Outage Effectiveness Measurement Methodology

Technical Report

MAINTENANCE MANAGEMENT & TECHNOLOGY

Outage Effectiveness Measurement Methodology

1004830

Final Report, November 2004

EPRI Project Manager
R. Chambers

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

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Framatome ANP, Inc.

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

CITATIONS

This document was prepared by

Framatome ANP, Inc.
An AREVA and Siemens Company
400 South Tryon Street, Suite 2100
Charlotte, NC 28285

Principal Author
M. Bonasera

Secondary Author
K. R. Barker

Project Manager
M. W. Kelly

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Outage Effectiveness Measurement Methodology, EPRI, Palo Alto, CA: 2004. 1004830.

REPORT SUMMARY

The efficiency of an outage program and the correctness of the outage process are important to the continuous improvement and long-term success of the plant. This report, based on a collective of industry experience, EPRI publications, and power conference data, is an aid to utility and plant management and staff to understanding the outage effectiveness methods and metrics relative to outage planning, execution, and post-outage operations.

Background

The current business environment challenges plants to minimize the cost of planned outages. As such, it is necessary to optimize work task identification, prioritization, planning, and scheduling. Generally, significant effort is expended in preparing for a planned outage. However, all too often, the execution of planned outages is not suitably evaluated to identify successes, shortcomings, and failures.

Measuring success requires that outage goals are established and understood. Further, and arguably more importantly, for an evaluation of the outage to have meaning, both the efficiency at which work is executed and the correctness of the work processes must be evaluated. Thus, it is not sufficient for a task to be completed on time and on budget, but rather, the right task must be executed in the proper manner, at the proper time, and on budget.

Objectives

- To develop a methodology to measure effectiveness of plant outages
- To define metrics for evaluation of outage costs
- To describe the process of critical path analysis and define metrics and methodology for measuring the effectiveness of the outage schedule
- To define the metrics for measuring the effectiveness of work package planning and walk-down completion
- To define the metrics for measuring the effectiveness of the availability and readiness of spare parts and materials
- To define the metrics for measuring the outage completion and post-outage activities

Approach

EPRI outage workshops were conducted in 2003 and 2004 to identify the areas of planned outages that program members considered important and by consensus felt should be covered in this EPRI report. These included:

- Outage cost metrics
- Critical path analysis measures
- Work package planning effectiveness
- Parts and materials availability measures
- Outage effects on post-outage operation

Drawing on research into the collective experience of program members, previous EPRI work on maintenance management, and other published industry knowledge, the project team developed a methodology and metrics for measuring the effectiveness of plant outages covering the previously noted topical areas.

Results

Continued improvement and long-term success are driven by a realistic evaluation of the effectiveness of an outage. This report provides a framework that utility and plant management and staff can follow to gain an understanding of the methodologies and metrics used in evaluating a plant outage. These metrics can then be applied to measure the effectiveness of a fossil plant planned outage.

By defining goals, targets, and performance indicators, this report establishes a standardized approach to outage effectiveness measurement that can be applied across the power industry. It allows users the flexibility to select methodologies and metrics applicable to their needs. The report can be used in conjunction with EPRI's *Outage Management Guidelines for Fossil Fueled Power Plants* (EPRI Destinations 2005 and 2006, Project 69B) for a complete framework for the planning and execution of plant outages.

EPRI Perspective

Developing a standardized methodology for measuring the effectiveness of plant outages will guide continuous improvement of outage execution.

This report is part of EPRI's development efforts under the Maintenance Management and Technology Program, Program 69, Outage Management Project Set. This project set is focused on providing the necessary tools to assist plants with lowering outage costs, reducing outage duration, extending outage frequency, improving safety, and increasing plant operational flexibility.

Keywords

Outage
Metrics
Outage cost
Critical path
Work package

CONTENTS

1 INTRODUCTION

Outage results are used to evaluate the degree of success in achieving management's outage objectives. Such an evaluation must consider not only the efficiency of various aspects of the outage program but also the correctness of the outage processes. Continued improvement and long-term success are driven by a realistic evaluation of performance effectiveness.

This report identifies a methodology and key parameters for measuring the effectiveness of a fossil plant planned outage. The metrics are intended not only to measure success but also to guide continuous improvement of the outage planning and execution process, which will be described in detail in 2005 in *Outage Management Guidelines for Fossil Fueled Power Plants*.[1] A glossary of outage-related terms is included in Section 2 of this report.

1.1 Purpose

The purpose of this report is to aid utility and plant management and staff in understanding outage effectiveness methods and metrics relative to outage planning, execution, and post-outage operations. It focuses on goals, targets, and performance indicators to provide a basis for a standardized approach to outage effectiveness measurement.

The methodology and metrics are applicable to scheduled outages at any type of power plant and are recommended for any group or individual involved in evaluating the success of an outage.

The usefulness of the methodologies and metrics presented will vary, based on the applicability to the user. Such applicability is dependent on user-specific factors, such as the tracking process or management system used. Users should select from this report the methodologies and metrics applicable to their needs.

It is recognized that because of the great diversity of power plant generating missions, varying capacities, availability requirements, staffing levels of site and corporate resources, levels of reliance on original equipment manufacturers (OEMs) and contractors, the purpose of a particular outage, and a number of other factors, not all the methods or metrics outlined herein will have equal weight for all users.

[1] *Outage Management Guidelines for Fossil Fueled Power Plants*. EPRI Destinations 2005 and 2996 Project 69B (Project 052521). Palo Alto, CA.

This report identifies outage effectiveness methods and metrics applicable to:

- Outage costs
- Critical path analysis
- Work package planning and walk-down completion
- Spare parts and materials availability and readiness
- Outage closure and post-outage operation

1.2 General

Performance effectiveness is measured both qualitatively and quantitatively by observation of work activities, inspection and monitoring of equipment performance, corrective actions, test and operating data, cost reports, retention of as-found and as-left data, and in short, by examining all aspects of outage conduct. Measurements are trended to identify barriers to achieving goals and objectives so that needed improvements can be identified and implemented. Improving outage effectiveness will contribute to:[2]

- Improved safety
- Greater post-outage unit reliability
- Support of the resolution of any environmental issues
- Minimization of unplanned capacity loss
- Prevention of significant equipment failures
- Reduction of the cost of maintenance
- Incorporation of new technologies and advanced outage processes
- Management of the risk associated with outage activities
- Improved human performance
- An improved work culture that supports continuous improvement

There is no single performance metric that can suffice to evaluate the effectiveness of an outage. Many power generators conduct internal evaluations on various aspects of outage improvement. This report is an effort to establish a methodology for measuring fossil plant outage effectiveness that can be applied across the industry.

1.3 Use and Application Guidance of Outage Metrics

In general, when establishing outage metrics using the guidance provided herein, there should not be an expectation that every described metric should be used and tracked. The intent of this report is to provide a listing and description of metrics from which to choose. Users of this report

[2] *Outage Management Benchmarking Guideline*, EPRI, Palo Alto, CA: 2003. 1004383.

should have a pre-assessment of the performance of the organization during completed outages. In those areas where key activities are required to be performed or in areas of observed weaknesses, there should be a selection of one or more metrics that would adequately measure a level of success for the organization. In selecting metrics, it is important that the focus be on the total organization as much as possible to gain buy in. Selecting too many metrics can result in a negative impact due to the difficulties in tracking and collecting the information.

2
GLOSSARY

AF: Availability factor. The sum of all service hours, reserve shutdown hours, pumping hours, and synchronous condensing hours in a given period, expressed as a percentage of the total number of hours in the period.

AH: Available hours. The sum of all service hours, reserve shutdown hours, pumping hours, and synchronous condensing hours in a given period.

Air Incidents: An event in which an air permit compliance requirement is not met. This can be an emission exceedance, failure to meet a compliance deadline, or failure to provide a written report or notification.

CEF: Capital equipment factor. The ratio of the equivalent availability factor to the annualized capital equipment cost.

Code of Accounts: A list of all account names and numbers used in a company's general ledger.

Critical Path: The sequence of activities upon which the overall completion date of the outage is dependent. Delay in the critical path has a direct impact on the schedule of the entire outage.

EAF: Equivalent availability factor. Available hours minus the sum of equivalent planned derate hours, equivalent unplanned derate hours, and equivalent seasonal derate hours, expressed as a percentage of the total number of hours in the period.

EFDH: Equivalent forced derate hours. The sum of all unplanned derate hours, each having been transformed into equivalent full outage hours. Calculated as the Σ (unplanned derate capacity x derate duration ÷ net maximum capacity).

EFOR: Equivalent forced outage rate. The sum of forced outage hours and equivalent forced derate hours expressed as a percentage of the sum of forced outage hours, service hours, synchronous hours, pumping hours, and equivalent forced derate hours during reserve shutdowns.

EH&S: Environmental, Health, and Safety.

EPA: Environmental Protection Agency.

EPDH: Equivalent planned derate hours. The sum of all planned derate hours, each having been transformed into equivalent full outage hours. Calculated as the Σ (planned derate capacity x derate duration ÷ net maximum capacity).

