxes, compressed air and gas systems, and other applicable equipment.
- Ultrasonic and acoustic leak detection surveys should be performed at three-month intervals, once baselines and problems are defined and critical indications addressed.
- Plant operations should establish a survey route and prepare data sheets, and perform routine surveys with input from ***Plant*** PDM engineers, plant engineering and maintenance personnel.
- Plant operations should report survey results to ***Plant*** PDM engineers. Technical direction is to be provided by ***Plant*** PDM engineers.
- ***Plant*** PDM engineers are responsible for coordinating data, assigning problem severity, initiating action, coordinating post-maintenance follow-up testing, documentation distribution, and case closure.
- Coordination of acoustic leak detection data with Infrared Thermography data is important (refer to Thermography Section 4.2.2.2)
- Training recommendations are provided in Section 4.5 of this report.

4.2.2.5 Lube Oil Analysis

- Monitoring services should be provided on critical rotating equipment on 3-month intervals, once baselines and problems are defined and short term critical indications are addressed.
- ***Plant*** chemist and laboratory technicians should carefully extract and screen the lube oil samples. The samples should be properly packaged and mailed for

analysis by a laboratory specializing in the analysis of the physical properties of lubricating oils, and the quantifying of wear particles in the equipment lube oil.

- The resulting data should be provided to and reviewed by ***Plant*** chemist, ***Plant*** PDM engineers and Corporate Engineering.
- Contract or central laboratory analysts should be very familiar with the equipment being sampled and its operating environment. A careful assessment of the materials of construction should be made for each component to assist the analyst in diagnosing problems.
- ***Plant*** PDM engineer is responsible for coordinating data, assigning problem severity, initiating action, coordinating post-maintenance testing, documentation distribution, and case closure.
- This program should be based on standard software, which is agreed upon by the plant, for maximum service value. Software is managed by the plant.
- Lube oil analysis is used to quantify and track wet sump bearing and gear health in both driving and driven equipment.
- Lube oil monitoring program costs are controlled most effectively if testing needs are triggered by indicators and graduated accordingly.
- The location and installation of quality sample points are the responsibility of ***Plant*** PDM engineers and Mechanical Maintenance /Electrical Maintenance personnel. Particular care should be exercised in this step. The method of extraction of the oil from sample points will make or break this technology. Repeatable data is of paramount importance.

4.3 Organization

4.3.1 Organizational Roles, Responsibilities and Recommendations

The organization is in place to support a formalized Predictive Maintenance program; however, depending on technological responsibilities, some adjustments at the regional and plant levels may be required.

Plant PDM engineers are the first line of equipment defense. The PDM engineers have proficiency in PDM technologies and the data/information from internal and external sources, assisting in or providing the analysis, assigning problem severity and communicating to those responsible for taking action. The PDM engineers should be involved in all problem resolution discussions, corrective actions, and post maintenance testing/histories and case closures. The PDM engineers have the responsibility for managing the equipment based on information at the plant. That person must be given authority, working through the appropriate chain of command, to cross departmental communications and decision-making boundaries. The plant Assessment team recommends that ***Plant*** PDM engineer's position in the organization chart be changed.

Plant Services Department is responsible for the equipment experts in support of plant customers and they are the second line of defense for plant equipment troubleshooting. They are a "fast action" postured team, ready to respond to plant problem indications communicated by the plants, either electronically or by telephone. They normally defer field work at the plants to the Power Generation Engineering Department. They must stay in close contact with the office to respond to problems as they arise. Technical support management serves to dispatch root cause evaluation to equipment experts, and then to Corporate Engineering for fast resolutions. Operation Services will research problem histories, consult Corporate Engineering for PDM information then, after all known information is reviewed and the problem characterized, discuss corrective action with the plant or defer to Engineering for further evaluation.

The PDM program, housed in Lotus Notes, is a primary communication conduit for action initiation. Daily and weekly reports are transmitted, in addition to plant curtailment incidences. Problem loop closure is communicated company-wide by way of "circular" letters coordinated by the Operation Services Group. Operation Services has an important role in ***Utility's*** program. They could serve in a coordinating function to guide the optimization and formalization of PDM on ***Utility*** system. They could sponsor consistency in the approach, application equipment, software, and information communication/exchange. The EPRI M&D Center, recognizing the importance of their role, recommended that an ***Utility*** "PDM Coordinator" position be created. That position is depicted in Figure 4-3.

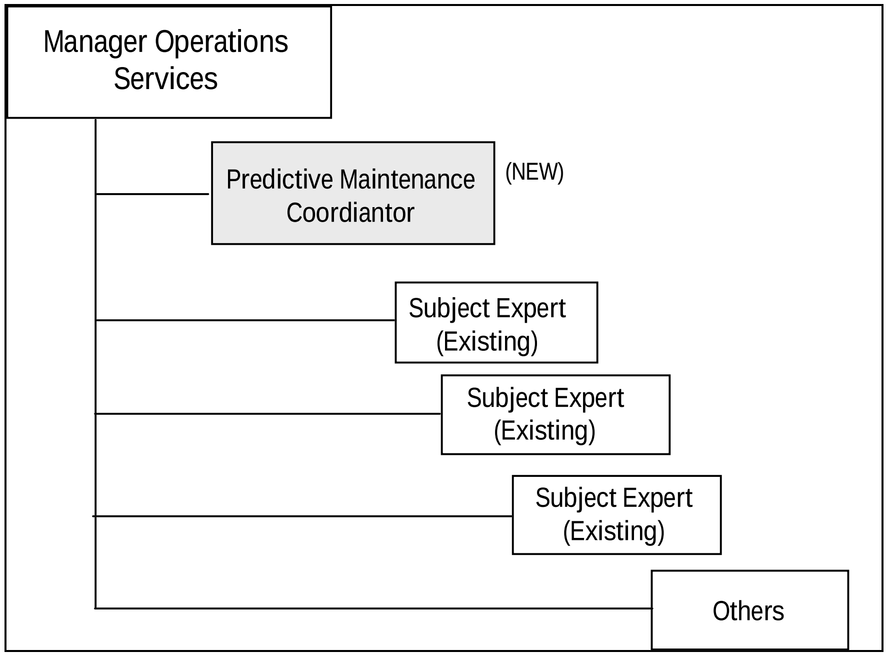


Figure 4-3: Proposed PDM Coordinator Position

Corporate Engineering, in support of plant customers, is the third line of equipment defense. PDM engineer positions are in place within Corporate Engineering. They are charged with outage planning, labor resources, and small project work (<$500K). In addition, Corporate Engineering provides the primary technical support, PDM resources and program technology services that the smaller ***Utility*** facilities lack. The ***Plant*** PDM and Corporate PDM resources are a team and must rely on each other. Teamwork is important for optimum benefits from PDM at ***Utility***; therefore, both the regions and the plants will house the high expertise in PDM technology.

The Power Generation Engineering Department also plays a key role in optimizing the balance and mix of maintenance strategies in use at ***Utility***. They provide the ProActive Maintenance (PAM) facet of a PDM program. Not only do they provide the majority of the on-site (field) technical support for large projects (>$500K), both outage and non-outage, they perform the engineering necessary for root cause resolution of more complicated and time-consuming problems that may require redesign or replacement of components. The Power Generation Engineering Department is the fourth and final line of defense for plant equipment.

A task-oriented representation of departmental PDM program roles and responsibilities are depicted in Figure 4-4, with a description of the ***Plant*** PDM engineer's Roles and Responsibilities as follows:

- Produce the plant equipment health report.
- Conduct periodic equipment condition assessment meetings.
- Coordinate and ensure PDM program technology training of plant personnel.
- Prepare and evaluate plant PDM cost benefits and analyses.
- Coordinate data collection and analysis, initiate action and coordinate post-maintenance follow-up testing, documentation, distribution, and case closure.
- Establish and maintain plant and support organization communication channels.
- Manage plant PDM newsletters and periodicals.
- Coordinate analytical resources and intradepartmental activities, interplant PDM liaison functions and be the information net-worker.
- Review and adjust the PM schedule and tasks based on PDM information.

