RECLAMATION

Managing Water in the West

Facilities Instructions, Standards, and Techniques
Volume 6-2

Conduct of Power Maintenance

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

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14. ABSTRACT

This volume identifies the philosophy, practices, tools, resources, and assessment needed in the maintenance of Reclamation power facilities, including major pumping facilities. The organization and administration of maintenance is intended to meet Reclamation's mission and achieve a high level of safety and reliability that is accomplished through effective implementation and control of facility activities. This volume includes quantitative indicators for measuring performance. These indicators are intended to be used for local management and for power review of operation and maintenance purposes. Maintenance of facilities and equipment primarily used for water storage and conveyance is not covered.

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DISCLAIMER

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1.0 General

Reclamation has responsibility for the generation of hydroelectric power and conveyance of water for authorized project purposes at its dams, powerplants, pumping plants, and pump-generating plants. These assets are worth billions of dollars and are essential to the interconnected power system and water supply system. Therefore, they must be maintained adequately to protect the public investment, improve safety and environmental integrity, enhance reliability, and reduce cost of the facility. A well-defined maintenance management program is necessary to accomplish these goals. Studies show that most maintenance departments in the United States operate at between 10 and 40 percent efficiency and that nearly 70 percent of equipment failures are self-induced, meaning that failures are caused by not performing maintenance or by performing it improperly. These statistics should not be acceptable to facility managers and certainly not to maintenance managers. The implementation of policies, standards and best practices improves the likelihood that Reclamation power facilities will be maintained in the best interests of the citizens of the United States.

2.0 Scope

This volume discusses the philosophy, practices, tools, resources, and assessment needed in the maintenance of Reclamation power facilities, including major pumping facilities. Maintenance of facilities and equipment primarily used for water storage and conveyance is not covered.

The organization and administration of maintenance is intended to meet Reclamation’s mission and achieve a high level of safety and reliability that is accomplished through effective implementation and control of facility activities. Reclamation’s managers recognize that protecting the environment and improving safety and operations and maintenance are compatible goals. The practices developed and implemented by Reclamation’s managers enable Reclamation facilities to be operated and maintained in the best interest of the organization. The documentation of practices and procedures through the application of standards establishes a consistent maintenance approach for the facility and staff.

3.0 Management Role in Facility Maintenance

Area office management is responsible for the maintenance of all assets associated with Reclamation’s power and pumping facilities. Reclamation’s managers are responsible for the safe, effective, and efficient operation of all structures and equipment associated with the fulfillment of this responsibility.

Management's role is to provide adequate direction to staff for the safe and efficient maintenance of these facilities. Since proper maintenance is a deliberate act, maintenance practices and procedures should be documented for historical and consistency purposes. Each manager must ensure that such documentation is current and relevant, and that it reflects the maintenance goals of the responsible office and Reclamation. The documentation of the maintenance practices and procedures should provide sufficient detail to ensure staff can be consistent without encumbering creativity and stifling improvement.

4.0 Benchmarks and Performance Indicators

This volume includes quantitative indicators for measuring performance. These indicators are intended to be used for local management and for Power Review of Operation and Maintenance (O&M) purposes. Facility managers are also expected to meet all Government Performance and Results Act (GPRA) and Program Assessment Rating Tool (PART) requirements. Contact the regional GPRA and PART coordinator for more information.

5.0 Definitions

5.1 Administrative Work (AD)

A work type not specifically associated with maintenance (e.g., procedure development, training, or travel).

5.2 Availability

A measure that reflects how much of the time a generating or pumping unit is capable of providing service, whether or not it is actually generating or pumping. Typically, this measure is expressed as a percentage by dividing the time available by the period of time under consideration.

5.3 Backlog

All work documented in work orders that is anticipated to be accomplished but is not yet approved or scheduled.

5.4 Business Practice

A rule which organizational members are expected to follow when conducting business processes.

5.5 Business Process

A group of logically related tasks that use the resources of the organization to provide defined results to support the organization's objectives.

5.6 Calculated Priority

A numerical value that is used to determine the relative importance of the work to be performed for maintenance scheduling. It is the sum of the work order priority and the equipment priority.

5.7 Condition Monitoring

A process of monitoring critical measurement points/quantities on equipment while it is in service for the purpose of determining equipment condition and identifying required maintenance.

5.8 Corrective Maintenance (CM)

A work type for maintenance activity which restores an asset to a preserved operating condition. It is normally initiated because of a scheduled inspection or a routine check that finds the asset or component is no longer within a prescribed tolerance or in an acceptable operating condition.

5.9 Commitment Tracking (CT)

A work type that is used to track recommendations made to a facility. The recommendations include, but are not limited to, safety, hazardous waste, incident review, power, O&M and life safety code inspections.

5.10 Condition-Based Maintenance

Maintenance based on actual conditions obtained from non-invasive testing, operating, and condition monitoring.

5.11 Deferred Maintenance

Deferred maintenance is maintenance that was not performed when it should have been or which was scheduled and was, therefore, put off or delayed for a future period.[1]

5.12 Emergency Maintenance (EM)

A work type for maintenance that is not anticipated but must be performed immediately to ensure reliable operation of the facility or component in the facility.

5.13 Failure Codes

A standardized set of conditions used to categorize equipment failures.

5.14 Forced Outage

The unscheduled removal of a generating unit, transmission line, or other facility component from service.

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[1] Statement of Federal Financial Accounting Standards (SFFAS No. 6) definition.

5.15 Job Plans

A document that identifies the required steps, craft, labor estimates, parts and materials, and special tools for performing the maintenance task(s) on a piece of equipment.

5.16 Maintenance

An activity used to inspect, repair, replace, or improve a component at a facility.

5.17 Modification Package (Job Packet)

A set of documents that identify modifications to facility equipment or systems.

5.18 Generating Unit Outage

The period of time when a generating unit is unable to provide service. Outages are classified as either planned outages or forced outages.

5.19 Maintenance Manager

The designated Area Office, Field Office, or Regional Office person who is responsible for establishing the maintenance philosophy, procedures, and business practices for the maintenance activity and is accountable for its execution within the respective office's jurisdiction.

5.20 Planned Outage

The period of time when a generating unit, transmission line, or other facility component is scheduled with the control area operator to be removed from service.

5.21 Predictive Maintenance

Maintenance that is performed based on a known set of conditions, such as number of operations or length of operation.

5.22 Preventive Maintenance (PM)

A work type for maintenance that is conducted on a regular frequency to prolong the life of equipment and prevent premature failures. PM includes equipment inspection, lubrication, adjustment, cleaning, and testing, and replacing incidental parts, such as filters and simple belts. PM is a combination of proactive maintenance and scheduled overhauls and may be augmented by techniques such as reliability-centered maintenance, predictive maintenance, and condition monitoring.

5.23 Proactive Maintenance

Maintenance that is structured to anticipate equipment problems and prevent or reduce Corrective or Emergency Maintenance.

5.24 Reliability-Centered Maintenance (RCM)

Maintenance that focuses on components of mission-critical equipment whose failure will prevent that equipment from performing its function.

5.25 Safety Work (SAF)

A work type reserved for maintenance associated with safety.

5.26 Special Maintenance (SP)

A work type for maintenance normally associated with rehabilitation and extraordinary maintenance (RAX), which includes large capital improvements or the installation of new equipment.

5.27 Short Notice Outage Work

A list of required repairs on generation and support equipment that can be completed during an unscheduled forced outage.

5.28 Skipping PM

A PM that has been closed without labor hours being charged to it.

5.29 Temporary Modification

Changes made that will be further altered when the equipment can be removed from service for a longer period of time at a later date and permanent modifications can be accomplished.

5.30 Weekly Work Schedule

A process by which management assigns work orders based on the priority of the work (calculated priority) and the required resources versus the available plant resources.

5.31 Work Flow

A site-specific process by which work moves through different statuses in a systematic manner from the initiation of the work order until it is closed.

5.32 Work Order

An electronic and/or paper document that is used to identify, plan, engineer, approve, and record work.

6.0 Maintenance Basic Business Practices

6.1 Introduction

For Reclamation's facilities to operate reliably, a certain minimum level of maintenance business practices must be adhered to. Reclamation Maintenance Managers are responsible for developing business practices for their respective facilities. The business practices should address the following elements to ensure Reclamation expectations are being met.

6.2 Elements

- All maintenance activities should be documented with work orders.
- Work orders should be used to track maintenance activities from start through completion.
- When using the Capital Asset and Resource Management Application (CARMA) (see section 8.0), all assets utilizing maintenance resources must be identified.
- All recurring Preventive Maintenance work should be planned for labor and parts/materials.
- Facilities Instructions, Standards, and Techniques (FIST) Volumes 4-1A and 4-1B provide the basis for most maintenance activities. Documentation is required using a written variance (found in Appendix D of the Power Review of O&M Guidebook)[2] when FIST recommendations are not utilized.
- The use of standing work orders should be limited. Standing work orders may be an ineffective method of capturing equipment history and maintenance costs, and often serve as a hiding place for ineffective usage of maintenance personnel time.