EUDH: Equivalent unplanned derate hours. The sum of all unplanned derate hours, each having been transformed into equivalent full outage hours, calculated as the Σ (unplanned derate capacity x derate duration ÷ net maximum capacity).

ESDH: Equivalent seasonal derate hours, calculated as (net maximum capacity minus net dependable capacity) x (available hours ÷ net maximum capacity).

Early Finish Date: The earliest time an activity can be completed without using any project total float.

Early Start Date: The earliest time an activity can be started without using any project total float.

Environmental Violations: Formal, written notification from a regulatory agency that a federal, state, or local environmental law, regulation, standard, or permit condition has been violated or that an environmental event has resulted in the payment of a fine, penalty, or settlement.

FOF: Forced outage factor. The sum of all forced outage hours in a given period expressed as a percentage of the total number of hours in the period.

FOH: Forced outage hours. The sum of all hours experienced during unplanned (forced) outages and start-up failures.

Float: The units of time available to an activity before it impacts the critical path. The sequence of activities with the least amount of float (≤0) is the critical path.

Hammock: The process of summarizing individual activity durations into a single activity.

Late Finish Date: The latest time an activity can be completed without delaying the project.

Late Start Date: The latest time an activity can be started without delaying the project.

Lead and Lag Times: The time duration between successive activities.

Level 1 Schedule: The outage Level 1 Schedule provides an overall view of the outage plan, schedule, and key milestones, including shutdown and startup. This schedule provides baseline versus current projection capability and serves as the basis for periodic management reviews. This schedule will show starting dates and ending dates for major activities planned for the outage.

Level 2 Schedule: The outage Level 2 Schedule is a summarization of outage work activities with sufficient detail to define the critical path and to provide a basis for monitoring and controlling actual versus planned work performance.

Level 3 Schedule: This schedule is a detailed, logic-based schedule developed for projects or other complex work evolutions in support of summary work activities in the Level 2 schedule. The purpose is to provide the project manager or outage project lead with sufficient understanding of job interrelationships and the requirements of day-to-day management in order to anticipate and avoid potential problems. Detailed schedules are generally developed independently and later merged to form the Integrated Outage Schedule.

Milestone: A significant or important event of zero duration that summarizes the start or completion of several related activities or decisions.

NMC: Net maximum capacity.

OSHA: Occupational Safety and Health Administration.

Outage Scope: Scope of work tasks planned or performed during the outage.

PH: Period hours. The number of hours in a given period.

Planner: Individual responsible for taking a work order and identifying the task, material, resources, time required, and budget necessary to complete a work order.

Predecessor/Current/Successor Tasks: Tasks that are sequentially associated whereby the current task is associated in the schedule with a prior task and a following task.

Technical Resources: Resources that include skilled and unskilled craft labor, tools, and materials.

Scheduled Outage: An outage that is scheduled well in advance and is of a predetermined duration. Scheduled outages might last for several weeks.

SOF: Scheduled outage factor. The sum of all hours experienced during planned outages, maintenance outages, and scheduled outage extensions of any maintenance outage and planned outage expressed as a percentage of total number of hours in a period.

SOH: Scheduled outage hours. The sum of all hours experienced during planned outages, maintenance outages, and scheduled outage extensions of any maintenance outage and planned outage.

SR: Starting Reliability. The number of actual unit (or equipment and/or system) starts expressed as a percentage of the number of unit (or equipment and/or system) start attempts.

Task List: A compilation of activities or individual work tasks.

UOF: Unplanned outage factor. The sum of all hours experienced during unplanned (forced) outages, start-up failures, maintenance outages, and scheduled outage extensions of any maintenance outage expressed as a percentage of total number of hours in a period.

UOH: Unplanned outage hours. The sum of all hours experienced during unplanned (forced) outages, start-up failures, maintenance outages, and scheduled outage extensions of any maintenance outage.

Work Breakdown Structure (WBS): A chart used to list tasks for each project. It separates tasks and shows time and resources required to complete them. The chart is then used to develop the schedule.

Work Package: The file that contains all documents, including work order, task list, safety plan, environmental plan, material list, schedule, budget, and resources required to complete the work.

3 OUTAGE COSTS

3.1 Outage Budget

The outage budget and cash flow projections are generally established months prior to final outage planning and outage start. Tracking of actual outage costs is performed to measure the effectiveness of outage planning and estimating. Outage cost control is managed by performing detailed tracking, trending, and analysis of outage costs during the outage. Cost control allows for recovery plans to be developed if costs begin to vary markedly from the budget.

Standard: Actual outage costs are consistent with budgeted outage costs. Desired outage ratio ≤1.06[3]

Measure: Outage Cost Ratio = Actual cost (including all change orders) ÷ Outage budget

Standard: Change order costs are consistent with associated budget changes. Desired change order ratio ≤1.02[4]

Measure: Change Order Ratio = Actual cost ÷ (Budgeted cost at pre-outage scope freeze plus cost of approved changes)

3.2 Business Cases

The cost of a plant outage is a measure of the expenditure of capital, resources, and other assets against the benefit(s) realized from that expenditure (that is, value). The benefit realized from an outage is far greater than the common notion of simply fixing the plant to run another day. The money and effort spent on an outage are used to buy:

- Recovered lost megawatts
- New, additional megawatts
- Reduced heat rate
- Improved reliability
- Avoided O&M costs
- Reduced capital equipment costs

[3] *Outage Management Benchmarking Guideline*, EPRI, Palo Alto, CA: 2003. 1004383.
[4] Ibid.

When evaluating effectiveness of outage costs, the processes used to control outage costs should be understood as either providing cost management or providing added value.

3.2.1 Megawatt Recovery

The recovery of lost megawatts (MW) is measured by a performance test. The post-outage net plant (or net unit) capacity measurement is compared to the pre-outage net plant (or net unit) capacity measurement. Capacity recovery unit cost is a measure of the value of the outage relative to restoring generation capacity. Capacity recovery efficiency is a measure of success in realizing capacity recovery opportunity. Capacity recovery effectiveness is a measure of how well the outage cost achieves efficient recovery of megawatts.

Measures: Capacity recovery, ΔMW = Post-outage MWnet minus pre-outage MWnet

Capacity recovery unit cost = Actual total outage cost ÷ ΔMW

$$\text{Outage efficiency}\Big|_{\text{Production Recovery}} = \frac{\Delta\text{MW}}{\text{Rated MW}}$$

$$\text{Outage effectiveness}\Big|_{\text{Production Recovery}} = \frac{\text{Actual total outage cost}}{\text{Outage efficiency}\Big|_{\text{Production recovery}}}$$

3.2.2 Megawatt Gain

The gain of additional megawatts can be estimated by an engineering calculation based on the specific upgrade project undertaken during the outage and measured by a performance test. Depending on the project, manufacturer guarantees might be included in procurement contracts for the project. The post-outage measurements are compared to the pre-outage measurements. Capacity improvement unit cost is a measure of the value of the outage relative to increasing generation capacity. Capacity improvement efficiency is a measure of success in realizing capacity improvement opportunity. Capacity improvement effectiveness is a measure of how well the outage cost achieves efficient gain of additional megawatts.

Measures: Capacity improvement, ΔMW = Post-outage MWnet minus pre-outage MWnet

Capacity improvement unit cost = Actual total upgrade project cost ÷ ΔMW

$$\text{Outage efficiency}\Big|_{\text{Production Improvement}} = \frac{\Delta\text{MW}}{\text{Rated MW}}$$

$$\text{Outage effectiveness}\Big|_{\text{Production Improvement}} = \frac{\text{Actual total outage cost}}{\text{Outage efficiency}\Big|_{\text{Production improvement}}}$$

3.2.3 Heat Rate

Heat rate is the measure of production efficiency, generally quantified as net plant (or unit) heat rate (NPHR) measured in BTU/kW-hr (KJ/kW-hr) by performance test. Post-outage measurements are compared to pre-outage measurements. The outage effectiveness measure on production efficiency quantifies the unit cost of such efficiency improvements. Heat rate effectiveness is a measure of the value of the outage relative to generation production.

Measures: Production efficiency = NPHR

$$\text{Outage efficiency}\,\big|_{\text{Production Efficiency}} = \frac{\text{NPHF}_{\text{Pre-outage}} - \text{NPHF}_{\text{Post-outage}}}{\text{EAF}_{\text{Pre-outage}}}$$

$$\text{Outage effectiveness}\,\big|_{\text{Production Efficiency}} = \frac{\text{Actual total outage cost}}{\text{Outage efficiency}\,\big|_{\text{Production Efficiency}}}$$

3.2.4 Reliability

Reliability is a good measure of continuing improvement. Pre-outage and post-outage comparisons must be made; measures are then weighed against total outage cost. Reliability improvement efficiency is a measure of success in realizing reliability improvement opportunity. Reliability improvement effectiveness is a measure of how well the outage cost achieves efficient improvement in reliability. Reliability effectiveness is therefore a measure of the value of continuing improvement, indicated by constant or improving reliability while lowering unit production costs. Reliability effectiveness is a measure of the value of the outage relative to improvements in reliability of generation production.

