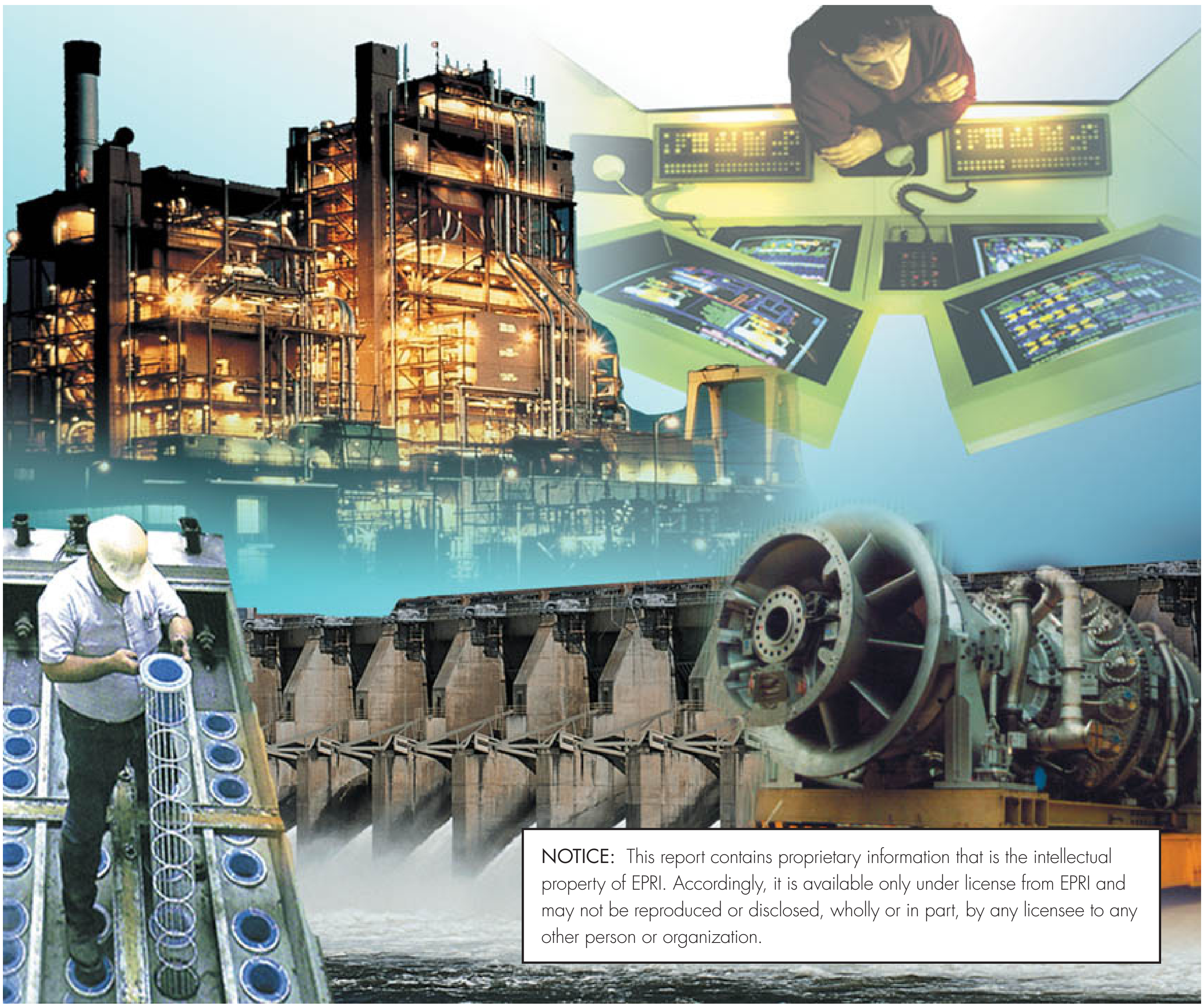
Lean Maintenance and Kaizen Continuous Improvement

Application to Fossil Power Generation



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PRODUCT DESCRIPTION

This report addresses the emerging interest in application of Lean and Kaizen continuous improvement methods within the power generation industry. These methods have successfully evolved in manufacturing over the past decades but are just beginning to appear in process industries such as power generation. This report will provide background to companies considering Lean implementation.

Results and Findings

Lean and Kaizen principles can be adapted from their well-established roots in the manufacturing sector and applied to maintenance of power generating stations. Early adopters have shown success by embedding key elements of Lean and Kaizen into broader business improvement initiatives that are corporatewide. Lean process improvements can augment existing plant reliability improvement initiatives to achieve corporate goals of increased reliability at lower operating cost. Lean and continuous improvement should be a strategic element of long-term workforce planning.

Challenges and Objectives

Aging plant equipment, staff turnover, and reduced maintenance budgets are key challenges affecting operations and maintenance of today's fossil generating fleet. Traditional maintenance management practices will not address the future business needs. Lean and Kaizen have potential to significantly improve company performance, but there are unique challenges associated with their successful implementation—for starters, company leadership needs to understand and strongly support the culture change needed to implement Lean and Kaizen. The objective of this report is to provide strategic input regarding these approaches to companies that are seeking substantial process improvements.

Applications, Value, and Use

The report provides valuable background information for companies that are assessing the potential for applying Lean and Kaizen continuous improvement concepts. (The actual implementation phase typically involves guidance and support from specialists.) Many power generation companies have ongoing efforts to improve work execution, planning, scheduling, and use of maintenance management systems. This report describes how these maintenance processes can be addressed using Lean.

EPRI Perspective

With today's fossil generation business drivers, performance goals relating to maintenance costs and equipment reliability cannot be met without substantial process improvements. Lean and Kaizen principles can be effective components of any broad corporate continuous improvement initiative. It is anticipated that over the next five years, several power generating companies will adopt Lean tools and strategies. EPRI's fossil maintenance program will continue to seek opportunities for industry collaboration to promote Lean and continuous improvement.

Approach

Lean maintenance was investigated using several recently published books and documents. The key elements are summarized in the context of fossil power plant maintenance. Similarly, Kaizen continuous improvement was investigated using published resources and web articles. Information of particular interest to power generators who are considering improvement initiatives employing Lean or Kaizen principles is highlighted in the report, along with examples from early adopters.

Keywords

Lean
Maintenance
Continuous improvement
Maintenance process
Work management
Reliability

ABSTRACT

This report addresses the emerging interest in application of Lean and Kaizen continuous improvement methods within the power generation industry. Industry drivers are forcing reductions in operations and maintenance budgets and staffing levels, with a continued expectation of high levels of plant availability. Business practices that have proven to be effective in the manufacturing sector can be successfully adapted by power plant maintenance organizations to both reduce costs and maintain availability.

Research on the application of Lean concepts to maintenance is undertaken and summarized in this report, with a focus on the issues and needs of power generation. In addition, Kaizen continuous improvement methods are explored and reported. Finally, issues associated with potential implementation in power generation are discussed, with some industry examples. The report is recommended primarily for companies that are aware of the potential advantages of Lean and Kaizen but are in the early stages of planning their corporate initiatives.

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CONTENTS

1 INTRODUCTION 1-1
Background 1-1
Report Objectives 1-2
Report Scope 1-3
Terminology and Definitions 1-3

2 CHALLENGES FACING TODAY'S MAINTENANCE ORGANIZATIONS 2-1
Reduced Budgets and the Current Business Environment 2-1
A Transitioning Workforce and Decreasing Component Expertise 2-1
Managing Work Prioritization 2-2
Understanding Risk Associated with Equipment Failure 2-2
Planning and Scheduling 2-2
The Effective Balance of Corrective to Preventive Maintenance 2-3
Establishing Maintenance Metrics 2-3
Summary: Isn't Our Industry Already Lean? 2-4

3 PRINCIPLES AND KEY ATTRIBUTES OF LEAN MAINTENANCE 3-1
Definition of Lean Maintenance 3-1
Maintenance Process Elements Affected by Lean Implementation 3-2
Types of Waste Observed in Fossil Power Plant Maintenance 3-4
Human Resource Management 3-4
Inventory Management 3-4
Quality Management 3-5
Information Management 3-5
Component/Systems Knowledge Management 3-5
Seven Deadly Wastes 3-6
Lean Concepts and Tools 3-7
Application of Lean Principles to Five Key Maintenance Functions 3-10

Spares and Inventory Management 3-10
Inventory 3-10
Access to Materials....................3-11
Additional Lean Considerations 3-11
Planning and Scheduling....................3-12
Preventive and Predictive Maintenance....................3-12
Elements and Benefits of Planning 3-13
Planning Skills and Specific Tasks Involved 3-13
Steps in the Planning Process 3-13
Work Programs....................3-14
Scheduling 3-14
Work Order Management 3-15
Communication 3-15
Work Order System Data Integrity 3-15
The Computerized Maintenance Management System (CMMS) 3-16
Work Execution 3-17
Worker and Material Movement....................3-18
Fix-it-Now Teams....................3-18
Tool Management....................3-18
Technology 3-19
Training....................3-19
Kaizen Improvements 3-20
Corrective Action 3-20
Event Significance Levels 3-21
The Discipline of Effective Root-Cause Analyses....................3-21
Corrective Action Phase 3-21
Lean Examples....................3-21
Automotive Industry....................3-22
Chemical Processing Industry 3-22
Air Force Maintenance Depot....................3-23
Naval Repair Shipyard....................3-24

***4* PRINCIPLES AND KEY ATTRIBUTES OF KAIZEN PHILOSOPHY....................4-1**
Overview and Definition 4-1
Kaizen Versus Innovation—The Role of Each 4-2

Process-Oriented Versus Results-Oriented 4-3
The PDCA Cycle 4-4
The DMAIC Process........ 4-6
Roles of Management, Supervisors, and Workers........ 4-6
Kaizen Events 4-7
Kaizen and the Company Culture 4-8
The Employee Suggestion System 4-8
Considerations for Implementation 4-9
Suggestion Forms........ 4-10
Suggestion Deployment........ 4-10
Customer Focus 4-10
Kaizen Implementation Examples........ 4-11
Hershey's........ 4-11
Topy Industries 4-12
Komatsu 4-13

5 STARTING AND SUSTAINING LEAN AND KAIZEN INITIATIVES 5-1
Key Differences Between Traditional Processes and Lean/Kaizen 5-1
Emphasis on Equipment Reliability Rather Than Reducing Waste........ 5-1
Fire-Fighting Versus Proactive Style 5-2
Spares and Material Inventory........ 5-2
Operations and Maintenance 5-2
Managing Repeat Component Failures........ 5-3
Labor Versus Management 5-3
Sustainable Continuous Improvement........ 5-3
Challenges and Strategies to Implementation in the Power Industry........ 5-4
Challenges........ 5-4
Management Strategies 5-4
Initiative Overload 5-5
Cross-Functional Organization 5-5
Metrics 5-5
Training........ 5-6
Tips for Starting........ 5-6
Managing Negative Perception of Lean Program Implementation........ 5-7

Achieving Sustainability......5-8
Continuous Improvement Tools......5-9

6 EXAMPLE IMPLEMENTATIONS OF LEAN AND CONTINUOUS IMPROVEMENT IN THE POWER INDUSTRY......6-1
Overview......6-1
Company A......6-1
Company B......6-2
Organizational Factors and Program Scope......6-2
Company A......6-2
Company B......6-2
Initiative Rollout......6-3
Company A......6-3
Company B......6-3
Employee Considerations......6-3
Company A......6-3
Company B......6-4
Events and Projects......6-4
Company A......6-4
Company B......6-4
Challenges and Successes......6-5
Company A......6-5
Company B......6-5
Summary Comments......6-5
Company A......6-5
Company B......6-6

7 CONCLUSIONS AND RECOMMENDATIONS......7-1
Conclusions......7-1
Recommendations......7-2

8 REFERENCES......8-1

A TOOLS FOR CONTINUOUS IMPROVEMENT PROJECTS......A-1

LIST OF FIGURES

Figure 4-1 Improvements Through Innovation and Kaizen 4-2
Figure 4-2 The PDCA Cycle Applied to Kaizen Problem-Solving Projects 4-4
Figure 4-3 Interaction of PDCA and SDCA Cycles in Kaizen Standards Improvement 4-5

LIST OF TABLES

Table 1-1 Lean Maintenance and Kaizen Terminology 1-3
Table 3-1 Examples of Waste Observed in the Maintenance of an Aluminum Processing Plant 3-7
Table 5-1 Project Follow-Up Practices That Contribute to Kaizen Event Sustainability 5-9
Table A-1 Continuous Improvement Tools Used to Analyze Data... A-1
Table A-2 Continuous Improvement Tools Used to Generate Ideas A-2
Table A-3 Continuous Improvement Tools Used in Working with Teams................................. A-3

1 INTRODUCTION

Background

The fossil power generation industry is challenged in today's business environment to improve plant reliability while reducing cost of generation. Non-fuel costs associated with operations and maintenance (O&M), although a fraction of total power production costs, are subject to continued downward pressure. Capital spending on mandatory environmental control projects defers improvements to existing generation equipment, increasing the risk of unplanned outages due to effects of equipment aging.

Despite these budget pressures, many generating plants have sustained or even improved plant reliability by adopting more effective asset management strategies and maintenance work processes. Successful processes and technology adopted by the industry in the past decade include the following:

- Plant reliability optimization (PRO) [1]
- Boiler tube failure reduction (BTFR) [2]
- Reliability centered maintenance (RCM) [3]
- Preventive maintenance (PM) basis implementation [4]
- Risk-informed maintenance prioritization [5]
- Improved outage management [6]
- Improved planning and scheduling [7]
- Adoption of computerized maintenance management systems (CMMSs) [8]

Because of a globally competitive marketplace for goods, the manufacturing sector has seen increasing interest in applying the concepts of Lean production to improve product quality, reduce waste, lower cost, and thus increase market share [9]. Automobile manufacturers, most notably Toyota, have implemented Lean and Kaizen concepts over decades to reduce waste, improve processes, and sustain profits. Applications of Lean and Six Sigma concepts in production have increased dramatically over the past two decades, with numerous books, web sites, and trade journal articles describing methods and implementation.

Some service industries such as retail, healthcare, and transportation have adopted Lean programs. However, application of Lean concepts to process industries such as petrochemical and power is lagging behind other industrial sectors. Web searches show some emerging applications in the petroleum refining industry [10]; however, Lean implementation in power generation facilities is not well documented at this time. The unique attributes of process plants compared to conventional manufacturing plants may contribute to the delay in adopting Lean concepts. These attributes include the asset-intensive nature of power generation, the need for maximum plant availability, and a culture that tends to encourage reactive management and reward "firefighting." The earlier regulated business environment prior to the 1990s did not encourage lean thinking, as O&M costs were often part of the rate base. It is difficult for some industries to recognize how a process that is successful in other business models can be applied to their own, especially if management and labor are resistant to change.

One outgrowth of Lean manufacturing deals specifically with the maintenance function. This is referred to as Lean maintenance, and it has applications in conventional manufacturing as well as in process industries [11]. Lean maintenance supports Lean manufacturing and in fact is considered by some to be a prerequisite for success in instituting Lean manufacturing. Looking at maintenance as a profit center rather than a cost center is fundamental to Lean and promotes the idea of investing in maintenance to achieve a future return in production efficiency. A second related element of Lean and Six Sigma implementation is that of continuous improvement, termed *Kaizen* by practitioners. The term Kaizen is of Japanese origin and refers to gradual, incremental improvement as opposed to periodic improvement "jumps" achieved through technology innovation. As with Lean, Kaizen has created significant interest in some industrial sectors and is documented extensively in the literature and on web sites [12].

The Electric Power Research Institute's (EPRI's) Fossil Maintenance Management and Technology research area is tasked with researching processes and technology to achieve improved plant availability at lower cost. EPRI-member advisors have indicated emerging interest by their company executives in exploring the adoption of Lean concepts by their generation plants. The research documented in this report should assist in informing the industry as Lean and Kaizen implementation plans are developed. Implementation strategies are vitally important to the ultimate success of any process improvement initiative.

Report Objectives

The objectives of this report are to:

- Introduce the fundamentals of Lean maintenance and Kaizen
- Compare these methods to traditional or existing maintenance processes and philosophies
- Discuss barriers to implementation of Lean maintenance and Kaizen by typical fossil power generation companies
- Propose successful strategies for implementing Lean maintenance and Kaizen

Report Scope

This report focuses on the concepts of Lean maintenance and Kaizen that are considered relevant to the current fossil power generation industry. Extensive material of a generic nature on these subjects exists already in the open literature and will therefore not be covered in detail here.