[2] Found at intranet site http://intra.usbr.gov/~hydrores/pomreview/

7.0 Maintenance Management

7.1 Introduction

Effective maintenance management provides the necessary coordination, control, planning, execution, and monitoring of equipment maintenance activities.

7.2 Elements

Roles of Plant Staff

Plant staff must know the processes by which the maintenance activities are managed. A process should be developed to gather feedback from plant staff on improvements in maintenance management. Accurate job descriptions are an integral part of a maintenance program.

Facility Maintenance Philosophy

A facility maintenance philosophy describes the general approach used in maintaining the facility. A basic philosophy would encompass maintenance as a preventive type. Another maintenance philosophy would be the embodiment of reliability-centered maintenance. The Maintenance Manager should document and communicate to plant staff the maintenance philosophy the manager decides to employ. It is critical that plant staff understands what equipment will be maintained, overhauled, replaced, or run to failure. This prevents confusion for facility staff when conducting maintenance.

Maintenance Skills Training

Training of maintenance personnel should not be overlooked. A significant amount of required maintenance is the result of improper or poor maintenance previously performed on the equipment/facility. Skill training of maintenance staff is essential to the effective performance of facility maintenance.

Maintenance Performance Reports

Performance reports are one method by which Maintenance Managers can gauge the effectiveness of their maintenance programs. Management should monitor maintenance performance through the reports listed in FIST Volume 6-1, Management of Power Facilities. Maintenance Managers should analyze maintenance program performance by using work order information contained in CARMA, performing on-site visits, and reviewing facility performance indicators.

8.0 Maintenance Management System

8.1 Introduction

Reclamation utilizes the CARMA as the maintenance management system for power facilities.[3] CARMA includes the commercial computerized maintenance management system (CMMS) software MAXIMO™. The utilization of CARMA for the development, planning, scheduling, and documentation of maintenance at Reclamation facilities is an important component in the management of Reclamation's assets.

8.2 Elements

CARMA incorporates the following elements:

Accountability

Accountability is simply the process of closing the loop. If a maintenance management and reporting system is open-ended, it is doomed to failure. There must be a vehicle to ensure that tasks have been completed, parts are on order, equipment is scheduled, and people are paid. CARMA is that vehicle.

Work Order Generation

Work orders should be generated for all maintenance. Some facilities utilize trouble reports (TR) for identifying deficiencies and then convert the TR to a work order upon approval. Many simply create the work order directly.
As a "best practice," facilities should train all staff in the usage of CARMA and they should, at a minimum, be able to generate a work order or trouble report.

8.3 Work Planning

- Work orders should be planned for crew composition, size, hours, and materials.
- Work should be scheduled in such a manner as to allow time to organize the supporting documentation, material, tools, and other resources prior to assigning work.
- Work should be categorized by the type of activity.
- Work should be prioritized.
- Where possible, work should be identified with, or linked to, specific components within the facility. Identifying work with areas instead of equipment is ineffective for cost tracking and equipment history.
- Tasks should be standardized where possible.

[3] Formerly known as the Reclamation Enterprise Maintenance Management System (REMMS). More detailed information on the use of CARMA can be found in at http://intra.do.usbr.gov/remms/

- Accurate estimated hours are essential to allow for scheduling of maintenance. The time to complete the tasks should be estimated to ensure adequate resource assignments. Time from completed tasks that are similar in nature can be used to adjust the estimated time or develop the initial estimate. The local office CARMA support group has the ability to look at PM histories and recalculate the estimated hours to allow better scheduling of work.

Work Order Statuses

Work order statuses are found in the CARMA Business Practices. It is essential that work orders have the correct status at all times. The statuses will reflect where the work order is in the facility-specific workflow process.

Work Flow

A facility should tailor workflow to match the organizational structure. Specific workflow tasks should be assigned to the appropriate individual or group. The workflow process should be documented (e.g., flowchart) and staff should be trained. (See Appendix A for a sample workflow chart).

Maintenance Personnel (Organization / Roles / Responsibilities)

It is important that the facility's maintenance organization roles and responsibilities are understood by all maintenance staff.

These core duties should be assigned to appropriate staff:

- Initiating work orders
- Approving work orders
- Planning and estimating
- Scheduling
- Tracking, analyzing and reporting
- Performing work
- Completing and closing work orders
- Providing feedback to originator

Work Order Priorities

Work order priorities, along with the employees allowed to set those priorities, should be identified in the facility's workflow process. (See also PM Priorities.)

- **Priority 4 ─ Critical**
  Actions required immediately to prevent or correct situations that could endanger the health or safety of employees or the public, cause an environmental release, or cause immediate and severe damage to plant equipment.

- **Priority 3 - Urgent**
  An action required to mitigate or correct an equipment or component problem that restricts plant operation or causes a loss of generation or water release.

- **Priority 2 - Normal**
  Actions assigned and coordinated on a routine basis to perform corrective work that supports plant operation (e.g., planned outage work).

- **Priority 1- Low Priority**
  Activities that do not impact plant operation and availability (e.g., painting, lighting, inspections, etc.) or activities that can be placed on hold (e.g., activities on hold due to budgetary reasons).

Equipment Priorities

Establishment of equipment priorities in CARMA will assist schedulers in the development of the work schedule. The list of recommended equipment priorities is in Appendix B.

- **Priority 4 - Critical**
  Equipment directly related to safety, environmental protection, generation, or water delivery.

- **Priority 3 - Essential**
  Equipment (auxiliary equipment) that supports generation or water delivery; its failure would cause the loss of generation or the ability to deliver water.

- **Priority 2 - Basic**
  Equipment (auxiliary equipment) that supports generation or the delivery of water but a failure of which will not cause the loss of that capability. Any auxiliary equipment that has an installed backup capable of delivering 100 percent of its requirements (e.g., sump pumps, governor oil pumps, etc.).

- **Priority 1 - Ancillary**
  Equipment that is not associated with the delivery of water and power. Equipment that is strictly in a support role for the facility or structure; the failure of that equipment would not cause the failure of an essential piece of equipment (e.g., ventilation fans).

Calculated (Work) Priority

The work order priority added to the equipment priority produces the calculated or work priority. This numerical value is an effective tool for prioritizing maintenance work to be undertaken.

PM Priorities

PM priorities should be identified in CARMA when establishing the PM program. When the PM work order is issued, the calculated priority is based on the PM priority plus the equipment priority.

- **Priority 4 – Critical**
  Tasks required to meet regulatory or personnel / equipment safety requirements (e.g., relay or breaker maintenance, testing personal protective equipment, crane or elevator inspections).

- **Priority 3 – High Priority**
  Tasks that directly affect power or water delivery (e.g., unit annual inspections, governor alignments or voltage regulator testing).

- **Priority 2 – Normal**
  Tasks that indirectly affect power or water delivery (e.g., cooling water pump or auto greasing system inspections).

- **Priority 1 – Low Priority**
  Activities that do not affect plant operation and availability (e.g., sump pump, air compressor or roof inspections).

Work Types

- Proper categorizing of work is essential to provide accurate reporting and to allow management to trend maintenance work

- The following is a list of approved work types that are included in the "Definitions" section:
  - AD – Administrative
  - CM – Corrective Maintenance
  - CT – Commitment Tracking
  - EM – Emergency Maintenance
  - PM – Preventive Maintenance
  - SAF – Safety
  - SP – Special Maintenance

- Acronyms of these work types are allowed for internal reporting requirements. For corporate reports, any work-type acronym will contain one of the preceding work type abbreviations but not more than one (e.g., PM-UA Preventive Maintenance – Unit Annual).

- Management must remain cognizant of percentages of each work type based on person-hours. This allows the identification of trends by the maintenance group. In general, as the percentage of PM work decreases, it will be followed by a corresponding increase in corrective maintenance, and vice-versa.

Maintenance History

- Equipment history in CARMA must reflect the maintenance work that has been performed on the equipment.

- For CM, a facility best practice is to have the maintenance craftsperson record the problem and what was corrected on the paperwork order under "Description." Failure codes, photographs, and notes from the staff on aspects of the activity not covered in the initial task description should also be included. The narrative portion of his information should then be entered into the work order long description in CARMA and the failure codes entered into the appropriate fields. This will serve as a living history for the associated piece of equipment and provide capability for failure analysis.

