ELECTRIC POWER RESEARCH INSTITUTE

Asset Management Guidelines Development

2019 Update

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EPRI Project Manager

B. Desai

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

Coplanar Consulting, LLC

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NOTE

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Coplanar Consulting, LLC
893 Princess Drive
Yardley, PA 19067

Principal Investigator
M. Lebow

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ABSTRACT

This report updates the preliminary results of efforts to develop new guides for helping power delivery organizations adapt and implement best practice asset management. Although proven and in wide use in the power generation sector, effective asset management processes have not been as widely applied in power delivery due to a host of challenges.

To help address these challenges, EPRI initiated a series of efforts to provide information and guidance to assist power delivery organizations in understanding and applying asset management principles. These efforts first resulted in *Guidelines for Power Delivery Asset Management: A Business Model for Program Implementations*, EPRI, Palo Alto, CA: 2004. 1008550. The following year, the work was enhanced with the publication of *Guidelines for Power Delivery Asset Management,* EPRI, Palo Alto, CA: 2005, 1010728. In subsequent years, EPRI work focused on addressing the needs for analytical tools and equipment performance data bases identified in these guidelines.

With the successful development and acceptance of a number of EPRI analytical tools and data bases and the increased appreciation of asset management principles for guiding power delivery organizations, it was deemed appropriate to revisit the Power Delivery Asset Management (PDAM) Guidelines to make certain that they fully address current utility needs. This report documents the initial results of work to produce an updated PDAM guide. Working with utility advisors, the first step was a review of the existing guide, followed by the preliminary identification of several areas where additional information would be useful. In particular, more discussion and guidance around the application of PDAM to maintenance, risk assessment and management, and performance measures were considered to be valuable and some initial new material for these topics is presented here.

Building on the existing guidelines, using this report as a starting point and working with members, EPRI will continue to review and updated the PDAM guide.

Keywords
Asset management
Power delivery
Substations
Transmission

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1 INTRODUCTION

This report presents the preliminary results of efforts to develop an updated guide for helping power delivery organizations adapt and implement best practice asset management.

Background

Although proven and in wide use in the power generation sector, effective asset management processes have not been applied as widely in power delivery due to a host of challenges. These challenges include:

- Wide diversity in power delivery organizations sizes and structures.
- The potential value created by the asset management process has many possible dimensions, including financial returns, system reliability, public and worker safety, and stable rates.
- Various stakeholders, including internal ones (for example, operations, planning, and engineering) and external ones (for example, investors, customers, and regulators), perceive the created values differently.
- Need to accommodate multiple uncertainties both in future equipment performance and service requirements in order to best evaluate and manage risk.
- Difficulty in aligning individuals, who make decisions and implement programs with their own perspectives, to higher-level corporate objectives.
- Difficulty in aligning actions focus on individual devices to higher-level corporate objectives.

In addition to these systemic issues, and in part a consequence of them, no consensus path to power delivery asset management (PDAM) implementation has emerged.

To help address these challenges, EPRI initiated a series of efforts to provide information and guidance to assist power delivery organizations in understanding and applying asset management principles. These efforts first resulted in *Guidelines for Power Delivery Asset Management: A Business Model for Program Implementations*, EPRI, Palo Alto, CA: 2004. 1008550. The following year, the work was enhanced with the publication of *Guidelines for Power Delivery Asset Management,* EPRI, Palo Alto, CA: 2005, 1010728. In subsequent years, EPRI work focused on addressing the needs for analytical tools and equipment performance data based identified in these guidelines.

With the successful development and acceptance of a number of analytical tools and data bases [1, 2, 3] and the increased appreciation of asset management principles for guiding power delivery organizations, it was appropriate to revisit the PDAM Guidelines to be certain that they fully addressed current utility needs. The result was *Asset Management Guidelines Development: 2018 Update.* EPRI, Palo Alto, CA: 2018. 3002012681. This report further updates the guide.

Power Delivery Asset Management

The principles of asset management [3] will be discussed in detail in the following section, but some explanation at this point will be helpful in understanding the scope of work reported here and how the existing Guidelines were developed.

In essence, asset management is the establishment and execution of a series of interrelated processes that assure that all decisions related to the allocation of resources are evaluated against, aligned with and made to optimize the achievement of the organization's goals for financial and operational performance and tolerance for risk exposure. Some key characteristics of PDAM are:

- Policy, goals and objectives designed to drive performance
- Documented programs, decisions on resource allocation and application based on those policy, goals and objectives
- A longer term, proactive perspective of cost and performance and future risk exposure

For asset management to be most effective, processes must be in place to guide resource allocation decisions. For example, for maintenance and replacement programs to be effective there must be processes to ensure the direction over time tracks an organization's mission and goals. Section 3 is aimed at explicitly identifying these processes, the relationships among them and the data required for their full implementation.

Drivers for PDAM

The central area of conflict for power delivery organizations is defined by the opposing objectives of cost containment and preservation, or in some cases improvement, of the quality of service. These goals must be accomplished in the presence of two key constraining issues.

Aging Asset Base

Many in the industry believe that a significant percentage of the power delivery equipment base is at or close to the end of its useful life, the so-called design life. There is no formal definition of design life but the general usage is that it is the age beyond which risk of failure will become increasingly unacceptable. The concept arises from the fact that the original equipment designers and purchasers did not expect the equipment to be in service much beyond that age. Utility equipment engineers commonly use an age of forty years to estimate design life for power delivery equipment but there is no technical basis for this number and there are many examples of equipment functioning reliably well beyond that age and, of course, many that never achieved age forty. Nonetheless, it is well accepted that the risk of equipment condition deterioration and wear-out failure increases as equipment is used and ages and approaches some defined end of its useful service life.

Many of the power delivery systems in the United States experienced a rapid expansion in the 1960s and 1970s corresponding with significant national economic growth and increased electric consumption. Much of the equipment installed in that timeframe is still in service and the equipment installed during that peak expansion is now 40 to 50 years old. Much of the recent literature concerning aging transmission assets deals with power transformers because they are usually the single most expensive component in the delivery system but the same situation exists for distribution system equipment. Replacing this significant population of older equipment will require a large capital investment and hence the interest in managing the aging asset problem.

Resource Limitations

In the last decade there has been a net decrease in the utility labor force. In step with the power delivery industry's rapid expansion of the equipment base in the 1960s and 1970s, a similar increase occurred in the size of the workforce. More recently, the economic pressures resulting from business changes have resulted in a significant reduction in the number of people employed in the utility industry, both skilled craftsmen and engineers.

This reduction, coupled with the retirements of those remaining, means that skilled technical, craft and engineering expertise is in increasingly short supply. This shortage exacerbates the challenges of dealing with an aging asset base and the ever more complex issues of operating and maintaining systems under pressure to contain costs and maintain quality service. Consequently, most utility equipment experts are fully engaged in dealing with emergent problems and system growth and have little time to assess equipment fleets and improve maintenance and replacement programs. Similarly, there are resource limitations on gathering the detailed historical and condition data and on-site inspection and testing results one would ideally wish to review to assess an equipment population.

Project Scope

The objective of the work reported here is to review and update the existing Guidelines and provide any identified additions that will assist utilities in adopting best practice power delivery asset management.

PDAM recognizes that, at the highest levels, asset management processes should be very similar for most utilities. However, PDAM also recognizes that the approach to and application of these processes will differ from company to company due to individual circumstances, including the wide range of customer requirements, electric infrastructures and organizational structures.

In the Guidelines, PDAM is presented as a broad approach suitable across the power delivery industry but also recognizes and accommodates important distinctions. The revised Guidelines expand on these distinctions.

From one perspective, there are many similarities between transmission and distribution substations. The major equipment types are the same: transformers and breakers. The maintenance objectives are also the same: maintain the desired performance levels as economically as possible, but there are some important differences. Distribution equipment is much less expensive. The lower replacement costs make it hard to justify the level of maintenance, monitoring or testing that transmission equipment warrants. Distribution stations are configured differently and are, obviously closer to the customer. Problems in distribution stations have a greater chance of affecting customer reliability indices and switching options are often more limited. Most distribution stations are unmanned and often remote.

There are differences in the basic equipment designs also. Because of their smaller sizes, commodity marketplaces and lower prices, design margins may be less in distribution equipment. These, and other reasons, mean that PDAM focused maintenance and replacement programs would be different for both classes of station. After all, the drivers and constraints are different. In addition, the fact that there are such large numbers of very similar equipment in distribution may provide a better possibility of developing statistically meaningful hazard rate and life expectancy curves based on real-world data. A larger utility may have sufficient data for meaningful distribution equipment life analysis using only internal data. But even large utilities may require pooled data, such as from EPRI's Industry-wide Databases, for transmission equipment life analysis. This topic will be addressed in more detail later. Another identified area for additional effort is the development of performance metric for transmission equipment that would parallel the familiar SAIDI and SAIFI so useful in distribution.

The past Guidelines discussed risk assessment and management in the broadest context of asset management but did not provide detail. Similarly, performance measures were reviewed at a higher level. Additional detail on both topics has been identified as valuable for PDAM and candidate material for each is presented in this report.

The unbundling of power delivery functions, discussed in earlier Guidelines versions, has not progressed at the pace envisioned in 2005 and some adjustments in guideline terms have been made.

Report Organization

This report is divided into six sections. In addition to this introductory section, included are:

Section 2. Power Delivery Asset Management Overview

Section 3. The Power Delivery Asset Management Model

Section 4. Maintenance and Power Delivery Asset Management

Section 5. Performance Measures

Section 6. PDAM and Risk

Section 7. Conclusions and Recommendations for Additional Work

Section References

1. *Industry-Wide Failure and Performance Database: Analysis Methodology and Results – Substation Assets*. EPRI, Palo Alto, CA: 2018. 3002012686.
2. *Circuit Breaker Asset Management Analytics Software Version 4.0*. EPRI, Palo Alto, CA: 2017. 3002010216.
3. *Guidelines for Power Delivery Asset Management*. EPRI, Palo Alto, CA: 2005. 1010728.

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POWER DELIVERY ASSET MANAGEMENT OVERVIEW

This section outlines the basics of power delivery asset management and describes the principles and fundamental processes of PDAM. Much of the material in this section is derived from *Guidelines for Power Delivery Asset Management* [1] and those interested in more detail are referred to that document. It is postulated that these fundamental concepts are still valid and applicable to an updated guide.

For the foreseeable future, utilities will need to manage an array of potentially conflicting business objectives, including the need to maintain competitive economic performance, improve customer satisfaction, maintain high reliability, address regulatory uncertainty, and comply with increased environmental regulation. The result is that many utilities are considering or have moved towards implementing informal or formal asset management concepts and driving decision-making based on minimizing equipment life-cycle cost and risks and maximizing benefits. A structured asset management approach has been successful in many other industries and, when properly adapted to utility needs, can provide the processes and tools to develop the most effective programs for building, operating and maintaining today's power delivery infrastructure.

Power Delivery Asset Management begins with the fundamental premise that all asset management decisions made by utilities should contribute to stakeholder values, as set forth in the organization's goals and policies. PDAM provides the tools for and applies this premise in decision processes at every level of the organization. The resulting alignment of decisions with criteria and metrics derived from those charged with establishing the organization's direction ensures that every asset management and resource allocation decision consistently supports the organization's strategic objectives and delivers value to the stakeholders.

The concept of asset management has been fundamental to the business of electric utilities throughout their history. Companies have always endeavored to manage their assets, employees, capital, and equipment to deliver as much perceived value as possible, and these efforts have been highly successful. However, several aspects of the traditional ways of conducting business in the electric power industry have changed. At many power delivery organizations, senior management has become more engaged in setting detailed performance goals and objectives that are designed to inform decisions at the operational levels. Some organizations have unbundled traditional vertically integrated utility functions via the sale of assets or entire operations, or by redefining roles and responsibilities (see Figure 2-1). In some circumstances, the roles are assigned to different enterprises, while in other cases; organizations within the same enterprise now perform these functions. In some cases, formal service level agreements have been established to define the roles and obligations of the three parties, especially through outside contracting for task previously performed internally. Even where no corporate separation has occurred, recognizing these distinct roles, however labeled, is helpful when exploring asset management concepts.

Figure 2-1
Defining utility management roles

Each of the distinct functions, whatever the particular organization's labels, has a well-defined role. The "asset owner," or senior management, is the regulatory license-holder represented by the highest levels of management within the organization that owns or, in the case of governmental agencies, directly controls the assets. The asset owner may or may not be a part of the organization that operates and maintains the assets. This level directly interacts with all key stakeholders (for example, customers, shareholders, regulators, employees and financial agencies) and asset managers. The senior level sets the business goals and policies, parameters of risk, cost and performance, and the budget for the organization. For example, the asset owner sets annual capital and operating budgets, customer satisfaction measures, and fuel mix risks. When asset management practices are applied in an organization below the enterprise level, an operating unit for example, the senior management to which the organization reports carries out the role of asset owner. (For convenience, this report applies the term "asset owner" in all cases since there is no distinction between the asset management roles of "senior management" or "asset owner.") This level determines the operating context for the asset manager, focusing on corporate governance and goals, regulatory issues, and other stakeholder relationships.

The "asset manager" develops asset strategies and policies and directs risk management, investment and maintenance planning (not work scheduling), and contract management. The asset manager sets the policies and procedures for the service provider(s) and decides how and where money is to be spent for both capital improvements and maintenance. For example, the asset manager sets feeder outage goals, equipment maintenance intervals, and replacement criteria. In short, the asset manager decides what to do and in which budget cycle to do it to support senior management's or the asset owner's goals.

The "service providers" focus on the core skills of scheduling personnel to deliver programs efficiently and effectively to meet defined service levels. They provide and schedule resources to perform work on the assets. For example, service providers set maintenance staffing levels, tool requirements, and work schedules. Rather than decide where or how to invest budgets, the service provider decides how to do work. These tasks may be performed internally or contracted out.

As utilities developed these new business models and the technology to support their engineering expertise to meet the emerging challenges, there has been a gradual change in focus towards power delivery asset management practices. However, asset management is about more than maintenance or capital investment issues that are usually the first areas for attention. At its best, asset management represents the ability to understand and manage the trade-offs between risk, cost, and performance in order to optimize the financial and service performance of the three distinct roles—asset owner, asset manager, and service provider—that result from a fundamental approach to managing assets.

What is an Asset?

An asset is any resource that is important to an organization's functions and requires management. The organization's assets are used to service and supply end users or to facilitate performing such services. Asset owners direct the acquisition, operation, and maintenance of assets to provide and support service delivery. Therefore, an asset possesses service potential or future economic benefit. In the power delivery industry, physical assets such as transmission and distribution system equipment are the most commonly considered. However, the more comprehensive application of asset management principles might also consider time, people, data and knowledge, and know-how to be assets. Fundamentally, an asset has value that persists, and often changes, over time. This implies that assets have both a useful and an economic life, which may not coincide in length. For practical purposes, only assets with significant value are considered in the asset management process. The management of financial assets is not within the scope of PDAM.

What is Asset Management?

Many formal definitions and approaches to asset management have been developed. At its most basic level, asset management is a fundamental business activity that involves the effective use of resources to create value. However, such a description is not particularly helpful in understanding PDAM. Asset management is difficult to define comprehensively simply because it has so many dimensions. Asset management is simultaneously a business philosophy, a process, and a set of technical tools.

As a business philosophy, asset management:

- Is an approach to managing the organization's assets that is organization-wide and considers both short and longer term performance and risks
- Strives to collect and understand data and information from all aspects and departments involved with assets and their performance
- Is holistic and may be applicable to all operational areas in an organization, or focused on specific areas
- Is propelled by policy goals and objectives grounded on objectively measured performance
- Takes a long-term perspective on cost and infrastructure performance
- Is forward looking and seeks to predict and anticipate
- Is applied to all aspects of every element of the organization

As a process, effective asset management:

- Has senior management support
- Develops policies and plans based on clear goals and objectives and implements optimized program delivery and procedures designed to support those policies and plans
- Requires decisions on resource allocation based on review of alternatives and their projected costs and performance
- Requires that risks are fully assessed and managed
- Develops organizational roles and responsibilities regarding asset management
- Promotes consistent practices across various organizations within an enterprise
- Documents plans (for normal operations and responds to unexpected events and changing circumstances) that maintain focus on goals and objectives)
- Is interdisciplinary, combining both engineering and economic tools and processes so that business functions become an integral element of operations
- Requires effective communication within and outside the organization, and established mechanisms for performance review and adjustments to correct for deviation from desired results

As a set of technical tools, asset management:

- Requires effective management systems
- Requires the best available, current, and accurate information on assets and asset performance
- Requires well-developed decision support analyses for evaluating tradeoffs and prioritizing actions

Power Delivery Asset Management

Numerous organizations have published formal definitions for the asset management process. Following the recent development and adoption of infrastructure asset management, most definitions originate from overseas organizations concerned with public service oversight and specifically designed to be asset neutral (for example, the assets could be railroads as well as public housing).