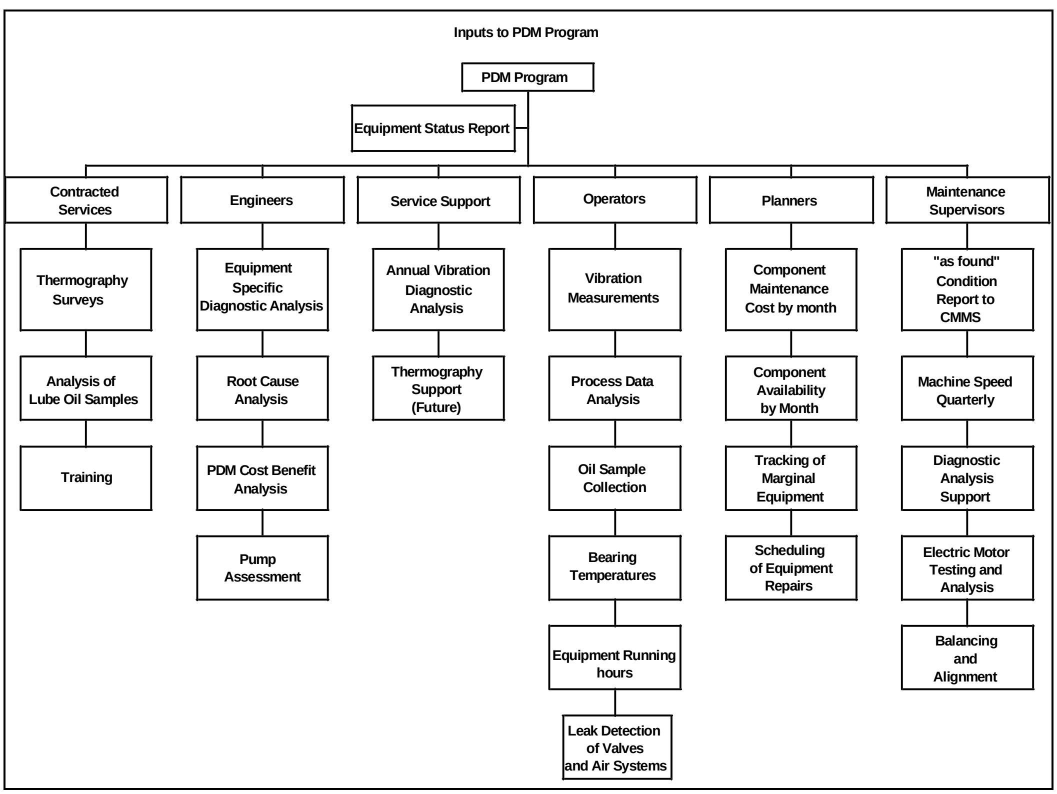


Figure 4-4: Roles and Responsibilities

4.3.2 Maintenance Work Flow

The EPRI M&D Center recommends that ***Plant*** Planning and Support Management meet with the ***Plant*** PDM Engineers to develop a new maintenance work flow that includes the PDM process (Figures 4-5 and 4-6). Examples are provided. The PDM engineers should hand carry the new conceptual maintenance work flow diagram through the organization for review and comments. Once the comments are addressed, a "final" version of the modified process can be issued officially. This process flow should be reviewed for effectiveness periodically and, if needed, corrected.