- The review of equipment history is invaluable to develop proactive strategies to deal with systemic equipment failures.

- Copies of work order and associated documents should be retained and a copy of the work order with all the information about what was corrected should be made available to the initiator to close the loop on the work order system and maintain communication between maintenance and other facility groups like Operations and Engineering.

Materials and Tools

All parts, materials, supplies, and special tools used to accomplish maintenance should be identified in the appropriate work order.

Seasonal Maintenance

Some maintenance is of a seasonal variety. Facilities that are seasonal, or have maintenance that is seasonal, should consider modifying their PM so they are issued only during maintenance months. This will prevent having to cancel the PM.

Failure Analysis

- Failure codes should be used when completing work orders to categorize the cause and remedy of failures.

- The use of equipment failure hierarchies and failure codes allows the identification of recurring equipment failures. The use of failure reporting allows the accumulation of data on equipment failure causes.

- These data can be analyzed to make proactive maintenance management decisions. Patterns of failures can be detected and analyzed to determine the cause and assist in determining what corrective action is needed.

- Decisions to replace/rehabilitate equipment or to change the PM cycle can be based on failure analysis. In addition, such analysis can expedite trouble-shooting efforts.

- Failure code utilization enables maintenance personnel to track the occurrence and development of similar failures and to determine whether the failure is random or cyclical in nature.

- The result of this analysis brings the benefit of failure consequence and occurrence knowledge and the potential for elimination and mitigation of its effects. This, in turn, leads to better resource and equipment utilization, work order management, and optimization of inventories.

The following should be documented using the failure codes in CARMA:

- The functions and associated desired standards of performance of the asset in its present operating context (functions).

- In what ways can it fail to fulfill its functions (functional failures)?

- The cause(s) of each functional failure (failure modes).

- What happens when each failure occurs (failure effects)?

- In what way does each failure matter (failure consequences)?

- What should be done to predict or prevent each failure (proactive tasks and task intervals)?

- What should be done if a suitable proactive task cannot be found (default actions)?

Performance Indicators

The following performance indicators are from FIST 6-1, Management of Power Facilities, Section 13.3.C.

- Management should consider developing and posting performance indicators for the facility. Reports can be generated from CARMA to summarize these indicators. Some examples of performance indicators are:
    - Number of Generated Work Orders
    - Number of Completed Work Orders
    - Number of Outstanding Work Orders
    - Number of Outstanding Work Orders more than 30 Days Past Due
    - Percent of Rework

- Number of PM Work Orders
- Number of PM Work Orders Completed
- Number of CM Work Orders
- Number of CM Work Orders Completed
- Number of EM Work Orders
- Number of Scheduled versus Non-Scheduled Work Orders
- Total and Per Unit Forced Outage Rate
- Total and Unit Availability Rate
- Production Costs ($/MW and $/MWh)
- Mean time between failures
- “Cost per” reports
- Scheduled compliance report

Completion of Maintenance Work

At least 90 percent of maintenance work, excluding special work, should be completed on an annual basis. This percentage can be found by comparing the total number of work orders completed in the current FY to the total work orders generated in the current FY plus any outstanding work from the previous year. The completion of maintenance work is an indicator of whether the facility is staffed and funded properly. Additionally, it can show the effectiveness of the facility maintenance program.

Planning Work

As a standard, all non-emergency work should be planned and at least 80 percent of work should be completed on time. Planning work is essential to the efficient operation of a facility. When maintenance priorities change on a daily basis, maintenance staff can become frustrated and disillusioned.

Charging Work

All completed work orders should have time charged against them. Not charging hours to a work order causes invalid cost accounting of maintenance on specific equipment.

Open Work Orders

The total number of Open Work Orders (not closed, completed or canceled) should be no more than 10 percent of the total Work Orders completed in the last 365 days. Each facility should identify the total number of PMs completed each year.

Outstanding PMs

The total number of outstanding PMs (greater than 30 days past the due date) should not be greater than 5 percent of the total PMs issued in the last 365 days.[4]

[4] The due date for PMs of any interval is generally 30 days from the issuance date. Thirty days past the due date, the PM is outstanding as defined in the CARMA Facility Maintenance Report.

9.0 Preventive Maintenance (PM)

9.1 Introduction

PM is basic, proactive maintenance performed on equipment and facilities with an established frequency, either time- or meter-based. The main goal of performing preventive maintenance tasks on a periodic basis is to extend equipment life and ensure its capability in support of the facility's goals and targets.

PM can be a simple task, such as an adjustment, or a complex activity, such as a complete overhaul. PM tasks can be performed when the equipment is shut down or while the equipment is running. The frequency selected for performing PM tasks takes into consideration the maximum time allowable before failure or extensive and costly CM work is performed. Defining the right tasks and their associated intervals for execution is an important factor in limiting the cost of PM work without sacrificing the PM program value.

Because PM is predictable, budgeting, planning, scheduling, and resource leveling are easier. PM traditionally has been the standard maintenance practice in Reclamation and maintenance standards defined in FIST Volumes 4-1A and 4-1B are preventive-type. Therefore, PM is the current benchmark for maintenance as measured by the Power Review of O&M (see Section 20.0).

However, PM as a maintenance philosophy should be used judiciously. Rigid adherence to PM may be cost ineffective and may introduce equipment failure by its intrusive nature. Maintenance managers may choose to apply other viable, proven techniques such as Reliability Centered Maintenance (RCM), Predictive Maintenance, or Condition Monitoring to supplement or enhance their PM program. However, since PM is the recognized standard, adoption of other techniques must be consciously chosen, effectively implemented, and properly documented. Deviation from PM standards must be agreed to by the area/project manager.

9.2 Elements

- PM requirements for powerplant equipment are contained in Reclamation FIST volumes.

- Each piece of equipment should have a job plan developed and scheduled with a PM in CARMA based on the requirements contained in FIST Volumes 4-1A (Maintenance Scheduling for Mechanical Equipment) and 4-1B (Maintenance Scheduling for Electrical Equipment).

- Job plans should be of sufficient detail to ensure the work is performed accurately and consistently. They should identify steps to complete the work, taking into consideration the skill of the craft performing the work.

- PM job plans should be reviewed for adequacy on a 3-year cycle.

- All PMs must have an associated job hazard analysis (JHA) and site-specific operating procedure.

- Job plans should list crafts, labor estimates, materials, special tools and supplies, along with links to drawings and job hazard analysis procedures.

- A facility "best practice" is to have a PM–to-CM ratio of between 6 and 8 PMs for every CM. A higher ratio may mean too much PM, and a lower ratio may mean not enough PM. The only way this can be determined is if staff document corrective maintenance performed during the PM process with a follow-up CM work order. (Note: this rule-of-thumb ratio does not apply to critical equipment and systems where maintenance is mandated as essential for reliability or for safety and environmental compliance).

When conducting PM

- The supervisor should discuss the daily PMs with staff prior to sending them out on assignment.

- Equipment outages should be coordinated with the operations staff.

- During the actual PM, safety is the highest priority. Staff must review and adhere to the JHA when performing maintenance.

- The supervisor should check crew members from time to time to ensure that PMs are being accomplished correctly and safely.

Feedback following the PM

- Crew members should notify their supervisor of the PM completion and any problems identified.

- PMs are important historic documents and crew members should be encouraged to mark up changes to PMs and get those to their supervisor for review.

- Supervisors should give craftspersons feedback concerning the effectiveness of their actions during the PM since this is a most important aspect of a PM program. Constructive feedback given to the individual craftsperson will do more to promote a successful, reliability-based PM program than anything else.

PM documentation

- All craftspersons should be required to document any issues associated with the equipment on which the PM was performed.

- When a condition is discovered that requires a repair or replacement or an expenditure of funds and labor hours outside the scope of the PM instruction, a CM-type work order should be written as a follow up to the PM work order that generated the inspection activity. The "has follow up work" field, if properly used, helps measure the effectiveness of a PM system.

- The supervisor should review the completed work orders daily to ensure accuracy.

- If equipment PM or repair data is unclear or incomplete, the work order should be returned to the craftsperson for additional input. This data will later be used to make reliability decisions. Reliability is a prime goal of any good PM program.

- The goal of PM documentation is that all maintenance tasks, scheduling, parts procurement, and labor are documented for future use. With each piece of documentation, equipment history is preserved.

Skipping PM

- PMs should be completed as soon as possible after they are issued. In general, a PM should be skipped when it is obvious that it will not be completed prior to the PM being issued again.

- Facilities should avoid issuing PMs, having them remain open, issuing the PM again, and then completing both of them.

- PMs will be considered completed if the associated work order is closed with time charged against it.[5]

- Canceling should be reserved for PMs that should not have been issued (e.g., human or MAXIMO™ error). Canceling legitimate, uncompleted PMs provides an inaccurate view of PM completion. Uncompleted PMs should be closed with a note of explanation.