Chapter 2 provides a brief overview of the challenges facing maintenance organizations in the current business environment. This discussion provides an important basis on which to assess the potential value and suitability of new processes and philosophies relating to maintenance.

Chapters 3 and 4 cover Lean maintenance and Kaizen, respectively. Their key elements are introduced and explained in the context of fossil power generation.

Chapter 5 summarizes key implementation issues and strategies.

Chapter 6 describes recent examples of implementation of Lean maintenance in the power generation industry.

Terminology and Definitions

Table 1-1 contains a list of some key terms used in Lean maintenance and Kaizen.

Table 1-1
Lean Maintenance and Kaizen Terminology

Term	Acronym	Definition
Total productive maintenance	TPM	Concept emphasizing tight integration of maintenance and production staff to ensure equipment reliability and minimize downtime.
Total quality management	TQM	Strategy emphasizing awareness of quality at all organizational levels.
Kaizen		Gradual and continual improvement in processes involving all levels of the organization.
Lean maintenance		Philosophy that seeks to eliminate all forms of waste in the plant maintenance processes.
Statistical process control	SPC	The use of statistics to monitor, analyze, and control a process to create improvement.
Process-oriented management		Management approach that focuses on how the employees perform their job more than on results.
Results-oriented management		Management approach that focuses primarily on results and related controls, performance, and rewards.
Value stream		Sequence of activities required to design, produce, or provide a specific good or service, along with a description of value added at each step.

Table 1-1 (continued)
Lean Maintenance and Kaizen Terminology

Term	Acronym	Definition
Kanban		Component of a just-in-time inventory system in which visual signals are used to indicate withdrawal of parts or flow of in-process materials.
Value stream mapping		Analysis of all activities associated with providing a specific good or service, including the flow of information, materials, and worth.
PULL		Orders for process inputs based on actual demand rather than projections.
Computerized maintenance management system	CMMS	Enterprise tool used to manage all preventive and corrective maintenance; repository for planning documents, as-found condition, repair actions, and actual resource requirements.
Corrective maintenance	CM	Maintenance required to return a component or system to functionality following failure.
Preventive maintenance	PM	Maintenance performed in advance of component or system failure to prevent future failure.
Reliability-centered maintenance	RCM	Approach to plant reliability that focuses on a systematic analysis of component failure modes and effects.
Poka-yoke		Mistake-proofing of a task or process to reduce potential effects of human error.
Jidoka		Lean manufacturing concept that stresses the importance of identifying abnormal conditions and immediately stopping the process when observed. Improvements to the process are then made. In general, Jidoka emphasizes need for quality to be "built in" rather than "inspected in."
Hoshin Kanri		Concept involving the development and communication of a strategic mission throughout the organization.
	PDCA	Adaptation of the Deming wheel for continuous improvement programs; the letters refer to *Plan*, *Do*, *Check*, *Action.*
Just-in-time training	JIT training	Concept of delivering training on tasks just prior to needing it, to improve knowledge retention and avoid time spent in unnecessary training.
On-the-job training	OJT	Concept of learning tasks by performing them "on the job," initially with supervision and evaluation.
	DMAIC	Quality improvement process used in Six Sigma; acronym for Define, Measure, Analyze, Improve, and Control.

2 CHALLENGES FACING TODAY'S MAINTENANCE ORGANIZATIONS

The power generation industry today faces many challenges to sustaining continued reliability of the current fossil fleet. The expected future transition to new power generation technology will take time and involve uncertainties—both technical and regulatory. In the meantime, a significant portion of electricity demand over the next decade will continue to be met by the existing fleet of aging fossil generation assets. The need to reduce waste and continually improve O&M of plants not only applies to the current fleet, but is equally important to the emerging new technologies. It is vital, therefore, that the industry adopt improved O&M practices in existing plants and in turn transition these practices to new plants in the future. The following sections briefly highlight industry challenges related to plant maintenance that are relevant to the subject of Lean maintenance and Kaizen.

Reduced Budgets and the Current Business Environment

Deregulation, increasing focus on shareholder value, and emergence of independent power producers has driven an increasingly short-term focus within the electricity generation business. As the largest non-fuel expense in a fossil plant, the maintenance budget is under constant pressure. The response of the maintenance organization could either be to defer preventive maintenance or to increase efficiency of a proactive maintenance strategy (that is, do more with less). The first option will eventually have negative consequences on future plant reliability. The second option is the only way to achieve sustained performance improvement.

A Transitioning Workforce and Decreasing Component Expertise

In 2006 the U.S. Bureau of Labor Statistics reported that more than 50% of the current utility industry workforce is over 50 years of age, with 30% eligible for retirement within five years. Age demographic data also shows that less than 20% of utility workers are under the age of 35. A significant transitioning in the industry workforce across all skill categories will occur over the next decade. The replacement workforce will have different backgrounds, pre-employment training, and learning methods, as well as greater aptitude with computer-based information and process management systems. Familiarity with power plant components (design, operation, failure modes, and maintenance) will not be as strong with the new workforce. Much of the senior workforce has been in the industry for decades, with extensive on-the-job training and in some cases valuable plant commissioning experience. With respect to the implementation of new business concepts such as Lean maintenance and Kaizen, the younger workforce may be more adaptable and willing to accept these new practices.

Managing Work Prioritization

There is an increasing need to prioritize maintenance activities in the current fossil generation industry. Organizations are forced to identify the preventive and predictive maintenance tasks that provide the greatest benefit-to-cost relationship in terms of projected reliability improvement. Resource limitations are driven by budget constraints, cuts in capital spending on older plant components, and the desire to reduce planned unavailability. The concept of using risk associated with equipment failure as a key parameter for prioritizing maintenance activities is understood, but there are significant challenges to widespread and systematic use of a risk-informed process. These challenges include difficulty in assessing component failure probabilities, difficulty in estimating consequential damages and/or financial loss, and the lack of an optimization analysis approach that reduces subjectivity and can be deployed across an enterprise. Work prioritization is viewed as a key component of eliminating waste in the maintenance function.

Understanding Risk Associated with Equipment Failure

As mentioned in the preceding paragraph, the accurate assessment of risk associated with equipment failure is challenging, but key to prioritizing maintenance tasks. There are two elements to risk: the probability of equipment failure, and the associated consequence—primarily the cost of plant unavailability and repair. Failure probability projections are often based on historical data for similar equipment. Ideally, the historical failure data is accurately reported, relates to specific failure modes, and is pertinent to the specific equipment being analyzed (with regard to design and operational history). Likewise, consequence projections can be based on historical data on repair costs, impact of failure on plant capacity, and time required to return equipment to service. The fossil power generation industry lacks an effective failure probability database that is failure mode based and addresses both the component and system levels. Further, significant judgment is needed to address the uncertainties in failure probability caused by various past and future plant operational characteristics and preventive maintenance practices. Lean concepts emphasize reduction of waste (an example of waste would be allocating resources to low-priority maintenance). Therefore, development of more accurate estimates of risk associated with decisions on maintenance intervals and scope will need to be emphasized. Significant gains can be made through effective use of computerized maintenance management systems (CMMSs) to track both failure rates and repair time/costs. Over time, this data can be an effective basis for future estimates, and the statistical relevance can be improved by sharing of data among generating companies.

Planning and Scheduling

Effective maintenance planning and scheduling is critical to achieving performance goals of power generating plants. EPRI has published several documents on the subject of planning and scheduling [7, 13] and the related subject of work package development [14, 15]. Effective planning and scheduling improves maintenance efficiency by ensuring that the appropriate expertise, tools, materials, and operations support are arranged prior to initiating a maintenance activity. Highly reactive behavior is discouraged by minimizing sponsored work and using "fix-it-now" teams to ensure that emergent work does not impact planned preventive or corrective maintenance activities. Work backlog must be reviewed and managed on a continual basis. Effective organizations realize that planning and scheduling are different functions, requiring unique skill sets, but must be coordinated to ensure that no job is scheduled if the job package is not expected to be available. Failure to adopt and sustain an ongoing multiweek work prioritization process often leads to reactive maintenance management. Perhaps no aspect of fossil plant maintenance can immediately benefit more from Lean strategies in waste reduction than that of planning and scheduling.

The Effective Balance of Corrective to Preventive Maintenance

Changing from a reactive to a proactive maintenance culture is one of the most difficult challenges facing fossil power generation today. Many organizations are in a constant fire-fighting mode and thus cannot take the initial steps toward achieving the desired balance. The result of excessive corrective maintenance is higher maintenance costs and lower availability. There is an increased recognition of the importance of establishing, and constantly reviewing, the maintenance basis for power plant equipment. A systematic approach to defining an effective preventive and predictive maintenance regime based on knowledge of failure modes and effects will eventually lead to an optimized balance of corrective to preventive maintenance. Further, ranking preventive maintenance tasks on the basis of risk, or vulnerability, will help manage what is often an excessive number of preventive maintenance tasks resulting from initial deployment of a maintenance basis. Management commitment is essential to sustaining the transition from reactive to proactive maintenance. The journey can be costly at first, but pays off when the optimum balance is achieved, resulting in the reliability increasing with a corresponding lower overall maintenance cost. Optimizing corrective to preventive maintenance is an essential element of Lean maintenance. Excessive corrective maintenance wastes resources.

Establishing Maintenance Metrics

Establishing effective metrics is essential to achieving continuous operations and maintenance improvement. Well-designed metrics can drive improved performance; however, poorly designed metrics can have a negative effect on performance by creating incentives that are not aligned with the organization's goals. Fundamental to effective metrics is an underlying set of processes that are well designed and support the corporate goals. One common problem in establishing metrics is to focus too much on lagging metrics rather than leading metrics. Both lagging and leading metrics are important, however applying lagging metrics at lower organizational levels is ineffective. Staff at all organizational levels need to clearly understand the connection between their activities and the high-level results-based metrics. Kaizen acknowledges the difference between management's focus on **process** versus a focus on **results**. Metrics associated with adherence to processes are typically leading metrics that are well understood by specific staff assigned to work within these processes. Lagging metrics are typically associated with process results. The assumption that imposing a uniform set of lagging metrics across the enterprise will drive improved performance is often incorrect. A commonly used maintenance-related metric is *wrench time,* defined as the percentage of total time charged to a maintenance task that is actually spent performing "hands-on" work on the equipment. Wrench time will be improved by implementation of waste reduction strategies associated with Lean manufacturing.

Summary: Isn't Our Industry Already Lean?

In summary, maintenance cost-cutting is not the same as Lean implementation. The fundamental difference is that cost-cutting directives flow down the organization, whereas the savings from Lean flow up as a result of changes in fundamental process elements, tools, and continuous improvement strategies. Cost-cutting directives generally impact critical maintenance initiatives designed to improve long-term reliability. The result has an adverse effect on the level of corrective maintenance required, leaving even fewer resources available for proactive measures and preventive maintenance. The most desirable situation is for maintenance resource requirements to decline over time as a result of implementing and sustaining improved processes. These processes must increase the ratio of preventive to corrective maintenance and eliminate waste in work management and execution. Achieving this goal may require an initial investment in a company's maintenance program.

3
PRINCIPLES AND KEY ATTRIBUTES OF LEAN MAINTENANCE

In this chapter, Lean maintenance will be described starting with a high-level definition, followed by a discussion of related elements. The fundamental concept of Lean is not difficult to understand; however, the practical deployment of these concepts involves many challenges. Lean describes a philosophy, not a new process to replace a company's current reliability initiatives. In this sense, its implementation need not be disruptive. Chapter 5 will discuss implementation in more depth. Although Lean concepts were first applied to manufacturing, it was soon realized that much of the philosophy also applies to maintenance in an asset-intensive business such as power generation. Currently, many articles, web sites, and technical resources are devoted specifically to Lean maintenance.

Definition of Lean Maintenance

Stated simply, *Lean maintenance* refers to the practice of reducing waste in all processes and tasks relating to production asset maintenance. Lean practices can apply to a number of maintenance process elements, ranging from work management to inventory management to root-cause analyses, just to name a few. What is common to traditional applications of Lean in manufacturing is the need to objectively examine process details from the perspective of waste reduction, modify the processes to achieve waste reduction, and implement a continuous improvement effort to achieve sustainability. Defining the customer's needs is a fundamental concept of Lean production. The customer in Lean maintenance is plant operations, which require the maximum value from maintenance resources expended.

In the broader application to manufacturing, another definition of a Lean initiative can be stated as follows: examination of the value stream to eliminate any activity or cost not adding value to the customer or product.

Maintenance Process Elements Affected by Lean Implementation

Reducing waste in maintenance activities can be addressed at a number of levels and across a range of maintenance process elements. A holistic approach to Lean implementation is most effective; however, it is practical to address only a number of specific elements at one time. Below are ten key process areas with brief explanations of where waste can be reduced.

1. **Work Planning.** Effective planning reduces one of the major sources of waste in maintenance: poor wrench time caused by lack of coordination with operations, storeroom, and tool supply. A detailed work plan identifies all resources needed, enabling the scheduler to coordinate. Poor work planning can also contribute to maintenance errors, which is another form of wasteful activity. Studies show that time saved as a result of planning is a factor of 3–5 over the time invested [11].
2. **Work Scheduling.** The scheduler matches resources to tasks, coordinates with operations, prioritizes work for the optimum interests of the enterprise, and projects the need for resources to handle unplanned corrective maintenance. Inefficient scheduling can lead to waste in the form of underutilized staff or poor coordination with plant operations, leading to idle time by maintenance staff.
3. **Work Order Management System.** Written work orders, managed through a CMMS, eliminate waste due to poorly communicated maintenance instructions. In addition, the CMMS can be an effective feedback and archival tool for capturing the as-found equipment condition during preventive/corrective maintenance, as well as the actual resources needed for any maintenance task. Although time is required to enter information into the CMMS, it is more than offset by effective planning in the future due to reliable information. Effective training of maintenance staff on the CMMS will reduce waste associated with input and retrieval of information.
4. **Inventory Management.** In an ideal maintenance program, spare parts and stores are available "just in time" for their required use in PM or CM tasks. Poor inventory management introduces waste by creating excessive unused stock, or the opposite situation of unavailability of material when needed for emergency maintenance tasks. Waste also results from a poorly managed storeroom that is unable to locate and efficiently retrieve material when needed by maintenance staff.
5. **Predictive/Preventive Maintenance.** Predictive maintenance will reduce the waste associated with overly conservative time-based maintenance. Predictive maintenance will also reduce the waste associated with unplanned corrective maintenance resulting from failures that could have been predicted through condition monitoring. Within an effective predictive maintenance program itself, waste could be present in the form of nonoptimal technology exam intervals. Waste is also possible through lack of a systematic process for technology exam results to be processed and archived for use in alerting equipment condition status. Regarding preventive maintenance, waste can be present in the form of too little or too much preventive maintenance. Optimizing PM tasks based on a continual reassessment of risk (the product of failure probability and consequence) is the least wasteful of PM resources. Finally, poor quality of preventive maintenance task execution can lead to waste in the form of maintenance-induced failures.

6. **Corrective Maintenance.** A certain amount of corrective maintenance will be necessary even in a Lean organization. Examining an organization's processes for executing corrective maintenance can highlight Lean opportunities. Levitt describes firefighting organizations and hospital emergency rooms as examples of Lean process implementation in dealing with unplanned events [11]. Much like the fossil power generating plant, hospitals and fire stations know it is not "if," but "when" there will be a need to move swiftly and with minimum error. Lean in this situation can be accomplished by having standardized maintenance plans on file; materials, equipment, and supplies available; and dedicated tool sets devoted to correcting the most common component failures (for example, boiler tubes).
7. **Outages.** Power plant maintenance outages are perhaps the most costly, and least Lean, aspect of the overall maintenance process. Fat is traditionally built into outages and justified by the need to maintain critical path schedule. Three main targets for improving outage Leanness are a) performing more detailed planning, b) minimizing emergent work, and c) removing any activities from the outage scope that could be completed outside the outage.
8. **Operations.** The concept of total productive maintenance (TPM) in the manufacturing sector describes the expansion of the machine operator role to include routine maintenance tasks. The analogous situation in fossil power generation is the process of assigning some predictive maintenance tasks to plant operations, a practice already used in some generating plants today. Lean is introduced by the fact that operations staff already has control of the equipment, and is located nearby so that no travel is necessary. There are intangible benefits to assigning operations staff duties that increase their opportunities to have "eyes and ears" on the plant equipment.
9. **Engineering.** Lean is not solely associated with maintenance planning, scheduling, craft, and technician activities. Some of the largest potential reductions in maintenance waste can be achieved within the engineering function. First, engineering staff must take the lead in efficient application of the RCM process for establishing the maintenance basis. Knowledge of failure modes and effects is critical to optimizing the preventive maintenance program, and this requires engineering input. Second, engineering plays a key role in performing root-cause analyses, which reduce wasteful repeat failures. Finally, engineering can improve equipment design to eliminate some failure modes, making the related preventive maintenance activity unnecessary.
10. **Training.** Lean can be introduced to the maintenance organization through cross-training of maintenance staff. Cross-training allows flexibility in planning and subsequently reduced idle time associated with waiting for availability of specific expertise. Cross-training improves problem-solving skills and could potentially result in reduced staffing needs. In addition, the training process itself could be made Lean through the use of worker task performance evaluations to pinpoint skill deficiencies and deliver only specific areas of training needs.