Although certainly accurate, these definitions may be limiting for the purposes of power delivery asset management. Therefore in the context of this report, power delivery asset management is defined as:

A structured, integrated series of processes to align all decisions with business goals and values and designed to maximize the life cycle benefits of power delivery asset ownership, while providing the required service performance and risk exposure levels and sustaining the system going forward.

- This definition includes assets of any form and services of any type.
- PDAM is "structured" because asset management is accomplished with documented and consistent processes and procedures. All decisions can be related to and support the organization's goals and policies.

- PDAM "maximizes the life cycle benefits of power delivery asset ownership" because the purpose of asset ownership is to produce benefits for all stakeholders. Examining costs and benefits over an asset's lifetime assures that all contributions are taken into account.
- PDAM "provides required service levels" because minimizing costs and maximizing benefits are not the only considerations. Performance service levels also must be considered for both the short and longer term.
- PDAM "provides required risk exposure levels" because resource allocations are to be made with an explicit understanding of the associated risks for achieving the desired benefits and service levels.
- PDAM "sustains the system" because a well-designed asset management program considers both short-term and long-term projected performance and risk considering all potential costs and benefits.

Asset Management Premise

Power Delivery Asset Management begins with the fundamental premise that all asset management decisions made by utilities should contribute to stakeholder values, as set forth in the organization's goals and policies. PDAM applies this premise in decision processes at every level of the organization. The resulting alignment of decisions with criteria and value measures derived from the asset owner's or senior management's direction ensures that every asset management and resource allocation decision consistently supports the organization's strategic objectives and delivers value to the stakeholders.

Consequently, PDAM should begin with a comprehensive process for defining organizational values (for example, financial considerations and non-financial considerations, customer satisfaction, environmental stewardship, and risk). The definition of "organization" could be an entire company, a regional unit or even a department. PDAM then provides a way of linking asset management decisions to higher organizational objectives. The explicit and quantitative consideration of uncertainty should be included in this process of decision-making. Properly applied PDAM assures consistency across time and across the organization. The strategic planning process is important for articulating values to drive both tactical asset management and long term direction.

PDAM integrates these features into a decision-making approach that relies on analysis methods and good data. The result is a systematic approach to business decisions that helps utility managers organize, structure, and evaluate the functions they perform, while managing the assets required to support those functions.

Best-practice asset management is about aligning key processes across the entire asset lifecycle to higher-level strategies and values. The core competencies lie in the decision-making processes. The key is to optimize tradeoffs among various financial and non-financial metrics, not simply trying to manage risk or lifecycle cost. Asset management decision-making is guided by performance goals, draws from both economics and engineering, covers a long time horizon, and considers a wide range of assets. PDAM requires the cost and risk assessments among alternative actions and resources allocation strategies from the both the asset and system performance perspectives. It also allows a more comprehensive, performance-based comparative analysis among projects.

Implications of an Asset Management Approach

Utilities considering asset management are attempting to move toward risk-informed, performance-focused decision-making that minimizes equipment lifecycle cost and maximizes lifecycle benefits. A structured asset management approach has been successful in many other industries. When properly adapted to power delivery, such an approach can provide the processes and tools to operate and maintain the power delivery infrastructure. Within an asset management framework, the contribution and support of a higher level, over-arching strategy drives all risk management and asset capital and O&M decisions. The major challenge for power delivery asset owners, managers, service providers, and operators is to align their decisions with these goals and objectives through the use of asset management tools and processes. Within an asset management framework, all performance criteria are derived from goals and policies set down by the asset owner, and all decisions are developed to support those goals. The core PDAM competencies lie in the decision-making processes. In optimizing performance across the entire asset lifecycle, the asset manager should be supported by integrated business processes and decision support tools aligned with key stakeholders' (especially the asset owner and service providers) values. The asset manager uses these processes and tools to manage asset lifecycles, and to manage the internal and external service providers. These processes and tools and their elements can be summarized under the groupings listed below:

- Communications
  - Accurate and timely information flows to both owner and service provider
  - Documented, consistent decision-making
  - Performance measures, standards, and benchmarks
  - Useful outputs, effectively presented
- Data Collection and Analysis
  - Complete descriptive demographic data for all pertinent (higher value) assets
  - Complete data for asset operation and maintenance
  - Quantitative asset and system condition and performance measures
  - Metric to assess progress to achieving goals
- Strategy
  - Evaluation of asset performance and influencing factors
  - Risk goals and measures
  - Evaluation of lifecycle costs and benefits
  - Performance-prediction capabilities
- Planning
  - Engineering and economic analysis tools
  - Alternative analyses procedures
  - Project prioritization procedures
  - Evaluation to balance short- and long-term objectives

- Implementation
  - Contract management
  - Results monitoring and reporting
  - Continuous feedback procedures

Benefits of Asset Management

Asset management may affect nearly every part of the power delivery enterprise, from planning, engineering, construction and maintenance to finance and information technology. However, asset management is not just another management reconfiguration. Instead, asset management is a specific approach to running the organization. It brings a particular perspective to the manner in which an organization conducts its existing procedures and develops new ones, applies expertise and makes decisions. PDAM offers techniques and principles to use in planning, policy-making, project selection, data gathering, program tradeoffs, and management system application, aligned with the organization's higher-level goals.

Asset management benefits include:

- Assure that all asset decisions are policy driven
- Build, maintain, and operate facilities most cost-effectively
- Achieve desired performance levels
- Optimize long-term benefit/cost ratios
- Allocate available resources efficiently to support the organization's overall goals and policies
- Measure and focus on performance and results
- Improved repeatability, credibility, and accountability for decisions

PDAM links the customers' and regulators' requirements and expectations for power system availability and performance with system management and resource allocation strategies. A complete asset management process tracks progress made in achieving performance measures derived from the asset owner or senior management goals and also evaluates the business processes used relative to the goals and performance criteria. There are processes to project and evaluate the potential benefits and risks of alternative actions and resource allocation strategies on achieving the desired goals and objectives. The focus is on assets and system performance and the associated data, including operating and maintenance costs, risk exposure, and future resource requirements. This comprehensive approach can provide benefits to both the organization and its stakeholders.

In addition to aiding the decision-making process, asset management also supports fact-based communication among asset managers, asset owners and stakeholders. The availability of objective, credible and relevant information benefits all those participating in decision making. Decisions can be based on documented current performance and estimates of future performance. The information supporting the asset management processes—both data and information results from analysis—provides decision makers and stakeholders with a better understanding of the return on investment, economic tradeoffs, accountability, and performance impacts.

In addition, asset management offers access to data and information that enables decision makers to rapidly identify and focus on key issues. The approach enhances a decision maker's ability to evaluate and communicate the possible results of selecting a preferred alternative. The documentation explaining and justifying the choice of a given strategy also is improved. Such a systematic, documented and process-driven approach can improve communication to stakeholders and provide the asset manager a defensible rationale for capital investments and other actions.

Requirements for Asset Management

Establishing effective PDAM systems and procedures requires effort, investment, and a business commitment to developing, implementing, and maintaining an asset management approach and the elements needed to support it. Although PDAM can be accomplished in a phased implementation, the ultimate goal is to implement most or all of the following components:

- Developed and documented policies and business practices, with assigned responsibilities
- Developed and consistently applied procedures, performance criteria, and measures
- Asset inventory
- Quantitative condition and performance measurements
- Performance prediction capabilities
- A lifecycle view of costs, risks and benefits
- A suite of engineering and economic analysis tools
- Performance monitoring systems
- Processes for performance review and adjustments

A key to effective asset management is good information – timely, reliable, and accurate data to support the PDAM processes. Information technology, including relational databases to integrate individual management systems, monitoring systems, databases, and other analytic tools, should complement PDAM decision-making processes, as well as organizational roles and responsibilities.

A Holistic Power Delivery Asset Management Process

The original Guidelines report included an introduction to the principles of asset management and presented new power delivery asset management conceptual business model. Figure 2-2 shows the key role that this model was expected to play in EPRI's overall asset management work.

To enable the broadest possible application, the guide was designed to be equally useful to the many different forms of power delivery organizations. The material included is applicable to both public power and investor owned utilities and organizations of various sizes. The business model is independent of an organization's management structure or functional boundaries.

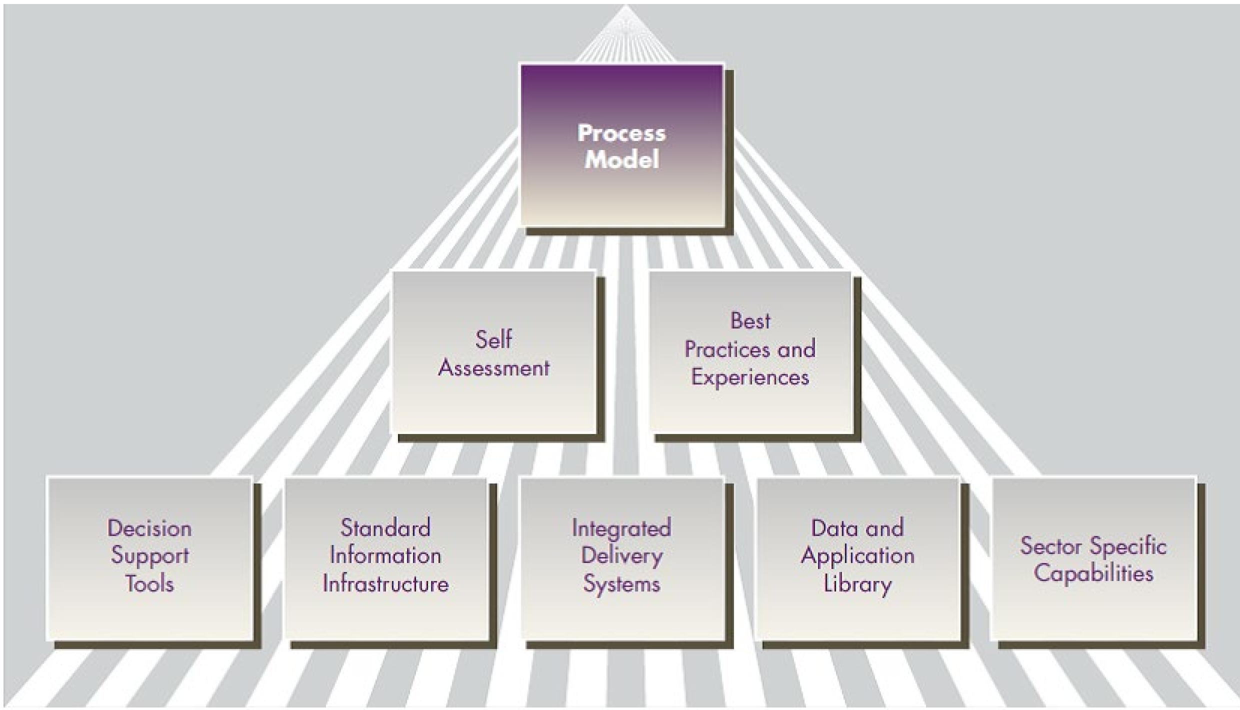

Figure 2-2
Development of the process model described in this report is a key aspect of EPRI's overall asset management work.

The power delivery asset management conceptual business model presented in the next section provides a visual representation of the functional elements of a complete PDAM implementation and the interrelationships of these elements. By introducing the fundamental elements and concepts of asset management, the guidelines were meant to serve as an introductory primer for modern asset management practices, present the initial steps to translating general asset management principles to the power delivery industry, and provide a starting point for transmission and distribution managers interested in understanding what modern asset management entails. The model itself serves to better define the PDAM processes and to identify data and analytical tool requirements for individual elements and processes. In the 2005 report, selected portions of the model have been expanded to illustrate processes at a more detailed level and assist in guiding the development of key performance indicators for PDAM, identification of PDAM decision support tools, and recommendations for PDAM phased implementation steps.

Summary of Asset Management Concepts

- Decisions on asset acquisition or replacement, operation, maintenance, and retirement are driven by performance requirements derived from the asset owner's goals.
- Resource allocation decision processes with evaluation of alternatives that include a comparison of lifecycle costs, benefits, and risks of ownership.
- Clearly defined and understood processes that identify responsible parties for all aspects of assets and system performance.
- Performance monitoring and measurement against meaningful standards should be established and maintained.

Section References

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3
THE POWER DELIVERY ASSET MANAGEMENT MODEL

One key goal of EPRI's PDAM work is to develop a visual representation of the functional elements of a complete power delivery asset management implementation and their interrelationships as shown in Figure 3-1. Modeling the PDAM concept illustrates the interfaces among the various components and shows the required inputs and expected outputs. The model helps to better define the important PDAM processes and to guide subsequent development work to identify data and analytical tool requirements for individual elements and processes.

For the broadest possible application, this model has been designed to be equally useful for many different forms of power delivery organizations (for example, various different sizes of public power and investor-owned utilities). The model elements are independent of the organization's management structure or functional boundaries. A broad approach was used in model development. Wherever possible, organizationally neutral terms and process identifiers were used. The model is intended to be truly generic (for example, no blocks are labeled "Engineering" or "System Planning"). Recognizing the likelihood of a phased implementation, the models can be as easily applied at the utility department level as at a section, facility, or even asset level, with only modifications to the meaning of asset owner, senior management and other stakeholders. In each case, the functional representations for asset management concepts remain the same.

The power delivery asset management model in Figure 3-1 is neither a process nor data flow diagram, but instead includes elements of both. The objective is to illustrate a conceptual representation of best practice PDAM without the constraints of a formal process diagram. Equally important, is the objective to describe PDAM at a level of detail that allows specifications of functions, data and decision support tools to be developed.

Some liberties were taken in the degree of complexity shown for purposes of simplicity. Figure 3-1 purposely is not consistent in the level of detail among the various processes depicted. For example, the Analysis Performance Modeling and Prediction process combines together in one block many more sub-processes than the Develop Action Plan process. The purpose here is to show all the key functional concepts and interactions in order to provide a complete visualization for a PDAM implementation. Other authors may combine and arrange the PDAM model elements differently but the overall functions should agree. One purpose of constructing this conceptual model is to illustrate the functional boundaries and data exchanges among the various processes, wherever they may reside in any particular organization's implementation.