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[5] There may be instances where the work order is completed without time charged to it in CARMA,--e.g., contractors or other agencies performing the work.

10.0 Maintenance Planning

10.1 Introduction

Prior to maintenance being performed, it should be planned. Planned maintenance is significantly more effective than unplanned or reactive maintenance. Management should look at how planning is being accomplished at their facility, by whom, and how detailed and successful the planning is.
Most maintenance workers desire to have a planned regimen of work laid out for them whenever possible. They do not like to be stopped midstream in a job (planned work) and then be diverted to other duties or tasks. If this happens several times a day, this can cause worker confusion and frustration and can sometimes lead to other errors (i.e., procedural or safety). It is also inefficient as much time is lost in switching back and forth between jobs.

10.2 Elements

- The separation of planning and execution is a good management practice. However, at some small facilities, this may not be cost effective or practical.

- The responsibilities of planning and scheduling person(s) are as follows:

  - Develop job plans and schedule PM.
  - Develop PM procedure time line.
  - Provide material support needs for PM procedures.
  - Identify specialized test equipment, heavy equipment, and other specialized tools and equipment required to complete the PM.
  - Coordinate equipment outages.
  - Track status of other maintenance tasks.
  - Develop and post weekly maintenance schedules.

11.0 Maintenance Scheduling

11.1 Introduction

Scheduling of maintenance is just as important as planning. A posted schedule allows facility staff to look at the big picture when it comes to facility maintenance. It allows time for the operations staff to plan for clearances and standby equipment. It also allows management to be aware of upcoming maintenance activities to identify potential conflicts.

11.2 Elements

It is the responsibility of the planning/scheduling person(s) to attempt to achieve some level of planned maintenance. These actions include planning of all work in the backlog, entering priorities on this work which helps to rank the backlog, providing accurate and timely status inputs, and indicating hold situations.
It may be impossible to eliminate emergency work; however, actions can be taken to minimize its occurrence and to trend such actions.

Weekly Work Schedule

A weekly schedule of work is an effective tool for managing maintenance backlog and staff. It is a process of identifying work order priorities and required resources and assigning work based on available resources.

Resource Leveling

A routine in CARMA called resource leveling allows for the automatic scheduling of maintenance based on Priorities, Required Resources, Work Order Status and Resource Availability.

Work Order and PM Hierarchies

The arrangement of PMs and work orders in a hierarchy allows easy scheduling of maintenance items. As an example, when scheduling a unit annual that is arranged in a hierarchy, only the parent work order requires the scheduled date. All of the children work orders will change automatically. This is a great time-saver.

CARMA

CARMA (MAXIMO version 5.2 and later) contains supported functionality for linkage to Microsoft Project Manager. This is the preferred planning/scheduling tool for Reclamation.

12.0 Outage Management

12.1 Introduction

Skilled outage management can pay dividends to a facility in increased availability and reduced costs. It is a good idea for management and staff to understand the cost of a day of outage time.

Depending on the size of a main unit, an outage day can result in lost revenue ranging from $5,000 to $250,000. This number should be calculated for a given facility and shared with facility staff. Proper planning and scheduling of outage tasks can greatly reduce facility outage time and lost revenue.

12.2 Elements

- The first step in outage management is to define the scope of the outage.
- The scope should include start and finish dates, as well as milestones for the outage.
- The facility should also define large resource contingent items, required items, and low-priority projects.
- The outage should be discussed with facility and supervisory staff.
- The facility needs to get all players involved. This will allow the development of a more accurate outage schedule. Involvement will additionally build ownership and commitment among supervisory staff.
- A list of tasks must be generated.
- Outstanding work orders from CARMA should be printed.
- Clearances and JHAs should be developed in advance.
- The development and use of pre-outage inspections will help identify equipment problems that may not be noticeable after the unit is shut down. An infrared camera is an invaluable tool for checking electrical equipment at full load prior to shutting the unit down for maintenance.
- Information should be solicited from plant personnel about the condition of the equipment. This will help identify any other issues associated with the equipment.

Determine resources for each task

- Accurate job plans in CARMA means much of this work is already accomplished.

- The number of maintenance personnel and hours required for each task are essential to schedule development.
- Any special tools that will be needed for the task should be identified and reserved.
- All materials required for the task should be identified, ordered, and on-hand prior to the outage starting. Critical time is often lost waiting for materials to arrive.

Determine conditionally based tasks

- Tasks that have to be done in a specific order must be identified and arranged accordingly.
- Tasks that cannot be done simultaneously must be identified. (Example: cavitation repair and governor testing.)
- Safety must also be considered when determining the order for tasks. What clearances are in effect will determine what work can be accomplished.
- It is usually a good idea not to have different crews doing different work on the same equipment at the same time.

Develop the outage schedule

- Coordinate with stakeholders and Power Marketing Administration (PMA).
- Make the schedule reasonable and build in time for problems and contingencies.
- Schedules should list task or job name, the start time, the craft, number of personnel, and duration.
- PERT[6] charts are an excellent tool for developing a schedule.

Publish the outage schedule

- The schedule should be available to all employees as well as supervisors. This will keep all staff informed of the outage progress. The Reclamation intranet site is a great place to publish a real-time outage schedule.
- Long-term outage schedules should be posted to ensure that training, travel, and vacations do not impact outages.
- The schedule should be discussed with employees.

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[6] Program Evaluation and Review Technique

- The schedule should be readable and easily updated.

Work the plan

- Someone should be responsible for coordinating and tracking the outage. Preferably, it should be a rotational assignment among facility supervisors. This is important since outage management is a learned skill and it gives the supervisor the big picture for what is occurring.

- There should be regular meetings about the outage and they should include discussions about:
  - Completed tasks
  - Upcoming work items (look at conflicting tasks)
  - Problems, delays and solutions

- The schedule should be updated to keep plant personnel involved and informed of the outage progress.

- Supervisors should be held accountable for the schedule.

- If the schedule is not met, supervisors should review the schedule more closely next time and give more and/or better input.

- Through this process, supervisors will improve their planning and estimating.

13.0 Coordinating Maintenance Activities with Other Entities

13.1 Introduction

The coordination of maintenance activities with stakeholders is an essential part of an effective maintenance program. Facilities should work with stakeholders to schedule maintenance activities in a systematic and proactive manner.

13.2 Elements

- Typically, Reclamation facilities schedule maintenance activities when there is a low demand for power and/or water.

- Maintenance staff should also consider periods of time when the cost for electricity is at its lowest.

- Other areas of consideration are line outages, streambed work, weather patterns, etc.

14.0 Maintenance Reporting

14.1 Introduction

Reporting on maintenance planning, progress, and accomplishment is essential to effective maintenance management. The proper report can give the maintenance manager significant insight into the successes and problem areas in the maintenance program. Using timely reports, maintenance managers can reprioritize, reallocate staff, or use other techniques to keep the maintenance program on track.

14.2 Elements

- Maintenance reports should be established and used at each facility to monitor planning, progress, and accomplishments of maintenance.
- Some reports should be designed to identify problem areas (e.g., outstanding PMs).
- Reports should be reviewed periodically by managers to identify areas for improvement.
- Several reports developed for the Reclamation power program exist in CARMA and can be run with little effort.
- New reports can be developed to meet maintenance managers' needs.
- Ad hoc queries in CARMA can augment established reports.
- The timeliness and quality of data in CARMA reports are dependent on the timeliness and quality of the data entered into the system.

15.0 Control of Plant Inventory

15.1 Introduction

The organization of the warehouse is one of the more critical functions in maintenance management. Most existing storerooms are improperly stocked because of the tendency of maintenance personnel to purchase with bankcards and/or accumulate critical individual parts and supplies outside the warehouse system. This circumvents the important warehouse responsibility to meet the needs of all work in progress and emergencies, so that each maintenance function is fully served. Keeping parts and supplies outside the warehouse system prevents adequate material management and often results in work orders not including a listing of and cost accounting of parts and materials.

For effective warehouse management, it is essential that maintenance work orders be planned for parts and materials. It is also essential that the warehouse be managed to provide the needed parts and materials in a timely fashion. Maintenance and warehouse staff and managers must work together to ensure that the warehouse system is fully integrated with and supports maintenance.

15.2 Elements

- The warehouse must be audited and inventoried in its entirety, including the accumulated parts and supplies. Parts and supplies must be easily located within the storeroom.

- Parts must be entered into the CARMA by identification number, location and cost center(s) that use the part.

- Parts must be cross-referenced to equipment. This will allow maintenance personnel to locate any specific item and/or part each time they make a search.