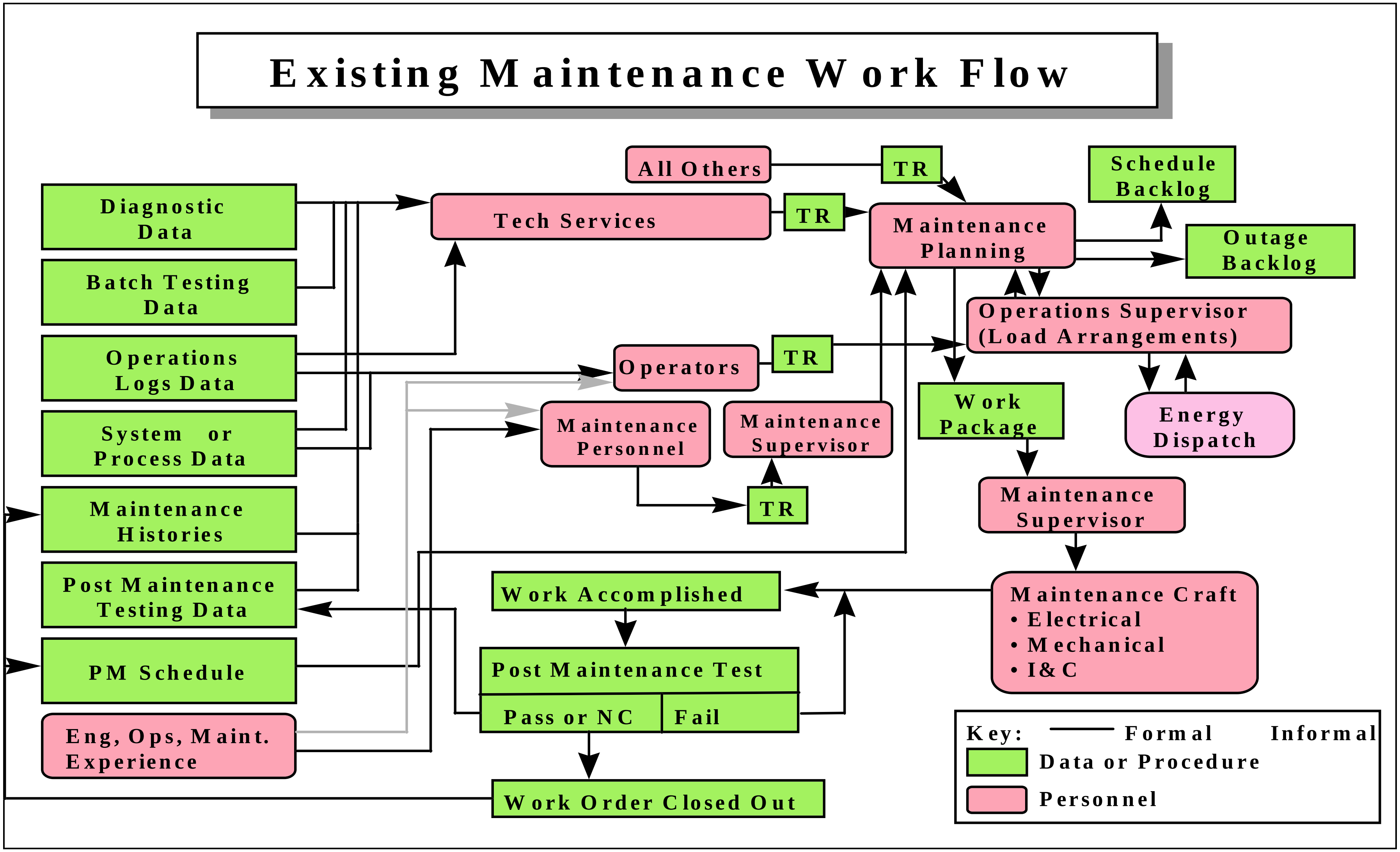


Figure 4-5: Work Flow without PDM Implementation

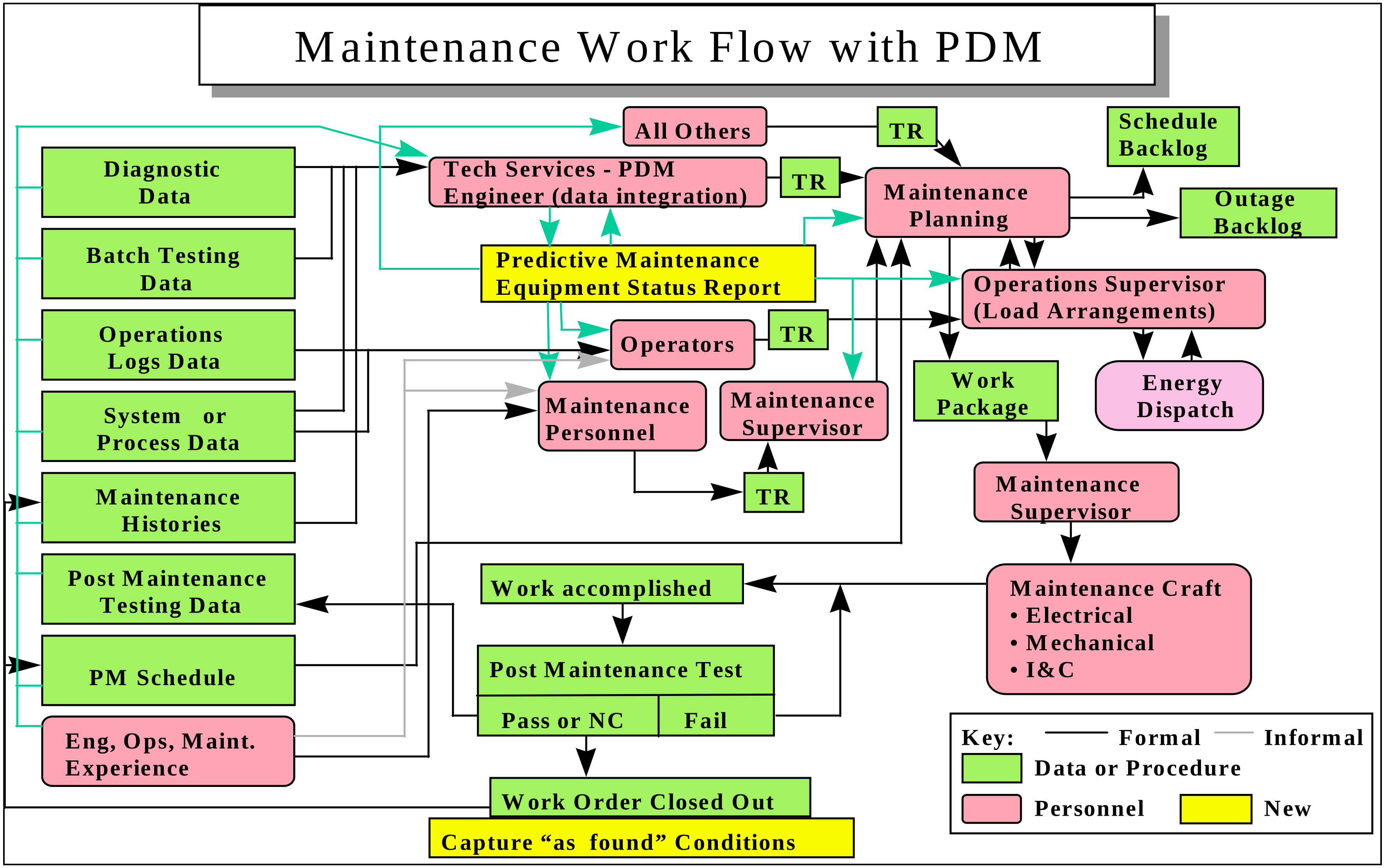


Figure 4-6: Work Flow with PDM Implementation

4.4 Financial

The cost to implement a comprehensive PDM program for ***Plant*** is summarized in Table 1. The costs are organized into initial program setup and equipment purchases and annual recurring equipment and consumables, as well as ***Plant*** Central Support and subcontracted labor. The initial startup costs are assumed to be amortized over a five-year period.

Projected gross and net benefits are also indicated. These are based on typical cost benefit data from other fossil plant PDM program implementations, and adjusted to address specific opportunities which exist for ***Utility*** based on recent histories of plant equipment failures.

The benefits-to-cost consider four potential plant controllable costs:

- operation and maintenance.
- controllable fuel (thermal performance).
- revenues gained through increase of availability and or reduction of EFOR.
- extension of equipment life and/or avoidance of capital expenditures.

The following table is an example of the annual potential net benefits, with the total start-up costs amortized over the first three years.

Table 4-1
Plant PDM Program Costs and Expected Benefits

Program Element	Total Start-Up Cost	Annual Recurring Cost	Gross Expected Benefit	Net Expected Benefit
Periodic Vibration Monitoring	$47,840	65,600	$300,000	$218,500
Infrared Thermography	$86,124	$21,280	$550,000	500,000
Lube Oil Analysis	$14,384	$21,792	$200,000	$173,500
Electric Motor Testing	$44,392	$45,880	$200,000	$139,300
Acoustic Leak Detection	$11,820	$8,760	$150,000	$137,300
Integrated PDM Program	$137,472	$153,696	$2,700,000	$2,500,500
O&M Workstation	$240,320	$20,976	$900,000	$799,000
TOTALS	$581,992[(1)]	$337,984[(2)]	$5,000,000	$4,468,100

(1) Approximately $198,700 is ***Utility*** labor and $383,292 is for equipment and subcontracts. These costs are amortized over the first three years of the project.
(2) Approximately $270,480 is ***Utility*** labor and $67,504 is for equipment and subcontracts.

4.4.1 Planning and Estimating Guides

The program costs and expected benefits in Table 4-1 were extracted and summarized from the following Planning and Estimating (P&E) Guides for each of the program elements. Also included on the Guides are the cumulative net benefits for a five-year period.

4.4.1.1 P&E Guide - Periodic Vibration

Planning & Estimating Guide
System: Periodic Vibration Monitoring

Annual Gross Benefits: 300,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied	1	N/A	$15,000	(3)	$15,000
Site Supplied	1	N/A	$5,000	(3)	$5,000
Software					
Vendor supplied	1	N/A	$9,000	(3)	$9,000
Training Tuition's	5	Course	$900	(2)	$4,500
Misc. expenses	1	N/A	$1,000	(3)	$1,000
			Material Subtotal		$34,500

Labor	Qty	Unit	Unit Cost		Total
Engineering	10	man-days	$320	(4)	$3,200
Training	30	man-days	$288	(2)	$8,640
Secretarial	5	man-days	$300	(7)	$1,500
			Labor Subtotal		$13,340

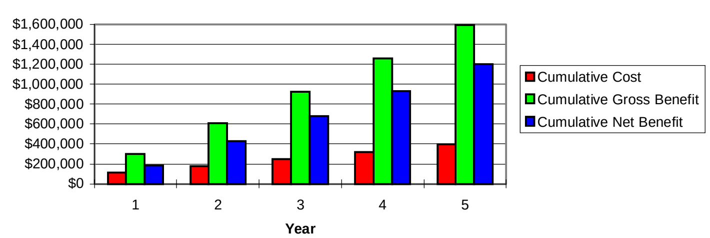
Total Start-up Cost $47,840

Annual Operation & Maintenance Costs

Plant Labor (Mech.)	200	man-days	$288	(5)	$57,600
Training Labor	10	man-days	$400	(4)	$4,000
Training Tuition's	2	course	$1,000	(6)	$2,000
Equipment Lease	1	N/A	$2,000		$2,000

Total Annual O&M Cost $65,600

Pay Back Period



Notes:

1 Based on typical findings on 3 units - 75 machines (10%=7.5 machines) Typical savings $80,000/machine $600,000 per year gross benefit including avoided PMs. (50% of benefit to PDM Program.)
2 Vibration analysis training should be provided to PDM Engineer and Operation Services Personnel and various plant mechanics.
3 Purchase "Plant" periodic vibration analysis equipment and hand-held meter for "Plant" personnel.
4 OS / Plant PDM engineers support for initial survey equipment walkdown, research, tagging set up program, initial data acquisition and engineering analysis support.
5 Station personnel to perform data collection and analysis for vibration monitoring, balancing, alignment and training in lube oil analysis techniques. PDM engs. to gather other equip. operating data.
6 Training conducted annually.
7 Computers, printers, consumables, misc., etc.