Types of Waste Observed in Fossil Power Plant Maintenance

It is useful to describe the various categories of waste present in most current fossil power plant maintenance processes. This report section will help readers identify where waste may be present in their organizations as they initiate their Lean programs. There are five basic areas where Lean principles can be applied to reduce cost of maintaining fossil plant assets:

- Human resource management
- Inventory management
- Quality management
- Information management
- Component/system knowledge management

The following paragraphs provide more detail on the five waste categories.

Human Resource Management

This category is perhaps the most visible form of waste. It includes idle time spent by maintenance staff waiting for any resource needed to complete the assigned maintenance task. This includes waiting for tools, supplies, instructions, another worker, operations tag-out, and safety equipment. A second form of waste in this category is unproductive time. This includes all non-idle time spent on the maintenance task that is not categorized as “wrench time” (that is, time spent directly with the equipment). Examples of unproductive time include time spent mobilizing all resources at the specific location where the maintenance will be performed. Some mobilization will always be necessary; however, it is often accomplished in a wasteful manner. A third form of waste is associated with non-optimum utilization of human resource skills. An example would be assigning maintenance personnel to tasks that are either above or below their skill levels. Deficiencies in the maintenance training program produce waste that falls into this third category as well. Failure to provide cross-training in multiple disciplines, or to update and refresh training programs, will affect the ability of the staff to provide value to their potential.

Inventory Management

Another very common source of waste in maintenance involves the inability of the plant’s inventory management system to provide needed spare parts, materials, and supplies in time to permit the task to be undertaken as scheduled. Poor inventory management involves a number of waste-producing aspects. There is an ongoing struggle between the tendency to overstock (the preference of the maintenance staff) and the tendency to understock (the preference of the accounting staff). Optimum stocking levels are a goal that can never be attained in practice, and there would not be a static target even if it could be attained. However, it is evident that many inventory management practices today could nonetheless be improved significantly. Most of the waste in inventory management stems from poor stocking processes (which lead to the inability to locate material when needed), frequent discarding of unused material, and inadequate integration of the inventory management system with the CMMS. Ability to predict demand for parts and supplies, based partly on accurate historical data, is key to approaching the goal of "just in time" inventory management. A more detailed discussion on improved inventory management can be found later in this chapter.

Quality Management

Poor quality of maintenance contributes to costly rework, which is an obvious form of waste. In process industries the cost of downtime is generally high, and some repair tasks require significantly high "overhead" activities associated with machine disassembly/reassembly. It would be very wasteful to have to repeat these maintenance steps due to an error that can only be corrected following a lengthy disassembly. In these cases, the consequences of rework are very significant. Poor quality on a main generator rewind that results in the need for a second, unplanned repair is an extreme example. Major plant outage durations are being shortened at the same time that companies are relying more on vendors and contractors. The result is a higher risk of quality-related problems. Plant owners must select vendors based not just on price, but on an assessment of quality as well. Within the plant's internal maintenance organization, quality must be achieved through continual process improvements, rather than relying solely on post-job inspections. Some waste is accrued by creating the maintenance error, even if it is discovered prior to returning the equipment to service.

Information Management

Poor or inefficient management of information critical to maintenance tasks is another category of waste. Essentially, waste is introduced by not using the CMMS to its full potential, or by entering incorrect data, or by inefficient use of labor in the entry of information. Lost opportunities to reduce waste through continual improvement programs occur when the CMMS database is not used to a) assist inventory management, b) track actual labor against estimates, c) identify maintenance basis violations, or d) report as-found equipment condition. A second source of waste is the myriad of paperwork and forms used to control business processes. Often, the number of these forms, and the manner in which they are routed within the organization, exhibit significant waste. Paperwork studies can be performed that track flow, timing, and resource needs associated with paperwork. These generally reveal a surprising level of inefficiency and waste. Finally, a third potential source of waste in information management is failure to create an effective repository or library of reports and reference resources relating to maintenance. Enterprise systems are increasingly used as "virtual" libraries to facilitate distribution throughout the organization. Past outage reports are an example of critical engineering and planning department reference material that needs to be readily available.

Component/Systems Knowledge Management

This is another category of "lost opportunity" to reduce waste. The most Lean maintenance program is one that continually seeks to reduce the need for both preventive and corrective maintenance. The results of engineering Lean projects are not as visible as those involving improvements to maintenance staff efficiency; however, the impact on the financial bottom line can be significant. How can engineering improve the company Lean initiative? The three main strategies are 1) continually improve predictive maintenance to enable tracking of damage mechanisms, 2) optimize PM intervals, and 3) design out failure mechanisms. The common proficiency required for each of these strategies is a working knowledge of component or system failure modes. This knowledge is often informally maintained in the heads of engineers, and it grows with experience. This informal method of knowledge management is inefficient and often leads to knowledge loss due to staff attrition.

Seven Deadly Wastes

Literature on Lean manufacturing often refers to seven deadly wastes (also referred to as the seven “speed bumps”). These wastes are relevant to maintenance functions as well, so they will be presented here. The seven deadly wastes are listed below, with brief comments on how they may be interpreted in maintenance tasks:

1. **Searching**. Time spent locating tools, parts, supplies, people, the job site, and so on.
2. **Delays**. Waiting for release of equipment for maintenance, or paperwork.
3. **Transportation and Material Handling**. The need to move material or people in order to commence value-added activity.
4. **Making Defects**. In the maintenance world, defects are maintenance errors that require rework; in some cases errors are latent and are not noticeable until there is an attempt to return the equipment to service.
5. **Overprocessing**. More paperwork than is necessary to accomplish effective job control.
6. **Overproducing**. Performing excessive preventive or predictive maintenance tasks.
7. **Storing Inventory or Work in Progress**. Less than optimal spares and supply inventory management.

Levitt [11] provides some excellent examples of waste in maintenance activities obtained from observations made at Alcoa’s Point Comfort Texas plant. Table 3-1 summarizes these findings.

Table 3-1
Examples of Waste Observed in the Maintenance of an Aluminum Processing Plant

Category	Examples of Waste				
Parts and Materials	Time spent ordering parts	Incorrect parts ordered	Not planning for long lead items	Unused parts discarded	
Planning	Task incorrectly scoped or defined	Workers going to jobs unprepared	Planners having insufficient knowledge		
Scheduling and Communication	Supervisors unaware when job is ready	Workers pulled off a job to handle emergency work	Emergency work tasks that are not really emergencies	Equipment not tagged out and released to maintenance	Inflexible break and meal times
Tools and Equipment	Tools unavailable	Tools not operating properly	Need to share large lifting equipment	Hoarding of large equipment	Waiting for scaffolding
Work Execution	Poorly performed PMs due to lack of necessary skills	Component rebuilds not to specification	Patching, not fixing root cause of problems due to resources		
Staffing and Training	Insufficient cross-training	Poor knowledge capture and documentation	Reinventing the wheel too often	Too many supervisors, not enough workers	

Lean Concepts and Tools

The fundamental concept of Lean maintenance is to reduce all resource needs (inputs) to the lowest possible level consistent with achieving the desired level of equipment reliability (output). To achieve this goal requires removing waste from all processes and activities (at any level). Identifying the value stream is a fundamental concept to Lean implementation. Waste is defined as any resource or activity related to the process that is not contributing value to the end "product," in this case defined as equipment availability. It is important to emphasize that implementing Lean is not so much a **program** as it is a **discipline, set of practices,** or **mind-set**. In that sense, Lean can be effective within the context of any existing plant maintenance or reliability program. Lean maintenance is not typically implemented as a small number of large projects, but rather a large number of projects that each yields a small, sustained reduction in waste. The accumulation of these savings can be significant.

A few of the tools and concepts used in Lean projects are described below.

Process Mapping. In this activity, flowcharts are created that define the **actual** process (as opposed to the designed process). The actual process contains the waste in the form of excess paperwork, workarounds, and incomplete job control. An effective technique of process mapping first involves weeks of data collection, in which copies of all process paperwork (either in paper form or on a CMMS) are collected. This includes not only the official paperwork, but any unofficial paperwork used by individuals as well. Notes attached to the paperwork should indicate how they are used and who uses them. Following data collection, an extensive analysis phase charts the movement of paperwork through the organization to show the complexity, duplication, and inefficiency. Levitt [11] cites reductions of 20–30% in paperwork as a result of using this type of process mapping. The overall Lean goal is that all staff spends less time on paperwork. A practical method for process mapping and streamlining is to use Post-it notes on a whiteboard. The notes contain process elements, and the arrows show the process flow. A process improvement team using this highly visual method can generally find and remove wasteful steps, material, or people movement.

Spaghetti Diagrams. This process creates diagrams and analyzes the physical movement of maintenance staff and material throughout the course of completing a specific PM, predictive maintenance (PdM), or CM task. Inefficiencies are quickly evident in spaghetti diagrams in the form of repeated trips to the storeroom, tool bin, operations, or break room. In a large facility such as a power plant, these trips can contribute to significant wasted time. Once mapped, it is clearer where trips can be consolidated, removed, or shortened by more efficient job planning. Wrench time can be improved through prestaging of tools, parts, and supplies. This technique is most effectively applied to repeated tasks such as periodic PM tasks, where the resulting efficiency gain can provide repeated benefits.

5S. This Lean term stands for *sifting, sweeping, sorting, sanitizing,* and *sustaining*. 5S is a Lean discipline that increases workplace efficiency through organization and maintaining cleanliness. Benefits of 5S include removal of any unnecessary tools or material, and efficient organization of the remaining necessary items to ensure that minimal effort is needed to retrieve and utilize tools. Use of shadowboards for hanging tools is an example of 5S implementation in a workshop. Although originally considered a tool for management of workshops, 5S principles can also be applied to portable work environments such as maintenance trucks and job boxes. A large challenge, and the key to successful 5S implementation, is sustaining the efficient workplace organization once it is created. This requires discipline and an ongoing effort. A related term (**6S**) includes *safety* with the other five elements to account for the need to improve environmental safety and occupational health.

Lists. Referred to as "pointer lists" by Levitt [11], these are lists of wasteful activities and are developed by small groups of workers during brainstorming sessions. It is useful to define categories beforehand for these lists, to allow focus. During brainstorming, the emphasis is on collecting items for the lists, not solving the problems or attacking the causes of waste. In subsequent steps, these lists are refined to identify effective Lean projects starting initially with "low hanging fruit" projects to achieve early successes. Some lists are developed by researching data rather than by brainstorming sessions. Examples of these lists include most frequent CM tasks, most used storeroom part, most expensive repairs, and so on. The CMMS is a valuable resource for this data.

Job Observation. This refers to the process of placing an objective observer in an area of maintenance activity, within a maintenance team, or near the storeroom. The only role of the observer is to have an outsider's perspective of the process or task being viewed, which permits easier identification of wasteful activities. To be effective, it is best to select observers from outside the group or process being studied, since waste is not always evident to the "inside" staff. When deploying a program of job observation, care should be taken so that it does not appear to be singling out any particular group, so a "round-robin" approach should be considered.

Error-Proofing. This refers to the process of examining a maintenance task to eliminate or significantly reduce risk of human error. This approach is often overlooked when the focus becomes how to manage human performance. The most effective human error reduction method does not involve human behavior directly, but instead involves removing the possibility of human error. In Lean manufacturing, error-proofing is sometimes called *Poka-yoke,* which refers to use of a device or application of a procedure to prevent defects.

Standard Work Instructions. This is an aspect of maintenance planning that standardizes work packages to maintain a consistent quality level and allow a range of staff to use them easily.

Total Productive Maintenance. In power generation facilities, this concept describes the assignment of some PdM tasks to operations rather than maintenance staff. It is more commonly used in manufacturing processes to describe the advantages of machine operators taking on more responsibilities traditionally assigned to maintenance. The advantages of employing TPM concepts in power generation include the efficiency gained by the proximity of operations staff to the plant equipment. Additional considerations include the potential need for additional operations staff training, and the need for operations staff to interact with the CMMS.

Instruction and Training. Although in general, instruction and training are not unique to Lean, there are a growing number of resources available that are devoted to Lean implementation. The Society of Manufacturing Engineers (SME) offers several instructional videos at www.sme.org.

Kaizen. The Kaizen philosophy, described in the next chapter of this report, is considered a Lean tool. Many forms of waste can most effectively be removed through a gradual, incremental continuous improvement process. Kaizen also emphasizes the need to involve all levels of the organization in continuous improvement, which encourages staff who are most likely to see waste to reduce it.

Lean Software Applications. A number of simple computer-based tools are now available to assist in Lean implementation. One web site, www.systems2win.com, offers a Microsoft Excel add-in that integrates process mapping (spaghetti diagrams), value stream analysis templates, and "fishbone" root-cause analysis templates into a single tool.

Displays. This refers to the use of clearly visible displays to chart progress toward a cost-cutting goal, or to show a planned project implementation schedule (such as a Gantt chart). Displays encourage a team atmosphere, which is essential to both Lean and Kaizen implementation.

Application of Lean Principles to Five Key Maintenance Functions

This report section will go into more depth on five key fossil plant maintenance functions by providing ideas and guidance on how Lean principles can be applied.

Spares and Inventory Management

Inventory

The two primary forms of waste to attack in a Lean inventory management project are inventory levels that are not optimal and excessive resources (time and staff) needed to access the inventory. First, we will discuss inventory levels. Levitt [11] describes the "creative tension" between allowing maintenance staff to decide on proper inventory (that is, excessive inventory) versus allowing the accounting staff to decide (that is, too little inventory). It is likely that the optimum lies somewhere between these two strategies. Inventory will consist of a range of materials, from common consumables to critical spares that may never be used. Different strategies for selecting inventory levels may be adopted across this range of material categories. For supplies and consumables, historical usage data pulled from work orders in the CMMS can be invaluable when deciding on stocking levels. This presumes that the past work order data is reasonably accurate and is relevant to future expected needs.

Another element of Lean stockrooms is the use of bar codes and inventory management software. A bar code should be referenced to a unique master part list number, which contains all the history of usage, cost, vendor, generic type, warranty, and part description. Additional stock can be ordered automatically based on a predetermined lower stock level (re-order point). Bar code and inventory management systems are now used by virtually all retail businesses; thus, the technology is mature and deployable in an enterprise software system. Equally as important as an inventory tracking system is the requirement to record all parts and materials used on the appropriate work order. Additional information should include quantity used, date, and asset number for which the parts are used. By entering this information on the work order, material can be assembled in advance of the crew arriving at the storeroom, thus increasing wrench time. A useful guide to inventory management can be found in EPRI report 1014241 [16].

Stocking levels for critical spares should account for the probability of a component failure resulting in the need for a spare. This strategy has been termed "just in case" to contrast with the well-known "just in time" inventory management strategy employed in Lean manufacturing. Failure consequence is also a factor in determining if a spare should be classified as critical. This information on failure probability and consequence should be part of the technical basis for the plant preventive maintenance program. A Lean recommendation, therefore, is to use a risk and criticality ranking process (based in part on information that should be already available and used to develop the preventive maintenance program) as a basis for defining critical spares inventory.

Access to Materials

Efficient access to inventory starts with the proper storage facility. Key attributes of a Lean stockroom are the following:

- Adequate size, for both shelved storage as well as receiving
- Good lighting
- Controlled access
- Suitable environmental control to avoid material damage

Staffing levels of the stockroom need to take into account times of peak usage during the day, and especially during outages. If the stockroom is not staffed on a 24-hour basis, some means for allowing material retrieval must be devised that does not compromise the need to correctly record material removal.