- An equipment history analysis must be created and dormant or excess stock items identified. Once identified, excesses are tagged for salvage or scrap, keeping inventories viable.

- The creation of appropriate warehouse inventory levels is essential based on the real-time usage that is justifiable. Procedures for spare part receipt, issue, audit, salvage and scrap must be formulated. A written directive to produce a clear understanding by all personnel is essential.

- Warehouse and maintenance personnel must be trained in all aspects of data entry relevant to their job duties. Access or entry into the warehouse must be restricted to authorized personnel.

- A facility must identify parts, material, and consumable requirements. This is especially important for PMs and unit annual outages.

- All inventory data must be entered into CARMA and will be maintained current.

- Equipment vendor lists can be very helpful because they will usually maintain parts lists by equipment type and model.

- When parts or materials are received by the warehouse and then issued to maintenance personnel, they must be received in CARMA in order for the costs to roll up to the work order. Failure to do this will prevent material costs from accurately being rolled up to the job and equipment.

- The parts requirements of planned preventive maintenance tasks should be used in CARMA to generate a parts list for planned preventive maintenance.

- Bar coding, continuous inventory, and demand and usage data can be integrated using CARMA to minimize on-hand inventory and still avoid stock-outs.

16.0 Condition Assessments – Hydro Asset Management Partnership (HydroAMP)

16.1 Introduction

The development and implementation of condition assessments (CA) is driven by the need to monitor the condition of major powerplant equipment and meet Department of the Interior-mandated facility condition assessment requirements.

The CA process will serve as a tool for facility managers to understand the condition of their equipment and to better prioritize needed maintenance or replacement activities. Once the CA process is set up in CARMA, it will be integrated into the facility's normal maintenance procedures.

16.2 Elements

- HydroAMP is a partnership formed between Reclamation, Hydro Quebec, the U.S. Army Corps of Engineers and the Bonneville Power Administration.

- FIST 6-3, HydroAMP Condition Assessments (in development), provides technical details for conducting condition assessments.

- This partnership has developed a set of CA (Condition Assessment) guides that are used to evaluate large generation assets in hydropower facilities.

- Assessments are conducted thorough CARMA PM Job plans that are scheduled annually.

- Key parameters are evaluated on each piece of equipment and point values are assigned to the parameter.

- The point values are entered into the condition-monitoring portion of CARMA and each piece of equipment is automatically scored good, fair, or poor, based on the total point values.

- The condition of each piece of equipment is reported annually via CARMA and the combined rating of all equipment is used to evaluate the facility as good, fair or poor.

17.0 Condition-Based Maintenance

17.1 Introduction

Condition-based maintenance is maintenance based on actual conditions, obtained from non-invasive testing, operating, and condition monitoring. This type of maintenance practice can lower the overall maintenance cost, improve productivity, and lower maintenance-induced equipment failures.

17.2 Elements

Appendix C provides technical information and recommendations for implementation of condition-based maintenance practices.

18.0 Reliability Centered Maintenance

18.1 Introduction

Reliability centered maintenance (RCM) focuses maintenance on components of mission-critical equipment whose failure will prevent that equipment from performing its function.

18.2 Elements

- Appendix D, (Sample) Desktop RCM Process, provides a methodology to review the facility PM Job plans and determine how they may be revised to become more effective in preventing mission-critical equipment failures. In order to better understand how equipment fails and what procedures can be established to prevent these failures, the facility should utilize failure codes in CARMA to document equipment failures.

- All RCM information and decisions must be documented in a way that makes them fully available and acceptable to the facility and Area/Project manager.

19.0 Control of Facility Modifications

19.1 Introduction

Operation, maintenance, and modification of equipment must be made in accordance with sound operations, maintenance, and engineering practices. This section covers modifications to major plant systems that result in a change in operations and maintenance practices or structural design. This includes, but is not limited to, maintaining accurate prints (drawings), design specifications, technical manuals, maintenance procedures, and operating practices.

19.2 Elements

- Minor plant modifications--for example, wiring changes or the removal or addition of small components that will not affect the operation of a piece of equipment or system--may be documented with a marked-up print or sketch forwarded to the Engineering Team Leader.

- Plant Permanent Modifications - Systems and Equipment should be modified as follows:

    - A CARMA work order should be generated to track all work and costs associated with the modification.

    - A modification package should be developed, and include the following:

        - A detailed description of the proposed changes

        - Marked-up drawings showing the proposed changes, or if the system is new, sketches or drawings of the new system

        - A list of materials including specifications and suppliers

        - Technical manuals of any new equipment

    - The facility engineering group or designee of the Facility Manager should review the package for the following:
        - Completeness
        - Accuracy of prints and other documents
        - Sound engineering practices

    - Operations staff should review the package for changes to Standing Operating Procedures (SOP) or practices, and any changes to the operating procedures or practices should be added to the modification package.

    - Maintenance staff should review the package for changes to maintenance procedures. Any changes to the maintenance procedures should be added to the modification package.

    - The modification package should be forwarded to the appropriate group responsible for the modification. The responsible group will install the modification in accordance with the modification package.

- Any additional changes done during the implementation of the modification must be documented.

- Upon completion of the modification, the package should be forwarded to Engineering staff to:
  - Finalize a set of as-built prints.
  - Replace all old prints with a copy of the new prints

- Operations staff should update current SOPs with new SOPs.

- Maintenance staff should:

  - Incorporate any changes to the associated maintenance procedures

  - Ensure new spare parts are placed in the inventory system and obsolete spare parts are excessed.

  - Replace any outdated technical manuals with the new manuals.

  - Update plant historical files with a copy of the modification package.

- Temporary Modifications

  - Temporary modifications are modifications to the facility and are not controlled by a job plan or clearance. The modifications will include, but are not limited to, the following
    - Lifted leads
    - Electrical jumpers
    - Disabled annunciation alarms
    - Disabled relief or safety valves
    - Temporary instrumentation

  - Temporary modifications should be done as follows:

    - The individual initiating the modification must notify the control room and a special condition tag should be hung to identify each and every temporary modification.

    - Modifications that could affect plant operations should be reviewed by the maintenance manager, operations manager, or engineering lead.

20.0 Power Review of Operations and Maintenance (PROM)

20.1 Introduction

Minimum requirements for the PROM are defined in the associated directive and standard (FAC 04-01). The directive and standard defines the need to address power operations and maintenance (O&M) as well as power management to comprehensively ensure a sound and effective program. The PROM relies on more specific and better-documented requirements than in the past. Safety, to the degree it affects Power O&M, is addressed but a comprehensive safety review is not included under the PROM.

More information and resources on the PROM are available at the website http://intra.usbr.gov/~hydrores/pomreview/.

20.2 Elements

- The PROM provides for three levels of Power O&M review:
  - A Denver-led comprehensive facility review (CFR) once every 6 years.
  - A region-led periodic facility review (PFR) once every 6 years.
  - An area office-led annual facility review (AFR) conducted annually on a fiscal year basis.
  - The CFR and PFR alternate, thus ensuring an outside review once every 3 years.
  - The AFR is generally conducted solely by local maintenance managers and staff, but may involve other offices and is a practice that affords the best, and earliest, chance of discovery and correction of oversights or problems in the local power program.
- The power review at each Reclamation power facility is accomplished by measuring O&M accomplishments, practices, and procedures against Reclamation's standards and business practices. In addition to the general health of the power O&M program, the PROM addresses focus areas of:
  - Electrical maintenance
  - Mechanical maintenance
  - Power operations
  - Power management

- The findings of the reviews are published in a report. Recommendations are categorized by focus area and importance. The area office must review the report recommendations and track them until their completion via the Commitment Tracking process (see Section 21.0).

- The area office may follow other criteria than those documented in the FIST volumes provided that this variance is justified, documented, and approved by the area manager, and still promotes sound O&M of the facility. It is recognized that standards, as written, do not apply in all situations and that mitigating factors such as consciously chosen, proven, and advanced management techniques (e.g., reliability centered maintenance) can alter the need to rigidly follow the standards. However, the standards are the benchmark for the PROM and variance from a standard must be based on proven, recognized, and generally acceptable methods and must be clearly communicated to reviewers.

- Management awareness and tracking of recommendations is strongly emphasized in the PROM. Specific responsibilities are assigned for apprising management of the status of reviews and recommendations and for ensuring that recommendations are tracked and implemented.

21.0 Commitment Tracking

21.1 Introduction

Commitment tracking is a process by which Reclamation's power facilities track recommendations from reviews and incidents. These include, but are not limited to, the PROM, hazardous waste, safety, incidents, life safety code, and universal accessibility.

21.2 Elements

- Reclamation's power facilities have used multiple systems to track recommendations associated with the different reviews. A single system is a more effective tool to track these recommendations.