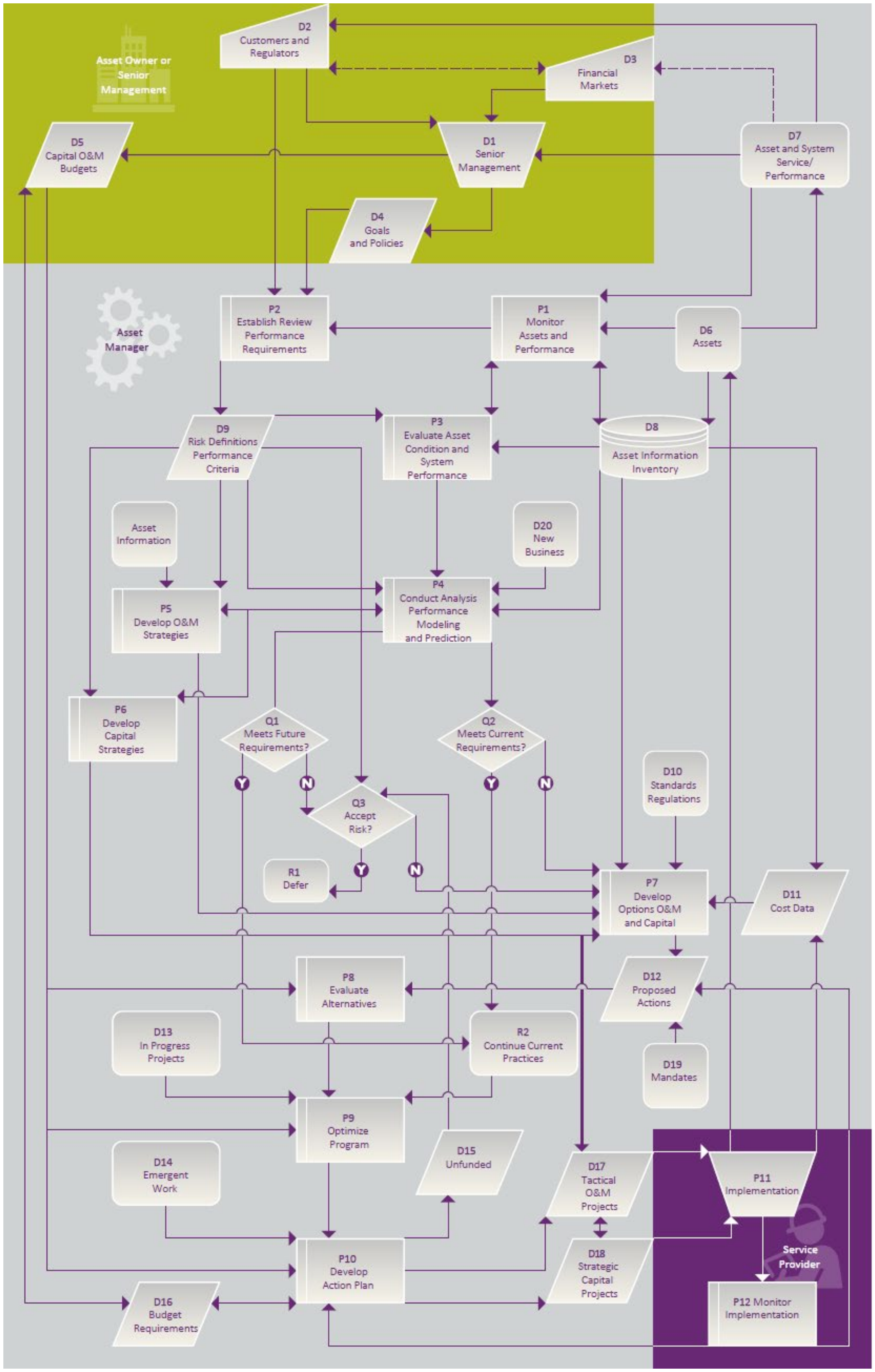

Figure 3-1
The power delivery asset management model

A brief description of some key aspects of the PDAM process will aid in putting the guide review process in perspective. More detailed explanation of each included element is provided later. The diagram in Figure 3-1 clearly shows the responsibilities of the three parties. As depicted, all asset-related decisions should be guided by the goals of the asset owner, senior management and other key stakeholders. The asset manager's responsibility is to direct resources to their optimal uses, as defined by the organization and its stakeholders. The service provider carries out the actions requested by the asset manager. Ideally, asset management applies at all levels, in all time frames, for capital investments as well as ongoing operations, continually balancing different and often conflicting goals. Labels in bold text refer to diagram blocks.

Goals and Policies

The asset owner (or senior management) is the initiator for PDAM. The owner sets the business parameters, risk boundaries, and operating context for its assets for the operational and longer-term horizons. This level also sets the operating context for the asset manager and, for power delivery, focuses on corporate governance as the regulatory license-holder. In general, the owner is represented by the highest levels of management within the organization that owns or, in the case of governmental agencies, directly controls the assets. The asset owner may or may not be a part of the organization that operates and maintains the assets. Owners directly or through senior management interact with key stakeholders (for example, customers, shareholders, regulators, employees and financial agencies), as well as asset managers. The asset owner sets the Goals and Policies and the Budget for the organization.

The asset owner or senior management should develop and clearly communicate well-defined high-level Goals and Policies and a strategic framework for operating the organization. These goals should be translatable to clear business objectives and measures of performance. Some goals, such as desired internal rates of return, might be very specific and quantifiable. Other goals, such as improving customer perception, may be less specific and incorporated in a long-range plan resulting from a strategic planning process. It is the asset manager's responsibility to translate these goals and policies into measurable objectives. Included here may be an outline of business processes and organizational responsibilities and roles reflecting the asset owner's policies and philosophies. These goals and policies often start with a mission statement and are used to set performance metrics for subsequent processes.

Policy formulation seeks input from various stakeholders, and reflects customer priorities and concerns. Stakeholders can include the asset owner's parent company, shareholders, regional operating organizations, state and federal utility, safety and environmental regulators, local governments and the public at large. Each of these groups may have different goals and metrics. Some may be very specific and short term, such as specific earnings per share target or an availability factor. Other goals and metrics may be less well-defined or longer term. These stakeholders (particularly regulators) also may have different constraints on actions that can be taken. These are "must do" or "must not do" types of inputs. The asset owner relies on the leadership, vision, values, business objectives, and judgment of the organization and its senior management to establish how to weigh tradeoffs between competing goals and produce a consolidated set of goals and operating policies.

Performance Assessment

Assessment of asset and system condition and performance provides quantitative data and information about the performance of the **Asset Inventory** in meeting established **Performance Criteria** and information that can be used in subsequent analyses to predict their ability to meet these requirements in the future (an important input for maintenance process planning). Asset condition assessment and performance measurements and tracking form the basis for asset life cycle management. They provide a basis for adjustments to the various outputs of subsequent processes, ensuring that expected performance goals are met and providing indications where changes are required. Effective asset condition assessment in relation to its service performance is needed to understand and predict the deterioration that leads to reduced asset performance in the future. Assessments of system performance and implementation also may be conducted by external stakeholders (for example, customer perceptions of infrastructure condition, or regulator assessment of the provision of services), and these are valid inputs for analysis as well. These evaluations are a key process of PDAM. Understanding the current condition of an asset or the current level of performance provided by a system provides vital information for a series of asset management maintenance decisions and a starting point for predicting future performance.

Determining the current level of system performance usually entails straightforward calculations, such as summing the number of customer interruptions. Tracking equipment condition parameters has a number of uses. The most obvious use is for deciding whether some immediate corrective action is indicated. For equipment, many of these evaluations are part of normal maintenance activities. However, it is important that the history of these activities not be "islanded" in the maintenance system. Rather, this information should be available to the larger PDAM process, of which maintenance is just a part. In addition to triggering maintenance, such information should be used to determine how well past asset management decisions have been implemented and whether the expected improvements have resulted. This assessment information also can provide a starting point for projecting future asset or system condition through the use of deterioration models and also to refine existing models.

Explanation of Model Elements

Model Input/Output Definitions

D1 – Senior Management or Asset Owner

This functional level sets the business parameters, risk boundaries, and operating context for its assets. The asset owner or senior management also sets the operating context for the asset manager and, for power delivery, focuses on corporate governance as the regulatory license-holder. In general, the owner is represented by the highest levels of management within the organization that owns or, in the case of governmental agencies, directly controls the assets. The asset owner may or may not be a part of the organization that operates and maintains the assets. Owners directly or through senior management interact with key stakeholders (for example, customers, shareholders, regulators, employees and financial agencies), as well as asset managers. The asset owner or senior management sets the **Goals and Policies** and the **Budget** for the organization.

D 2 – Customers and Regulators

Customers and Regulators include all recipients of the services provided by the organization or organizations that own and/or operate the **Assets** and all regulatory bodies, including local, state and federal, that can influence operation of the organization, regional transmission operators and the general public. The service levels provided with the assets directly impact customers and RTO's. Regulators, through formal reporting and customer feedback, monitor service and asset performance and can mandate actions directly impacting the organization's performance requirements. Regulators also are influenced by and can in turn affect the **Financial Markets'** perception of the organization.

D3 – Financial Markets

Financial Markets are the markets that the **Asset Owner or Senior Management** uses to obtain both short- and long-term financing. These markets and associated financial institutions are aware of the organization's service levels and asset performance, as well as the traditional business financial indicators. The markets also interact with the **Regulators** as described above indirectly through bond ratings and stock valuations. Financial markets can heavily influence the **Asset Owner or Senior Management**'s **Goals and Policies**.

D4 – Goals and Policies

The Senior Management or **Asset Owner** should develop and clearly communicate well-defined high-level **Goals and Policies** and a strategic framework for operating the organization. These goals should be translatable to clear business objectives and measures of performance. Some goals, such as desired internal rates of return, might be very specific and quantifiable. Other goals, such as improving customer perception, may be less specific. It is the asset manager's responsibility to translate these goals and policies into measurable objectives. Included here may be an outline of organizational roles and responsibilities and business processes that reflect the asset owner's policies and philosophies. These goals and policies often start with a mission statement and are used to set performance metrics for subsequent processes.

Policy formulation seeks input from various stakeholders, and reflects customer priorities and concerns. Stakeholders can include the asset owner's parent company, shareholders, regional operating organizations, state and federal utility, safety and environmental regulators, local governments and the public at large. Each of these groups may have different goals and metrics. Some may be very specific and short term, such as specific earnings per share target or an availability factor. Other goals and metrics may be less well-defined or longer term. These stakeholders (particularly regulators) also may have different constraints on actions that can be taken. These are "must do" or "must not do" types of inputs. The **Asset Owner** relies on the leadership, vision, values, business objectives, and judgment of the organization and its senior management to establish how to weigh tradeoffs between competing goals and produce a consolidated set of goals and operating policies.

D5 – Capital O&M Budgets

The Senior Management or **Asset Owner**, at the highest levels determines the organization's financial framework, sets both capital and operating budget limits taking into account desired operating service levels, revenue forecasts, regulatory constraints, costs of capital, financial goals and performance, and expectations of the markets.

D6 – Assets

The organization's **Assets** service and supply end users or facilitate performing such services. The reason **Asset Owners** acquire, operate, and maintain an asset is to support service delivery. Therefore, an asset possesses current service potential or future economic benefit. For power delivery, physical assets such as transmission and distribution system equipment are the most commonly considered. However, a more comprehensive application of asset management principles might also consider time, people, data, and knowledge as assets to be optimally managed. The common understanding of an asset in any context is that it has value that exists over time. This implies that assets have both a useful and an economic life, which may not coincide in length. For practical purposes, only assets with significant value are considered in the asset management process.

D7 – Asset/Service Performance

Asset and Service System Performance represents the final output of all the processes of the organization. These terms are used in the broadest sense, and there are two distinct but related aspects to asset/service performance. The organization's **Assets** are used to provide services to customers – end user service levels, often referred to as system performance in power delivery – and these can be measured by various metrics. Examples for power delivery include SAIFI, SAIDI, and energy-not-delivered and these are developed in the **Evaluate Asset Condition and System Performance** process. In addition, individual assets or groups of assets are expected to perform at certain levels, which may or may not affect end user service levels. Examples here include equipment failure rates, return on investment, and maintenance costs. The service levels provided with the assets directly impact customers and are directly influenced by **Asset** condition and operating procedures.

D8 – Asset Information and Inventory

Asset Information and Inventory includes a collection of databases that hold complete, current, and accurate information on system performance, asset condition and performance metrics, failure and replacement histories, asset location, age, specifications, and costs. An **Asset's Performance** can only be accurately established in the total context of its use. Therefore, data on operations and maintenance histories and costs, as well as the asset's importance or criticality to system performance measures should also be recorded.

D9 – Risk Definitions Performance Criteria

Risk Definitions Performance Criteria is the set of qualitative and quantitative values that were developed in the **Establish Review Performance Requirements** process. They set performance goal levels and risk boundaries that support the asset owner's goals. Power delivery risk is discussed in more detail in Section 6.

D10 – Standards and Regulations

Regional operating organizations and system operators, state and federal utility, safety and environmental regulators, and state and local governments may impose conditions that constrain the development, definition or timing of various action plans. The asset manager in the **Develop Options** process must consider these **Standards and Regulations**.

D11 – Cost Data

Cost Data is the information needed to price developed options accurately. Data comes from external suppliers and service suppliers, asset records, and internal cost accounting sources.

D12 – Proposed Actions

Proposed Actions are a set of activities that have resulted from the **Develop Options** process to address identified service or performance shortfalls or new goals. Possible actions include repair or replacement of an existing asset, addition of new assets, and changes and additions to operating or maintenance procedures. Each proposed action is associated with a complete description, estimates of costs over its lifecycle, and evaluation of expected benefits and risk reduction. More than one alternative may be proposed to meet a specific need. Competing alternatives are analyzed in the **Evaluate Alternatives** process.

D13 – In Progress Projects

In Progress Projects include projects continuing over from previous years or planning cycles that are in progress and expected to be continued, if they are not displaced in the **Program Optimization** process.

D14 – Emergent Work

Emergent Work is all emergency or unanticipated work that must be conducted. Time response may require direct input to **O&M Projects,** but should be accounted for in the **Develop Action Plan** process also to assess budget or resource impacts on other work.

D15 – Unfunded

Unfunded projects or other actions have a ranking as determined by the **Optimize Program** process such that a limited financial budget or other resource limitations precludes their implementation (that is, "below the line projects"). They may be deferred or resubmitted after final review of the risk of not proceeding in the **Assess Risk** decision process.

D16 – Budget Requirements

Budget Requirements is the sum of all funds required to implement the results of the **Develop Action Plan** process. The business needs for funds may exceed the original allocation. In that case, this output would show the shortfall and, carried through from previous processes, the associated risks and potential benefits for considering budget changes by the Senior Management or **Asset Owner**.

D17 – Tactical O&M Projects

Tactical O&M Projects is the list of actions that address short-term and O&M issues. This includes routine maintenance and testing, as well as possibly some capital work such as equipment installation that may utilize the same resources. For simplicity, included here implicitly is the work management process that evaluates all current and emergent work for assignment, determines resource requirements, requests outages, and develops schedules. The **Service Provider** may perform some of this work scheduling.

D18 – Strategic Capital Projects

Strategic Capital Projects is the list of actions that are considered to be capital investments. Capital and O&M workflows should be coordinated in order to maximize efficiencies and minimize resource constraints.

D19 – Mandates

Mandates includes all legal, government, or contract obligations that may or may not be performance driven in the sense that they align with explicit performance criteria. Such mandates often bypass the **Develop Options** process, but in some cases, can be addressed in more than one fashion. In the latter case, possible options should be developed.

D20 – New Business

New Business is demand growth that may require new assets or system capacity expansion. For power delivery, this is load growth or new customers. New demands are analyzed in the **Analysis Performance Modeling and Prediction** process to determine whether or not some action is required to maintain or achieve the desired performance levels.

Model Process Definitions

P1 – Monitor Assets and Performance

Monitor Assets and Performance is the process of collecting data that reflects **Asset and System Performance** and condition. There are multiple processes, both manual and automated, used to monitor and measure both end user service levels and the performance of individual components, assets, or groups of assets. Inspections, testing, on-line monitors and trouble call tallies are examples of these monitoring processes. The outputs of these monitoring processes are stored in various databases, the **Asset Information Inventory**, throughout the organization for analysis, direct reporting, and subsequent use in other processes. Only data that has an identifiable use in a subsequent process should be collected. The adequacy (timeliness, precision, and so on) of the data outputs of this process should be corrected by feedback from all subsequent processes that make use of the data (not shown).

P2 – Establish Performance Requirements

The **Goals and Policies** of the Senior Management or **Asset Owner** are used to develop criteria for decision-making and measurements of asset and system performance towards achieving those goals. To accomplish this, performance indicators, specific qualitative or quantitative measures that allow performance against a benchmark to be assessed, are required. This step involves transforming the high level strategy into a set of decision criteria for evaluating actions at the lower levels. These criteria could be numerical, such as average restoration time requirements, or they could be qualitative, such as a decision that a safety related task has the highest priority. They range from internal business and engineering indicators to customer and financial perspective indicators. Whatever form they take, the criteria and performance requirements should be constructed to allow the asset manager to use a mechanism for prioritizing activities that is consistent with the high-level strategy, goals, and policies of the senior management or asset owner. The next step after establishing performance criteria in this process is risk identification and an assessment of constraints, which define success criteria and unacceptable risk. The impacts from requirements for regulatory compliance are also included here.

P3 – Evaluate Asset Condition and System Performance

The **Evaluate Asset Condition and System Performance** process takes inputs from the **Monitor Assets and Performance** process and either directly or with added calculations compares them with desired levels from **Risk Definitions and Performance Criteria**. Gaps or anomalies in performance levels may be identified here. Additional input comes from the **Asset Information Inventory,** to put the monitoring data in context. The major output is a series of values that reflect the condition assessment of the system, groups of assets, individual assets, or asset components. Examples are outage numbers and durations, number of equipment failures, and cost totals for a specific number and kind of task. This process addresses directly measured performance metrics and values with the objective of determining current asset condition or performance level.

Evaluations of asset and system performance provide factual and quantitative information on the performance of the **Assets** in meeting established **Performance Requirements** and information to predict their ability to meet these requirements in the future. Performance monitoring forms the basis for management of an asset throughout its life. It facilitates adjustments to the various outputs of subsequent processes, ensuring that program performance goals are met and providing indications where changes are required. Effective asset condition assessment in relation to its service performance is needed to understand the deterioration that leads to reduced asset performance in the future. Evaluations of system performance also may be conducted externally (for example, **Customer** perceptions of the quality of infrastructure condition, or **Regulator** assessment of the provision of services), and these are valid inputs for analysis as well.