Measures: Availability factor (AF) = AH ÷ PH x 100%

Equivalent availability factor, EAF = (AH – EPDH – EUDH – ESDH) ÷ PH x 100%

$$\text{Outage efficiency}\,\big|_{\text{Reliability}} = \frac{\text{EAF}_{\text{Post-outage}} - \text{EAF}_{\text{Pre-outage}}}{\text{EAF}_{\text{Pre-outage}}}$$

$$\text{Outage effectiveness}\,\big|_{\text{Production Efficiency}} = \frac{\text{Actual total outage cost}}{\text{Outage efficiency}\,\big|_{\text{Production efficiency}}}$$

Labor hours per year (spent on maintenance due to reworks or unplanned corrective maintenance compared to planned maintenance activities)

OSHA citations per year (versus a set goal)

EPA citations per year (versus a set goal)

3.2.5 Operations and Maintenance (O&M) Cost Avoidance

The avoidance of operations and maintenance (O&M) cost and the resulting benefit are measured in efficiency and effectiveness terms. Post-outage measurements are compared to pre-outage measurements. The unit cost of O&M cost avoidance is a measure of the value of the outage relative to O&M costs. O&M cost avoidance efficiency is a measure of success in realizing O&M cost reduction opportunity. Capacity improvement effectiveness is a measure of how well the outage cost achieves efficient gain of additional megawatts.

Measures: O&M cost differential, ΔO&M = Post-outage minus pre-outage O&M costs

O&M cost avoidance unit cost = Actual total outage cost ÷ ΔO&M

$$\text{Outage efficiency}\big|_{\text{O\&M Cost}} = \frac{\Delta\text{O\&M}}{\text{Pre-outage O\&M cost}}$$

$$\text{Outage effectiveness}\big|_{\text{O\&M Cost}} = \frac{\text{Actual total outage cost}}{\text{Outage efficiency}\big|_{\text{O\&M Cost}}}$$

Productivity measures the available generation per unit of labor and material costs (that is, O&M). This measure is an indicator of the individual contribution of employees. Pre-outage and post-outage comparisons must be made; measures are then weighed against total outage cost.

Measures: Productivity = Available hours x available capacity ÷ Total O&M costs

Equivalent forced outage rate:

EFOR = (FOH + EFDH) ÷ (FOH + SH + EFDHRS) x 100%

Equivalent unplanned derate hours:

EUDH = Unplanned derate hours x derate capacity ÷ NMC x 100%

Unplanned outage hours (UOF) = UOH ÷ PH x 100%

Forced outage factor (FOF) = FOH ÷ PH x 100%

Scheduled outage factor (SOF) = SOH ÷ PH x 100%

Reliability effectiveness = EAF ÷ annual non-fuel O&M cost

3.2.6 Capital Equipment Cost

The capital investment needs to be measured on the basis of realized equipment improvements. Continuing improvement is indicated by constant or improving reliability while lowering annualized capital equipment investments. Keep in mind, however, that this measure is meaningful only when viewed over a period of several years because this measure is heavily influenced by deferments. Pre-outage and post-outage comparisons must be made; measures are then weighed against total outage cost.

Measures: Availability factor (AF) = AH ÷ PH x 100%

Equivalent availability factor (EAF) = (AH – EPDH – EUDH – ESDH) ÷ PH x 100%

Capital equipment factor (CEF) = EAF ÷ Annualized capital equipment cost

4
CRITICAL PATH ANALYSIS

4.1 General

The critical path method (CPM) is widely used to schedule outage work. The CPM schedule is the key management tool for planning the work, scheduling time and resources, tracking progress, and calculating the effectiveness of the overall outage process. Effectiveness is determined by the following metrics:

- Was the outage completed on schedule?
- Was the outage completed within budget?
- Was the outage work completed with a minimum of disruptions?
- Were the information, equipment, materials, people, and tools available when needed?
- Was the outage performed with the safety of personnel and plant equipment in mind?
- Was the planning, scheduling, and tracking system used in a timely and proactive manner to isolate problems?

In general, time is of the essence for outage work because getting back on line as soon as possible and improving the availability of the plant to produce power creates revenue. In multi-plant systems, the end of one outage allows other plants to come down for their respective scheduled outages.

The schedule is the primary tool for managing the outage. The following is a discussion of considerations for implementing an effective scheduling program.

4.1.1 Discussion

CPM analyses use computers and software created especially for that purpose. Software is available commercially that will meet the needs of the outage planner. There are a number of scheduling software programs available, and the selection of the software to be used will depend on an assessment of the overall needs of the outage management and reporting effort.

These needs might include:

- Ability to apply multiple calendars (for example, daily, hourly) and add shift work
- Ability to apply resources, such as craft labor and equipment usage, to activities

- Ability to apply budgets and actual costs to each activity
- Ability to apply work breakdown structure (WBS) codes or other intelligent codes to each activity
- Ability to apply and associate lead and lag times to predecessor/current/successor tasks
- Ability to create different reports and charts from the data for analysis and presentation purposes
- Ability to calculate the start and end dates, free float, and total float in the schedule analysis
- Ability to hammock activities, that is, to be able to collect individual durations of sub-activities into a summary activity
- Ability to compare actual schedules with target schedules

Having good software and people to operate it is only part of the equation for successful implementation. The following points should be seriously considered by any outage organization that wants a successful scheduling effort:

- A person experienced in project controls should manage the scheduling effort and, on a large outage, should have assisting subordinates.
- The CPM schedule should be comprehensive so that it includes all areas, including pre-outage planning.
- The schedule should integrate all work into one network document; there should not be separate schedules run by different departments or entities, such as subcontractors.
- All managers and supervisors involved in the work need to provide input to the schedule, accept responsibility and accountability for their portions and activities, and demonstrate buy in.
- Planning should take place early with frequent coordination in advance of the outage to make sure that all aspects of the outage work have been considered.
- Because events rarely go as smoothly as planned, the schedule should be seen as a living tool to be revised as conditions dictate to take timely corrective action or to achieve work-arounds when necessary.
- The schedule should incorporate levels of detail so that the right information is provided to the right people. Generally, three levels of detail will suffice: Level 1 schedule - top management, Level 2 schedule - second tier management, and Level 3 schedule - work package level.
- A fourth level might be needed for large work packages, and an action or task list using spreadsheet software might be needed.
- The schedule should have sorting capability so that only relevant information is given to those who need it.
- Reports should have a windowing capability so that specific time frames might be viewed or printed.

- The schedule should be a tool to assist management in identifying problems with achieving schedule dates, allocating resources, and missing budgets early on so that action can be taken to correct or lessen the impact of these problems.
- The schedule should encompass the work package system but not replace it. Generally, work packages will go into greater detail.
- The schedule should be updated daily when time is the critical factor. With outages, time generally is critical.

4.2 Method of Determining Critical Path

The basic premise of CPM is that there is one longest time path from start to finish of a project. This path consists of numerous activities tied together in a network. The basic elements of the network establish the critical path of the project. These elements include the activity, the expected duration of the activity, the predecessor activity or activities, and the successor activity or activities. In addition, there might be lead times required or desired between the completion of one activity and the start of the next activity. Likewise, there might be lag times between the completion of an activity and the start of another activity. Another input can be constraint dates, when an activity will be scheduled to start (or complete) on a specific date regardless of how the network calculates the start (completion) date.

Once the previous data are input into the network, the computer calculates all paths from start to end and returns both early start and early finish dates for each activity. It then does a comparison with a finish date (constraint) and does a backward calculation to establish late start and late finish dates. The early dates represent the earliest time an activity can be started and/or completed without using any project total float. The late dates represent the latest dates the activity can be started or completed without delaying the project. Thus, every activity will have associated with it four dates: early start, early finish, late start, and late finish. The path (or paths) with the least amount of total float is the critical path.

If no completion date is set for the outage, the longest path will have zero total float. If there is a designated completion date, the longest path might have positive or negative float. Generally, the first schedule runs will result in negative float, and the schedule logic, durations, or inter-ties (restraints) must be adjusted to remove this negative float.

4.2.1 Float

Float is the allowable time to accommodate delay between finish and start. The allowable time between individual activities is called free float, and the allowable time between all individual activities linked in the chain is called total float. The chain of activities with the least amount of total float is called the critical path. When total float goes negative, there is the possibility of the outage being delayed. When the word *float* is used without describing it as either free float or total float, it is generally understood to mean total float.

Float is often misunderstood and misapplied. For example, a supervisor might see that he has 10 days of float associated with an activity and so is not concerned that he is behind schedule. But if he uses up those 10 days of float, there is nothing left for all the succeeding activities to fall back on. Hence, float should be dealt with the same way contingency is used in budgeting money. If there is no contingency available and the project is still in the early stages, experience would tell us that a cost overrun is highly probable in the future. Likewise, if the entire float has been used up or mostly used up in all the paths leading up to completion, it is probable that the outage will not finish on time. Therefore, it is preferable to establish some float contingency.