Additional Lean Considerations

A number of additional Lean inventory management tips are as follows:

- Perform receiving inspection, to verify that the correct material was shipped, in the right quantity, and undamaged. Combine this inspection with the related activities of labeling and department notification.
- Perform inventory checks to ensure that materials are in assigned locations in the correct quantities and that orders are in place for any depleted stock.
- Continually reassess available vendors of common parts to ensure best quality, price, quantities, and delivery.
- Periodically evaluate parts or supplies that have not been used over a significant time period. Determine whether the reason is obsolescence, or if the part is considered a strategic spare that has a long lead time. Remove from inventory parts that are no longer needed.
- Manage all information needed in the event that compensation can be claimed for defects or failures of parts under warranty.
- Evaluate economics of refurbishing replaced components and maintaining these refurbished parts as spares.
- Apply Kanban principles to labeling of racks, parts bins, and floor space.

- Set up the tool bin like a library, with check-out and check-in procedures to manage tool usage and track responsible individuals.
- Set up a system to allow unused material assigned to a maintenance task to be re-entered into inventory. It is wasteful for excess material to be discarded simply because there is no return process or the return process is too time-consuming to be used by the maintenance staff.
- Where appropriate, consider establishing "satellite" storerooms to reduce wasted time in material retrieval. This decision, however, should take into account both the costs and the benefits. An alternative strategy would be to arrange for kitted materials to be positioned nearer the job site, without necessarily creating a new storeroom facility.

Planning and Scheduling

The effort to improve planning and scheduling has been shown to provide significant payoff in terms of increased wrench time [11]. Planning and scheduling is not a new concept associated specifically with Lean maintenance. It has long been recognized as critical not only to cost reduction, but to improved reliability as well [7]. Heisler [17] provides an informative overview of Lean concepts in planning and scheduling.

Planning is at the core of waste reduction and therefore should eventually be part of any company's overall Lean implementation program. It is not recommended, however, that attacking planning and scheduling be one of the company's first Lean projects, since it is generally a very large effort that could be disruptive if not managed effectively. The overall Lean program should first gain some momentum by completing smaller, "low hanging fruit" projects. Another reason that planning and scheduling should not be one of the first Lean projects is that typically an organization just starting the Lean journey struggles with a high ratio of corrective to preventive maintenance. In these cases there will be less preventive work (which is the work that can be most effectively planned).

Preventive and Predictive Maintenance

Planning preventive maintenance tasks is another role of the planning department. In addition to the benefits described below, use of a planner ensures that the work is properly documented in the CMMS, thus enabling "downstream" Lean activities. These include optimizing PM intervals, documenting as-found equipment condition, and handling feedback on actual time and materials required to improve future PM planning. What about the role of planning in predictive maintenance? Similar benefits of PdM interval optimization can be facilitated by the historical data contained in the CMMS. Another benefit of PdM planning and scheduling is inspection route optimization by logical grouping of tasks.

Elements and Benefits of Planning

An effective planning effort identifies and resolves all issues or problems in advance of scheduling the maintenance activity, thus avoiding the idle time associated with waiting to resolve those issues on the day the task is scheduled to be performed. The alternative to effective preplanning is “planning on the run,” in which the work stops and starts repeatedly as issues are encountered and resolved. The most common issues that planners seek to resolve **in advance** are the following:

- Availability of parts and materials and preparation of a tools and parts list
- Availability of any special hoisting and rigging equipment or personal protection equipment
- Assembly of a work package, consisting of drawings and clear instructions
- Availability of all maintenance skills needed (electrical, welding, and so on)
- Clearance with operations to allow release of equipment

Levitt [11] provides some interesting data from a study comparing wrench time for organizations that perform effective planning versus those that are more reactive. The study included 25 plants classified as “heavy industry.” The results itemize the savings achieved in eight categories resulting from planning, with the overall result being an increase in available wrench time of 30% (from 35% wrench time to 65% wrench time for a typical job).

Planning Skills and Specific Tasks Involved

Effective planning requires skill and prior experience in various maintenance roles. Additional attributes include organizational skills, effective communication, and a thorough knowledge of the CMMS. Many companies are reluctant to assign their most skilled maintenance personnel to the role of planning, since they are also valued for their ability to “fight fires” associated with corrective maintenance. It requires a solid management commitment to improved maintenance, as well as an expectation that the level of corrective maintenance will decrease, to dedicate the most skilled personnel to planning.

Steps in the Planning Process

The list below contains the key steps involved in the planning process. Many of these tasks can be facilitated by use of historical records on similar past work that is stored in the CMMS.

- Determine the scope of work
- Estimate the duration of the task (use past data from CMMS as guidance)
- List steps required to perform the task
- Decide on manpower needs
- Create a budget estimate
- Identify any safety considerations (visit the job site if necessary)

- Requisition needed parts, tools, and materials
- Create a job package containing drawings and specific instructions (consider use of “standard work packages” whenever appropriate, to save time and improve technical understanding by maintenance personnel)
- Coordinate any material movement required
- Work with operations for access and to coordinate tag-out
- Most importantly, communicate with all involved in the task

In summary, the five key elements of any maintenance task that must be planned and scheduled are labor, tools/materials/parts, information/instructions/drawings, operations release (custody of equipment), and any authorizations or permits required.

Work Programs

In the continuum of planning and scheduling, work programs provide the scheduling framework. Work programs control the total amount of maintenance resources available as a function of time over a given period. This should include any contracted resources, authorized overtime, absences due to training, vacation, and so on. The work program estimates what amount of these net resources are then reserved to deal with urgent or unplanned activities. The remaining resources must then be divided to address scheduled PM activities and backlog. Tracking and managing the priority of the work backlog in coordination meetings involves planners, schedulers, and system owners. Backlog, expressed in terms of time, is an important maintenance metric.

Scheduling

If the planning is completed properly and the work program is established, scheduling becomes a matter of selecting ready backlog and scheduled PM activity for the week. There are operations issues to consider that will influence the work selected for a given week. The scheduler must ensure that all five key elements of the maintenance job are arranged to “be in place” at the time the work is initiated. As mentioned previously, these five elements are labor, tools/materials/parts, information/instructions/drawings, custody of equipment, and any authorizations or permits required. One important Lean role for the scheduler involves the responsibility for continuous improvement. It is therefore valuable for each weekly coordination meeting to address the performance of the previous week. In particular, the team should address the causes for schedule compliance problems and how to improve the overall planning and scheduling process.

Work Order Management

An effective work order management process is essential to Lean maintenance. In addition to the immediate effect that a work order management system has on quality of maintenance performed, it has also been found to be a valuable source of essential data for other Lean projects. The dilemma facing many maintenance organizations is that a good deal of human interaction is required to enter and retrieve data from a work order management system. On the surface, this effort does not appear Lean, especially when the downstream benefits are less apparent or require time to evolve and become evident. Management commitment and an understanding that benefits will eventually outweigh the costs is an important factor in achieving Lean through the work order management system. Levitt [11] describes additional benefits of an effective work order management system on worker productivity and discipline, which are important intangibles.

Communication

Verbal instructions require little time to prepare but can often be misinterpreted or forgotten by workers, and because they are not written they leave no record for future use. Problems arise when workers substitute their own instructions for those they either misunderstood or forgot. Mistakes also include performing work on the wrong equipment. In the long run, therefore, the use of written instructions is Lean. Handwritten procedures are only marginally better than verbal. These too can be subject to misunderstanding due to illegibility, and they do not archive easily. The work order management system is the conduit for an essential two-way communication. In one direction, instructions are given to the maintenance worker. In the other direction, findings and actual resources required to complete the task are fed back to the planner. This process facilitates one of the most important elements of continuous improvement in plant maintenance.

Work Order System Data Integrity

Most power generating plants now employ some form of a computerized work order management system. However, simply employing a computerized system does not necessarily mean the process is Lean. In order to realize the Lean benefits from an investment in a computerized work order management system, the information that is collected and distributed must be complete and accurate. Incorrect data on maintenance instructions or maintenance history, if assumed to be correct, can contribute to future waste or lost opportunities for waste reduction. In summary, an effort must be made to make the effort of creating, entering, and consuming the data contained in the computerized work order management system as Lean and accurate as possible. Training will be an essential component of this effort.

Examples of lost opportunities to achieve Lean performance through a work order management system include:

- Parts and/or labor charged to an incorrect work order number; the extreme example of this is that a work order remains open for days or weeks and becomes a "standing work order" that includes several separate tasks.
- Entering incorrect actual time required, often evident by the actual time being identical to the estimated time in most cases.
- Ignoring the recording of small time increments with the assumption that they are not important.
- Performing maintenance without a work order to document activity.
- Not completing work order in a timely manner, and relying on memory to recall the important details.
- Failure to record the as-found condition of equipment (this misses a huge opportunity to provide important feedback to the preventive maintenance program that enables continued improvement of maintenance intervals). Some systems may allow uploading and archiving of digital photographs, which is an effective way to document as-found condition.

The above list includes practices you do not want to see happening. The three items below describe what information is desirable to obtain **from** the maintenance staff that is actually performing the work:

- A description of the as-found condition
- Steps or a process used to perform preventive or corrective maintenance; this could refer to any planning documents that are part of the work package but state just the exceptions or suggested improvements to the plan
- Accurate feedback on time required, safety issues, parts required, and all materials required, to compare with estimates if available

When a work order management system is first deployed, it may be obvious if data entered by maintenance staff is inaccurate or incomplete. Eventually, periodic audits should be sufficient to assess compliance.

The Computerized Maintenance Management System (CMMS)

The CMMS functions in today's power plants as the work order management system. If integrated with other business systems such as accounting, time-recording, and purchasing, the CMMS shares data across the enterprise and is less of a "silo." A high level of integration increases the level of work order data integrity, because now the stakeholders of accurate data include other functional areas rather than the maintenance department alone. Mandates for, and enforcement of, the proper recording of work order information can thus come from upper management.

What data can be extracted from a well-managed CMMS to improve Lean performance? A list of some items is provided below:

- **Component performance.** This includes data such as component life, or mean time between failures, or data on component reliability as a function of design or source. To the extent that this information can be mapped against operational history of specific components, valuable parametric relations can be defined that will enable more refined component life projections. Comparative analysis of the observed reliability of like components can pinpoint factors that contribute to degradation and failures.
- **Identification of inadequately protected failure modes.** A component failure mode that either has no associated preventive maintenance protection or has insufficient protection can be identified by mining the CMMS data. System or component engineers must then revise the preventive maintenance basis, or even better, design out the failure mode to reduce future occurrences of failure. To help take most advantage of limited technical staff resources, the CMMS can be mined to list these failure modes in priority order, starting with the ones that have historically shown greatest impact on availability or cost to repair.
- **Identify PM scheduling opportunities.** Unscheduled maintenance involving an outage or derate that occurs near the time of upcoming scheduled maintenance provides an opportunity to reduce waste. This can be done by rescheduling the planned maintenance to take advantage of the unit availability, thus saving the "fixed cost" associated with taking the unit off line or disassembly.
- **Identify training needs for maintenance staff.** The CMMS can be mined to identify staff whose performance could benefit from additional training. This could come from above-average need for rework, or a pronounced increase in time required for common tasks relative to other employees.

In summary, Lean organizations regard the CMMS or work order management system as more than just a tool to handle the work package. Cutting costs by not permitting adequate training on the system by all staff required to use it will lead to waste and lost opportunities. Levitt [11] mentions an approximate figure of 100 hours of training as typically needed by maintenance staff on a new CMMS. Another area of false economy is not devoting sufficient resources to CMMS data mining. To the extent that this requires additional training on various software functions, it needs to be provided. Also, if this mining task is assigned to the maintenance planning department, their workload needs to account for, and allow time for, this activity.

Work Execution

Work execution can include some of the most visible forms of waste in maintenance execution. Idle maintenance staff, numerous trips to and from the site or storeroom, reworks, and excessive time to complete tasks all contribute to waste. From a Lean implementation perspective, work execution can be a good place to start. These types of Lean projects are typically small, and bring immediate tangible results. These successes can then be built upon in future Lean projects that move into areas such as preventive maintenance optimization, inventory management, and CMMS implementation. There are various Lean strategies and initiatives that can be applied to work execution. These are summarized in the paragraphs that follow.

Worker and Material Movement

This is equivalent to improvements derived from time-motion studies performed for factory assembly line processes. In the case of fossil plant maintenance the work is not being performed on an assembly line or work cell, but rather at any of a wide range of plant locations. Travel to and from the work site should be minimized, as should trips to the storeroom. The “spaghetti” diagrams referred to earlier in the report are an effective way to document inefficient existing work processes by tracing the movements of workers and material on a map of the overall plant layout. Process improvements are made evident by comparing spaghetti diagrams before and after the project. Strategies for reducing the number of trips include the pre-kitting of materials and tools required for the job and using other staff to move materials to the work site (to avoid multiple trips if the quantity of material is large). The use of satellite storerooms positioned closer to remote but commonly used job sites is another strategy for reducing worker travel time.

Fix-it-Now Teams

As discussed earlier under planning and scheduling, fix-it-now teams are specifically designated to handle emergency corrective maintenance in Lean organizations. By taking steps to avoid interrupting staff assigned to planned maintenance activities, opportunities for wasteful activities are reduced. Being removed from a partially completed task to start a new job typically involves nonproductive time spent moving to the new site and waiting for other staff, materials, clearance, and so on before starting any productive activity.

Tool Management

Kanban concepts are applicable to “portable work areas,” just as they are to fixed-location manufacturing work cells or maintenance shops. The fundamental goal of managing tool access is to ensure that there is no wasted time spent either locating a missing tool or retrieving a tool. The key elements of Lean tool management include the following:

- Organize tools so that they are easy for the owner to access, whether it be in a job box or a shop. This also makes it easier to determine when tools are missing prior to the job.
- Secure the tools to avoid unauthorized access by others.
- Select a job box that permits easy movement from one location to another.
- Replace any defective tools immediately; do not wait until they are needed.

Technology

An effective Lean maintenance strategy will take advantage of any technology that saves time or reduces error, providing its use shows a favorable ratio of benefit to cost. This technology could include advanced tools, or systems that facilitate the collection and management of information. Some examples of technology that can eliminate waste are:

- Laser alignment systems
- Automatic lubrication devices
- Bar codes to identify equipment during PdM technology exams
- Portable data assistants (PDAs) to collect and/or retrieve information
- Low-cost infrared scanners
- Ultrasonic leak detectors
- Digital cameras to document as-found conditions
- Use of local cell phones (to replace walkie-talkies and intercom systems)

In evaluating the benefits and costs of deploying technology, ongoing costs of training users must be taken into account.

Training

Training is an essential element of Lean maintenance. The benefits include reduced chances for errors and rework. Elements of a Lean training program would include 1) cross-training, 2) just-in-time (JIT) training, and 3) structured on-the-job training (structured OJT). Successful cross-training can reduce the number of staff needed for a task, if that task requires the application of several different skills. Often, it is not the amount of work that requires the use of multiple staff, but rather the need for several specific skills. Too many specialists contributing only a portion of their time to a task can result in excessive idle time. Cross-training should be encouraged and rewarded.

Just-in-time training is another Lean training concept. JIT training is task-oriented and works best for infrequent, complex maintenance procedures. In these situations, it is difficult to retain knowledge unless the training is delivered just prior to undertaking the task. The paradigm shift with increased use of JIT training is that traditional training is now used to educate staff on how to obtain information rather than educating on technical details that are unlikely to be retained by the trainee. By not using JIT training, an organization could be overlooking Lean opportunities by either applying too much training or increasing risk of costly rework due to a low task proficiency. One strategy for deploying JIT training is by use of computer-based training modules. These modules can be accessed on a 24/7 basis, and used only when needed. Both of these attributes will reduce the amount of idle time and delays in task completion by maintenance staff due to the need for training. A common example of JIT training is the online help offered by many computer software applications today. Contrasting this online help to the alternative of lengthy formal software training makes it clear that JIT training is a Lean concept.

The third Lean element to training is on-the-job training. Like JIT training, OJT works best for focused activities at the task level. OJT is best suited for instruction on tasks that cannot be effectively delivered away from the job site. In effect, OJT is training by doing. In situations where errors could be costly or lead to safety issues, an evaluator can be present to verify that the task is performed correctly and to sign off on the employee's proficiency. By preparing step-by-step procedures in advance and including an evaluator, the OJT process becomes more structured.