P4 – Analysis Performance Modeling and Prediction

Performance modeling entails analyzing performance data and asset information from the **Evaluate Asset Condition and System Performance** process in order to predict the future condition of an asset, subsystem, or the complete system and how it may respond to future demands or stresses. This process is concerned with deriving, calculating, and analyzing indirect performance metrics and values. It works on identifying and understanding the causes of performance gaps, current risks and trending, and predicting future performance and risk. The general objective here is to predict future asset condition or system performance levels.

Modeling performance generally requires data on past performance of similar facilities or equipment and some understanding of the mechanisms of aging and wear that contribute to a decline in performance over time. Knowledge of how operating stresses may influence asset degradation over time (that is, aging models) is useful in this process. Expected future operating conditions are also required, including **New Business**. Analysis may also be required to identify the underlying causes of performance gaps or an unexpected asset condition through root cause analysis. Using various analytical, statistical, and simulation tools, this process determines such information as statistical failure data, predicted end of life, condition-based triggers to support proactive asset maintenance or replacement, the implications of deferred maintenance, probability and consequences of failures and other risks, and future rating limitations.

P5 – Develop O&M Strategies

The **Develop O&M Strategies** process develops operating and maintenance strategies and practices that are to be generally applied in the organization. Based on review and analysis of **Risk Definitions Performance Criteria** and risk assessments, industry practices, manufacturer recommendations and historical data, this process's outputs include maintenance procedures, value and timing of preventive maintenance tasks, condition-based maintenance triggers, maximum operating levels and other similar standards. This process includes reliability-centered maintenance analyses and updating. Maintenance that is not condition based goes directly to the O&M action plan process. This process translates performance criteria to task level activities. Equipment failures are analyzed here and result in one for one replacement (R2 Continue) or, if necessary, development of new options (P7) or new procedures.

P6 – Develop Capital Strategies

The **Develop Capital Strategies** process develops capital strategies generally applied in the organization. Based on review and analysis of **Risk Definitions Performance Criteria,** performance and risk assessments, costs and other economic consideration, this process's outputs include replacement triggers, spare unit criteria, and lifecycle costs modeling criteria.

P7 – Develop Options

The **Develop Options** process develops a set of **Proposed Actions** to address identified service or performance shortfalls or new requirements. These options are cost-effective alternatives for possible implementation compatible with the operating and maintenance and capital strategies of the organization. The options include additions, upgrades, repair, or replacement of an existing asset; addition of new assets; and changes and additions to operating or maintenance procedures. Each proposed action includes a complete description, estimates of costs over its lifecycle and lifecycle performance, and an evaluation of expected benefits and risk reduction developed in this process. More than one alternative may be proposed to meet a specific need, and a range of alternatives may be proposed for some performance issues. Competing alternatives are analyzed in the **Evaluate Alternatives** process. This is essentially an engineering and design process for power delivery and both capital and O&M are considered here.

P8 – Evaluate Alternatives

The **Evaluate Alternatives** process evaluates **Proposed Actions** where several alternatives have the same objective. For example, in power delivery, a task may be to choose the best combination of maintenance and testing tasks to keep a population of equipment operating at a specified level of reliability or to meet new load demand by upgrading an existing station or by adding a new station. The objective is to evaluate a number of possible project alternatives over a long period for a segment of the asset population, subject to defined conditions and limitations, and select the strategy that has optimal value based on the desired performance criteria and risk boundaries. This process relies on calculation of lifecycle costs and benefits so that alternatives can be properly evaluated. Valid economic models; data for acquisition, installation, operation, maintenance, and disposal costs; and quantification of benefits are needed.

P9 – Optimize Program

The objective of the **Optimize Program** process is to establish priorities between competing uses of resources for multiple objectives. This process evaluates **Proposed Actions** and the selected results from **Evaluate Alternatives** in order to identify the optimum mix (maximum total value or highest benefit/cost ratio) of different possible projects that produce different kinds of benefits, while not violating budget and other constraints and limitations. The optimal project mix has minimal total cost, while maximizing the aggregate benefits resulting from the project mix.

The process takes the **Proposed Actions** and prioritizes and ranks them according to the criteria developed in **Risk Definitions Performance Criteria**. Also included in the inputs are **In Progress Projects** carried over from previous years or planning cycles, which are to be evaluated. The key to successful asset management at this phase is the ability to evaluate candidate projects using a collection of attributes that describe financial and system performance implications in a consistent and logical basis with a process that fairly treats projects with different attributes, different time horizons, and responses to different customer and system needs and that is aligned with stated policy objectives and performance measures and targets. The process selects the best multi-year program of projects given a series of constraints and presents the implications of changes in budget levels when evaluating projects with different attributes.

The output of this process is a ranked action list that consolidates all projects and evaluates them relative to each other. The **Develop Action Plan** process uses the list to establish what projects will be conducted, given strategic goals and constraints related to long- and short-term planning and budgeting.

P10 – Develop Action Plan

The **Develop Action Plan** process takes the output from the **Optimize Program** process and produces grouped plans of actions for implementation. This process "rolls up" all successful candidate actions and associated budget requirements. It identifies a set of actions that can be implemented, given any set of available resources, and a recommendation of what actions should be implemented given anticipated resources. This is the proposed set of priorities submitted for approval. Included here is the final approval process for capital investments. Emergent work also needs to be considered in the action plan in order to assess budget and resource impacts and make adjustments for other projects if necessary. However, some circumstances may require rapid responses that may necessitate immediate action. In such cases, such consideration may take place after the fact.

P11 – Implementation

Implementation represents all actions to implement efforts associated with acquisition, installation, maintenance, refurbishment, replacement, and disposal of assets. In asset management terminology, this process is the main responsibility of the service provider. The service provider may be different for different actions and may be part of, or separate from, the asset manager's organization. This represents the main interface between the asset manager and the service provider(s). Included here are work and contract management, service level agreements by the asset manager and task design, work planning and scheduling by the service provider.

P12 – Monitor Implementation

The **Monitor Implementation** process monitors the work done to implement the approved actions. At one level, it is a check on the service provider, but it is also important to the larger asset management focus. It includes tracking of actual delivery costs as measured against expected costs. This information can be used to improve understanding of the true costs of various activities so that this information can be used to enhance future resource allocation decisions in **Proposed Actions** and in a few cases may necessitate review of proposed actions. Similarly, schedules are also monitored. Problems in implementation may necessitate changes in the **Develop Action Plan** process.

Model Decision Point Definitions

Q1 – Meets Future Requirements

A "yes" result for the **Meets Future Requirements** decision process means that, over the future planning period of interest, asset or system performance is predicted to meet all necessary requirements and that no changes need to be considered. A "no" result necessitates an evaluation of the future risk exposure in order to determine whether action is required.

Q2 – Meets Current Requirements

A "yes" result for the **Meets Current Requirements** decision process means that asset or system performance meets all necessary current requirements and that no changes are required. A "no" result means that action options must be developed to meet the performance gap.

Q3 – Assess Risk

A "yes" result for the **Assess Risk** decision process means that any risk associated with potentially not meeting future performance requirements for an identified criteria resulting from the **Analysis Performance Modeling and Prediction** process or with not implementing unfunded actions resulting from the **Develop Action Plan** process is low enough to **Defer** action. A "no" result requires further action.

Model End Point Definitions

R1 – Defer

Actions identified in preceding processes that will not be implemented end in the **Defer** end point. This is the result of the **Assess Risk** decision process when 1) assessment of the risk associated with a predicted future performance gap indicates that no action is necessary, or 2) the review of **Unfunded** projects or other actions whose ranking as determined by the **Optimize Program** process is such that limited financial budget or other resource limitations preclude their implementation.

R2 – Continue Current Practices

When the results of **Analysis Performance Modeling and Prediction** indicate that risk exposure is acceptable and no changes or additions are required, current practices can be continued. This may occur, for example, when analysis shows that an unexpectedly high equipment failure rate was due to circumstances not likely to reoccur or that they will be mitigated by some other action.

Section References

1. *Guidelines for Power Delivery Asset Management*. EPRI, Palo Alto, CA. 2005. 1010728.

4
MAINTENANCE AND POWER DELIVERY ASSET MANAGEMENT

The previous section introduced the fundamental concepts of PDAM. This section will expand the explanation of the integration of maintenance within PDAM.

The Core Maintenance Concept

Based on the principles of PDAM, the overriding purpose of a maintenance process is to support the goals and objectives of the senior management or asset owner. Many maintenance programs are purely equipment focused. That is, they are designed only around the requirements of the equipment without reference to the larger perspective of how the equipment performance can best support all of the organization's objectives. This narrow focus often puts maintenance programs at a disadvantage when competing for limited resources.

Utilizing asset management principles, the most effective maintenance process would be based upon a core mission statement that could be linked to higher-level missions, for example:

The purpose of the maintenance process is to achieve the specified levels of asset performance at acceptable costs and in compliance with all safety, health and environmental standards.

As required by PDAM, performance targets for asset reliability, availability and service life should be tied directly to business goals. Costs and compliance levels are established similarly. Within this framework, a PDAM focused maintenance process would have:

- Work requirements based on established standards and criteria for equipment condition or performance
- A screening process that ensures all performed work is justified and necessary to support performance goals
- A systematic decision process to evaluate and manage risks when selecting maintenance tasks
- Execution by the most cost-effective method
- Measurement of benefit achieved
- Performance metrics established, monitored and used as a basis for continuous review and improvement of maintenance and asset performance

The Maintenance Process

The only justification for an asset owner or senior management to purchase, install and maintain an asset is to receive benefits from the services the asset provides. This is as true for a circuit breaker as it is for a bucket truck. Of course the services may differ, for example contribute to safe and effective operation of the power system for the circuit breaker, but all service levels and their contribution to the organization's goals should be clearly specified, understood and monitored.

The only justification for maintenance is to preserve an asset's service level. Therefore, there should be a direct link between the desired performance level and the maintenance objectives.

Before exploring the maintenance process, the PDAM process needs to be understood in more detail. As shown in Figure 3-1, assets inventory and the services and performance they provide represent the final output of all the processes of the power delivery organization. These terms are used in the broadest sense, and there are two distinct but related aspects to asset/service performance. The organization's assets are used to provide services to customers – end user service levels, often referred to as system performance in power delivery – and these can be measured by various metrics. Examples for power delivery include SAIFI, SAIDI, and energy-not-delivered and these are developed in the **Performance Criteria** process.(Bold text refers to specific blocks of Figure 3-1.) In addition, individual assets or groups of assets are expected to perform at certain levels, which may or may not affect end user service levels. Examples here include equipment failure rates, return on investment, and maintenance costs. The service levels provided with the assets directly impact customers and are directly influenced by **Asset** condition and operating procedures. A later section will explore performance metrics in more detail.

The **Goals and Policies** of the **Stakeholders** are used to develop criteria for decision-making and measurements of asset and system performance towards achieving those goals. To accomplish this, performance indicators, specific qualitative or quantitative measures that allow performance against a benchmark to be assessed, are required. This step involves transforming the high level strategy into a set of decision criteria for evaluating actions at the lower levels. These criteria could be numerical, such as average restoration time requirements, or they could be qualitative, such as a decision that a safety related task has the highest priority. They range from internal business and engineering indicators to customer and financial perspective indicators. Whatever form they take, the criteria and performance requirements should be constructed to allow the asset and maintenance managers to use a mechanism for prioritizing activities that is consistent with the high-level strategy, goals, and policies of the asset owner. An associated step (not shown), after establishing performance criteria in this process, is risk identification and an assessment. The impacts from requirements for regulatory compliance are also included here.

The **Evaluate (**Asset Condition and System Performance) process takes inputs from the **Identify Gaps** process and either directly or with added calculations compares them with desired levels from **Performance Criteria**. Gaps or anomalies in performance levels may be identified here. The major output is a series of values that reflect the condition assessment of the system, groups of assets, individual assets, or asset components. Examples are outage numbers and durations, number of equipment failures, and cost totals for a specific number and kind of task. This process addresses directly measured performance metrics and values with the objective of determining current asset condition or performance level.

Evaluations of asset and system performance provide data and quantitative information about performance of the **Assets** in meeting established **Performance Requirements** and information to predict their ability to meet these requirements in the future.

Performance monitoring, both directly and indirectly, provides the basis for management of an asset throughout its life and indicates the need for changes to processes or procedures to ensure that program performance goals are met. Effective asset condition assessment in relation to its service performance is needed to understand the deterioration that leads to reduced asset performance in the future. Evaluations of system performance also may be conducted externally (for example, customer opinions of infrastructure condition, or regulator assessment of the provision of services), and these are valid inputs for analysis as well.

The maintenance process is included within the **Implement** process in Figure 3-1 along with all of the other tactical operations of PDAM. The initial step in developing a maintenance program is to develop maintenance strategies. This process develops maintenance strategies and practices that are to be generally applied in the organization. Based on review and analysis of risk definitions performance criteria and risk assessments, industry practices, manufacturer recommendations and historical data, this process's outputs include maintenance procedures, value and timing of preventive maintenance tasks, condition-based maintenance triggers, maximum operating levels and other similar standards.

Of course, maintenance currently is a well-established process in all power delivery organizations. In fact, some confuse good maintenance practices with asset management. Maintenance is an integral part of asset management, but only a part. The objective of an integrated asset management maintenance program is not to simply maintain equipment to some standard but to make certain that maintenance practices are developed in alignment with the organization's goals and objectives. Furthermore, assets are maintained to provide performance levels determined by an evaluation of the required benefits and risk tolerances and an evaluation of alternative actions.

The purpose of the next section is to describe how an existing maintenance organization can integrate into the asset management approach. An analysis of these maintenance processes will show that they are simply a special case of the larger PDAM model presented in the preceding section.

Maintenance Process Diagram

A more detailed view of the maintenance process is shown in Figure 4-1. Bold text refers to specific blocks in that diagram.

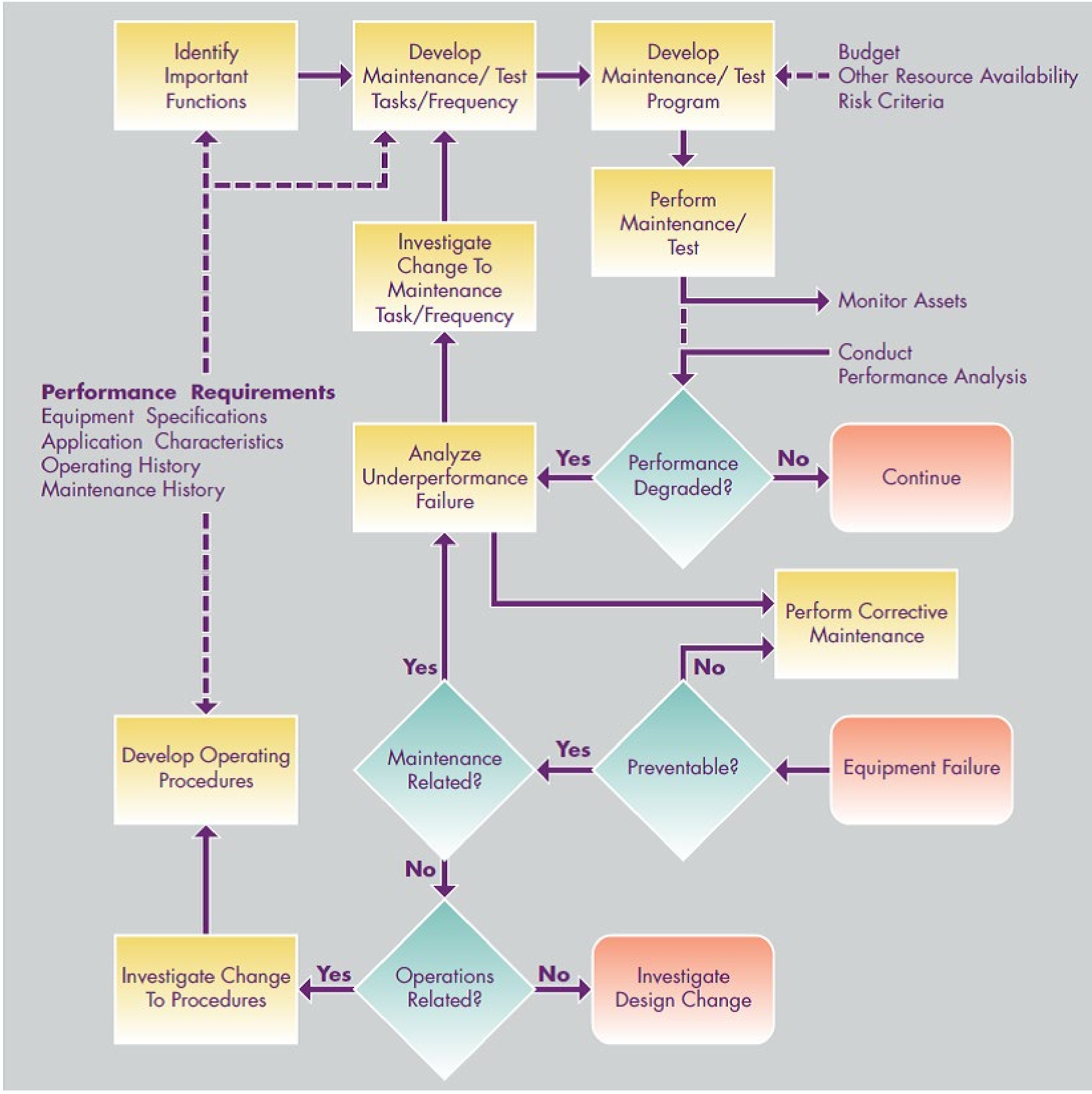

Figure 4-1
A PDAM maintenance process (Source: *Guidelines for Power Delivery Asset Management*)

The first step is to **Identify Important Functions** of the power delivery assets that are to be maintained. In addition to the expected equipment design specifications, this process should also consider the risk definitions and performance criteria developed from the senior management or asset owner's goals. This process aligns the asset's performance with the performance level required for the system of which it is a part. This means that identical pieces of equipment could have different performance requirements (for example reliability, availability) depending on where they are located in the power delivery system. These different performance requirements should translate into different maintenance requirements.