- CARMA should be used to track the many different types of recommendations along with cost estimates, true costs, schedules, and status.

- Each review and incident investigation should have a parent work order. The work order will be assigned to the facility with a work-type Commitment Tracking (CT).

- Each recommendation should be entered as a child work order to the parent.

- The category type should identify the review type. Examples:
  - SAF - Safety review recommendations
  - PO&M - Power O&M review recommendations
  - HAZ - Hazardous waste review recommendations
  - PI - Power incident recommendations
- The recommendation number is entered into the category information field.
- This will allow facilities to plan and schedule the recommendation and track its progress.
- The corporate data warehouse can be utilized by the regional offices for the tracking of all recommendations at facilities throughout the region.
- A summary report is available in CARMA for status of all recommendations.

22.0 Deferred Maintenance Annual Reporting Requirements

22.1 Introduction

Deferred maintenance is maintenance that was not performed when it should have been or was scheduled and which, therefore, was put off or delayed for a future period.[7] Tracking of deferred maintenance is a requirement of the Department of the Interior and the Federal Accounting Standards and Advisory Board.

22.2 Elements

- Corrective maintenance, safety, and special work orders with a calculated priority level greater than or equal to six will be reported as deferred maintenance if they meet either of the following criteria:
  - The work order was approved and scheduled, and the scheduled completion date has passed;

    OR

  - There is no scheduled completion date and more than one year has passed since the work order was created.
- Preventive maintenance work orders with a calculated priority equal to eight will be reported as deferred maintenance if they meet the following criteria:

[7] Statement of Federal Financial Accounting Standards (SFFAS No. 6) definition.

- The latest scheduled PM has not been completed. (If the latest scheduled PM has been completed, all previous PM work orders for that plan are considered completed.)

  AND

- The PM is an annual PM on safety-related equipment (e.g., cranes, elevators, relays and fire detection / suppression equipment).

  AND

- Hours have NOT been charged against the work order (indicating the work is not in progress).

  OR

- The PM is a main unit annual inspection that has not been completed in the last 18 months. (This takes into account that some facilities do not automatically schedule their annuals in CARMA and unit annual schedule dates change annually.)

23.0 FIST Volumes and Power Equipment Bulletins (PEB)

23.1 Introduction

FIST volumes and PEBs define maintenance standards for equipment in Reclamation facilities.

23.2 Elements

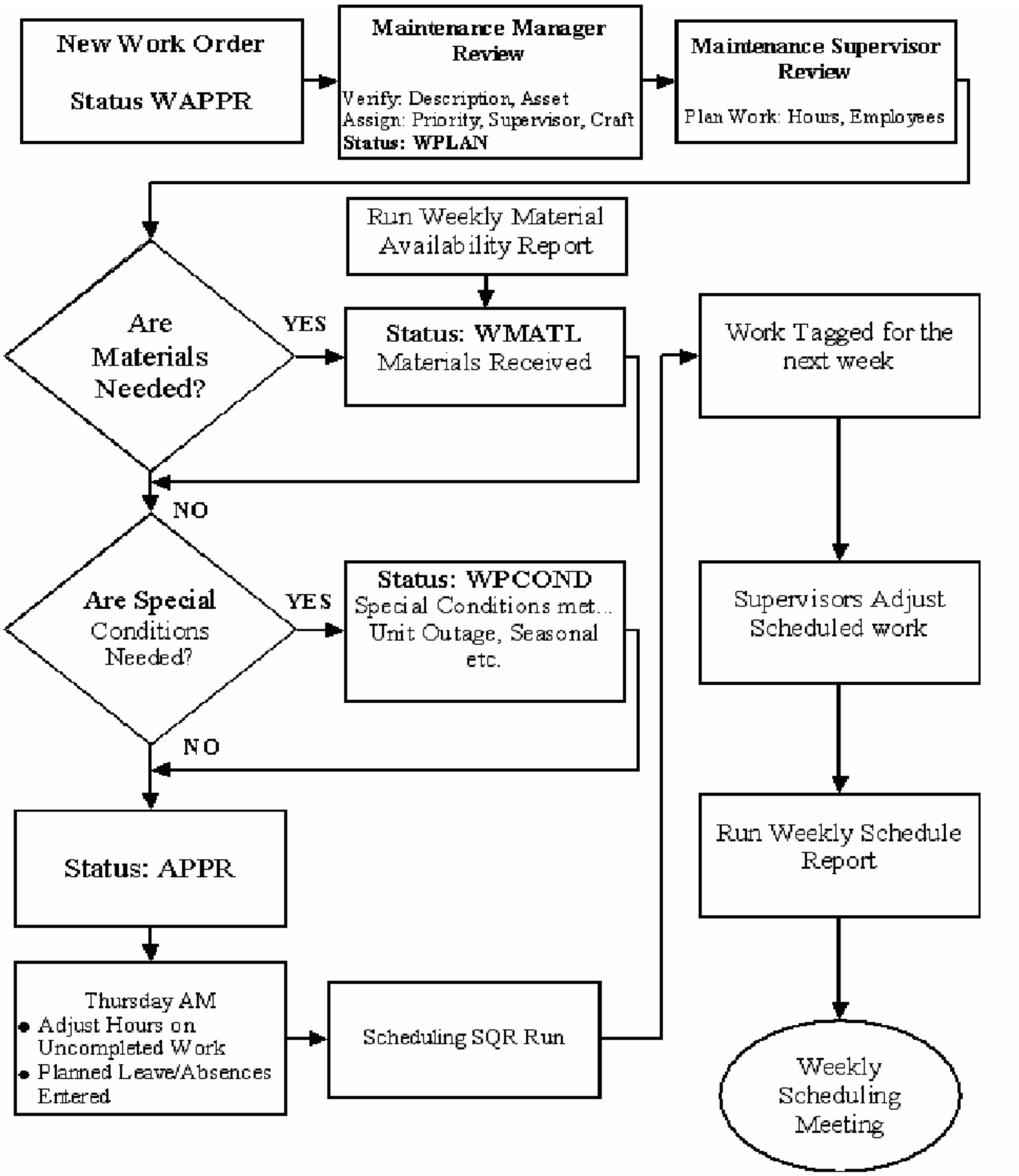
- FIST Volumes 4-1A (Maintenance Scheduling for Mechanical Equipment) and 4-1B (Maintenance Scheduling for Electrical Equipment) list the minimum maintenance standards. These two FIST volumes, in combination with vendor technical manuals and equipment maintenance philosophy, should be used to establish the facility's maintenance program.

- PEBs serve as a notification to facility staff about specific equipment issues or problems that require special attention.

- Variation from FIST volume standards must be documented through the variance process and should be approved by the area/project manager.

- FIST volumes can be found at http://www.usbr.gov/power/data/fist_pub.html

Appendix A - (Sample) Work Flow Process Reference Section 8.0



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Appendix B – Recommended Equipment Priorities Reference Section 8.0

Equipment	Priority
Air compressors	2
Annunciator/sequence of events recorder	2
Arresters	3
Auxiliary piping systems	3
Batteries	4
Battery charger	4
Bearings	3
Bushings	3
Buswork, enclosures, and insulators	3
Circuit breaker switch gear	4
Circuit breakers MCC	3
Circuit breakers, load center	4
CO_2 systems	3
Communication equipment	3
Control circuits	4
Control circuits	3
Cranes and hoists	4
Electric gates and doors	2
Elevators	2
Emergency lighting	2
Exciters	3
Fire detection and alarm systems and CO_2	3
Gates and valves	4
Generating units	4
Generator, emergency	4
Generator, portable	2
Governors	4
Guard gate	3

Equipment	Priority
Hoists	2
Hydraulic turbines	4
IT systems and hardware	2
Meters	3
Motor AC induction	3
Motor AC synchronous	3
Motor vehicle and heavy equipment	2
Motors DC	3
Outlet pipes	4
Packing/mechanical seals	3
Penstock and fixed wheel gates	4
Potheads and stresscones	3
Power cables	4
Pumps	2
Relay, auto transfer	3
Relay, protective	4
Relays	3
Ropes, slings, chains and rigging hardware	4
SCADA systems	3
Shaft couplings	2
Shop fabricated lifting devices and rigging hardware	1
Switch, disconnect manual	3
Switches, disconnect – medium and high voltage	4
Transducers	3
Transformer, station service	4
Transformers	4
Valve and outlet works	3
Voltage regulators	3

Appendix C – Condition Monitoring Recommendations, Reference Section 17.0

The following may be used as a guide to common condition monitoring practices and tools.

Current profiles

- Current profiles of motors and other electrical equipment can be a useful trend to monitor the degradation of equipment.