Five Year Cumulative Net Benefit: $1,196,621

4.4.1.2 P&E Guide - Infrared Thermography for "Plant"

Planning & Estimating Guide

System: Infrared Thermography (Plant)

Annual Gross Benefits: 550,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Thermo. Cameras	1	Camera	$65,000	(2)	$65,000
Computer/Printer	1	Computer	$5,000	(3)	$5,000
Software					
Vendor supplied	1	Program	$1,000	(4)	$1,000
Training Tuition's	3	Course	$2,000	(5)	$6,000
Misc. expenses	1		$2,500	(6)	$2,500
			Material Subtotal		$79,500

Labor

Engineering	5	man-days	$288	(7)	$1,440
Training	15	man-days	$288	(5)	$4,320
Network Support	3	man-days	$288	(6)	$864
			Labor Subtotal		$6,624

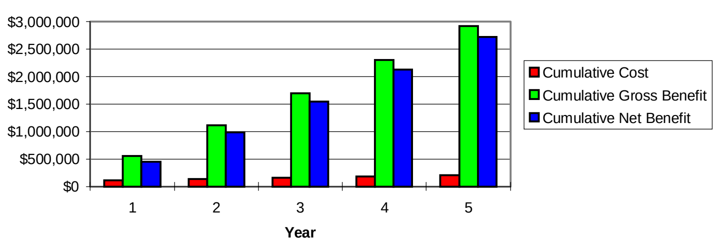
Total Start-up Cost $86,124

Annual Operation & Maintenance Costs

O&M Labor	50	man-days	$288	(8)	$14,400
Training Labor	10	man-days	$288	(9)	$2,880
Training Tuition's	2	course	$2,000	(9)	$4,000

Total Annual O&M Cost $21,280

Pay Back Period



Notes:

1 Based on performing electrical, mechanical and boiler surveys on 3 Units. Prevention of catastrophic equipment failure, avoided emergency work, and availability losses. Gross annual benefits using plant personnel (50% w/o PDM Program).

2 Purchase of thermography camera.

3 Dedicated computers for storing and analysis IR images. Color printer, monitor and Canon Xapshot digital camera.

4 M&DC Infrared Report - Software Integration Program (IR-SIP) support. hardware.

5 Both hands-on and classroom training for 2 "Plant" personnel.

6 IR-SIP support off the shelf software necessary.

7 Plant walkdown, equipment research, program set-up, survey coordination, engineering support.

8 Manpower to support periodic thermography inspections, data analysis and hands-on training.

9 Includes tuition and travel for two course slots. three course slots.

Five Year Cumulative Net Benefit:

$2,720,922

4.4.1.3 P&E Guide - Lube Oil Monitoring

Planning & Estimating Guide

System: Lube Oil Monitoring

Annual Gross Benefits: 200,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied					$0
Site Supplied					$0
Software					
Vendor supplied	?	Programs	$0	(3)	$0
Training Tuition's	2	Course	$1,000	(2)	$2,000
Misc. expenses	1				$0
			Material Subtotal		$2,000

Labor					
Chemist/Engr. Support	10	man-days	$288	(2)	$2,880
Maintenance Labor	20	man-days	$288		$5,760
Network Support	3	man-days	$288	(4)	$864
Training	10	man-days	$288		$2,880
			Labor Subtotal		$12,384

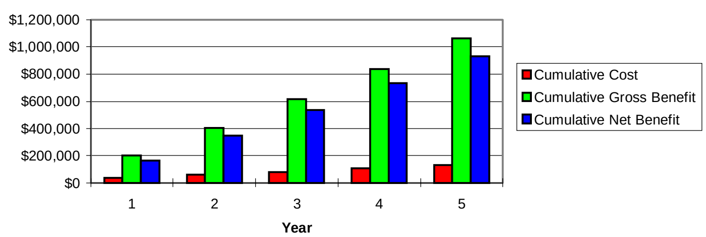
Total Start-up Cost $14,384

Annual Operation & Maintenance Costs

O&M Labor	24	man-days	$288	(5)	$6,912
Training Labor	10	man-days	$288		$2,880
Training Tuition's	2	course	$1,000		$2,000
Subcontracted	280	Samples	$30	(6)	$8,400
Misc. Support	1	N/A	$1,600	(7)	$1,600

Total Annual O&M Cost $21,792

Pay Back Period



Notes:

1 Based on early detection of machine fault conditions, and general machine condition through history of wear particles. and other contaminents detected. Approximately 100 machines included $400000 per year savings from early detection of bearing wear Analysis of oil condition also yeilds Inventory and waste handling benefit. (50% w/o PDM Program)

2 Training required in lube oil analysis and sampling for Plant personnel

3 Oil Analysis contractor provides software and support free of charge.

4 Labor for installation on plant network

5 Five days per quarter required to sample resevoirs, send oil samples to lab, review data and implement corrective measures.

6 Estimated from samples taken for all 3 units. (approx 100 machines quarterly, 30 under EMPM)

7 Sample bottles, siphons, labels and other expendible supplies.

Five Year Cumulative Net Benefit: $931,746

4.4.1.4 P&E Guide - Electric Motor Predictive Maintenance

Planning & Estimating Guide

System: Electric Motor Predictive Maintenance

Annual Gross Benefits: $200,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied					$0
Site Supplied	1	N/A	$5,000	(2)	$5,000
Software					
Vendor supplied	1	N/A	$500	(3)	$500
Training Tuition's	3	Course	$2,000	(6)	$6,000
Misc. expenses	1	N/A	$1,500	(4)	$1,500
			Material Subtotal		$13,000

Labor					
Engineering	78	man-days	$288	(5)	$22,464
Training	16	man-days	$288	(6)	$4,608
Network Support	15	man-days	$288		$4,320
			Labor Subtotal		$31,392

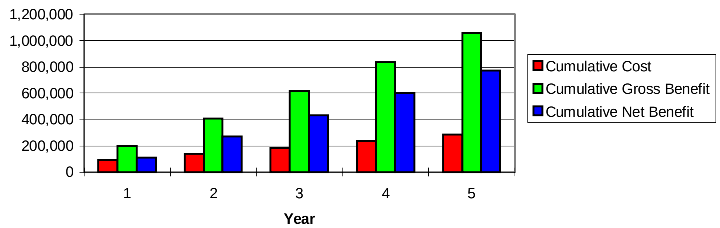
Total Start-up Cost $44,392

Annual Operation & Maintenance Costs

O&M Labor	125	man-days	$288	(7)	$36,000
Training Labor	10	man-days	$288	(6)	$2,880
Training Tuition's	1	course	$2,000		$2,000
Misc. Support	1	N/A	$5,000		$5,000

Total Annual O&M Cost $45,880

Pay Back Period



Notes:

1 Based on avoidance of 3 large electric motor failures ($180,000), two small failures ($20,000) avoided PMs, associated availability losses ($200,000), and life extention of all motors. Total station benefit of $400,000. (50% w/o PDM program.)

2 Assumes that one testing device will be purchased.

3 EPRI EMPM & MICAA Database Software

4 Misc Tools - current probes, strobes, DVM, cables, test leads, o'scope

5 System walkdown, equipment research, database set up, system coordination, engineering support.

6 Classroom and hands-on in plant (2 people for electric motor diagnostics and annual course tuition).

7 Includes testing of (30) 4kV and (10) 480 motors,alternate, QA program for small motors, Megger and PI Testing, Log and track motor running amps, broken rotor bar tests, heater functional Other PDM data analysis and review PM task review, educate other plant personnel.