Once there is a quantification of the performance requirements for an asset, maintenance tasks and their frequency can be specified to achieve the desired results in the **Develop Maintenance Test and Task and Frequency** process. Note that these linked processes broaden the maintenance task selection from an equipment decision alone to one integrated into the asset management framework. The next step is **Develop Maintenance Program**. Since maintenance budgets are limited to some level, there may not be funds for all identified tasks and tests. A program optimization process, similar to that described in Figure 3-1for the overall PDAM implementation, should be used to insure that maximum benefits are being received from the maintenance program.

Perform Maintenance/Test is the next step and it is important that the outputs of this process are available to the overall asset management process. These outputs include the relevant data from equipment history for completed maintenance activities, completed post maintenance test activities, predictive maintenance results, equipment condition data from completed PM, operator rounds, and any other sources of performance data. These data are a part of the maintenance process but they also have uses in developing performance and condition trends, developing aging models for predicting future performance levels, assessing whether past investments have had the desired results and a number of other key PDAM activities. Therefore, there should be a data link to make certain that information that comes from maintenance is available for other uses. One means to facilitate this is to have maintenance and test data reside in the asset information repository, rather than some separate maintenance database. It is also probable that information from non-maintenance activities can be of interest in the maintenance process and there should be a means to transmit this information.

Data from both sources should be evaluated to determine whether there is asset degradation. This determination is essentially a subset of the application of the previously described assessment algorithms for maintenance and test data. Here the process is usually much simplified and is often just a comparison of measurement results against asset specifications. An investigation of the asset deterioration may show that a change of maintenance tasks or frequencies would be warranted. If not, then another option may need to be developed (for example change in supplier or operating practices). In any case, corrective maintenance will be performed.

Equipment Failure is included here as a separate case. Philosophically, a failure could be considered as an extreme case of underperformance and with such a definition the general PDAM model would accommodate failures. In reality, most power delivery organizations treat failures as special cases. The first determination to make is whether or not the failure was preventable. For all cases except run-to-failure equipment, some effort commensurate with the equipment value should be made to understand the failure cause. It is recognized, however, that not all equipment failures justify a complete root cause investigation. If no cause can be determined, then the only course is to perform corrective maintenance and continue. Even in these cases, good failure history data should be recorded for possible future analyses, such as developing equipment hazard rate curves, and trend identification. Good failure records will also help to uncover generic problems with specific designs or applications.

If the failure was found to be preventable, then the next series of questions are designed to determine whether the failure was maintenance or operations related. If indicated, changes to the procedures or maintenance tasks should be investigated. If no other cause has been identified and the risk of another failure exceeds an acceptable level, then a design change should be investigated.

PDAM Maintenance Characteristics

Outlining the development of a complete maintenance process for a power delivery organization is well beyond the scope of this document and, in fact unnecessary. Maintenance is a well-established process in power delivery organizations and significant expertise has been acquired for keeping power delivery equipment in operating condition. On the other hand, maintenance departments are less adept at explaining how to value their contributions to the organization's performance. It is envisioned that PDAM will provide both a basis for demonstrating the relative importance of maintenance and a means to improve the effectiveness of existing maintenance programs.

Given the opportunity to build a maintenance program from the ground up one would begin by answering a series of questions about each asset starting with:

- What are the required performance levels for this asset?
- What is the required reliability?
- What is the required availability?
- What is the acceptable service life?
- What is the acceptable average annual maintenance cost?
- Furthermore, how does each particular maintenance task affect the asset's performance and how is the effect measured?

Unfortunately, generally there are no analytical answers to these questions available for power delivery equipment. Rather, the response a maintenance manager would be most likely to receive is something along the lines of: as high as possible, for as long as possible, for as little cost as possible. The direction would be clear, but it is difficult to make the necessary quantitative decisions without quantitative data. Furthermore, it is difficult to justify maintenance budgets or defend against cuts without an analytical basis. PDAM can provide a framework to address the lack of data and begin to provide for quantitative maintenance decisions.

- **Understand the operational policies and the service levels demanded of the asset to fulfill the service and policy requirements**. Power delivery equipment is not specified in terms of operational reliability. Industry standards may specify some design requirements, for example, number of operations for a circuit breaker, but there generally is no quantification of equipment reliability or availability. Similarly, system and substation designs may be chosen based on computer simulations that calculate an expected service level using nominal component failure rates but there is no link between the design values assumed and the components eventually installed. For older equipment, there is usually some degree of condition degradation but any effect on equipment performance is difficult to quantify.
- **Perform a risk assessment of each asset.** Maintenance resources are limited, and their use should be directed to the assets that most contribute to performance goals, especially risk levels. Another way of stating this is that maintenance should be prioritized to address those assets whose lack of performance has the greatest impact on system performance goals or risk exposure. (Risk is more fully discussed in Section 6.) What may occur as a result of a failure is directly related to where and how the equipment is used in the power system. A measure of the equipment's application failure consequences may also be referred to as the equipment's criticality by some. Formally risk can be defined as product combination of the probability of a

hazard causing loss occurring and the consequences of that loss. In the context of PDAM, the hazard of most interest is the failure of the equipment and, as discussed above, ascertaining the probability of equipment failure is difficult. Obtaining some qualitative measure of criticality may be easier. It is possible to determine the potential for significant failure and consequences – financial, environmental, safety and other adverse impacts on performance goals and rank assets or systems in order of their potential impact to the organization.

- **Define maintenance requirements based on the equipment's risk contribution analysis**. This will establish the most cost-effective maintenance approach for each asset based on the asset's contribution to system performance.
- **Select the best maintenance strategy for each asset**. Use the principles of RCM to choose condition-based tasks, time based tasks or corrective tasks.

For defining maintenance requirements and selecting maintenance tasks, consideration should be given to the characteristics of the equipment but also to the specifics of each application and the corresponding operational and environmental stresses. Identical types of equipment may require different types of maintenance due to different applications.

PDAM Maintenance Implementation

Maintenance is often organized on three levels:

- Maintenance plans are directed at specific equipment types, makes and models and are composed of tasks specific to that equipment
- Maintenance programs combine sets of maintenance plans and are used to organize and manage maintenance resources
- Maintenance strategies link maintenance programs to the organization's goals and objectives.

Maintenance programs generally are constrained by resource limitations, primarily economic. On the other hand, there are two main drivers for maintenance:

- **Safety.** The safety of the public and utility personnel is the primary consideration in any maintenance program. Safety involves maintaining equipment and systems so that they can be operated safely under any foreseeable circumstances.
- **Service Reliability.** Reliability of service is measured by the frequency and duration of customer service interruptions. The impacts of maintenance on interruptions, both planned and unplanned, and service reliability should be analyzed.

Ideally, to address the drivers effectively while working within the constraints, a maintenance process, which crosses all three levels, should:

- Plan equipment maintenance taking into account how maintenance interacts with other activities and events affecting service performance
- Be based on equipment reliability and availability goals that balance costs with achievable circuit performance, life cycle management and service requirements.
- Direct resources towards maintenance work that will best support meeting the organization's goals.

In reviewing a maintenance program, these questions present themselves:

- What is to be accomplished?
  - Short-term goals
  - Long-term goals
- How is progress measured?
  - Metrics
  - KPI's
- What is needed?
  - For goals
  - For measurements
- What is available?
  - Data
  - Analysis tools
  - Decision support tools
- How to fill the gaps?

When decisions are made about the level of reliability to be achieved in a system, attention must be paid to the economic factors, such as the incremental costs of reliability, the benefits expected from a change in reliability, and the allocation of the reliability investment among the system components.

PDAM Fleet Management

One of the most pressing needs for new and better tools to support power delivery maintenance, including replacement, is in the area of aging asset management. Even for those utilities not faced with a large aging asset problem, quality long-range planning requires a good understanding of the current and projected future condition of the asset base.

It is well accepted that the risk of equipment condition deterioration and wear-out failures increase as equipment approaches the end of its useful service life. The rationale and timing of increased maintenance or investment decisions in anticipation of this increased risk have been traditionally left to historic patterns and engineering judgment. This may result in higher costs to the utility and its customers if investments are not optimally timed, that is, if made too early, they may result in higher carrying costs; if made too late they may result in reduced service and higher failure costs. PDAM with an aging asset infrastructure makes it increasingly critical to identify equipment hazard functions of major asset classes and to understand the risks and influence of critical variables on equipment failure rates. With better failure rate information, risk based approach models of the underlying distribution of failures or "bath-tub" curve of each asset type can be developed to allow optimizing the risk-cost function in the maintenance planning and decision making processes.

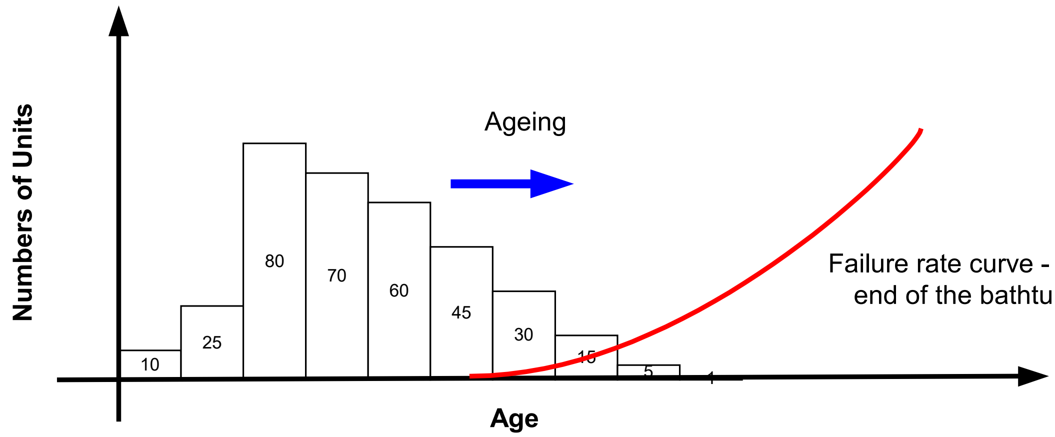

Figure 4-2
A hypothetical equipment age distribution and failure rate curve

Historically, projected equipment failure rates were computed by dividing the number of past failures by the equipment-years considered in the studies. These historical failure rates were assumed to be constant throughout the equipment life and used for replacement and spares planning. The more appropriate general situation is depicted in Figure 4-2. A histogram showing the number of units of a particular equipment type in several age brackets has been superimposed on a failure rate curve that shows an increasing failure rate with age for that type. The age profile of the units reflects previous investment patterns. As time progresses, an increasingly larger percentage of the equipment population will move into the range of higher failure rates. This type of histogram gives rise to the term “asset walls.” A significant concentration of a particular asset in a group of adjoining age brackets looks similar to a wall moving forward in time.

As illustrated in Figure 4-2, the assumption of constant failure rate only applies if the equipment in question is operating in the flat portion of the hazard rate curve. Furthermore, many factors can influence equipment performance causing variations in equipment failure rates with time and usage. These could include equipment age, loading, manufacturer and maintenance history. A better understanding of how these additional stress factors affect equipment performance is required to correlate the relationship of various parameters with the probability distribution of equipment time to failure and failure rate.

Approaching asset walls and new operating requirements make projections based on history increasingly risky. Planning maintenance, estimating future capital requirements and making the best effective capital funding decisions in the present requires a better understanding of asset performance projections over the long term. Understanding individual asset performance is important for tactical planning but understanding the collective performance for groups of asset types, often called fleets, is important for PDAM, especially where maintenance programs are not tailored to individual units.

Linking Maintenance to Equipment Reliability

Business pressures to contain costs while preserving service standards, including the spreading use of performance-based rates, have highlighted the lack of understanding of a quantifiable relationship between maintenance and equipment reliability. Intuitively, maintenance should improve equipment reliability and consequently system performance, but it is difficult to quantify any improvement. However, equipment failure rate models are required for power delivery organizations to plan, operate and maintain their systems at the required levels of reliability for the lowest possible cost. Managers would like to know what the increase in reliability would be for an incremental increase in maintenance funding or conversely, what is the impact of a reduction in maintenance on system performance.

Performance Measurement

The recurring theme throughout all of the above discussion is performance measurement. Good performance metrics are important for PDAM and effective maintenance. Properly established maintenance performance metrics provide:

- A basis for establishing maintenance objectives.
- A scale to measure maintenance effectiveness
- Insight into asset performance issues

The principles of asset management require that all are linked to the organization's operating goals. The next section will discuss performance measures in detail.

5
PERFORMANCE MEASURES

In a PDAM approach, decisions to allocate resources are based on policy goals and objectives and the resources required to obtain those results. This includes both maintenance and replacement decisions.

Performance measures enable organizations to translate high-level policy objectives such as service reliability into quantifiable expressions of results to be achieved. They provide information by which managers can make tradeoffs across competing needs and measure the effectiveness of results. There are three broad classifications for PDAM metrics:

- Measures
- Performance Measures
- Key Performance Indicators

Background Definitions

Before proceeding, it will be helpful to establish some definitions[1]:

Goal. A broad statement of the long-term results needed to accomplish the organization's mission and achieve its vision. Strategic goals are broad statements defining changes the organization hopes to achieve during the strategic planning horizon. Goals focus on outcomes or results and are qualitative in nature. Goals are defined as broad, ideal future conditions, the results the organization wants to accomplish. As an example, one of the possible goals for distribution could be:

- Reduce the number and duration of customer outages in every operating region.

Strategy. A strategy explains the way a goal or group of goals will be achieved. Strategies are statements of major approaches or methods for attaining each goal and resolving specific issues. An example strategy for the above goal is:

- Improve the reliability of the ten worst performing circuits in each service area.

Objective. Strategic objectives flow directly from strategic goals. They translate the quantitative expectations of goals into specific and measurable targets that the organization should meet to realize the goals. Objectives tell what the organization plans to achieve, who will do it, how to know when it is achieved, and what are the key performance indicators for tracking progress. Unlike goals, all objectives are expected to be met within the planning horizon. As an example, an objective to the above-stated goal to provide the best distribution reliability service in the state could be:

- Have no feeder with a SAIFI greater than x by y year.

Some additional definitions that will be useful in the following discussion:

- Input – the amount of resources used to conduct an activity
- Output – product or service; work completed
- Outcome – the results achieved by the output (for example, customer satisfaction)

- Target – the specific level of performance the organization is striving to achieve
- Measure – any meaningful indicator used to determine the magnitude or degree of something

It is important to keep in mind that not every measure relates to performance or is suitable to use as a key performance indicator.

Performance Metrics

Performance metrics are quantifiable and observable measures that support process and project objectives. They help guide progress to achieving those objectives. Performance targets are the specific levels of performance expected to be achieved. This target may be established for a particular time period and level of funding. It provides the basis for comparing actual performance data. SAIFI, for example, is not only a natural unit for measuring service value but also a way to measure performance.