- Current profiles of equipment can be recorded in CARMA and trended over time.

Flow and pressure

- Fluid flow and pressure can be utilized to determine equipment condition in a variety of different methods.

- Online flow and pressure measurement sensors can identify fouling of heat transfer surfaces, clogging of piping systems, and reduced pumping equipment capacity.

- Flow and pressure measurements and trends can be used as an indicator to the plant staff that a piece of equipment needs to be shut down for maintenance or replacement.

- Noise measurements.

- Visual obstructions.

Infrared Thermography

- Infrared thermography is an excellent way to detect incipient failures within electrical systems. In addition to being required as a preventive maintenance procedure (see FIST Vol. 4-1B), thermography also qualifies as a condition measurement technique.

- Certification as a thermographer by a nationally recognized thermographic institution is recommended.

- Poor and overloaded connections, insulation breakdown, and phase imbalance are just a few examples of the type of electrical problems an infrared camera can identify. Bad generator and motor coils, stators, or rotors can result in an increase in resistance and will produce heat that can be detected with an infrared scan as can loose connections and various insulator problems. Comparisons can be made to previous inspections or to similar equipment to identify where problems exist.

- Infrared thermography also can be used to identify mechanical problems like hot bearings, fouled heat exchangers, misalignments and HVAC system problems. Infrared can also be used to find structural problems such as the source of water leaks.

Training

- The single most important part of a good infrared monitoring program, after the selection of the monitoring equipment, is proper training.

- The greatest limiting factor in an infrared inspection is often the thermographer. The thermographer should be well-trained and should perform scans of equipment regularly to stay current.

- Knowledge of infrared theory, heat transfer principles, weather influences, and radiometer operation and limitations, as well as a thorough understanding of the system being inspected, are all essential.

Computerized Battery Monitoring

- Computerized battery monitors can automatically and continuously monitor station battery conditions including performing periodic testing, thus reducing the need for routine maintenance by staff. Functions generally include:

    - Specific gravity

    - Temperature

    - Connection resistance

    - Internal resistance

    - Periodic load testing

    - Computerized battery monitoring requires expertise in evaluating quantities and test results from the monitor. Some manual preventive maintenance will still be required even with a monitor.

Motor Protective Relays

- Motor protective systems (relays) can be applied to plant auxiliary motors to monitor the condition of important motors and provide continuous on-line indication of critical parameters and alarm for any abnormalities. In some cases, it may be possible to reduce preventive maintenance on motors by use of these protective systems. Functions generally provided with motor protection include:
    - Metering
    - Communications to outside systems
    - Data recording
    - Diagnostics

- Dozens of critical parameters are measured by motor protective systems and maintenance decisions can be made based on this information.

Transformer On-Line Dissolved-Gas Analysis

Reliable and accurate on-line dissolved-gas analysis systems are currently available to monitor transformer insulating oil condition. While this technology is used frequently to closely monitor transformers with known problems, it also can be used as a routine condition-based tool on any oil-insulated transformer. This could not only identify incipient internal problems, it also could reduce or modify the preventive maintenance schedule involving oil analysis. Continuous dissolved gas monitors:

- Require computer-based monitoring and expertise in evaluating sampling results

- May not be cost effective for smaller transformers

- Do not eliminate the need for periodic analysis of physical and chemical quantities of insulating oils – e.g., moisture, dielectric, IFT, acid, Furans, etc.

Carbon Dioxide (CO_2) Cylinder Weighing

- Periodic weighing of CO_2 cylinders is required to ensure adequate CO_2 is available to extinguish generator fires. This is a time-consuming preventive maintenance activity that requires an outage on the CO_2 system. Some facilities have begun continuous monitoring of CO_2 weight by use of load cells.

- Continuous monitoring should be observed daily by operators or alarmed upon loss of CO_2.

- This technique does not eliminate the need to pressure test cylinders.

Lubrication Analysis

- Oil analysis can be an excellent tool to determine the condition of the equipment's lubricating oil and can be used to identify problems in the equipment being lubricated. Wear particle analysis can identify specific problems within the equipment before the wear or particles have time to create/cause an unscheduled outage.

- Oil analysis can be used to determine when a lubricant should be changed or filtered instead of using time-based maintenance.

- For an oil analysis program to be effective, oil samples must be taken that are representative of the oil in the system. A sample taken from the bottom of a sump or skimmed off the top will probably not provide an accurate analysis of the condition of the oil. Ideally, the sample should be taken near the middle of the oil tub while the equipment is in operation in a non-circulating system or from a line upstream of any filter in a circulating system.

- Oil testing must be done on a consistent basis to be effective. Depending on the equipment, tests may be required monthly or quarterly. Test results should be analyzed as soon as possible either by the laboratory performing the tests or by knowledgeable Reclamation experts. Decisions on what maintenance to perform or not to perform can be based on this analysis.

- For more information on oil analysis, see FIST Volume 2-4, Lubrication of Powerplant Equipment.

Run Hour Meters

- Run hour meters on motor-operated equipment that operates intermittently can be a valuable tool to determine when maintenance is required.

- An increase in run time in pieces of equipment such as governor pumps or air compressors indicates a problem in the system such as leaks, restrictions, or worn parts.

- Readings should be taken at least monthly and the values should be trended to watch for any changes. Changes in operational conditions that may cause an increase in run time should be noted.

Runout

(see vibration monitoring and analysis)

Temperature

- Temperature monitoring and trending is a low-cost method to track equipment performance.

- Equipment temperatures can show poor lubrication, cooling system deterioration, bad alignment, or bearing failures.

- Temperature measurement is also a useful indicator of an electrical or mechanical condition such as the load applied to a thrust bearing. As a bearing fails, friction causes its temperature to rise.

Ultrasonic

- Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements.

- UT is an inexpensive and sensitive test for bearings, electrical activity, and air leaks.

Vibration Monitoring and Analysis

- Vibration monitoring and analysis can be a useful part of a preventive or predictive maintenance program. A variety of vibration monitoring systems exists. Some use permanently mounted sensors to continually monitor vibration levels, while other systems require readings to be taken periodically with handheld sensors. The type of system used depends on the equipment being monitored.

- Proximity Probe System ─ A proximity probe is a noncontacting type sensor which provides a dc voltage directly proportional to shaft position relative to the probe. In a hydroelectric powerplant or a large pump generating plant, proximity probes are used to measure the main shaft runout on the turbine/generator or pump/motor. A typical proximity probe system utilizes two probes per guide bearing location, radially mounted and 90 degrees apart. The monitors for the probes are centrally located and are provided with relays for alarm and shutdown, with continuous indication of shaft runout in mils. The optimum alarm and shutdown points will vary from unit to unit. The best way to set these points is experimentally. The runout amplitude should be measured from speed-no-load to full load, noting the normal amplitude of runout, as well as the amplitude at any rough zones. If operation in the rough zone is not desirable, the alarm should be set high enough above normal amplitude to prevent nuisance alarms but low enough to indicate when the unit is in the rough zone.

- If operation in the rough zone is allowed, the alarm point should be set above the maximum amplitude observed at any load. The shutdown point, if one is desired, should be set high enough to prevent nuisance tripping, but low enough to prevent damage to the machine.

- Accelerometer Systems – Several accelerometer-based vibration monitoring systems are available, varying greatly in complexity and capability. Accelerometers are light-weight vibration sensors that, as the name implies, provide an electrical output proportional to the acceleration of the vibration of the machine being checked. Although accelerometers are available that can measure low-frequency vibration (less than 5 Hz), they are primarily used for higher-frequency vibrations such as 1,800 rpm electric motors. Accelerometers are generally ineffective for use on slow speed equipment such as hydroelectric units, since the primary frequencies are low and the critical measurement is displacement.