Five Year Cumulative Net Benefit:

$773,852

4.4.1.5 P&E Guide - Periodic Acoustic Leak Detection

Planning & Estimating Guide

System: Periodic Acoustic Leak Detection

Annual Gross Benefits: 150,000 (1)

System Set-up Costs

Material

	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied					$0
Site Supplied	1	N/A	$5,000	(2)	$5,000
Software					
Vendor supplied					$0
Training Tuition's	1	Course	$2,000		$2,000
Misc. expenses	1	N/A	$500	(3)	$500
Material Subtotal					$7,500

Labor

Operations/Engr.	10	man-days	$288	(4)	$2,880
Training	5	man-days	$288	(5)	$1,440
Network Support					$0
Labor Subtotal					$4,320

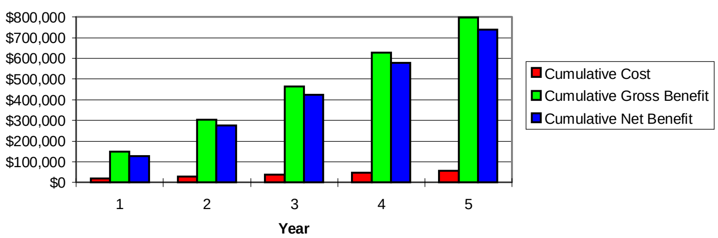
Total Start-up Cost $11,820

Annual Operation & Maintenance Costs

O&M Labor	20	man-days	$288	(6)	$5,760
Secretarial	10	man-days	$300		$3,000
					$0
					$0

Total Annual O&M Cost $8,760

Pay Back Period



Notes:

1 Based on typical findings on 3 units - Valves, steam piping, Pneumatic controls plant air systems, condenser tube leaks for heat rate improvement and minimizing equipment damage Used with IR Therm. on strategic valving. $400,000 annual savings (50% w/o PDM program)

2 Purchase of Equipment

3 Misc Tools - extra sensors cables, attachments, parabolic dish

4 System walkdown, equipment research, set up program, system coordination, engineering support.

5 Hands on training All process teams, at least one man per team should be trained.

6 One man surveys, 1 week per quarter

7 Follow-up Training conducted annually

Five Year Cumulative Net Benefit: $738,042

4.4.1.6 P&E Guide - Integrated Predictive Maintenance Program

Planning & Estimating Guide

System: Integrated Predictive Maintenance Program

Annual Gross Benefits: 2,700,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied					$0
Site Supplied	2	Computer	$5,000	(2)	$10,000
Software					
Vendor supplied	1	Program	$1,500	(3)	$1,500
Training Tuition's	1	Course	$44,000	(9)	$44,000
Misc. expenses	1	N/A	$1,500	(4)	$1,500
			Material Subtotal		$57,000

Labor	Qty	Unit	Unit Cost		Total
Engineering	60	man-days	$288	(5)	$17,280
Training	189	man-days	$288	(6)	$54,432
Planners	20	man-days	$288	(7)	$5,760
Secretarial	15	man-days	$200		$3,000
			Labor Subtotal		$80,472

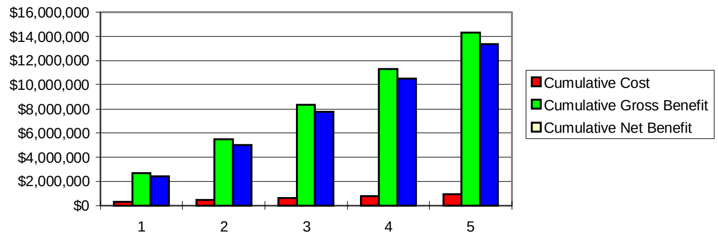
Total Start-up Cost $137,472

Annual Operation & Maintenance Costs

	Qty	Unit	Unit Cost		Total
O&M Labor	472	man-days	$288	(7)	$135,936
Training Labor	20	man-days	$288		$5,760
Training Tuition's	2	course	$2,000	(8)	$4,000
Secretarial	30	man-days	$200		$6,000
Misc. Materials	1	N/A	$2,000	(4)	$2,000

Total Annual O&M Cost $153,696

Pay Back Period



Notes:

1 Based on estimated impact of PDM Program. The dedication of 2 full time engineer to the PDM program gives a probability of success 75% of for each technology implemented. These benefits are reflected in each of the P&E Guides for each technology.

2 Computer connected to plant LAN 486 computer, 8MB RAM, 800MB HD Color printer, network card, modem

3 Commercial Software Programs

4 Small tools, disks, expendable supplies

5 System walkdowns, equipment research, database development, engineering support.

6 Labor for trainees, classroom and hands-on in plant. All personnel PDM LOA Training. Follow-on support for PDM Program

7 Historical data review, data analysis includes program operation, data analysis, reporting, communications, PM review, outage plan review, root cause investigations, interaction with the other plants.

8 The PDM engineer should be knowledgable of the latest test procedures and hardware and should be knowledgable in all technologies used in the plant's PDM program. This person should take available training whenever possible.

9 PDM Level of Awarenessmodules for 370 "Utility" personnel at the plant and support offices. 1/3 of $64,000 cost should be by support offices.

* PDM Course for numerous plant and central office personnel is included in O&M Workstation project.

Five Year Cumulative Net Benefit:
$13,381,202

4.4.1.7 P&E Guide - O&M Workstation

Planning & Estimating Guide

System: Operation and Maintenance Workstation

Annual Gross Benefits: 900,000 (1)

System Set-up Costs

Material	Qty	Unit	Unit Cost		Total
Hardware					
Vendor Supplied					$0
Site Supplied			$20,000	(2)	$20,000
Software					
Vendor supplied					$0
Training Tuition's					$0
Misc. expenses	1			(3)	$180,000
			Material Subtotal		$200,000

Labor					
Engineering	120	man-days	$288	(4)	$34,560
Training	20	man-days	$288	(5)	$5,760
Network Support					$0
			Labor Subtotal		$40,320

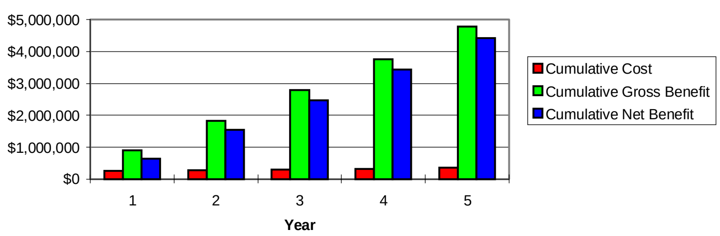
Total Start-up Cost $240,320

Annual Operation & Maintenance Costs

AEP Labor	32	man-days	$288	(6)	$9,216
Training Labor	20	man-days	$288	(7)	$5,760
Training Tuition's	2	course	$1,000		$2,000
Misc. Support		N/A	$4,000		$4,000

Total Annual O&M Cost $20,976

Pay Back Period



Notes:

1 Based on increasing the effectiveness of "Plant" PDM program by 20 - 25%.
2 Misc. computer hardware and software costs for "Utility-Plant" O&M Workstation implementation.
3 Total three year cost for O&M Workstation EPRI project which includes all development and start up costs for implementation.
4 "Utility" I.S. and Engineering labor for installation support.
5 "Utility" I.S. and Engineering labor for training.
6 "Utility" I.S. and PDM Engineer labor for system support.
7 Misc. "Utility" personnel labor.

Five Year Cumulative Net Benefit:
$4,426,538

4.5 Training

A crucial ingredient for successful PDM program implementation is training. PDM requires communication and participation from many plant and central support personnel as defined in this report. Each function of the PDM program to be performed by ***Utility*** personnel will require either PDM programmatic training, data collection and/or analysis training. The training courses and/or modules listed below are described in detail and are recommended for respective ***Plant*** and central support office personnel.

4.5.1 Predictive Maintenance Program and Technology Overview Training

A. Fossil Plant PDM Program Implementation

Utilities are now performing equipment maintenance primarily in response to failure or according to a time schedule. However, when repairs can be made earlier, they are usually simpler and requires less downtime; or, if equipment is known to be in good condition, scheduled maintenance can be actually omitted.