There are, in fact, two general classifications of performance metrics of interest to PDAM. Results metrics measure what has been accomplished. Process metrics measure how the results were achieved. One conceptual approach to developing a list of performance metrics is to use a process model formulation. Performance criteria defined in the development of the organization's goals can be considered as the outputs of various processes and can be measured. The inputs to the process that produce the result are measured by process metrics. Going back to the SAIFI example, the index is the result of a process with many inputs that can be measured such as vegetation management and equipment maintenance, each of which can be considered as a sub-process with its own process metrics (for example, maintenance backlog).

Defining and measuring performance metrics of both classifications is important for good asset management. It is important not only to direct resources properly to maximize value but also to utilize the resources efficiently and effectively in attaining that value. In addition, good asset managers want to respond to deviations in results metrics quickly. To do this, it is important to know what influences the result metric. Process metrics provide this information. Furthermore, most results metrics are lagging indicators. This is to be expected since they are the output of a process. A distribution manager only knows that the SAIFI metric has gone below target or has not been reached after the fact. Process metrics can be leading indicators (for example, maintenance backlog). Tracking and managing them can improve the performance of the result measure.

For power delivery, there are usually many inputs to a process that has a single result and one should be cautious about developing a performance measure for each. The potential benefit should out-weigh the cost of data collection and storage and it makes no sense to gather information that will not be acted upon.

In essence, a performance measure is appropriate for asset management if it supports better decision making about resource investment, and if the organization's actions could influence the value of the measure. Some additional issues to be considered:

- Does the measure reflect stated policy objectives?
- Is the measure important to the affected stakeholders, including customers, decision makers and implementers?
- Given available resources, can the measure be accurately and reliably monitored?
- Can the measure's value be feasibly predicted in different scenarios?

- Can output or program delivery measures be used to indicate early progress towards preferred outcomes, and show consistency between allocated budgets and performance targets?
- Are procedures in place to collect performance information efficiently and accurately, and to communicate results in a useful and usable manner to their intended audiences?

Guidelines for Developing a PDAM Measure

The selection of a performance measure is based upon attributes of the related objectives and goals. Consider the following when deciding which measure(s) should be used to track progress in attaining a goal or objective:

- Ascertain the desired result associated with the goal or objective?
- If a measure is mandated or required, should additional, supplemental measures be added?
- Examine the types of measures: input, output, or outcome. Is the goal or objective associated with operating efficiently (input/output), producing something (output—amount of work done); is it about the quality or timeliness of work (outcome?)
- Consider how the measure will be used apart from monitoring progress. For example, to verify compliance with a mandate, benchmark against other organizations, or to compare different groups within the organization?
- Who will use the measure?
- What specific data is required to measure progress toward or attainment of the goal or objective?

Key Performance Indicators

Key performance indicators (KPIs) are, in a general sense, the same as the performance metrics discussed above. However, the term has come to be associated with metrics that are tracked and reported to a higher level of authority. For this reason, KPIs usually focus on measuring accomplishments or results. The commonly used reliability indices are an example. They directly measure a dimension of customer service level that is the result of many factors – design, maintenance, capital investments, and so on Trigger parameters in performance-based rates can be considered as KPIs and they too are the result of many separate activities.

Key Performance Indicators are quantifiable measurements, agreed to beforehand, that reflect the critical success factors of an organization. They will differ depending on the organization. Whatever KPIs are selected, they must reflect the organization's goals, they must be key to its success, and they must be quantifiable. Key Performance Indicators usually are long-term considerations. The definition of what they are and how they are measured do not change often. The goals for a particular Key Performance Indicator may change as the organization’s goals change.

Key Performance Indicators help an organization define and measure progress toward organizational goals. Because so many factors can influence a high level KPI, it can be difficult to gain insight when some corrective action is required. For this reason, many organizations develop lower level KPI, for example: maintenance metrics such as number of backlog maintenance orders. In fact, KPIs can be useful at any level of the organization if they are properly chosen. Good KPIs should:

- Focus on accomplishments rather than activities
- Utilize readily available metrics
- Provide meaningful indication of performance to all levels of the organization

- Promote improvement
- Allow external comparison (benchmarking)
- Communicate progress

Customer Service Performance Measures

In the power delivery industry environment of today, customer service has become a critical issue while cost control remains just as important an element. As customers expect better service at lower cost, regulators are becoming more concerned about service reliability. The number of states enforcing distribution reliability standards continues to increase with more rate decisions tied to service reliability. The challenge for utility engineers and managers is deciding how resources should be spent on reliability to provide the customer the service required, at a price that satisfies all stakeholders. Utilities need to establish reliability and power quality as a core business strategy and take a longer-term view of performance improvement. Being a regulated distribution utility unquestionably requires focused attention on reliability and power quality. Service outages have been shown, in the greater part, to be due to distribution events – up to 92% of total outages2. Once reliability and power quality have been established as a priority business strategy, performance objectives need to be established. Objectives should be based on performance, not activity. For example, the frequency and width of right-of-way clearing is less important than the effectiveness of vegetation management operations as reflected by system reliability.

Customer service is of primary importance to any distribution organization and a number of indices have been established. Load point indices measure the expected number of outages and their duration for individual customers. System indices such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) measure the overall reliability of the system. These indices can be used to compare the effects of various design and maintenance strategies on system performance.

A key issue with reliability metrics is the debate about comparing these indices from one geographic area to another and exactly how the input data should be applied in making the calculations4. In addition, there are concerns about how to "normalize" the indices for adverse weather. Many state public utility commissions require utilities to compute and track certain reliability indices, but comparing them from region to region and utility to utility has been problematic due to differences in how the data is applied, system designs, weather differences, and operating requirements. Because of this, the indices are limited in their usefulness. If the calculation method is kept the same, they are useful within a specific geographic area in evaluating changes in reliability over time and as a measurement of the effectiveness of maintenance practices. Nonetheless, these indices are well established and several are listed below:

- Sustained Interruption Indices
  - SAIFI – System average interruption frequency index
  - SAIDI – System average interruption duration index
  - CAIDI – Customer average interruption duration index

- Momentary Interruptions
  - MAIFI – Momentary average interruption frequency index
- Load Based Interruption Indices
  - ASIFI – Average System Interruption Frequency Index
  - ASIDI – Average System Interruption Duration Index

Due to their widespread use, there is no need to discuss these indices further here. Suffice it to say that these could all be considered KPIs. No parallel indices have been established for transmission assets.

Some example KPIs used by power delivery organizations are listed below. This list is not intended to be exhaustive but rather to show the variety of possible indicators that can be tracked. The KPIs are grouped by reliability, safety, work processes, cost, equipment, and financial.

Reliability:

- ASAI
- CAIFI
- CAIDI
- LAIFI
- MAIFI
- SAIFI
- SAIDI
- Number of events without switching remedy
- Failures without switching remedy/Failures total
- Number of customers impacted by outage
- Number of customers impacted by distribution bus outage events
- Correct performance of protective equipment per event
- Number of distribution bus outage events
- Load not served
- Vegetation caused SAIFI
- Vegetation interruptions per 100 miles
- Distribution system vegetation management non-storm SAIFI contribution

Safety:

- Number of human errors events
- Man-hours without injury
- Lost workday case incident report
- OSHA reportable incident rate: by department
- Responsible vehicle accidents: by department
- Safety required training: by department

Work Processes:

- O&M costs per bay by voltage
- % Critical maintenance complete
- Restoration time
- Maintenance backlog
- PM hours/emergency hours
- CM work orders/PM work orders
- CM resulting from PM inspections
- Non-weather overtime as a % of regular time: by department
- Overtime hours by reason
- Overtime hours by reason as a %
- Distribution system routine trimming program scheduled vs. completed miles
- Jobs started on time: by department
- Work completed on time: by department
- Event investigation performance: by department
- Mapping & document services: work backlog
- Planned/completed as scheduled

Costs:

- Cost of maintenance
  - By equipment group
  - By equipment model/manufacturer
  - By area/region
  - By maintenance category
- PM/CM cost ratio
- O&M costs/MWh delivered
- O&M costs/MW installed
- Call Center Costs average/customer
- Distribution system trimming program cost per mile
- O&M cost/customer
- Capital costs/customer
- On hand inventory $/system Mw installed
- On hand inventory $/customer
- Planned O&M cost/emergency O&M cost
- O&M cost/Mw installed
- O&M cost/MWh delivered
- Capital cost/Mw expanded
- Capital cost/customer connected

- Total budget performance by department
- O&M budget performance by department
- Capital budget performance by department
- Spending on consumables, small tools and material: by department
- SF_6 Gas Use – replacement pounds per month

Equipment:

- Average equipment age
- % Tasks requiring custom-built parts
- Average equipment utilization factor
- Failure rate by equipment group
- Mean Time Between Failures – by equipment types, service areas
- Mean Time To Repair – by equipment types, service areas
- Substation SAIDI
- Substation SAIFI
- Pole replacement – miles inspected

Financial:

- Capacity investments/Capacity installed [$/MW]
- Capital investment/Total book value
- Book value/MW installed
- Book value/MWh delivered
- Inventory turnarounds
- Inventory costs/MW installed
- Inventory carrying charge

PDAM and Performance Measures

PDAM can help to identify performance measures to support resource allocation decisions regarding operation and maintenance. PDAM can also help to develop a framework for selecting appropriate performance measures and establishing performance targets.

At this stage of development, rather than attempting to recommend one set of performance measures suitable for any power delivery organization, it is more productive to define criteria for a useful performance measure in an asset management context. Although the selection of particular performance measures can influence what gets done, equal attention should be directed at the various ways performance measures are used and incorporated into maintenance processes. Utilities also face challenges in making the best use of available resources. However, there are significant differences across companies regarding service territory, organizational structure, policy objectives, system design, management processes, staff capabilities, data and performance measures already in place. Each of these factors has a bearing the performance measurements and approaches that will be most effective in a particular situation.

Without question, the paramount performance measures for distribution systems are the well-established reliability indices, SAIFI and SAIDI. Although the details of their calculation may differ, most distribution organizations track performance in these terms. More recently, several states have incorporated reliability indices into their regulatory structure and linked them to rates. Such performance based rate mechanisms make it easier to monetize the value of a reliability index but, as previously discussed, these indices are output measures. They are the result of the combination and interactions among a large number of variables. Asset and maintenance managers only can affect these output performance indicators by changing one or more of the controllable input variables.

The problem is that the relationship between changes in the inputs and the outputs are not well quantified. For example, it is clear that customer reliability can be influenced by substation equipment reliability and it is possible to determine how many customers would be impacted by a particular equipment failure by examining system topology and layout. The problem comes when trying to determine how equipment maintenance can improve a customer reliability index. What would be the corresponding improvement in customer reliability for increased equipment maintenance? Without quantifiable relationships, it is difficult to direct resources most effectively.

Secondary KPIs

Figure 5 -1 shows how both power quality and the number of interruptions influence a higher-level goal, reliable customer service. Forced interruptions are tracked by a number of previously reviewed reliability KPI's. Managing these indices is an important responsibility for distribution system operators but, as discussed earlier in this section, these are lagging, or output, KPI's. They only indicate a deviation from the desired performance after it has occurred. To better anticipate and control possible shortfalls in performance, one must identify and track the process inputs, the leading indicators. For the case illustrated in the figure, for example, some input factors to the maintenance process that could affect outage duration include:

- Crew productivity
- The Crew assignment process
- Crew skills and knowledge
- Availability of replacement parts

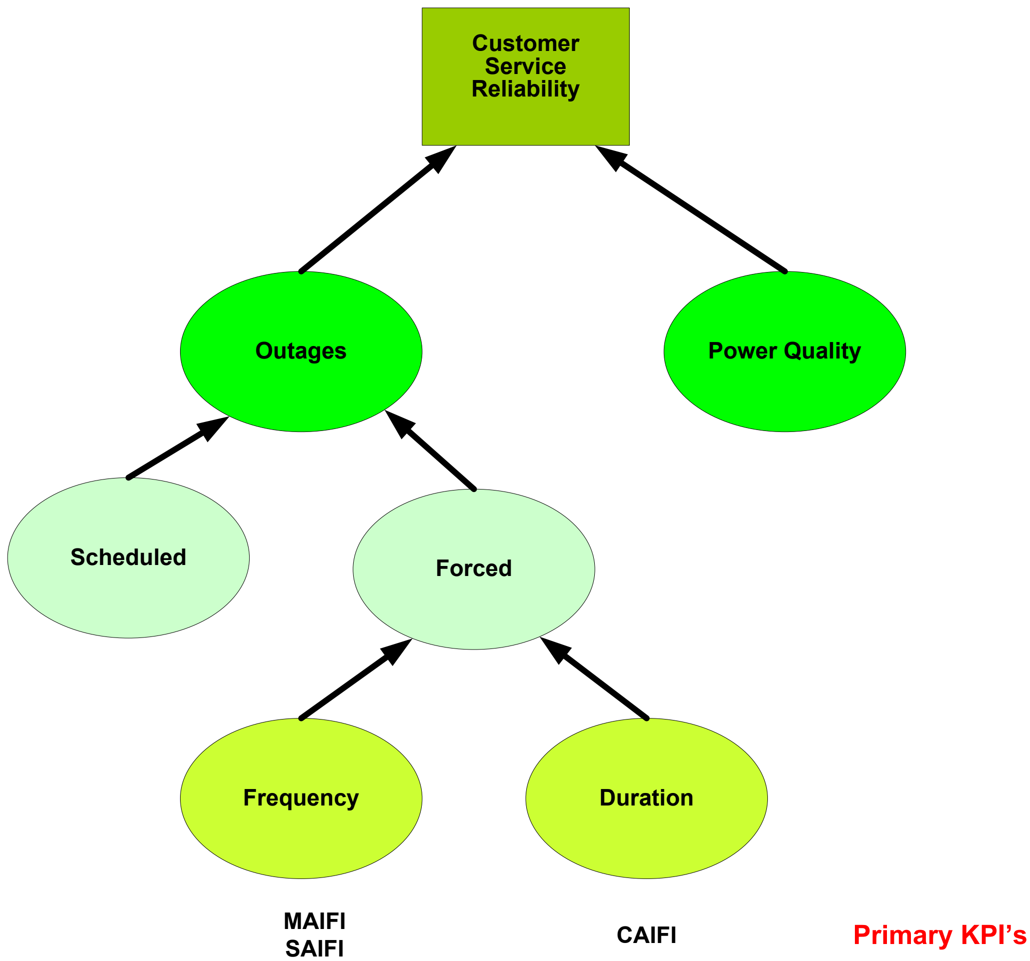

Figure 5-1
The relationship of primary kpi's to high level goals

Of course, there are many other factors and these four are often tracked as internal processes within a maintenance organization. However, their impact on higher-level goals such as customer satisfaction often is not considered or quantified. Without an explicit link, it is more difficult to justify reallocation of resources or manage proactively.

PDAM implementation should start by examining all the factors that influence a performance goal, then developing a relationship measure and finally setting performance targets. An illustrative but simplified example of the process might start with the question: What determines customer service reliability?

The important factors are:

- System
  - Operations
  - Design
- Equipment
  - Design
  - Condition

- Maintenance
  - Efficiency
  - Effectiveness

Focusing on maintenance, what are some secondary maintenance KPI's that can be tied to reliability? A partial list would include such measures as:

- Preventive maintenance backlog
- PM/CM cost ratio
- Vegetation incidents by line
- PM by equipment
- Equipment condition index
- Age
- Diagnostic tests results
- Time since last overhaul

The next step in the process would be to develop a set of management metrics to measure performance that would combine a number of secondary KPI's in order to provide a broad based leading indicator. The details of the process would depend on the organization's higher-level performance goals and metrics. Examples include:

- Corporate objectives or mission statement
- Balanced score card
- Incentive programs
- Performance-based rates

Links to the next level of KPI's would be established and then the secondary KPI's would be identified. The types and quality of data would drive this process available. Depending on the particular activity, tertiary KPI's may be established. Once the linkages were determined, influence models would be developed to quantify the relationships among the process inputs and the final output, the higher level goals. The entire process would start with simple models using available information expand with experience. The models would:

- Show where the organization is now
- Quantify and track changes in higher level KPI's as changes are implemented in lower level processes
- Compare areas, stations, equipment types to highlight good and bad actors
- Provide analytical support for changes in resource allocation
- Give people meaningful targets to which to manage

6
PDAM AND RISK

Background

In the broadest sense, risk can be considered as a measure of the uncertainty of business performance and as such is closely tied to the organization's performance goals. The subject of risk has been extensively studied for financial assets and is generally considered to be the risk of not achieving the expected financial return. Risk has also been studied in detail for the power generation and energy trading side of the utility business. Here the desire is to assess energy portfolio exposures to commodity markets and customer loads, evaluate overall portfolio risk in terms of cash-flow-at-risk or value-at-risk, and assist in designing portfolio risk management programs. For power delivery, risk management is not so well formalized.