This contingency is most readily calculated as a percentage of the remaining duration of the planned outage. For example, a 10% float contingency on a 40-day planned outage would mean any activity that had fewer than three days' float after 10 days into the outage (30 days remaining x 10%) would be considered critical. Likewise, after 20 days, any activity with float fewer than two days would be considered critical.

4.4.2 Resource Loading

CPM schedules can be resource loaded; that is, resources might be associated with individual activities, and the schedule will create a resource usage profile. Resources can be anything, but typically, they will be craft personnel needed to do the work. During the early planning stages, the outage manager and project planners will generally be aware of the critical trades in the area. It might be instrumentation and control (I&C) technicians, electricians, pipe fitters, boilermakers, millwrights, welders, or one of several other crafts. Resources required should come from analysis of the developed work packages.

After the critical resources are loaded into the schedule, computer analyses will create a usage profile. Once the profile is created for a craft, adjustments can be made in start and finish sequencing to level the need for certain types of craft. It would make no sense, for example, to require 25 pipe fitters on week one, 10 on week two, and 18 on week three. Obviously, it would be better to average out the need and have a steady number of resources during the bulk of the work, which in this example would be 18. By shifting some activities from week one to week two, the need for pipe fitters is leveled. This can be accomplished by inserting lead and lag times to the restraints for the activities to be shifted.

Another type of resource might be the use of a major piece of equipment, for example, the overhead traveling bridge crane in a turbine hall. This major piece of equipment might have to be shared with a turbine overhaul, replacement of condenser tubes, pumps, and so on. If the demand for this crane becomes too high, other pieces of lifting equipment might have to be brought in or activities shifted to accommodate crane availability. Crane usage and access requirements should be discussed at the daily meetings.

Resource planning requires detailed planning at the work package level, which is time consuming but will pay off in reduced labor costs if done properly and early.

4.2.3 Priorities

During the early planning stages, the O&M personnel at the plant will generally have a good idea of the equipment that needs the most attention during the planned outage. It is recommended that priorities be established for each work package. Priorities should be based on the plant work management system of priorities to capture the cost and outage budget in the work plan.

If the plant does not have an established system of priorities, a simple ABC system works well. Priority A would be for those work packages that are absolutely required to be done during the outage. Priority B would be for those packages that need to be done and could be accomplished during the outage. Priority C would be for those packages that the plant would like to do but can be postponed if need be or done with the plant in service after the outage.

By establishing priorities together with resource loading, scheduling of activities can be greatly enhanced. Priorities can be coded and associated with the activities, and then sorts can be made on different priorities.

4.2.4 Budgeting

Budget limits are generally established in long-term plans. Work scope and priorities should be built to work within the budget limits. Starting with the work packages, budgets can be applied to the schedule and profiled similarly to resources. Of course, the budget expenditures might not match up with actual cash flow simply because some items will have to be purchased long before they are actually scheduled to be installed. Most materials should be on the plant site at least 30 days before needed so they can be inspected, tagged, and stored for use. If an item is damaged, it can be returned and replaced. If a delivery is short, those items can be received in time.

4.2.5 Work Breakdown Structures (WBS)

WBS was alluded to previously as one type of code that could be applied to each scheduled activity that would enable sorting and reporting of groups of items for management of the work. It is not the intent here to go into great detail on this subject other than to mention this as a way of manipulating data in an intelligent fashion to provide for in-depth insight into what is happening and to analyze trends. A WBS is a coding scheme that sorts the work hierarchically into logical sub-groupings of physical space, function and/or system, and organization. The latter is sometimes called the organizational breakdown structure (OBS).

4.2.6 Metrics

The CPM schedule provides the following ways to measure work accomplished:

- **Counting**
  The simplest method is counting items completed compared with a scheduled target of items completed. This gives a big picture indication of how much has been accomplished. Counts can be displayed in chart form and curve form, the latter giving a sense of trends. Distortion can occur if there are a few large items (for example, a turbine overhaul) and a lot of smaller items because they all count individually as one item. The count could include categories for milestones, projects, tests, or tasks.
- **Percent Complete and/or Weighted Value**
  If the schedule has been loaded with budgeted costs, a weighted value for each activity (work package) as a percent of the whole outage can be calculated. By estimating the percent complete of each activity and multiplying this percent by its weighted value and then summing all these figures, an estimated percent complete of the outage can be calculated. By comparing this figure with the original or target schedule of percent completions, an indication of where the project stands can be estimated. This is more accurate than just counting activities completed because it weighs or values activities based on their cost.
- **Earned Value**
  Earned Value Reporting takes into consideration three variables:
  - Budgeted Cost of Work Performed (BCWP)
  - Budgeted Cost of Work Scheduled (BCWS)
  - Actual Cost of Work Performed (ACWP)

  A Cost Variance (CV) is calculated by subtracting the ACWP from the BCWP. Positive numbers are good; negative numbers are bad. For example:

  $$CV = BCWP - ACWP$$

  A Schedule Variance (SV) is calculated by subtracting the BCWP from the BCWS. Positive numbers are good; negative numbers are bad. For example:

  $$SV = BCWP - BCWS$$

  A Cost Performance Index (CPI) is calculated by dividing the BCWP by the ACWP, and a Schedule Performance Index (SPI) is calculated by dividing the BCWS by the BCWP. Ratios above 1.0 represent good performance and below 1.0 represent bad performance:

  $$CPI = BCWP \div ACWP$$

  $$SPI = BCWP \div BCWS$$

Most project control experts agree that these figures will give the most accurate estimate of outage performance when compared with simple counting or the weighted value system. However, earned value reporting does require that actual costs be collected against each activity, and therefore, a cost control system must be in place to capture costs by the WBS.

These earned value calculations also allow the estimation of costs at completion. Knowing the Budget at Completion (BAC), the Estimate at Completion (EAC) can be calculated using the following formula:

$$EAC = \frac{(BAC - BCWP)}{CPI} + ACWP$$

This equation assumes that the CPI will not change.

In summary, earned value calculations provide the most accurate assessment of where the project stands. However, it takes more time and resources to develop the network, assign codes, assign costs, track actual costs, and produce reports than with simpler methodologies.

4.3 Guidelines for Implementation

In the previous section, the use of computer-based systems for planning, scheduling, measuring progress, and managing costs for outages was discussed, and some metrics were suggested for use in determining effectiveness. This section discusses the practical considerations and the associated metrics of implementing a system that works.

4.3.1 Pre-Outage Planning

The overriding goal is to complete the outage on time and within budget and in such a manner that events go smoothly with few hitches and no accidents. Planning encompasses those activities necessary for completing the work, which means answering the following questions:

- What outage work is needed, and what priorities are associated with each work package?
- What long lead time items need to be procured?
- Who is responsible for getting each part of the work done?
- What resources are needed to accomplish the work?
- What pre-outage inspections and testing need to be done?
- What testing and startup activities are related to each work item?
- What safety concerns are related to each work package?
- Will some or all of the work be subcontracted?
- What subcontractor input is required at what stage in the planning process?
- What environmental testing is required?

- What completion testing or boiler tuning is necessary?
- What are the hazardous waste management requirements?

One metric that is hard to quantify is how well the planning process was conducted. How smoothly the outage goes will be a reflection of how well it was planned. Weekly meetings with key plant personnel should start several months in advance of the outage. Early meetings should include the plant manager, operations manager, maintenance manager, planning supervisor, and the designated outage manager.

The first few meetings will be to define the goals and scope of the outage, identify items that need to be procured early, and decide on what work needs to be subcontracted and what work will need a vendor representative present to provide guidance. An outage organization should also begin to be developed during the early meetings.

After the outage organization is in place, planners should begin looking into developing the work packages as the outage scope is identified. Planners need to be identified early enough to begin preparation of work packages. (See Section 5 on work packages.) Each work package should be assigned a WBS code and a schedule activity number. Resources required to perform the work should be identified so they can be loaded into the CPM. Budgets should also be developed for each work package and loaded into the CPM. The outage manager, planning manager, area coordinators, and planners need to meet formally on a weekly basis and informally, as needed, on a daily basis.

For major work, it might be necessary to bring in an outside contractor. This type of work would include a major turbine overhaul, major boiler repairs, condenser modifications, and so on. There might also be a need to use personnel from other plants or from a central organization as part of the team.

The CPM schedule should be started and run concurrently with the planning process. The use of prior outage schedules would be a place to start if they are available.

The final outage schedule should be available several weeks before the outage starts. This schedule will be the target schedule against which future work activity will be compared. A final meeting with the plant manager and his immediate subordinates should be held a week before the outage to review all plans and the schedule so that all parties are informed of the specifics of the outage.