Predictive Maintenance enables utilities to increase the efficiency of their maintenance activities. Predictive Maintenance (PDM) is a program that includes equipment history, monitoring, analysis, scheduling, and documentation. It also coordinates maintenance resources with operations. The program targets equipment maintenance that could compromise performance or safety and/or prevent excessive inspections and repairs. All of which have a positive impact on power production.

Since PDM pervades so much plant activity, personnel implementing a program should anticipate the programmatic as well as the technical, organizational, and financial aspects. Each PDM program must be custom-designed. This course introduces all major features of PDM, offers approaches to solving common problems; and, the attendees will have the opportunity to discuss their site-specific conditions that will affect their particular PDM program.

This course also gives a comprehensive approach for the introduction of PDM into the plant environment. It examines the functional aspects of PDM, as well as the technologies used. Following are some issues ***Utility*** personnel will face when implementing a PDM program:

- What impact can I expect to achieve with PDM?
- How do I convince management to support PDM activities?
- What equipment and technologies are available to conduct the monitoring?

- What steps do I take to get a program started?

To answer these questions, the course is broken into two types of training. Programmatic training, conducted the first day, helps attendees understand the organizational and financial aspects of PDM. Following these sessions, attendees are asked a series of discussion questions and are invited to give their views on the materials just presented.

The recommended attendees are:

- The Plant PDM engineers,
- Corporate Engineering PDM Support personnel, and
- Operations Services Group PDM Coordinator

B. PDM and Condition Monitoring Technologies Level of Awareness (LOA)

Predictive Maintenance can be a highly effective approach to controlling plant maintenance costs. Where PDM has failed, the primary cause has been lack of plant personnel and management "buy-in" to the PDM philosophy, programmatic approach and technologies. Therefore, to ensure that PDM is integrated into the ***Utility-Plant*** philosophy it is recommended that LOA training be conducted which will significantly increase the awareness of the PDM program and associated new technologies.

This training consists of four modules, four hours each in duration: Predictive Maintenance; Vibration; Thermography; and, Lube oil Analysis. The technologies are presented in a simple understandable format which answers three basic questions:

- What is the program or technology?
- How does the program or technology work?
- How will the program or technology benefit you and your company?

The recommended attendees are:

- Plant Maintenance Craft (Electrical, Mechanical, I&C),
- Plant Supervisors,
- Plant Production personnel,

- Plant Production Supervisors,
- Plant Management, and
- All central support personnel with PDM roles and responsibilities.

Each person will receive a total of 16 hours of training.

4.5.2 Periodic Vibration Analysis and Data Collection

A. Vibration Analysis Level I

Vibration monitoring has become the number one technology used by many utilities for Predictive Maintenance programs. Recent advances in personal computers and the availability of vibration walk-around boxes have facilitated data collection and analysis. If used properly, vibration monitoring can be a valuable tool to detect and diagnose machinery problems before serious failures occur.

This course covers the basics of vibration monitoring techniques and ways to apply them for the diagnosis of the condition of the plant's rotating machinery. This course will review the use, including pitfalls, of sensors, signal-conditioning equipment, filters, frequency analyzers, and the standard data loggers (vibration walk-around boxes). Experts teaching this course emphasize the practical daily problems facing plant personnel in the evaluation and use of vibration monitoring equipment.

Demonstrations cover measurement methods and equipment, vibration levels, and data analysis. Case histories from current ***Utility*** experiences are discussed. Participants also have the opportunity to discuss their own plant's activities.

The recommended attendees are:

- Plant Team Mechanics/Operations personnel, and
- The PDM Engineers.

B. Vibration Analysis Level II

Many utilities use vibration signature analysis (the assessment of vibration frequency, amplitude, and phase), to detect and diagnose equipment problems. Vibration diagnostic technology has progressed dramatically in the last decade. More and more utilities are applying these sophisticated time and frequency - domain analysis techniques to understand the characteristics of machinery response. The use of these techniques, and others, has expanded from occasional use in machinery troubleshooting to routine use of advanced techniques in periodic monitoring programs.

The value of these programs can be greatly enhanced with improvements in the basic understanding of the relationship between machinery dynamics and signal characteristics. A machine's vibrations are the product of the excitation forces and the response characteristics of the rotor, bearings, and pedestals. The major factor in the success of ***Utility's*** vibration program is the training and ability of the vibration analysis.

This course is one in a series on monitoring and diagnostics. This advanced course is a follow-on to the Basic Vibration Testing and Analysis course. The topics of this course emphasize:

- Machinery dynamics
- Instrumentation
- Using FFT analyzers for diagnostics
- Sources of vibration in machinery
- Advanced techniques such as multi-channel analysis

Utility engineers will also discuss case histories of vibration problems in power plant equipment. In frequent hands-on sessions, recognized vibration analysis experts will demonstrate equipment uses and techniques.

The recommended attendees are:

- Corporate Engineering Vibration support personnel and,
- The Plant PDM Engineers.

C. Vibration Hardware and Software Utilization Training

Typically, the vibration hardware and software vendor will provide this as part of the equipment purchase; and, this approach is recommended to ensure proficiency of utilizing the particular manufacturer's equipment selected.

The recommended attendees are:

- Corporate Engineering Vibration Support personnel and,
- The Plant PDM engineers.

D. Field Data Collection and Periodic Program Hands-on Training

This is intended for the personnel who will make field measurements with the data analyzers and the setup of software routes in the plant. This training consists of high level experienced instructors working hand in hand with ***Utility*** personnel.

The recommended attendees are:

- Corporate Engineering Vibration Support personnel.

4.5.3 Infrared Thermography Analysis and Data Collection Training

A. Infrared Thermography Level I

All objects emit thermal energy or heat. An infrared thermographic imaging system converts this heat into images. Through expert analysis, these images can reveal defects or problem areas in electrical systems, mechanical equipment, building envelopes, roofs, or any process that uses or produces energy. Early identification of these problems can save thousands, even millions, of dollars when considering the high cost of electrical and mechanical failures in terms of downtime, productivity, accidents, or even loss of life. Savings are realized when electrical, mechanical, and energy inefficiencies, as well as costly component failures, are prevented.

In everyday terms, it could be the difference between $600 to replace a breaker before it fails versus over $25,000 in downtime. With infrared thermography, plant managers can rest assured that almost every preventive precaution has been taken to reduce the chance of failure in their facility.

This five-day course is taught by a recognized expert in infrared thermography who has developed unique data acquisition techniques and has accumulated a statistical base of information as a result of conducting almost 10,000 thermography surveys. The course curriculum is structured according to the American Society of Nondestructive Testing (ASNT) for Level I recommendations. It covers the basic physics needed in infrared thermography, basic equipment operations, and the basic application and interpretation that is necessary to collect the data and effectively analyze the problems. Attendees can bring their own IR camera for use in the hands-on portion of the class to become more proficient in its use. A self-graded exam is given at the end of the course.

The course therefore meets the proposed general training requirements for ASNT Level I Thermal/Infrared Testing Certification. However, the ASNT may require demonstrations of competence in other non-destructive techniques such as acoustics, magnetic particle, etc., for certification. In addition, per ASNT SNT-TC-1A, each Utility is responsible for providing its own certifications.

Because of these issues, the EPRI M&D Center now offers Certification in Thermography only, providing the candidate attends a recognized course, passes a test, and provides evidence of a specified amount of thermography field experience (surveys, reports, etc.). There is a nominal charge for this Certification.

The recommended attendees are:

- The Plant PDM engineers and,
- The Plant Mechanic or Electrician and,
- Corporate Engineering Support personnel.

B. Infrared Thermography Level II

Infrared (IR) thermography technology and the use and application of the equipment have proven to be of substantial benefit to operating utilities for the early detection of equipment faults. A significant advantage in the use of thermography is that it is non intrusive and non contacting. The equipment and techniques can provide extremely accurate, repeatable, and reliable data; however, their sophistication requires that the thermographer be well trained. Therefore, the M&D Center offers this Level II IR Thermography course for those more advanced. It is recommend that students take the Level I (A.) course to be eligible for this Level II course.