Kaizen Improvements

Although Kaizen applies to all aspects of a manufacturing or maintenance organization, it is perhaps most easily applied to work execution. It is reasonable to expect that any procedure or work plan, when initially developed, has significant room for improvement through reduction of wasteful activities. This waste should be most evident to the workers actually performing the task. Supervisors and management must develop a culture that supports continual improvement by encouraging and considering all suggestions from any staff involved in maintenance. Some formal practices that can facilitate this continual improvement process include the following:

- Providing an opportunity to feed back improvement suggestions on the work order documentation prior to close-out
- Conducting post-job briefings between maintenance staff and work planners
- Creating incentives through a rewards program

Corrective Action

Corrective action, although not uniquely associated with Lean maintenance, must be considered a key element of any organization's Lean culture. The most significant level of maintenance waste reduction is to eliminate the need for maintenance through improved reliability. No reasonable amount of improvement to the efficiency of performing a maintenance task can equal the level of savings derived from avoiding the need for the task altogether. Corrective action, based on effective root-cause analyses, can contribute to the goal of maintenance task reduction. A useful reference document on corrective action programs for the fossil power generation industry was published by EPRI in 2008 [18]. This guide describes the overall program structure and organizational integration and contains a number of forms and checklists that can be adapted for use in a formal corrective action program.

With the focus of this report being on maintenance, corrective action and root cause are discussed relative to equipment failure events. An event root cause determination could be equipment-related, but in many cases it is related to human error. In either situation, the corrective action based on a root-cause analysis can reduce maintenance waste. If the failure is truly equipment-related, a design change to eliminate the failure mode might be possible. Failure events attributed to human error are very common, and could either be maintenance-induced or related to operations. In both cases, corrective action should improve the **process** and thus reduce the potential for event reoccurrence. In the case of maintenance, the corrective action may include an improved job package or improved training.

Event Significance Levels

EPRI's *Corrective Action Program Guidelines* [18] describes three event significance levels, each associated with a different level of rigor in the investigation type. A true root-cause investigation may only be justified for the small number of events per year in a plant that are classified as Level 1. An apparent-cause evaluation is less rigorous and used in Level 2 cases where the failure consequence is not as significant as Level 1. Finally, events of low significance can use data trending to assess apparent cause. This multilevel approach based on event significance classification reduces wasted effort associated with performing extensive studies on relatively minor events. It is important to reserve limited staff resources for the root-cause analyses that offer the greatest potential for gains in terms of improving reliability.

The Discipline of Effective Root-Cause Analyses

Formal training is important for leaders of root-cause investigations. Objectivity and a working knowledge of failure modes and effects are essential attributes. The leader must keep the investigation focused while not limiting discussion on potentially relevant issues. Essentially, a root-cause investigation comes down to asking a series of "why" questions. A weakness of many investigations is that the team does not go deep enough (that is, asking enough of the "why" questions). An example would be concluding that a bearing failed but not asking whether the root cause was a maintenance-induced error in the installation, or an improper shaft alignment. There is reluctance among inexperienced analysis teams to attribute the root cause to human error, even if it is justified. This is unfortunate, since many of these human errors can be avoided in the future through implementing process improvements in the subsequent corrective action phase. Although root-cause analysis software using tools such as "fishbone" diagrams can aid investigations, they do not replace the need for an objective, disciplined leader who drives to the real root cause and is not reluctant to identify the role of human error.

Corrective Action Phase

Following the root-cause analysis is a corrective action process. In a Lean maintenance organization, an assessment of benefit and cost will be performed prior to initiating corrective action. Corrective actions need to be concise, be measurable, and have milestones and completion dates. It is recommended that large tasks be broken down into subtasks, each with its own attributes. This is especially warranted if the high-level task cuts across different groups within the organization.

Lean Examples

Presentations of several case studies of Lean maintenance implementation in process industries are referred to in the agendas of past industry conferences and trade shows. An extensive web search conducted during the preparation of this report found only a small number of case studies actually documented in the open literature. It is likely that in many cases, Lean maintenance is successfully implemented, but effort is not taken to document the process, challenges, strategies, and benefits in the open literature. Some examples were found and are summarized in the following paragraphs.

Automotive Industry

A technical paper written in the early 2000s was found at the www.plant-maintenance.com web site [19]. The paper described application of Lean maintenance in an automotive manufacturing facility that employed 2500 people, of which 100 were involved in maintenance. Many good reference documents on Lean maintenance that were written in the late 1990s are provided in this paper. The paper identified eleven elements of Lean maintenance being implemented at this manufacturing facility, most of which are described earlier in this report chapter. The investigation covered only four of these eleven Lean maintenance elements: process mapping, mistake-proofing (Poka-yoke), TPM, and root-cause analysis. The quantitative analysis reported over an observation period of 30 months related primarily to wrench time, ratio of preventive to corrective maintenance, and machine availability. A qualitative assessment was performed in addition to the metrics tracking. Interviews and assessments made through observations indicated significant engagement by the maintenance staff in the Lean implementation, and strong management support for the initiatives. Thirteen areas of waste were identified, each with an approach defined for achieving waste reduction.

Quantitative results were presented by month over a 30-month period. The data showed an improvement in labor utilization of 25% over the time period. Dramatic improvements in the ratio of planned to unplanned maintenance were also noted. Lastly, the length of time between unplanned shutdowns steadily increased over the analysis period.

Chemical Processing Industry

This case study is summarized at http://www.tacook.co.uk/case-study.php?id=00059. The brochure summarizes the results of process improvements and related information technology implementation at a European company that provides services to chemical process industries. The Lean initiatives were primarily in the areas of creation of interdisciplinary project teams, effective use of an enterprise system for information management, and use of standardized work packages. The enterprise tool implementation effort emphasized the need to collect and manage all data that is relevant to maintenance planning and execution. The goal was to make all this information available to all staff who could benefit from the data to create process improvements. An emphasis was also placed on ensuring that data must only be entered once into the system. Significant staff training was provided on the use of the enterprise system, using workshops customized to specific job functions. These goals are aligned with the discussion earlier in this chapter regarding the need to eliminate waste and provide adequate training in the usage of a CMMS.

The reported results include a factor-of-two improvement in the ratio of planned versus unplanned maintenance activities. There was also an 8% reduction in the work-order cycle time. The proactive work planning initiative reduced planning costs by implementing a standard work process that addresses recurring downtime issues. A reduction of 5% in total plant downtime was reported, in addition to an overall reduction of 15% in total maintenance costs.

Air Force Maintenance Depot

This case study documented by the U.S. Environmental Protection Agency (EPA) focuses on the use of standard Lean practices to improve not only costs, but environmental safety and occupational health (ESOH) as well (www.epa.gov/lean/studies/robins.htm). The case involves a Lean initiative at the Robins Air Force Base aircraft repair depot in Georgia from 1999 to 2002. Initially applied to the avionics and wing shops, it eventually expanded to include all maintenance processes and related administration processes. The seven Lean elements employed by Robins AFB included the following:

- 6S
- Value stream mapping
- Rapid improvement events (Kaizen)
- Standardized work packages
- Point-of-use (POU) storage
- Cellular manufacturing
- Strategy alignment (Hoshin Kanri)

The above list aligns with several of the Lean initiative elements discussed earlier in this chapter.

The reported results for just the point-of-use initiative included a decrease in staff travel time by 1500 miles and a reduction in hazardous waste generation of 25%. Along with this was a reported increased in production. Several Lean practices were used to improve management of hazardous waste. Process steps were eliminated that reduced drum handling time and frequency. There was a reported 70% reduction in the number of times workers touched drums. Other reported improvements included the following:

- Resource productivity improvement of 30–50% (C-5 aircraft maintenance shop)
- $8 million savings in the first year (C-5 aircraft maintenance shop)
- Decrease in both hazardous materials use and waste generated on both the flight line (25%) and the shops (as high as 50%)

Naval Repair Shipyard

The process of maintaining large naval vessels shares many common goals and strategies with maintenance of power generation plants. The U.S. Naval Sea Systems Command (NAVSEA) has the mission of maintaining fleet readiness. The goals of equipment reliability and availability are common to both ships and power plants. An extensive list of 39 best business practice initiatives relating to naval vessel construction and maintenance are documented at www.jdmag.wpafb.af.mil/bestbusnavsea.htm. Four of the more relevant initiatives are briefly summarized as follows:

- The Advanced Industrial Management initiative describes the early implementation of CMMS tools at naval shipyards. This was a very large enterprise deployment involving over 10,000 users, and improvements in maintenance cost and scheduling were observed over the initial four years following software implementation.
- The Maintenance Effectiveness Review is essentially a review of the ship maintenance basis. Based on combined experience of design engineers and fleet operations and maintenance staff, 90% of the ship's planned maintenance tasks were reviewed. The reported result was a reduction of 41% in maintenance man-hours.
- In 2000, the Norfolk Naval Shipyard implemented a knockout process that essentially resembles a Kaizen blitz (described in the next chapter). The process involves the workers and management, as well as the use of facilitators. The emphasis is on rapid approval and implementation of solutions to barriers preventing productivity improvements. The article reports nine sessions conducted, with 210 separate initiatives approved, 95% of which were implemented within 90 days.
- The Lean Maintenance and Repair initiative strongly resembles Lean maintenance implementation in a power generation facility. A pilot implementation in the ball valve repair area at Portsmouth Naval Shipyard had the goal of a reduction in repair lead time from 75 to 30 days, cost reduction of 55%, and a reduction of work-in-process (WIP) from 80 to 20 valves. At the time the article was written, the lead time was reduced to 45 days and the WIP was reduced to 30 valves.

4
PRINCIPLES AND KEY ATTRIBUTES OF KAIZEN PHILOSOPHY

Overview and Definition

The term *Kaizen* is of Japanese origin and refers to the philosophy of continuous improvement. This improvement can be sought at any organizational level, from an individual's work process level all the way to improvements affecting an entire organization. The key concepts of Kaizen are that 1) the process is truly ongoing, rather than a series of short-lived improvement initiatives, and 2) Kaizen involves **all** levels of an organization—both management and workers. Cultural differences can strongly influence organizational behavior, in particular the value the organization places on achieving small incremental improvements in a business, manufacturing, or maintenance process. As will be discussed further in this chapter, U.S. and European companies have traditionally placed greater focus on significant, albeit infrequent, **innovation**-based improvements in process. These innovations are by nature often associated with technology improvements. Of course, Japanese companies also recognize the importance of technology innovation. However, these companies have also proven that in the intervening time between these discrete innovative changes are opportunities for numerous smaller **process** improvements. When put into place over time, these continual incremental improvements result in significant overall gains in the major business metrics such as production cost, reliability, quality, and lead time. In considering the importance of a rigorous continuous improvement program, imagine how unlikely it is that business or maintenance processes are nearly perfect when they are initially deployed. To assume initial perfection is of course unrealistic, yet organizations persist in not assigning proper emphasis on continuous improvement. Philosophically, Kaizen is strongly based on the premise that perfection can only be approached incrementally, not in the first deployment of a process.

Kaizen focuses on processes rather than results. Organizations that practice Kaizen establish a culture in which workers have an awareness of areas for improvement and are not afraid to identify them. This is sometimes referred to as being "problem conscious" and is the most essential element to achieving improvement. Kaizen is particularly effective in improving processes that cut across organizational boundaries. Problem solving or improvements that involve multiple organizations are often dealt with in a confrontational manner in Western companies, which is problematic since some of the more beneficial improvements involve organizational cross-cutting.

Kaizen Versus Innovation—The Role of Each

In contrast to Kaizen, innovation can be characterized as discrete improvement "events," each taking place over a relatively brief timeframe. These events substantially improve organizational performance. The improvements can either be the result of introducing new and innovative technology, or a major process re-engineering. Both innovation and Kaizen can improve an organization's performance and results; in fact, a balance of both is ideal. Innovation must be sought and implemented where it is deemed cost-effective. Technological innovations are being introduced constantly and have the potential to reduce time and cost associated with performing maintenance tasks. Once an innovation is implemented, however, the organization that effectively practices Kaizen will continue to actively seek and implement further **incremental** improvements until the next innovation is discovered and implemented. Successful organizations use both continuous improvement and innovation in proper balance to remain competitive and achieve their business goals. Figure 4-1 depicts improvement achieved through both innovation and Kaizen continuous improvement. Innovation is characterized by discrete events taking place over a short time period. Kaizen is gradual and continuous improvement at a rate that may decrease over time as the new standards eventually capture the achievable gains.

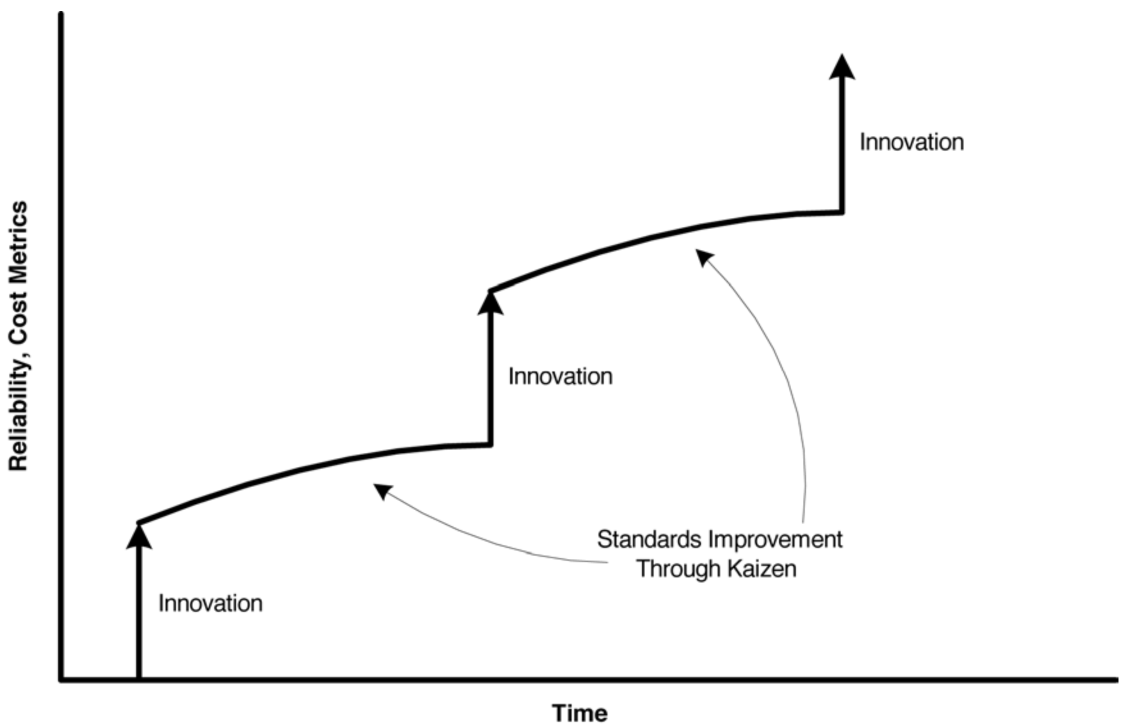

Figure 4-1
Improvements Through Innovation and Kaizen

Imai [12] provides an excellent list of attributes for both Kaizen and innovation that show the contrast between these two approaches to improving an organization's results. Some of these attributes are summarized in the bullets below:

- Kaizen change is gradual; innovation is abrupt.
- Kaizen involves many workers in an organization; innovation involves only a few.
- Kaizen promotes group thinking; innovation typically relies on individualism.
- Kaizen improves; innovation replaces with new.
- Kaizen requires little initial effort followed by a larger effort to maintain; innovation requires a large initial effort followed by a smaller effort to maintain.
- Kaizen is successful in a slow economy; innovation will be more successful in a healthy economy.

Process-Oriented Versus Results-Oriented

A key aspect of Kaizen philosophy is its focus on the underlying processes rather than simply using results as a measure of performance. The belief is that by putting the focus on the employee's actions (**process**), positive changes will be made that can eventually yield improved results. This concept is not unlike the ongoing challenge of balancing the use of leading and lagging metrics to improve performance of power plant operations and maintenance. It is easy to adopt a results-oriented approach to applying performance metrics, but the success of this approach may be limited if the plant staff cannot relate how their day-to-day process work affects these results metrics. It is a greater challenge to have the patience to focus on process first, with the confidence that it will eventually lead to the desired results improvement. The process-focused manager can be described as supportive and stimulative, while the results-focused manager is described as controlling. Imai [12] uses the terms *P-criteria* and *R-criteria* to describe how improvements are assessed for process-oriented and results-oriented organizations, respectively.

A good example of the contrast between P-criteria and R-criteria can be found in how organizations establish and conduct their employee suggestion system or where used, quality control circles (QC circles). In companies practicing Kaizen, QC circles are essentially a group form of the employee suggestion process. A process-oriented approach will establish goals and rewards that focus on the **parameters** that lead to success. These parameters relate to effort—for example, the number of staff involved, frequency of the meetings, and so on. A results-oriented approach, by contrast, will look primarily at the outcome of the suggestion process of QC circles in terms of bottom line performance indices. Management in a company that practices Kaizen will be actively engaged in evaluating and rewarding the staff at all levels. More discussion of the suggestion process is provided later in this chapter.