4.3.2 Outage Implementation

Once the outage starts, it is important that tight control of the work and good coordination take place among team members. Daily meetings and action lists are typically used to coordinate the work. The meeting should be conducted by the outage manager, and action items should be maintained by the planning group. Each planner should be given an opportunity to discuss the work going on under his or her responsibility, what problems there are, and how he or she plans to resolve the problems. These meetings should be held before the work shift starts and last about a half hour. The planning group should update the action list and have it available for the next meeting. These meetings should not be allowed to turn into problem-solving sessions, where solutions are not readily evident at the time. Problem-solving sessions should take place after the meeting with only the needed personnel attending.

Once a week, an overall outage meeting should be held to discuss performance. The CPM schedule should have been updated, sorts given to people in the level of detail they need, and the focus should be on the bigger issues. This meeting will generally be attended by key plant personnel as well as the outage team.

An important metric will be how effective these meetings are in coordinating the work; resolving problems; identifying contingency plans; and meeting schedule, cost, and safety objectives.

5

WORK PACKAGE PLANNING AND WALK-DOWN COMPLETION

5.1 General

The outage work package (OWP) defines the scope of work, labor and technical resources, materials for installation, reference materials, budget, time schedule, safety issues, pre-outage inspections, post-outage testing, and work sequences for a segment of the work to be completed during the outage period. OWPs should encompass the work associated with large and medium-sized efforts, and the work of smaller, similar-sized items might be combined into one work package. The outage manager and his team should define the scope of the overall outage work packages during the early planning stages.

OWPs need to be planned out and reduced to written documents well in advance of the outage. This will go a long way toward ensuring that people, information, equipment, special tools, and safety issues have been arranged for before the outage work starts. A completed OWP is also useful as a checklist of items needed to do or to have on hand before the outage starts.

5.1.1 Discussion

It is recommended that online forms be used for reflecting the information needed for the OWP. This will allow for input from various groups and dissemination of information to the outage team quickly and efficiently. Items that should be included on the OWP form include:

- Station name
- Outage number
- Outage dates
- OWP number
- Priority (A, B, C, and so on)
- Brief description of the OWP
- Responsible person and/or department
- WBS number
- Schedule activity number
- Scheduled start and scheduled completion of the OWP

- Budget cost, with breakdown of
  - Labor
  - Materials
  - Subcontracts
  - Other
- Detailed description of the work
- Job plan
- Job safety assessment (JSA)
- Labor resources needed by craft and by hours for each craft
- Preceding work needed to be completed prior to start
- Materials and equipment to be installed
- Verification that materials and special tools are on hand
- Stock materials to be reserved
- OEM/vendor technical advisors required
- Special safety measures
- Lock out and/or tag out requirements
- Special equipment and tools required
- Scaffolding requirements and coordination
- Pre-outage insulation removal requirements
- Pre-outage testing requirements
- Special inspections and hold points
- Environmental issues and disposals
- Pre-outage training requirements
- Pre-ops testing
- Post-ops testing

OWPs should also have preparer, reviewer, and approval signatures to ensure accountability. Signatures should be attached once the OWP is complete and ready for sign off.

5.2 Scaffold Coordination

5.2.1 Standard

Scaffolds should be set up and moved as needed to support the outage work. A scaffold coordinator should be assigned to plan, supervise, and coordinate the placement of scaffolding throughout the outage. Engineered steel scaffolding with quick assembly/disassembly features should be used in place of older pole and bolted knuckle coupling types.

5.2.2 Measures

The measures are:

- A scaffold coordinator is assigned to the outage.
- Sufficient scaffolding materials are on hand at the start of work to provide scaffolds as required.
- Scaffolding materials are in good condition and are of modern, quick assembly/disassembly design.
- Scaffold locations, sizes, and movements are planned to minimize re-scaffolding an area.
- Scaffolds are moved quickly and as needed.
- Scaffolds are set up at least one shift before they are needed at all times and broken down on the subsequent shift after they are no longer needed.
- The scaffold coordinator ensures that the previous are accomplished satisfactorily.

5.3 Major Equipment Coordination

5.3.1 Standard

Major construction equipment and its placement, if mobile, must be coordinated so that no work is held up waiting for equipment and no work is blocked due to access.

5.3.2 Measures

The measures are:

- Overhead traveling crane usage is planned for each shift.
- Mobile crane placement is coordinated in order to avoid disrupting other work in the area.
- Small auxiliary cranes, electric and manual hoists, and chain falls are checked before the outage starts to determine their usability.
- Sufficient welding machines, compressors, exhaust fans, pumps, and electric power are available to support outage work

- Large equipment removal access and replacement are planned.
- Temporary bridging is in place to support loads if need be.
- Protection measures are in place to preclude damage to roads and other passageways.

5.4 Materials Handling

5.4.1 Standard

All materials should be readily available when needed during the outage for release to outage craft supervision. A materials handling plan should be in place and used in conjunction with the work package development effort to identify that all materials are on hand, stored properly, tagged properly, and available when needed.

5.4.2 Measures

The measures are:

- All materials are checked upon receipt for damage, overages, and shortages.
- All outage materials are stored in accordance with a written storage plan.
- All materials are tagged with the outage number, outage work package number, work order number, vendor name, item description, piece numbers, and other descriptive information for ready identification
- All materials are stored in an easily retrievable part of the warehouse for quick accessing.
- All materials are stored in a controlled and secure location to prevent theft or use for other than the outage.
- All materials are released using a controlled system to positively and uniquely identify the material, to whom it was released, the company, and the authority to effect release according to pre-arranged policies and procedures.
- All releases are recorded in a computer database for tracking.

5.5 Insulation Removals

5.5.1 Standard

Insulation is removed from certain pieces of hot equipment and piping prior to outage start in order to enable immediate start of the outage work when the unit comes off-line. Safety measures are taken to prevent accidental burns.

5.5.2 Measures

The measures are:

- Insulation removals are planned well in advance.
- Safety personnel are advised.
- Areas and equipment are marked off with safety tape.
- Replacement insulation is on hand to re-insulate the equipment and piping.
- Proper agency notification is given.

5.6 Lock-Out and/or Tag-Out

5.6.1 Standard

To support safe work on electrical equipment, circuit breakers should be locked out at motor control centers (MCCs).

5.6.2 Measures

The measures are:

- If padlocks are used, keys are to reside with the outage manager or as agreed. Breakers locked out must be tagged with the name of the individual authorized to unlock the equipment.
- Breakers that cannot be locked must be tagged with a warning that energizing the circuit might be hazardous to the safety of workers; the name of the authorized individual to remove the tag must be written on the tag.
- Equipment, such as motors, must be tagged similarly when they have been de-energized.
- All clearance packages are prepared and reviewed by operations before outage start.

5.7 OEM/Vendor Support

Standard: OEM/vendor provides expertise on the inspection, repair recommendation and techniques, and safe return to service activities for systems and equipment.

Measures: OEM/vendor representatives are available, as necessary, to resolve plant technical issues. Appropriate controls are implemented to confirm the quality of the services and products supplied by non-plant organizations.

Contracts are in place by the targeted number of days prior to outage start to support vendor availability. This date should be identified as a schedule milestone.

Standard: The OEM/vendor provides the necessary planning information and parts and materials in a timely manner.

Measures: The OEM/vendor maintains a record of equipment, parts, special tools, and consumables for each piece of equipment (or system) provided to the plant.

Contracts are in place by the targeted number of days prior to outage start to support vendor parts support, and the parts are clearly identified. This date should be identified as a schedule milestone.

Standard: The OEM/vendor provides accurate price and delivery quotes.

Measures: Calculate price accuracy: actual price ÷ quoted price

Calculate delivery accuracy: actual delivery ÷ quoted delivery

5.8 Engineering Support

5.8.1 *Availability*

Standard: Engineering personnel are available for outage support.

The measures are:

- Calculate resource utilization: (total actual engineering hours) ÷ (# workers x 40 + overtime)
- Calculate budget utilization: actual cost ÷ budgeted cost
- Shared resources available from other company business units are identified and committed by a pre-outage milestone date.
- Targeted percentage goal of loaned employees from offsite organizations is supplied.

5.8.2 *Qualification*

Standard: Engineering activities are conducted so that outage performance supports reliable plant operation. Engineering provides the technical information necessary for successful outage completion and subsequent operation of the plant within the parameters defined by plant design.

The measures are:

- Engineering personnel support station outage goals for scope, efficient use of resources, maintenance support, risk management, configuration control, and duration. Long-range planning is effectively used for engineering activities, such as performance of major modifications and the implementation of engineering changes.