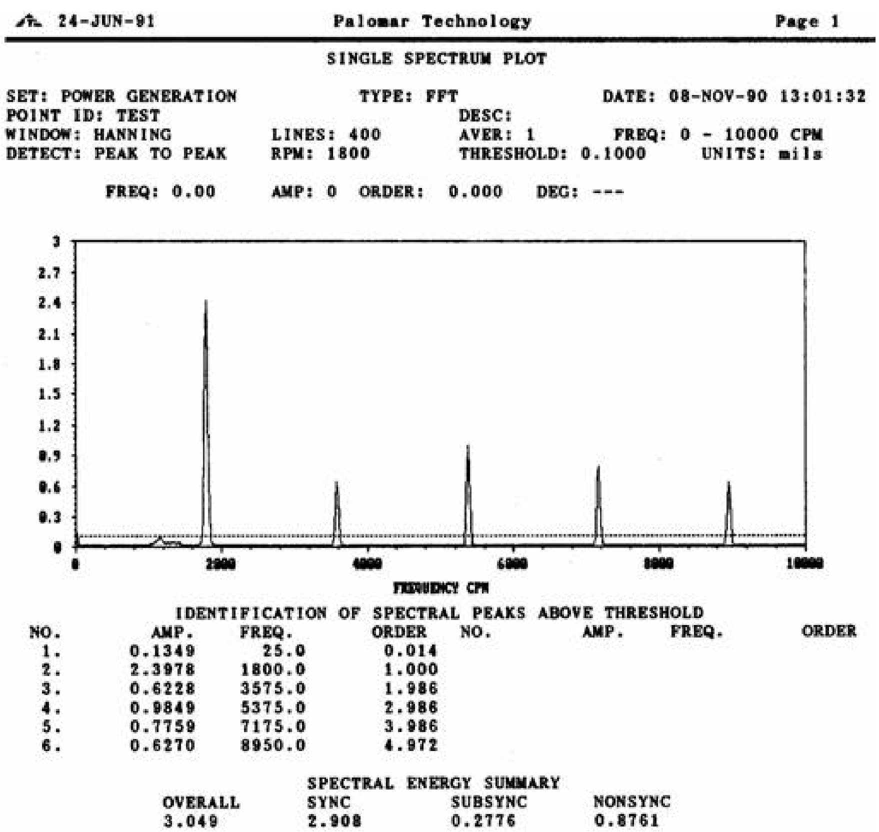
- Accelerometers ─ Depending on the system, accelerometers may be permanently mounted or handheld, or attached with a magnetic base. A typical accelerometer system requires periodic readings to be taken at different points on each machine. The data from these readings is usually stored in a portable recording instrument and downloaded to a computer. This data then must be analyzed and compared to previous readings to determine if there is a significant increase in the vibration levels, indicating an impending failure.

- Signature Analysis ─ A common means of analyzing vibration data is through the use of a spectrum plot. A spectrum plot is an X-Y plot where the X-axis represents the vibration frequency, usually in cycles per minute or cycles per second (Hertz), and the Y-axis represents vibration amplitude in acceleration, velocity, or displacement units. A spectrum plot features amplitude spikes or peaks corresponding to operating frequencies of components of the equipment being tested. The initial plot provides a signature of the vibration for that particular piece of equipment. An increase in the amplitude of vibration at any of the various frequencies, or the appearance of a new spike in subsequent plots, may indicate an operational problem or impending failure.

- Signature Analysis Program ─ A signature analysis program can be helpful in scheduling outages for bearing replacement on small motors and pumps. The amplitude of vibration at the bearing pass frequency will increase as an antifriction bearing starts to fail. Signature analysis is also a good tool for hydroelectric units. Spectrum plots from proximity probes at each of the guide bearings can be used to diagnose problems such as misalignment, unbalance, or draft tube surging. To be effective in dealing with hydroelectric units, spectrum plots should be taken frequently, since vibration levels will vary with the water level of the forebay and tailrace. Subsequent readings can then be compared to readings under the same operating conditions.

- Vibration Analysis ─ In order to perform vibration analysis, a basic understanding of the characteristics of machine vibration and some knowledge of use of the test equipment is required. Training is available from many of the vibration equipment manufacturers.

Condition monitoring points can be established in CARMA for trend analysis.


24-JUN-91 Palomar Technology Page 1

SINGLE SPECTRUM PLOT

SET: POWER GENERATION TYPE: FFT DATE: 08-NOV-90 13:01:32
POINT ID: TEST DESC:
WINDOW: HANNING LINES: 400 AVER: 1 FREQ: 0 - 10000 CPM
DETECT: PEAK TO PEAK RPM: 1800 THRESHOLD: 0.1000 UNITS: mils

FREQ: 0.00 AMP: 0 ORDER: 0.000 DEG: ---

IDENTIFICATION OF SPECTRAL PEAKS ABOVE THRESHOLD

NO.	AMP.	FREQ.	ORDER	NO.	AMP.	FREQ.	ORDER
1.	0.1349	25.0	0.014				
2.	2.3978	1800.0	1.000				
3.	0.6228	3575.0	1.986				
4.	0.9849	5375.0	2.986				
5.	0.7759	7175.0	3.986				
6.	0.6270	8950.0	4.972				

SPECTRAL ENERGY SUMMARY

OVERALL	SYNC	SUBSYNC	NONSYNC
3.049	2.908	0.2776	0.8761

FIGURE 1. SINGLE SPECTRUM PLOT

TABLE C-1. CROSS REFERENCE – EQUIPMENT TO CONDITION MONITORING TECHNIQUE

Equipment	Types of Mechanical Condition Monitoring	Types of Electrical Condition Monitoring
Air compressors	Lube oil analysis, run hours, temperature, ultrasonic, vibration monitoring & analysis	Infrared thermography
Annunciator / sequence of events recorder		Infrared thermography
Arresters		Infrared thermography, operations counter
Auxiliary piping systems		
Batteries		Infrared thermography, computerized battery monitor
Battery charger		Infrared thermography
Bearings	Lube oil analysis, ultrasonic, vibration analysis, temperature, ultrasonic	Infrared thermography
Bushings		Infrared thermography
Buswork, enclosures, and insulators		Infrared thermography
Circuit breaker switch gear		Infrared thermography
Circuit breakers MCC		Infrared thermography
Circuit breakers, load center		Infrared thermography
CO_2 systems		CO_2 cylinder weighing
Communication equipment		Infrared thermography
Control circuits		Infrared thermography
Coupling capacitors		Infrared thermography
Coupling, belt driven	Vibration analysis	
Coupling, direct driven	Vibration analysis	
Coupling, hydraulic	Vibration analysis	
Cranes and hoists	Lube oil analysis, vibration analysis	Current profiles, infrared thermography, motor protective relays
Electric gates and doors		Infrared thermography
Elevators	Lube oil analysis, vibration analysis	Current profiles, infrared thermography, motor protective relays

Equipment	Types of Mechanical Condition Monitoring	Types of Electrical Condition Monitoring
Emergency lighting		Infrared thermography
Exciters (solid state)		Infrared thermography
Fire Detection and Alarm Systems		Infrared thermography
Generating units	Temperature, vibration analysis	Infrared thermography
Generator, emergency	Lube oil analysis, vibration analysis	Infrared thermography
Generator, portable		Infrared thermography
Governors	Flow & pressure, lube oil analysis, run hours, ultrasonic, vibration analysis	Infrared thermography
Hydraulic turbines	Vibration analysis	
Motor AC induction		Infrared thermography, current profiles
Motor AC synchronous		Infrared thermography, current profiles
Motors DC		Infrared thermography Current profiles
Potheads and stresscones		Infrared thermography
Power cables		Infrared thermography
Pumps	Run hours, vibration analysis	Infrared thermography Current trending
Switch, disconnect		Infrared thermography
Transformer, dry type		Infrared thermography
Transformers, oil		Infrared thermography, dissolved gas analysis
Voltage regulators		Infrared thermography

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Appendix D - (Sample) Desktop RCM Process Reference Section 18.0

Job Plan Number: __________________ Craft: ________________________

Job Plan Title: ____

Is the PM Necessary? ☐ Yes ☐ No
If no, explain why? ____
____

Does the Job Plan have a JHA? ☐ Yes ☐ No
If no, complete a JHA for the existing job plan._________________________
____

What is the current schedule of the PM? (week, month, etc)_________________

Should the schedule be changed? ☐ Yes ☐ No
Why? ____
____

What is the priority of the PM? (Circle One)
- 4 – Regulatory Requirement (Dam Safety, OSHA, Record of Decision, etc.)
- 3 – Directly affects power or water delivery
- 2 – Indirectly affects power or water delivery
- 1 – Low priority

Do the FIST volumes cover this piece of equipment? ☐ Yes ☐ No

If yes, does the Job Plan adequately cover the recommendations of the FIST? ☐ Yes ☐ No

If no, make appropriate changes to the Job Plan to address the recommendations of the FIST volume. ____
____

Is there adequate detail in the Job Plan to complete the task? ☐ Yes ☐ No
If no, mark up the Job Plan appropriately. _______________________________
____

Continued on the next page.

Are the correct spare parts listed on the Job Plan? ☐ Yes ☐ No
If no, mark up the Job Plan appropriately. ________________________________

____

Should this or is this Job Plan conducted with other craft
Job Plans? ☐ Yes ☐ No
If yes, list appropriate Job Plan____

____

Could this Job Plan be accomplished with condition monitoring? ☐ Yes ☐ No

Completed By: ____________________________ Date: _______________

Supervisor Review: ________________________ Date: _______________

Changes completed by
CARMA coordinator _______________________ Date: _______________