Utilities must manage an array of potentially conflicting business objectives, including maintaining economic performance, improving customer satisfaction, providing high reliability, addressing regulatory uncertainty, and complying with increased environmental regulation. The result is that many utilities are considering or have moved towards implementing asset management concepts and decision-making procedures based on minimizing equipment life-cycle cost and risks.

As discussed earlier, Power Delivery Asset Management (PDAM) begins with the fundamental premise that all asset management decisions made by utilities should contribute to stakeholder values, as set forth in the organization's goals and policies [1]. PDAM applies this premise in decision processes at every level of the organization. The resulting alignment of decisions with criteria and value measures derived from the asset owner's or senior management's direction helps ensure that asset management decisions consistently support the organization's strategic objectives, performance goals and risk tolerances.

As a consequence, risk assessment and management are important elements in any well-developed asset management plan. A growing number of utility managers are applying resources to improve their understanding of and capability to make risk-based decisions. Therefore, there is increasing interest in the methodologies and tools needed to more accurately assess equipment performance and risk and to provide the quantitative information to support asset management and operations decisions.

Definitions

Before proceeding further, it will be helpful to establish some definitions for the terms used in this report.

Risk can be defined as a measure of the probability and severity of adverse effects [2].

There are two major classifications of power delivery risk:

- Technical risk
- Programmatic risk

Technical risks are usually associated with the performance of the power delivery equipment and system, including software of computer based devices. Common examples are the risk of not meeting a reliability target due to excessive equipment failures or the risk of spending more than budgeted for maintenance due to more maintenance activity than anticipated.

Programmatic risks are usually associated with new construction or replacement projects and would include cost overruns or schedule delays. Of course, programmatic risks exist in normal power delivery operations and maintenance activities also. The maintenance budget overrun mentioned above, instead of being due to poor equipment performance, could also be due to poor or incomplete budgeting or work practices.

Adverse effects can result from many factors for complex, technology-based and geographically dispersed organizations such as electric utilities. Power delivery managers must contend with risks that come from a wide variety of sources such as:

- Weather and other natural causes
- Human errors
- Technological failures
- Equipment
  - Software
  - Financial
- Political
- Cyber and physical attacks

The objective of the work described here is to develop tools for assessing performance and risk for substation equipment. Therefore, the focus of the remaining discussion will be on the technical risks associated with the operation of such equipment. This is defined as **operational risk** and is primarily concerned with the potential failure of the equipment to perform as expected. Examples include premature failure or lower than specified availability. The terms risk and operational risk will be used interchangeably for the remainder of this report.

A typical case might relate to the assessment of the risk associated with deferring investment in a transformer. In this case the business risk per year is the sum of the possible consequential costs of failure, the expected capital cost and the maintenance cost per year. The expected consequential cost is the product of the consequential cost if failure occurs times the probability that a failure occurs. Similarly, the expected capital cost is the product of the probability of failure times the inflated capital cost in the year that failure might occur. Another example would be the assessment of the risk of premature failure from increasing a transformer's loading in order to meet some system operating requirement.

Risk assessment is the attempt to answer the following questions [3]:

- What can go wrong?
- What is the likelihood of that occurrence?
- What are the consequences?

Answers to these questions help managers identify, quantify, and evaluate risks and their consequences. Substation equipment performance, and therefore the equipment's operational risk, is determined by a number of factors. Among them are:

- Design
- Construction
- Installation
- Application
- Operating environment
- Maintenance

Because of the complex interactions of these factors, the assessment of substation equipment operational risk requires a high level of equipment expertise. The loss of an important asset, say a tie line power transformer, will adversely affect one or more business performance measures (for example, equipment availability, wheeling revenue) Assessing this risk requires evaluating the potential for a short-fall in the affected performance measures and quantifying the probability of the transformer failure. Identifying the various ways in which loss may occur and their likelihood are tasks for transformers experts.

The following sections will discuss the risk assessment process. Because of the great variety of equipment and operational risks encountered in the power delivery industry and the wide variation in utility business practices, this discussion will be focused at the conceptual level. The objective is to provide a foundation that can be utilized to develop more detailed tools in a unified and consistent manner.

Risk management builds on the risk assessment process by seeking answers to a second set of questions [4]:

- What are the options?
- What are the potential costs, benefits, and risk?
- What are the impacts on future options?

The six primary steps in risk management are:

- Identification
- Assessment
- Analysis
- Mitigation
- Allocation
- Tracking and monitoring

The details of each step will depend on the type of risk being managed. The purpose of risk management is to minimize risks to acceptable levels, proportional to accomplishing the organization's related goals. Consequently, risk management utilizes and depends upon the outputs of the risk assessment tools. Asset management principles dictate that risk management must be an integral part of the overall management process.

Risk Assessment Requirements

Perhaps the most significant substation equipment operational risk is the unexpected failure of equipment. (Although most focus on the cessation of equipment operation, failure in the context of risk assessment is more generally the failure to meet any performance threshold derived from the organization's goals and objectives. For example, equipment availability is affected by maintenance outages as well as forced outages resulting from failure.) Operational risk, in mathematical terms, is the product of the probability of the occurrence of the failure event times the cost of the failure consequences.

Mathematicians call the failure rate curve, commonly called the bathtub curve, the hazard rate function. It gives the failure probability at each age. The hazard rate function defines the probability of surviving up to a certain age and then failing in exactly the next higher age bracket. If the general shape of the bathtub curve is assumed to be correct, then there are actually three distinct regions corresponding to different failure rates as shown in Figure 6-1.

It is clear that risk assessment implies a time dimension. In the long run, all equipment will fail. Therefore, part of the assessment process is the establishment of the time frame for the assessment and the proper utilization of any hazard rate function for that time frame. As an illustration, consider power transformers. When new, the risks of failure come primarily from a manufacturing defect. At any time of operation, failure may result from an external cause such a lightening. When the transformer is old, the risk is primarily that of wear-out. The familiar bathtub curve results from combining these three hazard functions over the transformer's life.

The appropriate hazard rate function will be determined by the assessment time horizon. In addition, the consequences also are a function of the assessment time horizon and the particular hazard being assessed. The costs resulting from an unexpected failure will likely be greater than those resulting from a wear-out failure, which can be better anticipated. However, quantitative data on hazard rate functions for substation equipment are sparse and providing such a curve valid for a particular individual unit is a major challenge for assessing power delivery equipment risk. EPRI efforts to address this need will be discussed later.

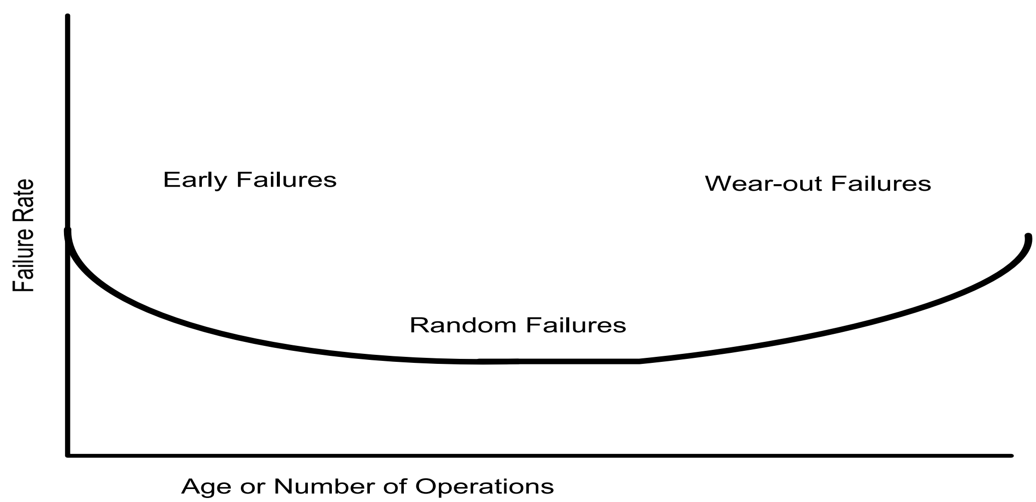

Figure 6-1
Failure rate bathtub curve

Assessing risk as the probability and severity of adverse effects requires knowledge of the hazards and threats to the equipment. These are multifaceted and can be represented only through multiple metrics. Equipment's susceptibility to a future failure is a function of its current state and future stresses. Furthermore, the equipment state is dynamic and changes over time and in response to future operational stresses.

The risk assessment process is not an end to itself but rather its results should be used to manage and mitigate risk. There are three fundamental approaches to equipment risk management. One is to control or improve the state of the equipment, for example, by performing preventive maintenance. The second is to reduce the effectiveness of the threat by actions that do not necessarily change the equipment state, for example, by installing lightening arresters. The third is to reduce the consequences, for example, by maintaining adequate spares. Determining the appropriate risk mitigation measures requires assessing the hypothetical risk and performance of the candidate approaches.

Ideally it would be desirable to be able to translate all of the consequences of equipment failure into financial terms. Obviously, some consequences, for example, capital cost, repair costs and replacement costs, can be evaluated directly in financial terms based on experience and recent price and cost trends. Unfortunately, there are other adverse impacts on a utility caused by equipment failure, which may be very important; but which are difficult to quantify in dollars and cents. Evaluating these consequences requires a set of business rules that will most likely vary from utility to utility.

Assessment Methodology Concepts

Because there are many different power delivery equipment types with fundamentally different designs and ratings from suppliers with different design philosophies and manufacturing techniques, simply applying any generic failure rate, if available, to a specific unit is of dubious value. Any industry average generally reflects the performance of all units in the study, some of which may be of poor design, subject to heavy operational duty, or receive poor or infrequent maintenance. The proportion of troubled and high performing units in a comparison study is generally unknown. Any industry average also would include units of every age, from new to those approaching end of life. Again, the proportion of each of these categories would be unknown.

There is another, even more basic problem, with applying the classic hazard rate curve to power delivery equipment. The wear-out portion of the hazard curve implies a direct relationship between age and deterioration. However, for major subsystems of critical power delivery components, wear-out is proportional to service duty and service duty is not always closely correlated with chronological age. For example, circuit breaker's mechanical linkages wear as a function of the number of operations and interrupter components deteriorate as a function of the accumulated interrupted current. For transformers, the aging rate of the insulation system is greatly influenced by oil temperature, oxygen and water content. Age alone is not necessarily sufficient to accurately place a unit on a hazard rate curve.

Depending on past operational stresses, the equipment's current condition may not correspond to that which would be expected for its chronological age. A unit with a history of heavy loading may exhibit a condition more like that of an older unit. In effect its apparent, or effective, age would be greater than its chronological age. Information about past loading and other stresses experienced by most power delivery equipment is not commonly available. However, effects of past operation can be expected to be reflected in the equipment's current condition. Therefore, for accurate risk assessment there must be some measure of the actual condition of the equipment so that the effective age can be determined.

Furthermore, power delivery equipment deteriorates through the accumulation of operational stresses and ultimately fails. Like all mechanical devices that are placed in service, the materials that are used in the equipment eventually weaken and deteriorate which in turn reduces the capability of the equipment to withstand future operational and environmental stresses. Consequently, future failure rates are also a function of future stresses. A unit that will be lightly loaded going forward will age at lower than nominal rate. Therefore, some measure of future operational stress should be determined and utilized for performance and risk assessments going forward.

The preceding discussion provides the conceptual basis for a substation equipment risk and performance assessment methodology as shown in Figure 6-2. Ideally, assessing the probability of an adverse effect requires a nominal hazard rate and the means to modify the probability calculation to account for equipment effective age and the magnitude of future stresses. At this time, nominal hazard rates for many substation components are not well established. In these cases, qualitative inferences must be made about the likelihood of future performance. Even in such cases, modifiers related to effective age and future stresses are appropriate.

Conceptually, the approach is quite straight forward. The complexity comes from the detailed equipment expertise that is required to apply it to produce meaningful and useful results.

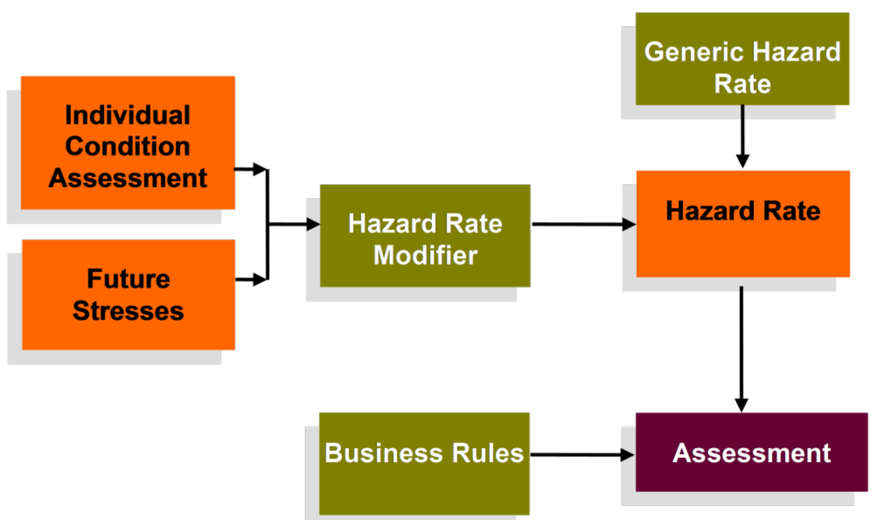

Figure 6-2
Substation equipment risk and performance assessment methodology concept

Equipment Performance Data Base

Translating acceptable risk levels into performance and maintenance requirements is of great importance to power delivery organizations for both planning and operations. The previous section illustrated how risk assessment and mitigation require knowledge about asset performance and the ability to project future performance to apply the concepts of risk management to substation equipment. Other EPRI efforts are underway to gather the data needed for the failure data for risk assessments discussed and other asset management applications. This work, Industry-wide Equipment Performance Database (IDB) can help provide important information to support the risk assessment process.

EPRI's Transformer IDB [6] is the most mature data base and is a collaborative effort to pool appropriate transformer operating and failure data in order to assemble a statistically valid population of many types of transformers. With sufficient data, it is possible to develop hazard rate curves for various asset management applications, including those described above.

In addition to assessing risk at the individual unit level, utility managers often wish to assess risk for an entire fleet of equipment. One of the most pressing needs for new and better tools to support power delivery risk assessment is in the area of aging asset management and here fleet risk and performance assessment can play an important role.

It is well accepted that the risk of equipment condition deterioration and wear-out failures increase as equipment approaches the end of its useful service life. The rationale and timing of increased maintenance or capital investment decisions in anticipation of this increased risk have been traditionally left to historic patterns and engineering judgment. This may result in higher costs to the utility and its customers if investments are not optimally timed, that is, if made too early, they may result in higher carrying costs; if made too late they may result in reduced service and higher failure costs.

An aging asset infrastructure makes it increasingly critical to identify equipment hazard functions of major asset classes and to understand the risks and influence of critical variables on equipment failure rates. With appropriate failure rate information, risk based approach models of the underlying distribution of failures or "bathtub" curve of each asset type can be developed to allow optimizing the risk-cost function in the maintenance and capital planning and decision making processes.