- Engineering personnel monitor and evaluate equipment and system performance by examining and trending the results of condition-monitoring activities, reviewing equipment failure history, analyzing availability and/or reliability information, and performing system walkdowns. Follow-up actions, based on identified problems, trends, and root cause determinations, are timely and effective.
- Comprehensive in-service, pre-outage testing, and post-outage testing is conducted so that equipment necessary for safe and reliable plant operation will perform within established limits. The testing program includes a description of scope and responsibilities, scheduling mechanisms, test procedures, and methods for program updates.
- Engineering activities are performed by or under the direct supervision of personnel who have completed applicable educational and qualification requirements for the tasks performed.
- Engineering personnel use technical information, such as design analyses, operating experience information, and fundamental engineering principles.
- Processes are in place to communicate technical information and recommendations to the outage team and O&M staffs.
- Engineering personnel are familiar with operating experience concerning their areas of expertise and use this experience to prevent and resolve equipment problems and improve plant performance.
- Engineering personnel use outside experts, such as vendor representatives or other utility experts, as necessary to resolve plant technical issues. Appropriate controls are implemented to confirm the quality of the services and products supplied by non-plant organizations.
- Engineering programs (such as those for monitoring flow-accelerated corrosion, in-service testing and inspections, and leak rate testing) are clearly defined and effectively implemented as required during the outage.

5.9 Craft and Technical Resources

5.9.1 Availability

Standard: Personnel are available for outage work.

The measures are:

- Calculate resource utilization: (total actual resource hours) ÷ (# workers x 40 + overtime)
- Calculate budget utilization: actual cost ÷ budgeted cost

5.9.2 Qualification

Standard: Personnel are trained and qualified to apply the knowledge and skills sufficient to safely perform outage work activities for the safe and reliable operation of the plant.

The measures are:

- Personnel capabilities, aptitude, and experience meet established criteria for their assigned positions.
- The personnel possess job-related knowledge and skills.
- On-the-job training and evaluation criteria are identified, completed, and documented prior to the assignment of personnel to independent tasks.
- Continuing training is implemented to maintain and enhance knowledge and skills and to address items such as plant equipment, practice and procedure changes, infrequently used and difficult skills, and lessons learned from operating experience.
- Training and evaluation methods and standards are sufficient to verify trainee and contractor competence for assigned functions.
- Initial and continuing training, including programs to develop and maintain managerial skills, are effectively implemented.
- Contract maintenance technicians and other non-plant maintenance personnel possess knowledge and skills equivalent to those of station maintenance personnel for their assigned functions and are task qualified prior to independent work assignment.
- Contract staff is supervised.
- Facilities, equipment, and tools are provided and maintained to effectively support training activities.

5.9.3 Work Quality

Standard: Work is performed in an efficient and effective manner, resulting in equipment performance and conditions that support reliable operation of the plant.

The following qualitative measures are used for a subjective evaluation of work quality. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- Personnel exhibit professionalism and competence in performing assigned tasks consistently, which results in quality workmanship.
- Tasks are performed by, or under the direct supervision of, personnel who have completed applicable qualification for the tasks to be performed.
- Personnel seek appropriate guidance before proceeding when uncertainties or unexpected conditions arise.

- Personnel accurately transfer pertinent information during turnovers.
- Personnel identify and pursue corrective action for human performance and plant deficiencies with a goal of maintaining equipment performance and material condition to support safe and reliable plant operation.
- Work is properly authorized, controlled, and documented.
- Documentation includes sufficient details of as-found and as-left conditions of the equipment and work performed.
- Work activities are performed in accordance with approved procedures, instructions, and drawings. These documents provide appropriate instructions and details, are technically accurate, and are consistently used to perform work in a safe, correct, and efficient manner. Craft and other outage personnel identify and provide timely feedback to correct procedure problems.
- Effective work practices are followed.
- Post-outage testing is performed, results are reviewed, and corrective actions are taken as necessary before equipment is released for service.
- Rework is identified, documented, and trended. Actions to determine causes and corrective actions to prevent recurrence, including periodic reviews for generic implications and trends, are taken to reduce rework.

The following quantitative measures provide an objective evaluation of work quality:

- Actual outage work hours versus scheduled work hours
- Work task schedule compliance
- Percentage of work tasks completed within the allotted budget
- Number of safety stand-downs
- Number of accidents or injuries
- Percentage of rework costs relative to total budget allocated for the work tasks
- Success rate on post-outage testing
- Starting reliability (SR) = actual starts ÷ attempted starts x 100%

5.10 Mechanical Equipment Readiness

Standard: At the completion of the outage, mechanical equipment will have been restored to its original operating condition or to an acceptable level of performance.

The following qualitative measures are used for a subjective evaluation of mechanical equipment readiness. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late.

The measures are:

- All leaks are repaired, or equipment and/or devices are replaced.
- Pumps, fans, compressors, and other rotating equipment have their output restored to original conditions.
- Scale, buildup, or other debilitating conditions on heat transfer equipment are removed.
- Excessive vibration of rotating equipment is corrected.
- Equipment is flushed, filters changed out, and lubricants replaced as called for by written plant maintenance procedures or the OEM/vendor.
- Safety and safety relief valves are tested and determined to be in good operating condition.
- Steam traps and vents are tested and determined to be in good operating condition.
- All electric, hydraulic, and pneumatic valve operators work.
- All piping slopes are adequate as required to drain lines. Hangers are adjusted as needed to achieve drainage.
- New equipment is installed in accordance with OEM/vendor recommendations.
- Post-operational testing confirms restoration of plant output and operating parameters.

The following quantitative measures provide an objective evaluation of mechanical equipment readiness:

- Work tasks completed on schedule, early, or late
- Work tasks completed within the allotted budget
- Percentage of rework cost relative to total budget allocated for the work tasks
- SR = actual starts ÷ attempted starts x 100%
- Equipment performance, post-outage versus pre-outage
- Vibration measurement on rotating equipment, post-outage versus pre-outage

5.11 Electrical Equipment Readiness

Standard: All electrical equipment, including switchgear, transformers, motors, MCCs, raceways, grounding, and conductors, is in good, safe operating condition.

The following qualitative measures are used for a subjective evaluation of electrical equipment readiness. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- All switchgear and MCCs are inspected to ensure that there are no loose cable terminations, grounding is in place, and there is no evidence of short circuiting.
- All temporary jumper cables are replaced with permanent connections.

- All switches and starters are in good operating condition.
- All busbars are checked to make sure bolts are tight.
- All motors operate as required with no undue vibration or noise and at safe operating temperatures.
- All raceways and conductors are in good operating condition.
- Any unsafe conditions are repaired to ensure the safety of plant operations personnel.
- All motors pass megger testing.

The following quantitative measures provide an objective evaluation of electrical equipment readiness:

- Work tasks completed on schedule, early, or late
- Work tasks completed within the allotted budget
- Percentage of rework cost relative to total budget allocated for the work tasks
- SR = actual starts ÷ attempted starts x 100%
- Equipment performance, post-outage versus pre-outage
- Motor vibration measurement, post-outage versus pre-outage
- Megger test measurement, post-outage versus pre-outage

5.12 I&C

Standard: Instrumentation and controls operate as specified. All computer functions operate satisfactorily as programmed. All main control board read-outs, indicators, and annunciators work as designed.

The following qualitative measures are used for a subjective evaluation of work tasks performed I&C equipment. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- All local gauges read accurately and in the range suitable for the conditions.
- All non-working gauges are replaced or repaired.
- All instrument and control wire and raceways are in good condition.
- Control valve air filters are checked and replaced as needed.
- All protective temperature sensing devices are checked and replaced as needed.
- Programmable logic controllers (PLCs) are checked and re-programmed as necessary to improve operations.
- Computer process and control system software is updated to the latest versions available.

The following quantitative measures provide an objective evaluation of instrumentation and control equipment readiness:

- Work tasks completed on schedule, early, or late
- Work tasks completed within the allotted budget
- Percentage of rework cost relative to total budget allocated for the work tasks
- SR = actual starts ÷ attempted starts x 100%
- Instrument performance, post-outage versus pre-outage
- Instrument drift measurement, post-outage versus pre-outage

5.13 Civil and/or Structural and General Building Services Readiness

Standard: All foundations, structural steel, safety rail, siding, roofing, towers, and so on, to be in good condition with no cracks or other discernable damage.

The following qualitative measures are used for a subjective evaluation of civil and/or structural and general building services readiness. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- All ground contours are maintained as per the original design.
- All storm and equipment drains are unclogged.
- Foundations are free from cracks and spalling.
- Chimneys are free from shell cracks.
- All structural steel is in place, in good condition, and painted.
- All siding and roofing is in place, inspected, and weather tight.
- All building services are available and reasonably convenient.
- Heating, ventilation, and air conditioning (HVAC) equipment operates reliably and maintains design conditions.
- Fire protection systems are checked to make sure they will work if called upon; for example, diesel fire pumps are tested to be sure that they start.

The following quantitative measures provide an objective evaluation of civil and/or structural and general building services readiness:

- Work tasks completed on schedule, early, or late
- Work tasks completed within the allotted budget
- Percentage of rework cost relative to total budget allocated for the work tasks
- SR = actual starts ÷ attempted starts x 100%

- Equipment performance, post-outage versus pre-outage
- Building services testing completed on schedule, early, or late

5.14 Material Handling Readiness

Standard: Coal and ash handling systems have been restored and are available for reliable operation.