The PDCA Cycle

The Deming Wheel, originally adopted to improve manufacturing operations, can be universally applied to any organizational improvement process. PDCA refers to a continuous cycle of *Plan*, *Do*, *Check*, and *Action* (see Figure 4-2).

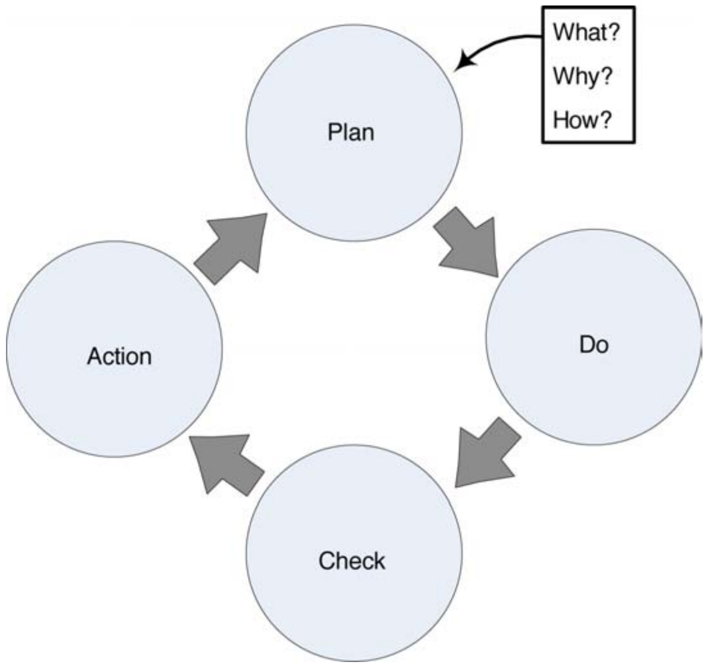

Figure 4-2
The PDCA Cycle Applied to Kaizen Problem-Solving Projects

In the context of plant maintenance, *Plan* refers to the planning stage of a process improvement project, *Do* refers to applying the plan, and *Check* refers to verifying that the desired improvement has been realized following implementation. The *Action* step is critical and refers to updating the organizational processes and procedures to fully implement and standardize the change. The *Plan* step can be further described with the subelements of *What*, *Why*, and *How*. Since the PDCA cycle is most often applied to problem solving in the context of continuous improvement, *What* refers to problem identification, *Why* refers to root-cause, and *How* refers to the solution plan.

Imai [12] proposes an adaptation of the PDCA cycle to describe this important standardization step. This adaptation is termed the SDCA cycle, for *Standardize*, *Do*, *Check*, and *Action*. Considering SDCA separately from PDCA acknowledges the unique challenges to upgrading standards, even if the improvement has already been demonstrated earlier in the PDCA cycle. In many situations where Kaizen projects are being considered, it is advisable to first standardize the existing processes using SDCA. Once stabilized, PDCA and subsequent SDCA cycles can be effectively applied. Figure 4-3 shows the interaction of PDCA and SDCA superimposed on the previous Figure 4-1. The curves labeled "standards improvement through Kaizen" contained in Figure 4-1 are shown in Figure 4-3 as being achieved through a series of discrete PDCA and

SDCA steps. These steps describe the ongoing process of planning, doing, checking, and standardizing. In summary, the PDCA cycle has broad application as a way to implement both Lean projects and continuous improvement projects. Standardization of any new process element is the most important step.

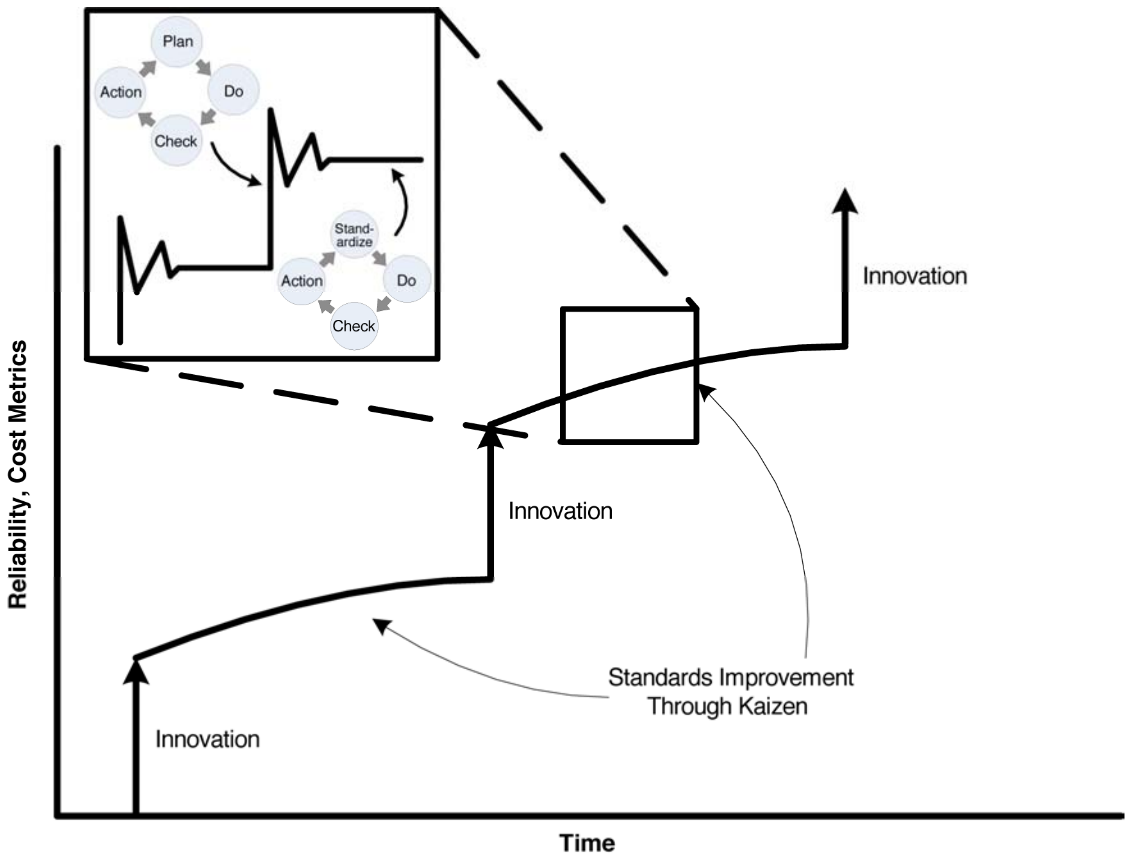

Figure 4-3
Interaction of PDCA and SDCA Cycles in Kaizen Standards Improvement

The DMAIC Process

A second process, DMAIC, similar to the PDCA cycle described above, has evolved out of Six Sigma quality control methodology. DMAIC is an acronym that refers to Define, Measure, Analyze, Improve, and Control. PDCA has a focus on continuous improvement methodology; however, DMAIC can also be applied to improvement activities. The key point is that the method utilized should be structured in order to be most effective. The following bullets provide additional information on the five steps of DMAIC:

- **Define.** This step actually defines the **project** (in this case referring to a continuous improvement task). The key elements include the scope, timeline, budget, and contributors. This step may include creating a description of the current-state process to be improved. Lastly, input from the customer is collected and reviewed to ensure that it will be a major factor in the project.
- **Measure.** This step is focused strictly on gathering data that describes the current-state process performance. Nominal values and variations are both important. This step not only provides insight needed for future steps, but also creates a baseline for comparison following improvement implementation.
- **Analyze.** This step seeks root cause(s) of process deficiencies using tools such as fishbone diagrams or statistical analysis.
- **Improve.** This step addresses the root cause(s) to create an improved process. It also includes initial improvement implementation and process monitoring to ensure that goals are met.
- **Control.** In this step, the process improvement is standardized. To achieve this, specific long-term monitoring is developed, with predefined actions in place for any performance issues. This step also represents the point at which the project manager transfers ownership of the improvement to the process owner.

Roles of Management, Supervisors, and Workers

An effective continuous improvement program should involve all organizational levels. Management, supervisors, and workers will each have different roles and responsibilities in the overall process of successful Kaizen implementation. In the past, the traditional role of management was to plan, and the role of supervisors was to direct. Workers had responsibility for performing the work; however, they were not encouraged to use their heads. In the future, organizational roles need to change so that workers and supervisors are encouraged to find and correct problems. Management's role is to create, support, and incentivize the overall company programs that enable these new roles for the lower levels of the organization. This business transformation is described by Michael Hammer in his book *Beyond Reengineering* [20].

Imai [12] describes a "top-down" and "bottom-up" approach that is used simultaneously by companies implementing Kaizen. Top-down is the role of management, and it describes the design and deployment strategy for continuous improvement and quality assurance programs. The bottom-up activities are undertaken by workers and supervisors and refer to the analysis and related PDCA or DMAIC activities undertaken within their areas of responsibilities. The top-down, or *design,* activities are primarily forward-looking. The bottom-up, or *analysis,* activities are focused on past performance that holds the key to future improvement.

"Bottom-up" analysis tools include CMMS data mining; root-cause studies using fishbone diagrams; process flow diagrams; and a range of data analysis methods such as Pareto analyses, scatter plots, histograms, and control charts. Likewise, "top-down" tools used by managers in the design role include relation diagrams, affinity diagrams, tree diagrams, and matrix diagrams. More information on these tools is presented in Chapter 5.

In summary, Kaizen (like Lean) involves relatively simple concepts and should not require potentially disruptive technology or major process re-engineering. It relies on the power of collective thinking that is encouraged by management. Management shows commitment by using employee-suggested improvements, and employees subsequently feel a sense of ownership and are thus more likely to sustain the continual changes.

Kaizen Events

One form of Kaizen implementation is the Kaizen "event," also referred to as a rapid improvement event or a Kaizen "blitz." A Kaizen event focuses on a specific predefined process improvement that has the potential to be addressed in an accelerated manner (in 3–5 days). It is important to understand that not all improvements can be defined in terms of a sustainable solution using Kaizen events. It recommended that these events be considered just one of the tools in a company's Kaizen toolbox. In many situations, the slower, more deliberate continuous improvement approach that involves a thorough root-cause analysis, process mapping, or data analysis is a more effective approach.

Attributes of a Kaizen event include:

- Use of a cross-functional team consisting of 6–12 members, with an equal mix of specialists, outsiders, and decision makers
- Focused team effort over several days, with minimal distractions
- Use of some analysis tools such as process mapping and spaghetti diagrams
- Use of an experienced event leader, with working knowledge of the fundamental continuous improvement tools and experience in leading teams
- Development of a plan or process for implementation of change developed during the event
- Empowerment of staff at lower levels of the organization, leading to an increased sense of engagement and ownership of the problem resolution

The physical location selected for the Kaizen event needs to ensure minimal distraction from the team's normal duties and should include basic equipment such as a whiteboard, flipcharts, tape, Post-it notes, a projector, and breakout rooms if needed.

Kaizen events can be highly visible within an organization, which can result in increased support for future improvement projects (providing there is observable success with the initial projects). For that reason, it is important to select process improvement topics that are well suited for the limitations of Kaizen events. This would include small improvement opportunities for which there is considerable existing insight into the problem root cause, or waste in the value stream. The ideal projects for a Kaizen event will be ones for which the solution is straightforward to implement. Critics claim that for larger improvement initiatives, insufficient time is spent during Kaizen events on finding the root cause, leading to lack of a sustainable solution.

Kaizen and the Company Culture

Most employees will naturally embrace an initiative that empowers them to add value to the organization and be recognized for their contributions. Therefore, one key to success of continuous improvement programs is to harness the collective skills and enthusiasm of the workforce. This is a key role of management. The program goals must be clearly stated, and management must be truly engaged in the process. Most staff members can perceive when management support is superficial, and if so, this will negatively affect their enthusiasm.

A supportive corporate culture is the single most important factor contributing to broad employee involvement in an enterprisewide continuous improvement effort. This requires a willingness to change on the part of all organizational levels and roles. Ongoing conflict between management and labor is a significant detriment to achieving this positive corporate culture.

The Employee Suggestion System

Perhaps the most effective way to introduce Kaizen into the company culture is through implementation of an employee suggestion system. As will be explained below, a suggestion system encompasses two of the key attributes of Kaizen: it involves all organizational levels and it has the potential to be sustainable. The paragraphs that follow describe attributes of an employee suggestion system that are equally applicable to maintenance as well as to manufacturing organizations. A suggestion system is strongly recommended as an element of a continuous improvement program. Use of an enterprise-level information system to manage the flow of contributed suggestions, reviews, and resulting actions is a Lean approach to implementation. This approach would, for example, allow valuable information to flow to maintenance planners.

Considerations for Implementation

Suggestions can be contributed by individuals or by small ad-hoc groups (sometimes referred to as *quality circles*). Both sources should be equally encouraged. Topics can cover a range of improvement categories. In plant maintenance, suggestion topics might address procedure improvement, efficiency, safety, work quality, parts/materials, and interaction with operations. For years, Japanese manufacturing companies have instilled a culture that promotes the suggestion process. Metrics track the number of suggestions contributed per employee, the number implemented, and the positive impact on company performance. Supervisors directly encourage participation and assist those employees who need help getting started. The number of submitted suggestions reported by these large manufacturing companies on a per-employee basis is immense. The resulting time required by supervisors and management for review would be impractical with the resource constraints on today's power plant maintenance departments. Rolling out the program on a small scale and then growing it at a pace that does not create frustration is therefore important. Imai [12] describes three stages of suggestion system implementation:

- Initially, management should simply encourage participation. This creates an awareness by the staff of how they are doing their tasks, and develops the important skill of "problem consciousness." It also gets employees familiarized with the suggestion form (an important element of suggestion system discussed further below).
- The next stage should encourage more substantial suggestions that require the ability to analyze problems. The tools and methods for this analysis may require some training. At this phase, suggestions from small groups are likely to be of greater value than those from individuals.
- Only when participation is embedded in the company culture, and suggestions are the result of analysis, should management should begin to focus on the economic benefits and include them as a factor in the reward process.

The above evolution takes time, perhaps as much as five years. In many Western companies, improvement initiatives are likely to be abandoned before reaching this point, due to lack of perceived payback. Even after successfully reaching the third step above, rewards should not be based exclusively on reducing costs, as this may negatively influence future participation. Other reward categories such as safety, work quality, and reduction of cumbersome tasks should remain important. Maintaining this balance is an example of being both process-focused and results-focused.

Experience has shown that there are two main success factors in implementation of the employee suggestion program: encouraging small group participation, and demonstrating a willingness to implement all worthy suggestions. Feedback to the employees should not consist solely of awards when a suggestion is implemented, but should also include reasons for suggestions not used. It is worth mentioning that one important intangible benefit of an active suggestion system is the positive effect it has on employees' "problem awareness." No continuous improvement initiative can be successful without this.

Suggestion Forms

Requiring the use of a suggestion submittal form is highly recommended. This is particularly effective if the system is managed using an enterprise software application. Key attributes of the suggestion form are:

- Including categorical information such as equipment type or process name that will allow future searches within the database. Also prompt for categorical information on the type of improvement expected as a result of using the suggestion (cost savings, safety, quality, and so on).
- Prompting for a clear definition of the problem the suggestion addresses.
- Requesting the basis for, and an estimate of, the financial benefit of implementing the suggestion, if applicable. This may need to be reviewed and adjusted by the supervisors or managers.
- Clearly showing the evaluation criterion on the submittal intake sheet, preferably in the same format used by the suggestion evaluators. Include in this evaluation criterion a process for scoring the suggestion (that is, how the various criteria are weighted and summed).
- Using same form to document and archive disposition of the suggestion.

Suggestion Deployment

It is important to keep the time duration between suggestion submittal and approval to a minimum. When a suggestion is implemented, opportunities for wider deployment on similar systems or processes throughout the enterprise should be actively sought. This leverages the benefit.