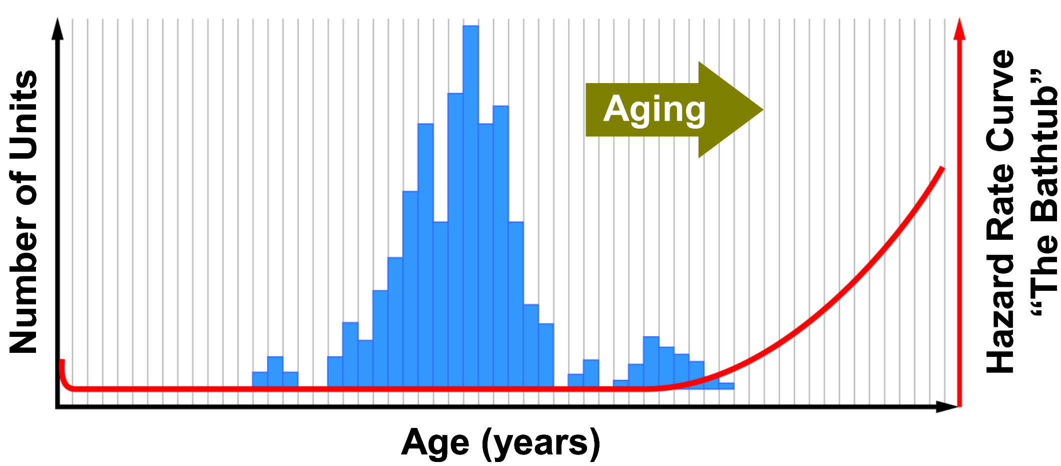

Figure 6-3
Hypothetical equipment age distribution and failure rate curve

Historically, projected equipment failure rates were computed by dividing the number of past failures by the equipment-years considered in the studies. These historical failure rates were assumed to be constant throughout the equipment life and used for replacement and spares planning. The general situation is depicted in Figure 6-3. A histogram showing the number of units of a particular equipment type in several age brackets has been superimposed on a failure rate curve that shows an increasing failure rate with age for that equipment type.

The age profile of the fleet reflects previous investment patterns. As time progresses, an increasingly larger percentage of the equipment population will move into the range of higher failure rates. This type of histogram gives rise to the term “asset walls.” A significant concentration of a particular asset in a group of adjoining age brackets looks similar to a wall moving forward in time.

As illustrated in Figure 6-3, the assumption of constant failure rate only applies if the equipment in question is operating in the flat portion of the hazard rate curve. Furthermore, many factors can influence equipment performance causing variations in equipment failure rates with time and usage. These could include equipment loading, manufacturer and maintenance history. A better understanding of how these additional stress factors affect equipment performance is required to correlate the relationship of various parameters with the probability distribution of equipment time to failure and failure rates among the fleets of different utilities.

Approaching asset walls and new operating requirements make projections based on history increasingly risky. Planning maintenance, estimating future capital requirements and making the best effective capital funding decisions in the present requires a better understanding of asset performance projections over the long term. Understanding individual asset performance is important for tactical planning but understanding the collective performance for groups of asset types, fleets, is important for a comprehensive strategic asset and risk management program.

Approaching asset walls are of general industry concern. Running critical assets to failure may entail unacceptable financial and operating risks. Because of the skewed demographic distributions common in many utilities and the fact that significant numbers of units may be at the back end of the failure rate “bathtub curve,” existing methods need improvement to provide informed long-range planning for effective management of this aging equipment.

Integral to the development of a fleet risk assessment is the ability to project the expected failures of the population at risk. In the basic case, this is calculated by convolving the hazard rate function with demographic data. The convolution is the sum of the products of the number of units in each age bin times the value of the hazard rate function for that specific age bin. The hazard rate function is fixed for a given population at the time of calculation; however for each year or interval into the future, the demographic distribution moves to the right, causing more overlap and higher numbers of projected failures.

The key to successful application of this approach is to establish the proper hazard rate function. As previously discussed, it is not a straightforward task to generate an accurate curve for the assets of interest. Quantitative data on the hazard rate function for most substation equipment are sparse but the assessment of risk at the fleet level may not need the same level of confidence required for individual unit decisions.

To consider business risk, probabilistically derived failure projections can be developed as a function of the asset management strategy being considered. Consequential costs are then factored in to obtain the business risk for each strategy. Associated with each strategy is an investment cost. In theory, if investment costs are increased the business risk should decline. At some point, carrying out analyses for several asset management strategies could identify an acceptable trade-off between business risk and investment.

The general concept is to project the number of likely failures going forward, as a function of selected asset management strategies. The underlying cumulative and density distributions for the selected hazard rates can be used in a Monte Carlo process to select the ages of the failed units. This biases the random selection of failed units such that the units that are selected fit the distribution that corresponds with the chosen hazard rate function. The demographic distribution is then adjusted appropriately to move ahead in time. Using this methodology, calculations can be performed for each proposed strategy on a year by year basis whereby the number of units that will fail is determined for the first year, the demographic distribution is adjusted to compensate for the failed units, and then the new demographic distribution convolved with the hazard rate function to calculate the number of failures in year two. The process of projecting the number of future failures can be continued for the number of years required for the associated risk analysis.

Integrating Risk Assessment into Asset Management

Figure 6-4 diagrams a framework for a PDAM approach to maintenance. Modeling performance usually requires data on past performance of similar facilities or equipment and some understanding of the mechanisms of aging and wear that contribute to a decline in performance over time. Knowledge of how operating stresses may influence asset degradation over time (that is, aging models) is useful in this process. Expected future operating conditions are also required, for example, increased transformer loading Specific, directed analysis may also be required to identify the underlying causes of performance gaps or an unexpected asset condition through root cause analysis and other forensic investigations. Using various analytical, statistical, and simulation tools, this process also determines such information as statistical failure data derived hazard curves, predicted end of life, condition-based triggers to support proactive asset maintenance or replacement, the implications of deferred maintenance, probability and consequences of failures and other risks, and future rating limitations.

There are two decisions in this process that the asset manager would like to make based on the present condition of the assets and levels of performance. The first is to determine whether the current state of either warrants taking some action now because of a current shortfall in meeting a desired risk or performance level. The second is to determine, given the present state, whether there is sufficient concern about a future shortfall in risk or performance to initiate mitigating action now.

Information comes from equipment monitoring and maintenance and power system operating data, including any smart grid sensors and systems, to the Apply Assessment Algorithms process. In the simplest case, this could consist of merely determining whether a threshold level has been crossed. For example, a reliability index for a particular feeder circuit has exceeded a target level and design options for reconfiguration are initiated. Another example would be if the incurred maintenance costs for an individual piece of equipment exceed some percentage of its replacement cost, then options for replacement are explored. Other short-term assessments may be more complex and could include some risk assessment such as loading above some limit.

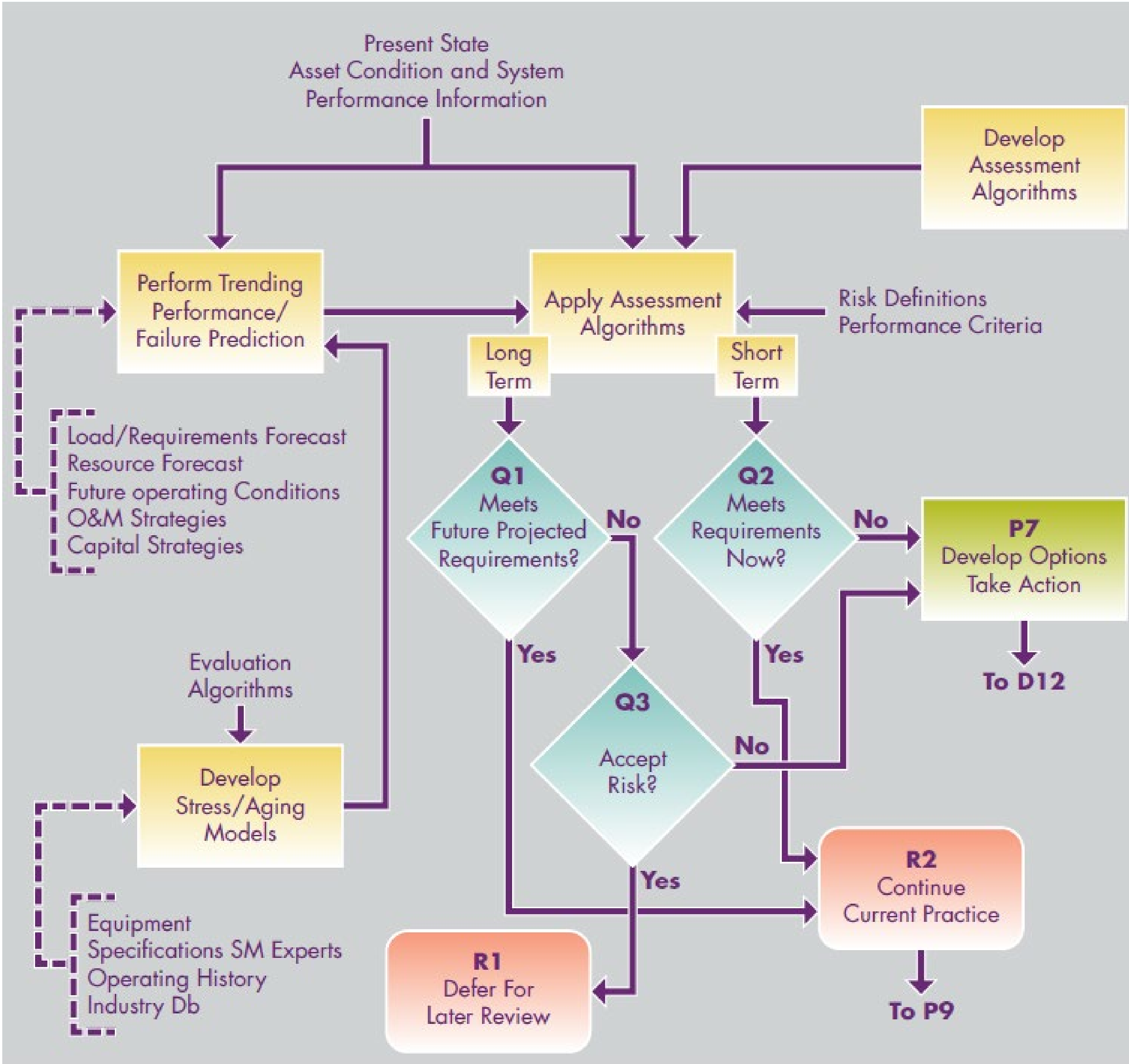

Figure 6-4
Integrating risk assessment into asset management

Long-term assessment algorithms may also be as simple as detecting a threshold level crossing. However, here the parameter crossing the threshold is not the current state but rather the projected future state. Obviously, this requires an ability to predict future performance. Obtaining this ability starts with Develop Stress/Aging Models. Building these models requires an identification of the mechanisms of deterioration for the asset or system and an evaluation of the rate of deterioration as a function of the various stresses (time, loading, and so on).

Ideally the stress/aging models would represent the dynamic deterioration process with a set of equations that could be used in Perform Trending Performance/Failure Prediction to provide a forecast of future deterioration and the asset or system state for a future time. To be most useful for risk management decision support, the deterioration processes should be described probabilistically. With such models, future states or performance levels could be represented as a probability distribution of states going forward. In some cases it may be possible to develop trending algorithms that can use data from condition monitoring to automatically update these deterioration models, make an assessment and provide an automatic notification of the need to consider taking action.

To predict future performance when the deterioration is not just a function of time but also of stress levels, the future stresses must also be predicted. If loading were one of the stress factors then a load forecast could be used for this purpose, for example. Future performance may also be affected by changes in operating or maintenance practices or by replacement of individual components within a system. Consequently, these factors may also have to be accounted for in projecting future performance. Not every asset decision warrants a detailed analytical approach. In some cases a simply extrapolation of past trends may be sufficient.

For some asset classes, the evaluation process could be automated. Others may be too complex or too infrequent to justify anything more than a manual analysis, for example, deciding whether a feeder circuit needs to be upgraded to accommodate a new industrial customer connection. For some decisions, sufficient data may not be available to approach the problem mathematically and expert judgment may be the only solution. The generic models presented here describe the methodology for all of these situations and for good asset management the model should be applied across the power delivery system.

If current requirements are being met, then current practices may continue. If there are no projected problems in meeting future requirements, current practices may continue also. If there is a projected shortfall in meeting requirements in the future, there are two choices. Accept the possible future risk and continue current practices, but catalogue the issue for future review, or decide on proactive action and develop options. Obviously, if current requirements are not being met, action must be taken also. Implicit in the Develop Options process is a determination of the causes of underperformance. Proposed actions are not limited to asset investments alone but also may include changes in operations and maintenance practices, design standards, training, contracting and any other controllable action that impacts asset and system performance. Assessment of the possible risks from the candidate options will help in the decision process.

The ultimate objective is risk management through the selection of the most effective mitigation plan. The general concept for evaluating mitigation options is shown in Figure 6-5.

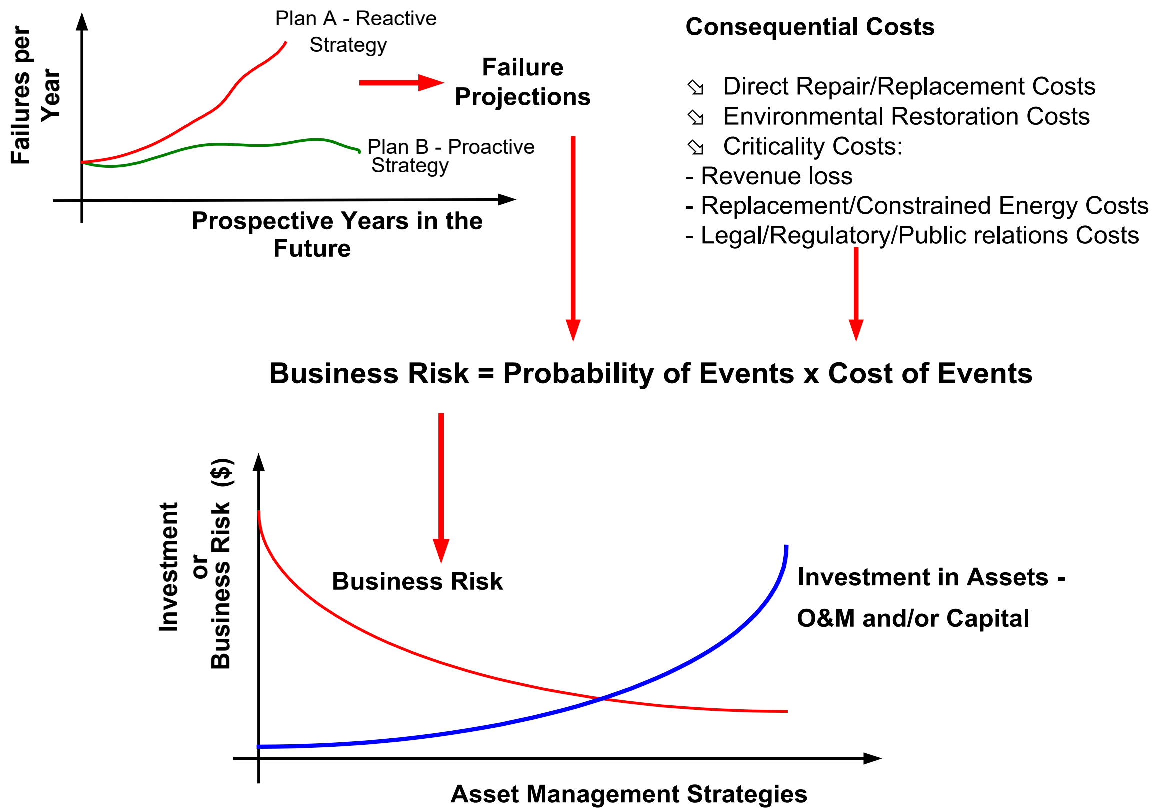

Figure 6-5
Using risk assessment to select mitigation strategies

Proper application of risk assessment tools can provide:

- Analysis of candidate asset management strategies using quantitative risk-based approaches that can reduce costs and improve other corporate performance measures
- Improved replacement needs projections that can facilitate savings through improved strategic procurement arrangements and spares assignment
- Improved credibility of capital requirement projections for senior management and regulatory scrutiny
- Reduced operating contingencies probabilities or consequences

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7
CONCLUSIONS AND RECOMMENDATIONS FOR ADDITIONAL WORK

Conclusions

With the successful development and acceptance of a number of EPRI analytical tools and equipment performance data bases and the increased appreciation of asset management principles for guiding power delivery organizations, it was deemed appropriate to revisit EPRI's 2005Power Delivery Asset Management (PDAM) Guidelines. Working with utility advisors, the objective was identifying any additions required to make certain that the latest version fully addresses current utility needs. This report documents the initial results of the work to produce an updated PDAM guide.

Recommendations

In the continuation of this effort, interested members will be invited to join a steering committee to help identify gaps and develop a priority list of additional guideline needs. In addition to the result from the utility review, areas for further development identified include:

- Better performance PDAM metrics for transmission equipment
- A more detailed replacement process model to parallel the maintenance process model presented here
- Incorporation of EPRI's decision support analytics into PDAM
- Integration of IDBs into the appropriate PDAM processes

Building on the existing guidelines, using this report as a starting point and working with members, EPRI will produce a new, updated PDAM guide.

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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
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