The following qualitative measures are used for a subjective evaluation of material handling readiness. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- Conveyor belts are checked for wear.
- Conveyor rollers are in good operating condition.
- Chutes, hoppers, bunkers, and slide gates are in good operating condition.
- All steel is in good condition.
- Ash piping is in good condition.
- Pipe bends are checked for wear.
- Pumps and blowers are in good operating condition.
- Barge unloaders, stacker-reclaimers, and car dumpers are in good operating condition.

The following quantitative measures provide an objective evaluation of material handling equipment readiness:

- Work tasks completed on schedule, early, or late
- Work tasks completed within the allotted budget
- Percentage of rework cost relative to total budget allocated for the work tasks
- SR = actual starts ÷ attempted starts x 100%
- Equipment performance, post-outage versus pre-outage
- Motor vibration measurement, post-outage versus pre-outage
- Motor megger test measurement, post-outage versus pre-outage
- Spillage and leakage eliminated or otherwise corrected

5.15 Utility, Clean-Up

Standard: Following the outage, the plant is to be returned to clean conditions.

The following qualitative measures are used for a subjective evaluation of the general plant cleanliness after outage. These measures could be associated with an in-outage milestone and noted to be present or observed, and if applicable, completed, either on time, early, or late. They are:

- All spills are cleaned up sufficiently to prevent slipping and falling hazards.
- All debris is removed from the operating plant areas and disposed of safely, either on site or off site, as required.
- All equipment that was replaced and repairable should have openings satisfactorily covered and protected.
- All waste fluids should be disposed of properly.
- All plant removal permits (that is, removal from premises) are accounted for.

6
SPARE PARTS AND MATERIALS AVAILABILITY AND READINESS

6.1 General

The timely availability of parts, materials, and services is a key element of a strong and effective maintenance program. Correct parts and materials in good condition are necessary to maintain design configuration and maintenance requirements for activities during normal operating periods and to support both planned and forced outages. Special services are needed periodically to provide unique or supplementary maintenance support.

6.2 Discussion

An effective materials management process ensures that parts, materials, and services are available when needed. Proper care of parts, materials, and equipment is required from the time an item is received until it is installed in the plant. This includes all phases of receiving, inspecting, handling, storing, retrieving, and issuing material. It also includes the return of unused parts and material to the warehouse. Many personnel are involved in some portion of the materials management process. Policies and procedures are established to clearly define the company and plant responsibilities and to ensure that proper parts, materials, and services are purchased, received, inspected, handled, and stored so that they are easily retrievable and usable when they are issued to support maintenance activities. These policies and procedures must be understood by materials management personnel and other groups that interface with the materials management process, such as purchasing, quality assurance, quality control, engineering, operations, and maintenance.

6.3 Metrics

Standard: Correct parts and materials in good condition are available for maintenance activities to support both planned and forced outages. Procurement of services and materials for outages is performed in time to ensure that materials will be available without impact to the schedule. Storage of parts and materials provides for maintaining quality and the shelf life of parts and materials.

The measures are:

- Policies and procedures are in place for early identification and timely procurement of parts, materials, and services. These procedures specifically describe the responsibilities of the company and plant personnel involved in the procurement function.
- These policies are understood by materials management, materials engineering, systems engineering, design engineering, procurement engineering, purchasing personnel, and other plant personnel who interface with the procurement process, such as maintenance managers and planning and scheduling personnel.
- As part of the design change process, spare parts needs are updated and outdated, and obsolete materials are removed from the stock system.
- Long lead parts and materials are available in advance of planned outages and verified to be correct prior to being needed in the field.
- Minimum and/or maximum stock levels are periodically reconciled to actual usage.
- Adequate engineering and technical review is done to ensure that purchased materials meet design specifications.
- Materials are receipt inspected to verify that procurement specifications are met. Non-conforming materials are controlled to prevent inadvertent use.
- Adequate records are maintained to ensure material traceability, if required.
- Special handling requirements are specified in procurement documents.
- Preventive maintenance requirements for spare components are properly specified and performed to specifications.
- Proper precautions are taken for storage of hazardous materials and chemicals, including separation and labeling requirements.
- Inventory levels are verified to actual count on a periodic basis.

6.4 Purchased Materials for Outage

Standard: Materials purchased for an outage are segregated, tagged, and controlled so that they are available when needed.

The measures are:

- Vendors are required to label, tag, or otherwise mark shipments with outage identification.
- Material receiving supervisors advise the outage manager or designated subordinates upon receipt of materials.
- Inspection is performed to determine if the correct materials have been received.
- Tagging of items indicates item description, vendor name, purchase order number, outage identification, and work package number.

- Items received are entered into a computer database indicating where the item is stored.
- Items are stored in a controlled area, such as a fenced area within a warehouse or in the yard, as appropriate.
- Receipt of items is noted on the work package.

6.5 Purchases Shown on Schedule

Standard: The outage CPM schedule should have procurement activities in the schedule for engineered, long lead time items, and key bulk materials.

The measures are:

- Purchase orders are identified in the CPM.
- Activities are identified for fabricate and deliver items.
- Lead time is identified as equipment on site 30 days before the start of the outage.

6.6 Capital and Large Purchases Tracked and Expedited

Standard: Frequent communication, generally weekly, with the OEM/vendor of large capital purchases is required during the manufacturing and delivery periods to ensure that equipment is received on schedule.

The measures are:

- The purchase order stipulates schedules for vendor drawing receipt, fabrication timetables, witness hold points, testing schedule, manuals, and contact person for checking on status.
- Vendor shop drawings are received on schedule.
- The vendor surveillance program is instituted for large capital purchases.
- Expediting reports are issued after each contact in a timely manner.
- Shop visits and vendor files are audited for shop fabrication material test reports, welder qualifications, weld inspection reports, and other documentation as specified in the purchase order.
- Installation, storage, operating, and maintenance manuals are received with or ahead of equipment delivery.
- Test documentation is received along with material certifications at the time of delivery.

6.7 Parts Identified as Needed

Standard: Parts identified during work package preparation are identified, procured, stored, and retrieved from storage 100% of the time.

The measures are:

- O&M manuals are reviewed, and parts are identified for outage work.
- Parts are ordered, received, tagged, and put into storage for outage at least 30 days before the start of the outage.
- Items are checked upon receipt at the site to ensure that the proper materials have been received.
- Parts are tagged properly so that it is clear what the parts are for.
- Unused parts are properly tagged and returned to the warehouse or parts room for repair or return to the supplier.
- Work order requests are prepared for all parts requiring repair.

6.8 Availability Tracked

Standard: There are at least three sources of supply for parts that are kept in stock. Sole source parts suppliers should be canvassed to determine the availability of specific items needed.

The measures are:

- There is frequent contact with suppliers to ensure that parts are available when needed.
- There is contact with sole source suppliers to ensure that parts will be available if and when needed.
- Contact memoranda or reports, highlighting any impending problems with supplies, are issued to management.

6.9 Last Allowable or Possible Dates for Kick-Out of Work Due to Lack of Parts

Standard: Where delivery issues cannot be avoided, analysis of the schedule needs to be done to determine the last possible date for receipt without jeopardizing the outage completion date.

The measures are:

- The priority of the work package is reviewed to determine the urgency of completion.
- All work packages are analyzed using the critical path method to determine if float is available.
- A work-around analysis indicates that work in jeopardy due to delivery issues can be delayed, depending on certain steps to be taken.
- Resource analysis determines that sufficient other resources will be available if the work package is delayed.

- Shift work has been analyzed to determine if the work package under consideration can be worked on multiple shifts.
- The work package is shifted to a new start date.

7
OUTAGE CLOSURE AND POST-OUTAGE OPERATION

7.1 Testing Acceptance

Standard: All tests are performed in accordance with established, written test procedures and protocols. Test results are recorded and acceptable and/or unacceptable outcomes determined. Tests can be performance based and reliability based.

The measures are:

- Where applicable, all tests are conducted in accordance with the American Society of Mechanical Engineers (ASME), the American Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), and the International Electrotechnical Commission (IEC) code testing requirements and criteria.
- Where applicable, tests should be conducted under the conditions and following the procedures established by the OEM/vendor.
- Test acceptance outcomes are adjusted for differences in parameters, such as ambient temperature or altitude.
- Tests are conducted under the supervision and surveillance of competent test engineers.
- Test results are recorded and analyzed.
- Unacceptable test results are always analyzed by competent engineers for the causes of failure.

7.2 Warranty Documentation

Standard: Explicitly stated warranty documentation should accompany the offer and be made a part of the purchase agreement.

The measures are:

- Warranty periods do not start from the date of delivery.
- Warranties run for an acceptable period of time after equipment is put into service.
- Warranties have minimal exclusions, sometimes called normal maintenance items.
- Warranties cover the replacement of parts and labor costs if materials or workmanship are defective.

- Complicated major equipment warranties, such as plant outages from a steam or gas turbine, are fully understood by management.
- Management understands limiting conditions of warranties and how they relate to periodic maintenance, change of lubricants, and so on.
- Management understands limited warranties.
- Management understands limits on consequential damages and liquidated damages.