Customer Focus

Kaizen philosophy states that it is customer satisfaction that sets the standard that must then be met by quality and cost requirements imposed by management. This concept is well understood in the manufacturing sector, particularly in consumer products, where buyers clearly signal their expectations in the marketplace. In power plant maintenance, the customer concept is less clear. Ultimately the customers are the ratepayers; however, they may not be able to clearly convey their expectations regarding maintenance (except an expectation that supply will always meet demand). Within the plant, the operations organization and the plant manager can be considered customers of the maintenance staff. They have clear expectations regarding plant reliability and availability. The task of the maintenance and operations management and supervisors is to establish and clearly prioritize strategic goals. These strategic goals are then met by lower-level staff achieving tactical and actionable goals established by management. So how can Kaizen customer focus be established in a power generation facility? The customer should be clearly identified, and attainable expectations should be established and communicated. Lastly, actionable goals that support achievement of the customer expectation should be established and monitored. The actionable goals should be unambiguous and the number kept to the minimum necessary.

Kaizen Implementation Examples

Research on examples of Kaizen implementation indicates that most are found in the manufacturing sector. A few of these are summarized in the paragraphs below.

Hershey's

Hershey's, a Pennsylvania-based manufacturer of chocolate and sugar confectionery launched a continuous improvement initiative in 2005 that is still ongoing. Prior to 2005, a team of industrial engineers was tasked with driving productivity improvements. Centralization of the industrial engineers in the 1997–2003 timeframe, coupled with the increased awareness of Lean manufacturing worldwide, resulted in the start of Hershey's World Class Manufacturing program in 2004. By 2005, six industrial engineers were on staff, and the Lean program took shape with an emphasis on improving work flow, the supply chain, and inventory.

A challenge at Hershey's was culture change. In 2005, a bottom-up strategy was taken to obtain management buy-in. By mid-2006, $8 million in savings were achieved through use of standardized work, 5S initiatives, and improved work flow. Challenges continued in deploying the World Class Manufacturing program across all plants, particularly in the area of standardized work. The centralized industrial engineering staff was also challenged to work more closely with the plants. During this time, the initiative was still being pushed from the bottom up, with some support from manufacturing management.

In 2006 a new senior vice-president of operations was hired and began pushing continuous improvement from the top down, starting with the hiring of a new vice-president over continuous improvement. More cultural challenges included the need to integrate the new top-down effort with the existing bottom-up effort already underway, while maintaining the motivation of the industrial engineering staff. The program name was changed at this time to the Hershey Improvement System, creating some additional challenges and confusion. By 2007, external resources were brought in to assist, and the continuous improvement program was more holistic and positioned for sustainability.

A five-step process to continuous improvement was adopted:

- **Problem identification:** value stream mapping, zero-based analysis, waste walks, brainstorming sessions, suggestion system
- **Prioritization:** categorized and ranked by value and complexity
- **Resource management:** aligning availability and resource prioritization across the organization
- **Improvement tools:** root cause analysis, Kanban, statistical process control, standardized work
- **Organizational behavior:** change management mind-sets

Findings of general interest from Hershey's continuous improvement program include the following points:

- The top-down approach energized the program and enhanced the bottom-up effort.
- It is necessary for the continuous improvement program to itself continuously improve, so prepare the organization for this through constant communication.
- Establish a process (such as the five steps mentioned above) that works best for your organization.
- Be patient, and use a mix of rapid improvement projects and ones that take more time.
- Standardize best practices, after testing and proving them out using an agreed-upon process.
- Train the trainer on key continuous improvement process elements, have a sufficient number of staff with necessary expertise, and put them in place before launching the initiative.

Topy Industries

The Topy Ayase Works is a 600-worker facility that manufactures automobile wheels. In the 1980s, management began to focus on improving the reliability of the 800 production machines used in the factory. A total productive maintenance (TPM) initiative was launched. The main elements of the program were 1) expanding PM activities to be the responsibility of production workers, not just maintenance staff, 2) improving maintenance workers' problem-solving skills, and 3) improving production engineering in areas of tool design and replacement procedures.

The Topy initiative first conducted extensive in-house training of production staff in the areas of basic maintenance skills. Next, a rigorous housekeeping effort was launched. The benefits of improved housekeeping include expanded opportunities to detect equipment degradation during the cleaning tasks and ease of detecting degradation due to increased cleanliness. A side benefit of the housekeeping effort was increased safety and worker respect for the equipment.

The focus of TPM is for workers to actively seek potential equipment problem areas and sort out those that they can correct versus those that require the attention of maintenance. Many of these tasks at the Ayase Works included routine PM activities such as lubrication and bolt-tightening. Over time, this work was incorporated into the daily routines, and eventually included process improvements to more easily check bolt tightness and add other foolproof devices such as limit switches.

Significant improvements were noted after TPM implementation. Breakdowns causing production line stoppage decreased from 1000 to 200 incidents per month. Oil leakage was reduced by a factor of five. Labor productivity increased by 32%, cost of defective parts decreased by 55%, and tool replacement time was reduced by over 50%. One important change that was noted following TPM implementation was that the maintenance staff was now able to devote time to higher-level activities such as diagnostics and leveraging their skills by conducting training of the machine operators. This is an important benefit of TPM and a key aspect of proactive maintenance.

Komatsu

Japanese heavy equipment manufacturer Komatsu was facing strong competition in the early 1960s, forcing the company to increase focus on Total Quality Control (TQC). Changes and initiatives included establishment of cross-functional management and implementation of quality control circles. Over time, the number of QC circles grew to hundreds and involved nearly 90% of the employees. Komatsu's TQC program eventually spread to suppliers, including overseas companies. It was noted that in Western companies, initial implementation of QC circles at the middle and lower management levels was more successful than starting immediately with workers. Executive involvement in the QC circles was critical, and involved annual presentations of success stories and award presentations.

Cross-functional committees were set up at Komatsu to oversee improvements in production cost, quality control, and production volume. Whereas the line organizations were responsible for achieving targets in their areas of responsibility, the cross-functional committees were involved in improving the systems and processes used by the line organizations. Use of cross-functional committees or matrixed staffing arrangements is not uncommon as a strategy to maintain focus on improvement by separating from the day-to-day tasks. A success cited by the quality control committee was a two-thirds reduction in QC check points in a manufacturing process.

The process for deployment of goals and company policies at Komatsu includes the use of a pocket handbook. The handbook is essentially customized for each employee by being divided into corporate, division, department, and individual levels. At each level below corporate, management is responsible for interpreting the higher-level goals and policies so they are specifically relevant to the division and department. At the employee level, the supervisor is responsible for defining individual goals and policies that support those at the higher levels.

5 STARTING AND SUSTAINING LEAN AND KAIZEN INITIATIVES

Lean manufacturing, Lean maintenance, Six Sigma, and Kaizen are examples of process improvement initiatives that have become well established in Japanese businesses. These efforts began in the late 1940s and have been evolving since. In Western organizations, the adoption of Lean and Kaizen has been significantly slower, with the first signs of use in the late 1980s. Within the United States, implementation has been most visible in the manufacturing sector, while it is presently much less evident in asset-intensive process industries such as petrochemical and power generation. The transition of Lean and Kaizen from manufacturing to process industries is apparently not a straightforward extension of Lean manufacturing. Within the power industry, deregulation and the resulting reduction in staffing and maintenance budgets starting in the early 1990s have resulted in plants being more reactive and less proactive. This has created a difficult environment in which to introduce new initiatives, even those that if successful could actually improve company performance with limited resources. This chapter will discuss topics related to starting and sustaining Lean and Kaizen initiatives.

Key Differences Between Traditional Processes and Lean/Kaizen

It is important to note that many elements of Lean maintenance are already in place, or are components of ongoing efforts by power generating companies to reduce operating costs and improve reliability. Lean/Kaizen improvements focus on reducing process waste while keeping equipment reliability and resources constant, ultimately reducing costs without cutting resources. In many cases, activities are not well integrated under an official company program. These common elements were discussed earlier in Chapter 3. Likewise, most companies involved in power generation have established some form of a continuous improvement program. There are differences from company to company in the success and impact of continuous improvement programs.

Emphasis on Equipment Reliability Rather Than Reducing Waste

The prime focus of today’s fossil maintenance organization is plant reliability. Companies seek to improve reliability, even while cutting operations and maintenance budgets. Loss of experienced staff through retirements creates an additional challenge to meeting this prime goal. The U.S. power industry developed in a regulated business environment, with less incentive to recognize and reduce waste compared to the manufacturing sector. In the current, mostly deregulated environment, a focus on recognizing and reducing waste is now more important but is often overshadowed by a reactive “fire-fighting” management style that remains focused on reliability. Perhaps the largest difference, therefore, between Lean maintenance and traditional processes is Lean’s focus on reduction of waste in all processes that support maintenance.

Fire-Fighting Versus Proactive Style

Many power stations continue to place a high value on ability of the maintenance staff to correct component failures and manage emergent work. This is understandable, especially given the very high cost of plant unavailability when the failure involves critical equipment. In some cases, the unintended consequence of promoting the firefighting culture is to devalue the importance of preventive and proactive maintenance. In other words, who should be recognized more: the staff members who help prevent the failure or those who correct the failure? It is human nature to overlook the means taken to avoid the **potential** event and instead focus on the visible and significant effort associated with handling emergent work. A Lean organization that has established proper metrics will consistently value and reward the often unnoticeable effort taken to prevent equipment reliability issues.

Spares and Material Inventory

The traditional approach to spares and material inventory management in power generation can be described as “just-in-case.” This is an often overly conservative approach to stocking spares that leads to waste. This approach can evolve if there is no defined process to continually re-evaluate inventory needs based on failure probability, risk, and criticality. The “just-in-time” approach used by Lean companies attempts to maintain the right amount of spares and material at the right time, while also considering risk and establishing a minimum inventory.

Operations and Maintenance

Power generating plants have traditionally been organized with operations and maintenance in their own silos. Improved integration of operations and maintenance in the process industry can streamline time required for maintenance tasks (better system tag-out procedures). Also, better coordination between operations and maintenance in work scheduling can reduce total planned unavailability. In the manufacturing sector, the analog to improved coordination between operations and maintenance is TPM, in which production staff takes a greater responsibility for routine maintenance, thus freeing up the maintenance staff to develop a more proactive strategy. A Lean company emphasizes integration of operations and maintenance.

Managing Repeat Component Failures

A Lean organization will respond to a situation involving repeated failures of a specific component or a fleet of components by implementing a design modification or operational change to remove the failure mode. In the past, power generating companies have not placed sufficient emphasis on elimination of failure modes, and essentially accepted failures as unavoidable. One key principle of Lean maintenance states that the elimination of need for maintenance is the ultimate form of waste reduction.

Labor Versus Management

The traditional division of labor and management in power generating organizations represents a challenge to Lean implementation. In a Lean organization, workers are empowered and given incentives to 1) cross-train, 2) suggest and implement improved processes, 3) be flexible in scheduling of work execution, and 4) continually expand skills. Sustainable continuous improvement cannot take place without the active involvement of workers who are inherently aware of waste and inefficiency in their areas of responsibility. Labor-management relations must be improved if they are an impediment to worker empowerment.

Sustainable Continuous Improvement

Many continuous improvement programs implemented at power generation companies do not prove sustainable. The main reason is lack of executive support coupled with a short-term focus requiring immediate benefit. Increasingly frequent management changes have brought corresponding changes in emphasis on continuous improvement or cost-reduction initiatives. Workers, who have the most important role in Kaizen, become disenfranchised with the constantly changing initiatives. Companies with strong Lean or Kaizen programs emphasize continuity, even through management changes. Visible executive and upper management involvement, even if on an infrequent basis, demonstrates this commitment. The company incentive and reward process is also designed to signal a priority on continuous improvement. In summary, the ideal sustainable Lean and Kaizen program is one that is sufficiently embedded in the corporate culture and day-to-day processes that it is less likely to change with new management. New executive and upper management should carefully evaluate the existing programs to assess their effectiveness and value prior to rolling out their own brand. There are always areas for improvements, but it is often best to build on what is already in place. The most mature Lean organizations will have an established training program that educates all workers, regardless of job function, on Lean concepts.

Challenges and Strategies to Implementation in the Power Industry

Challenges

Many successful applications of Lean and Kaizen have been documented in the manufacturing sector. Process industries such as power generation do not have a traditional manufacturing focus, and as a result the maintenance staff has difficulty visualizing how to implement Lean. Lean concepts from manufacturing can largely extend to plant maintenance if one considers the entire work management process as the "factory" and a maintenance task completed on time and within budget as the "product." The efforts of Lean and Kaizen will improve the maintenance "product" quality by lowering measurable process outputs such as amount of rework, number of maintenance-induced failures, and so on. Identifying the customer and focusing on improving quality and lowering cost of the product are common elements to both maintenance and manufacturing.

It is still accepted in many power plants to consider operations and maintenance cost-reduction efforts as being imposed from the top down within the organization, rather than evolving from the bottom up. Top-down initiatives achieve cost savings by delaying maintenance, whereas a Lean approach seeks sustainable cost reductions through proactive maintenance. This mind-set is an additional challenge to implementation of Lean and Kaizen.

A significant staffing reduction over the past decade at fossil power plants represents another challenge to Lean and Kaizen initiative implementation. A staff that is busy with reactive maintenance will view any new initiative as intrusive. This is particularly problematic if the organization has a history of initiatives that were launched but not sustained. The employee must feel part of the process, being rewarded for improvements regularly, rather than much later as quarterly/annual financial goals are met. This helps workers at all levels gain confidence that daily efforts toward continuous improvement are noticed.

Management Strategies

The twelve "tips for starting" listed in the next section of this chapter contain useful tactical ideas for Lean and Kaizen implementation. At a higher level, the most important implementation strategy element is obtaining consistent executive management support over a multiyear timeframe. This support must include the following shifts in management thinking:

- Traditional command and control must be replaced by delegation and empowerment. Management's role is to develop the framework, policies, and incentive guidelines that together create an internal business environment conducive to Lean implementation. In short, if a manager cannot get employees to create productive ideas, the manager must be willing to reassess his or her management style.
- Traditional focus on results must be shifted after initial implementation to process. Management must have confidence that improved process then leads to improved results (but not always immediately). The focus can gradually shift to include a balance of process and results, but only after the process improvements have gained traction.

Initiative Overload

Management should avoid creating "initiative overload" while trying to embed Lean and Kaizen into the corporate culture. It is not critical what name is assigned to the initiative; however, organizations are strongly cautioned against frequent name changes because these are often viewed by employees as new initiatives (even if the goal, scope, approach, and so on remain largely the same). It is advisable to pick an initiative name that broadly fits the current and future goals of cost reduction, quality, and continuous improvement, and then expect to adjust the scope and priorities as needed in the future while remaining under this consistent broad title.

Cross-Functional Organization

Another strategic issue to consider is the organizational changes that need to accompany the launch of a Lean and/or Kaizen program. The least costly approach is to assign new responsibilities to the existing line organization; however, with this approach the Lean or Kaizen initiative may not receive adequate focus. An alternative option is to consider a cross-functional organizational arrangement. In this arrangement, the Lean and/or Kaizen implementation team is dedicated to the initiative but works closely with each of the existing line organizations as needed to achieve the initiative goals. Advantages of cross-functional organizations include 1) the ability to maintain focus on initiative goals, especially when many are inherently cross-cutting, and 2) acting as a catalyst for improved integration of line organizational elements when this is critical to achieving Lean or Kaizen goals. The disadvantages of a cross-functional arrangement are the additional staff and the operating cost. A second issue with cross-functional arrangements is the potential for conflicting priorities within the line organization. The potential for these problems can be minimized with clear direction and communication from upper management or the use of standing committees. It is noted that many of the early adopters of Lean, including Toyota, pioneered the successful use of cross-functional organizations. Toyota's approach involves cross-functional *quality control* and *cost-cutting* committees that operate over eight line organizations [12]. Cross-functional committees are managed at the director level, and the matrix of responsibilities is very clearly documented.

Metrics

The management strategy on metrics has three important concepts:

- An organization cannot improve a process that is not measured. Oftentimes, key process metrics are not captured within enterprise business information systems but could be with minimal effort.
- The number of metrics affecting any one employee must be kept to the minimum level necessary to monitor the continuous improvement initiative.
- Metrics should be made relevant to each employee's roles and responsibilities, rather than relying on high-level corporate performance indices for all staff.

Adherence to the above concepts is a challenge to many organizations and requires management resources. However, this adherence is an important element of any continuous improvement program, such as Kaizen.

Training

Staff training is perhaps the largest cost component associated with a Lean initiative. Training is essential to success, and needs to involve all organizational levels. Training is the opportunity to communicate and align all staff on the initiative goals, as well as gaining proficiency with the basic tools of continuous improvement (see Appendix A). Use of strategic companywide meetings can both be efficient and be a visual signal of the corporatewide scope. There are many outside organizations that can provide this training on a contract basis. It may be more cost-effective to consider a "train the trainer" approach, in which a limited number of staff (internal consultants) are trained extensively and are then given the task of providing specific training at various organizational levels. Training is an area that requires strong management commitment if the Lean or Kaizen initiative is to be successful. It is critical to train the entire organization, regardless of job function. This helps to break down intercompany/departmental cultural barriers.