This five-day course is also taught by an expert in IR thermography who has developed unique data acquisition techniques and has accumulated a statistical base of information from almost 10,000 thermographic surveys. The course is structured according to the recommended training by the American Society of Non-Destructive Testing (ASNT) for Level II Thermal/Infrared Testing. It covers the physics, equipment operations, and application knowledge needed to analyze data and recommend solutions. This course is intended to teach practicing thermographers what they need for Level II Certification. A self-graded exam is given at the end of the course.

This course therefore meets the general training requirements for the ASNT Level II Thermal/Infrared Testing Certification. However, the ASNT may require demonstrations of competence in other non-destructive techniques such as acoustics, magnetic particle, etc., for certification. In addition, per ASNT-SNT-TC-1A, each Utility is responsible for providing its own certification.

Because of these issues, the EPRI M&D Center now offers Certification in Thermography only, providing the candidate attends a recognized course, passes a test, and provides evidence of a specified amount of thermography field experience (surveys, reports, etc.). There is a nominal charge for this Certification.

The recommended attendees are:

- The Plant PDM Engineers and Thermography support personnel and,
- The Corporate Engineering PDM Engineers.

C. Infrared Thermography Camera Operation

This training is typically provided by the IR camera vendor; and, this is usually provided as part of the equipment purchase price. This training is a brief revue of camera operations.

The recommended attendees are:

- The Plant PDM engineers,
- Plant Mechanic or Electrician and,
- Corporate Engineering Thermography Support personnel.

D. Periodic Thermography Hands-on Training

As part of the EPRI/***Utility*** thermography applications research program, hands-on field training is included which will train thermographers in setting up the plant mechanical and electrical equipment routes, and expose the students to practical field applications of infrared thermography in the fossil power plant.

The recommended attendees are:

- The Plant PDM Engineers,
- Plant Mechanical or Electrical, and
- The Corporate Engineering Thermography Support personnel.

4.5.4 Electric Motor Testing Analysis

A. Hands-on Electric Motor Testing

Electric motors in power plants are tested both on-line and off to determine their condition. It is important that the mechanical and electrical testing be done properly by trained personnel so that the test results accurately portray the motor's condition. By knowing the true health of the motor, significant benefits can be realized by either averting unnecessary PMs or preventing unexpected failures.

This four-day training course includes a one-day series of lectures and presentations on electric motors, the different types of motors and their applications, the faults that can occur and develop, and how to electrically test motors to determine machine condition. Demonstrations will be provided to familiarize attendees with the test equipment being used in days 2, 3 and 4. Also presented and discussed will be the application of other Predictive Maintenance technologies, such as motor current monitoring to detect broken rotor bars to evaluate motor condition.

On days 2, 3, and 4, ***Utility*** maintenance personnel (usually groups of 3-4 each day) will be taken into one of the plants for hands-on electrical testing of motors. The electrical testing is done off-line, and the plant is responsible for providing access to the appropriate motors to be tested.

Motor condition evaluation practices from current ***Utility*** experience are discussed. Participants also have the opportunity to discuss their own plant's testing procedures and problems.

An engineer from the EPRI M&D Center and a representative of a motor repair facility will provide the training for the motor testing. Please note that the training sessions can be modified to meet ***Utility's*** needs.

The recommend attendees are (for one plant only):

- The Plant Electricians,
- Plant Electric Motor PDM Program Coordinator,
- The PDM engineers and,
- The Corporate Engineering PDM engineer.

B. Electric Motor Diagnostics

Utilities are currently adding very little new generation. Emphasis has been on optimum utilization of present plants, primarily by improving plant reliability and availability and reducing the forced outage rate. Much attention has been focused on boilers, turbines, and generators. However, many of the large power plant motors, e.g., drive motors for boiler feedpumps, induced and forced draft fans, and reactor coolant pumps, are also critical to plant operations.

Substantial improvements in motor monitoring and diagnostic techniques have been made in recent years, although some have not been applied broadly in the utility industry. The aim of this course is to bring plant operating and engineering personnel up to date on the latest equipment and methods.

This course covers the basics of all types of motor monitoring and diagnostics equipment. Emphasis is on large motors because of their more critical nature. The course also emphasizes insulation systems in motors, since insulation failures constitute the major cause of motor downtime. Other areas covered include monitoring temperature, line current and flux, detecting broken rotor bars, and conducting vibration analyses.

The experts teaching this course focus on the practical daily problems facing plant personnel in their evaluation and use of motor monitoring and diagnostic equipment. Demonstrations cover equipment, application techniques, and data analysis. Motor stators are set up for various tests.

In a special session, participants learn how to use the Machinery Insulation Condition Assessment Advisor (MICAA), which is a computer program developed under EPRI sponsorship that guides novices through the steps in assessing the condition of motor stator and rotor windings. MICAA, which runs on a personal computer, determines the overall condition of the rotor and stator windings and suggests the main winding deterioration mechanisms, if any.

Case histories from current ***Utility*** experiences are also discussed. Participants have the opportunity to present their own plants' activities and problems. Attendees are encouraged to bring specific examples for assessing winding conditions. Bring nameplate data, operating information such as hours, starts, temperature, and any available test data.

The recommended attendees are:

- The Plant Electric Motor PDM Coordinator,
- Operations Services Group Motor Experts, and
- The Corporate Engineering PDM engineer.

4.5.5 Acoustic/Ultrasonic Leak Detection Training

To apply acoustics/ultrasonics to leaking valves, flanges, pressure vessels, plant air systems, etc., a one day hands-on training session is recommended. The training will teach plant personnel utilization of the instrumentation and practical application in the power plant.

The recommended attendees are:

- Various Plant Operators, and
- The PDM engineers.

4.5.6 O&M Workstation Training

As part of the O&M Workstation project, formal system administrator and O&M client application (user) training will be provided. This will be defined in detail as part of the O&MW and will be included in ***Utility's*** Implementation Schedule.

4.5.7 Training Schedule

A chart listing the various courses and the personnel who should attend is shown in Table 4-2. Provisions to record scheduled and completed courses is included in Table 4-3.

Table 4-2:
Planned Training Matrix

Course Name or Description	Advanced MasterTrend			Balancing Applications			Balancing Theory			Basic MasterTrend			Basic Vibration Testing & Analysis			Bearing Analysis			Electric Motor Diagnostics			Fluid Film Bearing Diagnostics			Generator Monitoring & Diagnostics			Infranalysis			Infrared Thermography Level I			Infrared Thermography Level II			Infrared Thermography Level III			IR Thermography/Certification	
Status Code:	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S	C	R	S
Person Attending																																									

4.6 PDM Implementation Schedule

A detailed PDM Implementation Schedule will be developed in cooperation with the plant PDM engineers immediately following the PDM Assessment roll-out. Assessment team personnel will develop a schedule for items described in Sections 4.1 and 4.3, as well as the training and O&M Workstation activities described in Sections

4.5 and 4.7. Implementation is understood to begin immediately following the assessment roll-out. This schedule, created in Lotus, is included in Table 4-3.