7.3 Safety

Standard: The protection of life and limb of the work force is paramount. The company emphasizes that personnel at all levels of the organization consider safety to be the overriding priority. This is demonstrated in decisions and actions based on this priority. The work environment and policies and procedures promote a safety-focused culture, and the attitudes and behavior of personnel are consistent with the policies and procedures.

The measures are:

- Personnel at all levels contribute to the safety culture of the work environment by:
  - Demonstrating respect for safety in all actions and decisions.
  - Demonstrating a questioning attitude by challenging existing conditions, considering the potential adverse consequences prior to proceeding, and being willing to stop work in the face of uncertainty.
  - Demonstrating a willingness to identify problems and ensure that they are corrected.
  - Accepting accountability for their own performances, including recognizing shortfalls and acting to improve.
  - Holding their co-workers accountable for their performances.
  - Using peer checking as a means of protecting themselves and others.
- Managers contribute to the safety culture of the work environment by:
  - Establishing standards and clearly communicating expectations that safety is the highest priority.
  - Maintaining an environment that welcomes identification and communication of problems.
  - Reinforcing individual behaviors that promptly and forthrightly identify problems.
- Work practice norms in the organization promote the safety culture by:
  - Instituting a lock-out and/or tag-out system that is in place and always implemented.
  - Explicitly embedding appropriate defenses, such as technical accuracy, precautions, cautions, and notes in procedures, processes, and equipment configuration to minimize the occurrences and consequences of inappropriate actions.

- Communicating to all personnel clearly defined responsibility and authority for implementing a conservative approach with respect to stopping activities and seeking assistance or guidance when faced with uncertain conditions. This expectation is reinforced frequently.
- Ensuring that safety concerns are promptly identified and resolved.
- Implementing training that reinforces safety practices and expected behaviors.

7.4 Environmental

Standard: The environmental impact that generation has on employees, community, and the region is minimized.

The measures are:

- Number of environmental violations
- Number of discharge monitoring report exceedances
- Number of air incidents
- Dollar amount of fines and penalties
- Permitted air emissions, measured in lb/MWh (kg/MWh)
  - NO_x emission rate
  - SO_2 emission rate
  - CO_2 emission rate
  - Particulate emission rate
- Hazardous waste production, measured in tons/year (kg/year)
- Total annual EH&S cost
- Total annual water use
- Number of other adverse environmental reports measured against a goal, for instance, asbestos violations, PCB releases, and other chemical spills

7.5 Cost Performance Index (CPI)

Refer to Section 4 for a discussion of CPI and other earned value terms. A CPI of 1.0 means that the cost performance was equal to the budgeted cost, or, in earned value terminology, the Budgeted Cost of Work Performed (BCWP) equaled the Actual Cost of Work Performed (ACWP). The formula for CPI is:

$$CPI = BCWP/ACWP$$

If BCWP is greater than the ACWP, the CPI will be greater than 1.0. This means the outage was done for less money than budgeted. Conversely, if the CPI is lower than 1.0, the budget was exceeded. The two digits to the right of the decimal point, when subtracted from one, will indicate how much the budget was underrun when converted to a percentage. For example, a CPI of 1.14 means the budget was underrun by 14%. If the CPI is 0.88, for another example, the budget was overrun by 12%.

Following completion of the outage, it is worthwhile to determine why the variance occurred. Was it the fault of a few items, or were the variances the result of many items? This examination will provide some ideas regarding what changes to make for the next outage. Perhaps a contingency for uncertainties needs to be added.

7.6 Schedule Performance Index (SPI)

As described in Section 4, SPI is a ratio of the BCWP to the Budgeted Cost of Work Scheduled (BCWS):

SPI = BCWP/BCWS

The SPI is useful in determining how well the outage is proceeding according to schedule while the outage is taking place. As most people who have worked on major projects of any nature know, the typical achieved percent complete takes the form of an S curve. Typically, work starts out slowly, accelerates at around the 20 percent mark, stays nearly linear until around the 80% mark is achieved, and then tapers off to the 100% mark. By studying the SPI during the execution of the outage, a sense of the shape of the S curve can be developed.

In actuality, the time and date of the completed outage compared to the target schedule has more meaning at the conclusion of the project. Did the four-week outage take five weeks to complete, or did some Priority C items not get done on this outage and were scheduled for a later outage? Should more float contingency be built into the schedule than was originally allowed for? For example, instead of a 10% float contingency criteria, should the next outage allow for 15%?

Most schedules are prepared so that the team is working toward the early start and early finish dates, which is as it should be, but realistically, emergent issues do develop and must be accounted for by work-arounds or other contingency plans. It is in studying the events of the outage after it is completed and incorporating the lessons learned that the prospect of improving performance on the next outage is enhanced.

7.7 Vendor Evaluations

Vendors should be evaluated at the conclusion of an outage to determine how well they supported the program and met their commitments for quality and schedule. Vendors who fail to meet the following standards should not be used for future supply.

Standard: Material was shipped on schedule, inspected, found to meet quality standards, and tagged properly, and the installation proceeded smoothly.

The measures are:

- The correct material was delivered.
- The material met the requirements of the specifications.
- Material was tagged properly.
- Documentation was adequate and met the specifications.
- Communications with the vendor were timely, and the vendor was responsive and cooperative.

7.8 Contractor Evaluations

As with vendors, construction and/or maintenance contractors should be evaluated at the end of the outage. Contractors who do not pass the evaluation should not be used on future outages.

Standard: The contractor should perform the work contracted for in the time frame and at the agreed-upon price. Workmanship should be first class with few corrective measures required.

The measures are:

- Contractor assisted in the planning of the outage as requested.
- Contractor assigned competent supervision to the work.
- Contractor assigned adequate numbers of qualified skilled labor to the project.
- Contractor worked to the schedule.
- Contractor abided by all safety requirements of the project.
- Contractor observed job site rules during the work.
- Contractor was pro-active in resolving any emergent issues.
- Contractor was cooperative with the outage team.
- Contractor did not seek additional compensation when not called for.
- Completed work was to the quality standard of the specifications.
- Contractor conducted the work in a way that did not interfere with operations.
- Contractor participated as requested in daily progress and problem solving meetings.

7.9 Return Rental Equipment

Rental equipment should be evaluated at the end of the outage to determine if the equipment was in good condition, operated without breaking down, was safe, and was of sufficient size and capacity to accomplish the work. Also of importance is the issue of equipment being delivered and picked up as scheduled. The rental costs should be evaluated to determine if another approach or arrangement might make more sense for the next outage.

Equipment essential for normal maintenance might be purchased rather than rented if needed frequently enough. A simple payback analysis can determine if a purchase makes financial sense.

All rental equipment should be returned as soon as possible after the outage to eliminate incurring additional charges. Early return discounts should be taken advantage of and recorded as cost savings.

7.10 Invoice Payments

Upon completion of the outage, final invoices should be paid on all purchases and contractor billings. If there are unsettled issues with the contractor, final payment or retention should be withheld until issues are resolved. In addition, any back charges levied against vendors for short or damaged materials and equipment need to be resolved. Invoices for performance-based contracts must reflect the incentives and/or penalties correctly. Early payment discounts should be taken advantage of and recorded as cost savings.

7.11 Final Cost Accumulations

Final costs should be accumulated within one or two accounting cycles of completing the work. This is generally practicable unless there are ongoing disputes over contractor billings, back charges, or delayed invoicing on the part of suppliers. Final costs should be allocated in accordance with WBS or Code of Accounts, if they differ.

A final outage cost report should be prepared and costs should be evaluated to determine opportunities to save money on the next outage or to better estimate the cost of maintenance for the next outage.

7.12 Accounting Close for Capital Equipment

From a tax accounting viewpoint, it is important that all costs be allocated to either expense or to capital investment. Expensed items are generally deducted at 100% of the cost in the tax accounting period in which they are incurred. Capital investments generally are depreciated and credits taken over a number of tax accounting periods.

From the viewpoint of property records, it is important to associate all costs with the capital improvement and to include all allocations prorated from common accounts. This effort of distributing costs against capital improvements, often called *unitizing,* can be facilitated by the use of a WBS set up to accumulate costs against individual capital improvements.

A
BIBLIOGRAPHY

EPRI Outage Management Workshop Notes, June 23–24, 2003.

EPRI Outage Management Workshop Notes, August 31–September 1, 2004.

Best Practice Guidelines for Maintenance Planning and Scheduling, EPRI, Palo Alto, CA: 2000. 1000320.

Developing Performance Indicators in Managing Maintenance, Terry Wireman, Industrial Press. 1998.

Outage Management Guidelines for Fossil Fueled Power Plants, EPRI Destinations 2005 and 2006 Project Task for 69B (Project 052521). Palo Alto, CA.

Outage Management Benchmarking Guideline, EPRI, Palo Alto, CA: 2003. 1004383.

Export Control Restrictions

About EPRI

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

EPRI. Electrify the World

Program: 1004830

Maintenance Management and Technology

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