Table 4-3:
Simplified Implementation Schedule

Task Description	Estimated/Actual Start	Estimated/Actual Completion	Responsible Individual
PDM Seminar/Training			
Appoint PDM Engineer			
Appoint Plant Electrician to PDM Program			
PDM Electrician Acquires EMPM Training			
Formalize EMPM Program Equipment List			
Begin Motor Testing			
Perform Motor QA Post Maintenance Tests			
Appoint Maintenance Mechanic to PDM Vibration + Balancing Efforts			
Maintenance Mechanic - Vibration + Balancing Training			
Maintenance Mechanic supports PDM Activities			
PDM Engineer meets with Maintenance Supervisor + Craft Personnel to outline responsibilities			
Evaluate Thermogaphy & Acoustic Leak Detection			
Develop purchase Specificatons for Thermography Equipment			
Submit Request for Quotations for Thermography Equipment			
Award Contract for Thermography Equipment			
Schedule Vibration Training			
Schedule Thermography Training			
Schedule Lube Oil Analysis Training			
Schedule Electric Motor PDM Training			
Develop PDM Report Databse on Plant LAN			
Gather Information for PDM Database			
PDM Program Implementation (Review PDM Plant Assesment Report)			
Evaluate and adjust Contracted Labor - Vibration and Lube Oil Analysis			
Review PM Tasks that can be delayed or eliminated based on Condition Assessment			
Develop Cost Benefits			
Formalize Performance Data Collection			
PDM Engineer investigates use of OPs log information for PDM Program			
PDM Engineer Investgates Periodic Leak Detection equipment for PDM Program			
EI Team Review with PDM Engineers and M&D Center			
PDM Program and Technology Follow-on Training for Maintenance Supervisors			

4.7 Operations and Maintenance Workstation

One of the primary reasons for performing a PDM Assessment at ***Plant*** is to understand how the plant conducted day-to-day business regarding plant equipment condition data collection, conversion of that data into information, and how corrective operation and maintenance activities were initiated. This is done to provide the necessary input for recommending the O&M Workstation configuration for ***Utility*** and ***Plant*** Support organizations.

As a result of the Assessment, various existing data sources are investigated as well as new technology data sources to be implemented. The following data sources are recommended for initial configuration of the O&MW for ***Plant***.

1. Maintenance Management/History System

   Maintenance records and cost information. (J-File - corporate mainframe database).

2. Lotus Notes application which communicates daily equipment problems over ***Utility*** network for response from the Operation Services Group and other ***Utility*** Central Support organizations. Also, circular letters are available for integration with the O&M Workstation (Lotus Notes - Central Server).

3. Periodic Vibration Monitoring

   This software, which is recommended to be purchased and utilized for data storage, manipulation and retrieval of rotating equipment vibration spectrums, waterfalls, overall RMS levels and miscellaneous notes, is recommended for integration. (Vendor to be determined - IBM PC Windows application).

4. Lube Oil Analysis Data

   It is recommended that lube oil analysis be electronically downloaded from the analysis lab to ***Plant*** for retrieval. Depending on the vendor, this data may reside on the same system as indicated in #3 above; therefore, resulting in one less module integration to O&MW. Data to be incorporated will be lube oil condition parameters such as viscosity, wear particles, contaminant concentrations, lube oil condition reports, etc.

5. Infrared Thermography Reporting Software.

   As part of the EPRI/***Utility*** thermography application project, the IR-SIP software will be installed on a plant computer. Infrared and visual images, along with data associated with the thermal anomalies, should be integrated with the O&MW. (IR-SIP - IBM PC Windows application).

6. Plant Distributed Control System.

   All plant process parameters and digital indications available from the plant DCS system should be integrated into the O&MW. [Bailey - POPS (Unit 1) Westinghouse WDPF (Units 2, 3)].

7. Various Sources of Reference Information

   Various sources of reference information were discovered as part of the Assessment. For example: Plant Electrical Maintenance Guides Unit Descriptive Articles; etc. As part of the O&MW implementation for ***Plant***, various reference sources, which are in electronic format, will be entered into the reference section of O&MW and mapped to the respective component or components.

   The O&M Workstation project will initially implement 6 - 10 copies of the client software which allows user access. It is recommended that a few of these clients be distributed at the Plant, Central office and Corporate Engineering, initially, and then expanded as the demand requires.

   The network drawing (refer to Figure 4-7) depicts the conceptual configuration of O&MW for ***Utility's Plant***. Following this Assessment, integration between the O&MW project team, I.S. personnel, and ***Utility*** network and computer systems support personnel, will take place to finalize the configuration and module selection.

   The O&M Workstation is designed to automate the Predictive Maintenance process in the power plant environment. Numerous functions which are indicated in the Roles and Responsibilities Section of this report will be automated; and, O&MW will also provide additional functionality in tracking and analyzing equipment condition information.

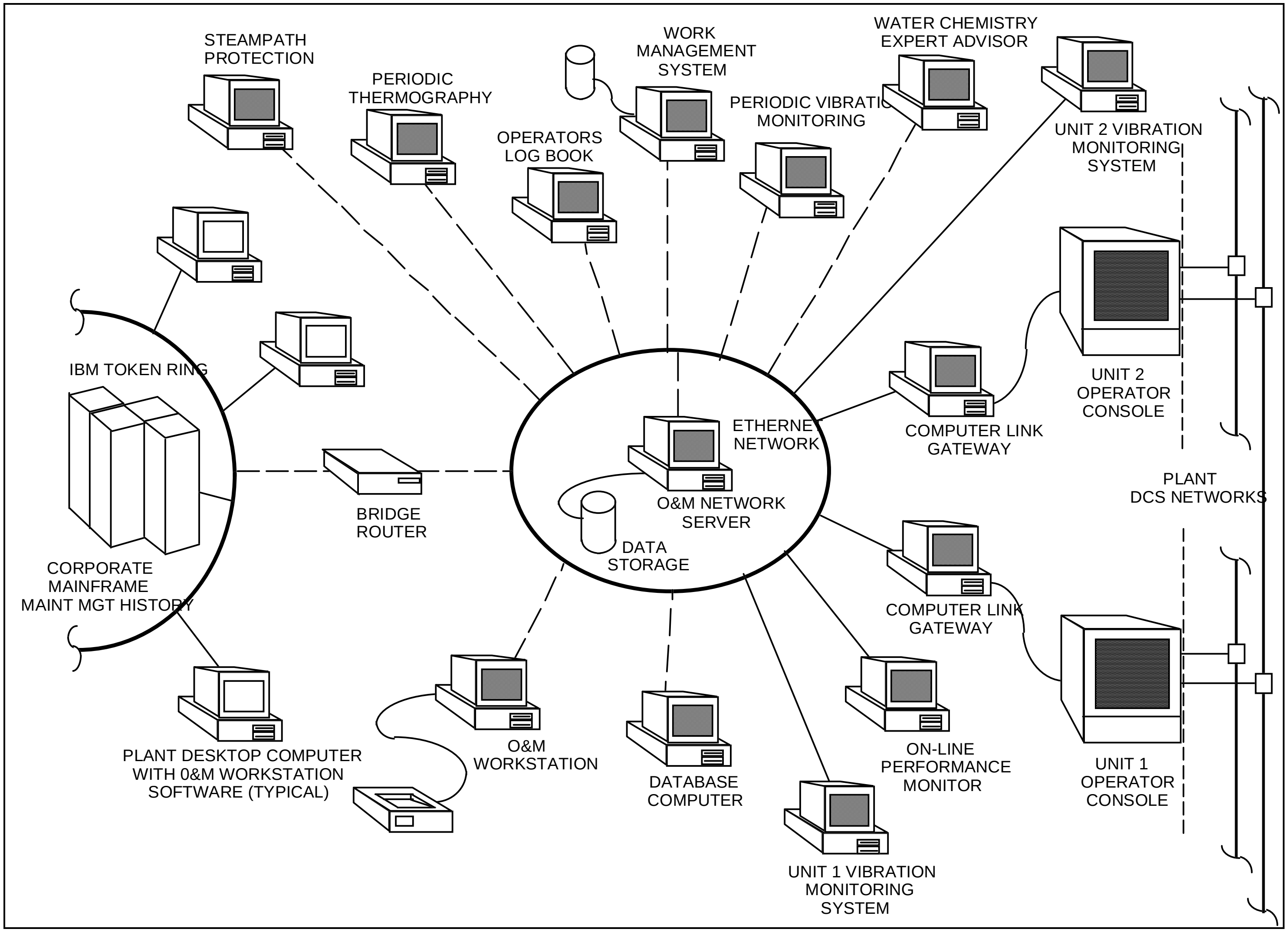


Figure 4-7: O&M Workstation Conceptual Configuration Drawing