Tips for Starting

There is no single success path for implementing initiatives such as Lean maintenance or Kaizen. The approach taken in each case must take into account the unique needs and issues of each organization. In reviewing the literature and case studies, a number of common ideas emerge. These are listed below.

- Lean maintenance is not a replacement for a plant reliability improvement or reliability-center maintenance initiative. These are mature strategies that require their own focus to be successful. Lean should be implemented as a parallel effort. If the plant is struggling with equipment reliability or backlog, consider first getting these issues resolved prior to launching a Lean initiative.
- With both Lean and Kaizen, start small and build on early, visible successes. Consider the initial projects to be more important for their effect on sustainability of the initiative than for the merits of their individual benefits. A company could start the Lean initiative, for example, with maintenance task efficiency improvements using spaghetti diagrams. Start the Kaizen initiative with an employee suggestion system.
- Do not try to improve any process that cannot be measured. Keep the list of metrics as small as possible and clearly tied to the process execution as well as the process results.
- Put a team in place within the organization that has been trained in continuous improvement tools and techniques of leading small-group activities prior to launching corporate initiatives.
- Visit peer companies that have launched Lean maintenance to obtain ideas and lessons learned.
- Obtain executive support with a clear understanding that the significant benefits may take 1–2 years rather than months to become evident and measurable.

- Try to focus on projects that take six months or less to complete, as multiyear projects may not be classified as continuous improvements, but rather step-change improvements.
- Foster "waste-awareness," "problem awareness," and a questioning attitude among employees. Emphasize that this is part of their job responsibilities, and can include observations and suggestions outside their area of responsibility. Train staff on the "five whys" of problem analysis to ensure that the true root cause is identified. Remove any cultural barriers or employee reluctance associated with self-reporting of human errors.
- Strengthen the post-job feedback communication by maintenance workers to planners. If the CMMS is used to collect this input, set up a prompt requiring some feedback on areas for improvement. Manage this feedback in a database that pushes this feedback to the planning and scheduling staff in a manner that can continually improve planning and scheduling.
- Create an employee suggestion program, but first ensure that all process elements and evaluation criteria are established beforehand. Initially, the suggestion award criteria should be set up to primarily encourage employee involvement, and then later to encourage high-value improvements. Commit to providing timely response to suggestions to avoid employee disenfranchisement.
- Ensure that there is effective communication, at all organizational levels, regarding the Lean or Kaizen program goals and expectations. Anticipate any employee concerns and be prepared with a response (example: will this result in staffing reductions?). Emphasize the need for improvement in order for the company to remain viable.
- Employees who lead continuous improvement projects should be good team builders and exhibit a hands-on approach to defining the problem. A good working relationship with all levels of the organization is required, with particular focus on the portions of the process that take place on the "factory" floor.

Managing Negative Perception of Lean Program Implementation

Some manufacturing companies that implement Lean production report initial negative perception on the part of the workers. Management teams are accustomed to skepticism on the part of workers in most initiatives; however, the typical perception of Lean has the potential to heighten concerns by staff. Questions such as "Will my position be cut?," "Will I be replaced by a contract worker?," "Won't this just add to my workload?," or "Will my wages be cut?" naturally occur in the context of a Lean initiative. These questions are understandable, especially in organizations with a tradition of top-down cost cutting, which usually results in a legitimate cause for concern by workers. The strategy for managing negative perception is to extensively communicate with employees, with a focus on the following:

- The fundamental difference between budget-cutting initiatives and Lean/Kaizen
- Business drivers critical to the organization's survival
- The expectation of increased employee responsibility, and thus empowerment

- The idea that Lean and Kaizen are not about eliminating positions, but instead about freeing up resources for the proactive work that is critical to improving metrics such as plant reliability
- The idea that cost savings that result from Lean/Kaizen projects should clearly reduce the pressure on management to eliminate resources (human or capital) for cost savings

It is important to remember that action without explanation is perceived as threatening. Also, the employees who will feel threatened are the same ones whose contributions are critical to success of Lean and Kaizen implementation. The Boeing Corporation put an extra focus on staff participation in an initiative they titled *Employee Involvement (*EI).

Achieving Sustainability

Lean projects and continuous improvement activities are only as effective as their sustainability. The importance of sustainability is such that it warrants special focus, not only following the project, but at inception of the project as well. It would be ill-advised, for example, to invest in an improvement activity if it has a clear impediment to sustainability that may be impossible to overcome. For many Lean projects, the key to sustainability is standardization. This is the goal of the *Action* step in PDCA and the *Control* step in DMAIC, as discussed previously.

The literature contains several references suggesting that Kaizen rapid improvement events often produce changes that are difficult to sustain. Critics claim that the accelerated process can fail to establish the correct root cause, and in addition can develop the wrong solution. The major attribute of Kaizen rapid improvement events is the constraint to complete the entire process in a matter of days, with some limited post-implementation follow-up. Proponents claim that by demonstrating rapid changes, the overall company continuous improvement effort benefits from the positive effect on staff involvement, enthusiasm, and “can-do” attitude. Perhaps the optimum strategy is to use Kaizen rapid improvement events, but to select projects carefully with awareness of the inherent weaknesses in the areas of root-cause identification and solution development. In carefully selected projects for which some initial understanding of the problem cause and potential solutions exist, rapid improvement events can effectively focus on the implementation phase.

Recent research on sustainability of Kaizen events has been published [21]. Event follow-up procedures were explored and analyzed empirically for effect on improvement sustainability from fourteen Kaizen events conducted in a manufacturing organization. The organization reportedly was effective in sustainability, claiming an 85% success rate. The list of follow-up mechanisms presented in Table 5-1 was cited by this company as effective (they are presented in approximate decreasing order relative to frequency of use).

Table 5-1
Project Follow-Up Practices That Contribute to Kaizen Event Sustainability

Practice	Description
Work area management support	Management supportive of the value of continuous improvement and the use of Kaizen methods
Avoiding blame	Avoiding blame or negativity when project results do not meet goals, or are different than expected
Audits	Regular audits conducted on changes implemented
Updating work methods	Training conducted following implementation, and updating of work process documentation and job descriptions
Employee involvement	Enabling employees to participate in improvement activities, and providing employees freedom to change work area
Follow-up infrastructure	Documenting and communicating Kaizen event follow-up action items, and allowing individual team members to work on action items
Employee encouragement	Recognizing Kaizen event participants; recognizing work-area staff not involved in Kaizen event but involved in sustainability; management encouraging use of general skills in the area of continuous improvement
Performance review	Regular review of performance data relative to Kaizen event; Kaizen team meeting as a group to review and adjust the implementation process; meetings with senior management and Kaizen coordinator to report on progress; informing senior management about follow-up and sustainability issues
Employee follow-up	Involving work area staff (not on Kaizen team) in follow-up and completion of event action items

Continuous Improvement Tools

Several reference documents are available, in the form of pocket guides that explain commonly used tools and techniques for continuous improvement projects. In one example book, 27 tools are described and divided into the following three categories [22]:

- Working with ideas (generating, grouping, deciding, implementing)
- Working with numbers (counting, measures)
- Working in teams (improvement roadmap, team roadmap)

Appendix A contains more detail on commonly used continuous improvement tools. It is recommended that companies starting a Lean or continuous improvement program distribute these pocket guides to staff, conduct training, and encourage their use.

6 EXAMPLE IMPLEMENTATIONS OF LEAN AND CONTINUOUS IMPROVEMENT IN THE POWER INDUSTRY

There are limited examples in the power industry of companies that have systematically applied Lean and continuous improvement strategies containing elements described in this report. These example implementations are valuable sources of ideas for companies currently considering their own initiatives. Successful practices that address implementation issues unique to today's power generation business drivers represent valuable findings from these case studies. Looking at multiple examples also reveals that there is no single correct implementation strategy.

Two example implementations of Lean and continuous improvement in power generation were investigated for this report. In interviews conducted with these two companies, topics included program initiation, executive support, organizational changes, worker involvement, and sustainability. The remainder of this chapter summarizes the findings from these interviews.

Overview

Company A

This company's Lean program is one element of a larger corporate initiative given the name Continuous Business Excellence (CBE). CBE has been in place since 2008, and its goal includes long-term sustainable improvements and savings in all business areas. Currently, the Power Operations Group has taken the lead in adopting CBE, but the program is planned to cover nuclear and transmission/distribution as well. Within the Power Operations Group, CBE encompasses outages, construction, and fuels. Currently the primary focus is on maintenance work execution and supporting functions.

Underneath CBE are continuous improvement initiatives such as a new employee suggestion program, and the Lean program. This company has a contract with an outside consultant who assisted in developing and launching the Lean program. To ensure consistency, Company A has maintained a working relationship with this consultant since rollout, but plans to reduce reliance on the consultant over the next 3–4 years.

Company B

This company began its Lean journey in 2004. The company does not maintain separate Lean and continuous improvement programs; instead it considers Lean to be its continuous improvement program. The Lean program integrates with both operations and maintenance in fossil and nuclear power generation. Company B used an outside business consultant to assist in development and rollout of its Lean program. In addition, strategic hiring of staff with Lean experience was used to create internal consultants. The Lean program has exceeded initiative status, and is now a core business function.

Organizational Factors and Program Scope

Company A

This company had the advantage of excellent executive support at the start of its CBE initiative, and this support continues today. The initiative was started by a senior vice-president who had experience in corporate continuous improvement and quality control programs at the General Electric Company. The CBE program has since received strong support from the CEO of Company A, who has appointed the senior vice-president to be accountable for the entire corporate program.

Company A uses a cross-functional organizational structure in which a limited number of dedicated CBE staff (called *leaders*) work with the line organizations. Lean events are conducted by the CBE leaders, but the event teams always include line organization staff at many levels. Currently, an effort is underway to develop “local champions” at the plant level who are trained in Lean processes but remain in the line organizations.

Coordination of CBE and Lean with other ongoing initiatives such as plant reliability is handled by a maintenance council. Plants continue to have an influence in how CBE and Lean are rolled out at the sites, and it is expected that not all plants will proceed at the same rate. Within the maintenance area, work execution is currently the prime focus. It is planned to eventually include supporting areas such as planning/scheduling and inventory in the scope of CBE and Lean. Company A is planning a CMMS upgrade in the future and is using this opportunity to incorporate Lean elements into the CMMS usage to further benefit planning, scheduling, and work execution.

Company B

At Company B, the Lean program was initiated in 2004 by the CEO, receiving the highest level of support. In 2006, a vice-president was appointed to oversee the Lean effort. This company uses dedicated Lean experts and site consultants to work with the line organization in a highly integrated manner to introduce continuous improvements through Lean.

Currently, the Lean program at Company B touches all aspects of both operations and maintenance. This includes work execution, planning/scheduling, maintenance basis, and engineering. With respect to the coordination with the plant reliability initiative at Company B, Lean concepts and tools are considered the essential elements of the plant reliability initiative. In summary, the reliability program is a key stakeholder utilizing Lean resources and methods.

Initiative Rollout

Company A

The early emphasis of CBE at Company A was employee involvement. This was considered important to achieving the needed culture change. Strategies included tracking employee participation in events, ensuring leadership involvement in events, and providing visible and continuous top-down support and communication. CBE was routinely discussed at leadership meetings, and consistency of approach was emphasized as it was introduced into other business sectors beyond the power operations group. The CBE program rollout publicity was at first low-key, but internal publicity gradually increased. There are now monthly newsletters, regular reports to the management team, and CBE articles in the company newsletters.

Company B

An effort was made at Company B to follow the 80-20 rule, meaning to focus on the 20% of potential projects that could supply 80% of the value. Further, Lean was launched with the understanding that the program itself would be continuously improved and to expect some course corrections. There was a significant level of internal publicity associated with rollout of Lean at Company B. The key message from inception was that Lean is “how we do business.” Lean is now regarded more as a corporate mind-set than an initiative in itself. Since 2004, Company B has organized four internal “Lean Expos” in which projects are showcased.

Employee Considerations

Company A

At Company A, training of CBE leaders was a key element of the initiative rollout. This was conducted by the business consultant. This company found it advantageous for its CBE leaders to obtain Six Sigma green and black belt training through local universities. The scope of training includes some key elements and tools commonly used in continuous improvement programs.

Initial employee reactions to CBE rollout involved some uncertainty, but not necessarily push-back. As with most companies, there had been past initiatives that were not sustained, and the concern was whether this would be yet another of these initiatives. Success factors for CBE include actively engaging workers in the events, seeking their feedback on the process, and showing visible and frequent leadership engagement.

Company B

Company B established "boot camps" for new employees that include training on basic Lean tools. Total training duration is five days.

Initial employee concern at Company B was addressed through unwavering management support, including at the CEO level. Additionally, some employees felt that Lean was just another initiative that would not be sustained. A clear and consistent message of support continues through funding and sustainability of Lean culture. In general, changing the culture of existing long-term employees is more challenging than with new staff who adapt easily to the new business processes. Successful projects, involvement of all levels of staff, and the "roll on" of site personnel into the Lean program along with the "boot camps" have helped mold employee culture. Lean concepts have become accepted as core business in many work areas.

Events and Projects

Company A

The CBE program at Company A involves a significant number of "Lean events." They are similar to Kaizen events as described previously in this report; however, Company A has chosen to use the term *Lean* as opposed to *Kaizen*. These events are the main feature of this company's Lean initiative under CBE. Like Kaizen events, Lean events at Company A involve a cross-section of staff levels, including staff members who are involved in the work execution. CBE leaders act as facilitators. At any given time in the Power Operations Group, there are 2–3 events ongoing. There are approximately 6–8 conducted during a typical month, totaling over 80 events in a 12-month period. Experience has shown that it is very important to control the scope of these Lean events. This involves discipline and the use of a "parking lot" for new issues discovered during the problem resolution/identification process.

Company B

Company B does not focus heavily on "events." The term *Kaizen* is rarely used. The focus instead is to partner with internal customers to find problems and then apply the right Lean solution process. Options for processes could include a quick "event" (called *one-hour problem solving*) or a longer-term effort if warranted. There is no required format for Kaizen-like "events." Instead, the right tool or process is applied in each case, depending on the nature of the improvement issue.

Challenges and Successes

Company A

Company A described several challenges. The first is getting all parts of the organization on the same page with respect to how the CBE program is conducted. Another challenge is in getting the improvement results obtained at one plant effectively communicated to other plants so they can benefit as well. A third challenge is defining how to measure success quantitatively. Lastly, there are challenges in managing expectations regarding the time lag between launching the initiative and seeing results in terms of savings.

Successes noted by Company A include the high level of support from employees. This employee support and engagement was noted by the consultant who is helping implement CBE and Lean as being above average relative to implementations at other companies. The high level of executive buy-in was also noted as a success, exemplified by the decision to place senior staff in the CBE leader role.

Company B

A significant challenge cited by Company B was countering the tendency of employees at all levels to view Lean as “extra work” as opposed to the “right work.” Management has maintained steadfast support for the use of Lean methods to manage problem solving and process improvement opportunities.

Company B points to the continued existence of the Lean program and associated Lean mind-set after nearly five years as a success in itself. Additionally, the effective integration of Lean with the ongoing plant reliability initiative was cited as another success. Company B reports being pleased with the extent to which techniques developed for continual improvement in the manufacturing sector were able to be applied to power generation. Company B sees improvement of reliability processes as eliminating waste from the business; hence the strong alignment with Lean concepts.

Company B strongly supports the philosophy of partnering with the customer and not having competing initiatives/programs. Lean is a mind-set to help the customer, not an initiative that might compete for attention.

Summary Comments

Company A

Assigning meaningful metrics to track CBE and Lean remains a challenging task. Company A is still working on the question of measuring productivity. There is, however, a strong emphasis on employee involvement and culture change at this early stage of implementation. There is a growing focus on linking the CBE and Lean events with the long-term workforce strategy at

Company A. This linkage recognizes that Lean initiatives are critical to meeting the long-term goals for reduced staffing at Company A. Waste must be reduced to achieve the necessary productivity improvements. With this in mind, Company A is now targeting Lean events at those specific areas where loss of staffing through attrition is expected in the future.

After just over one year, Company A reports some cost savings as a result of the CBE initiative. Prior to CBE, Company A estimated an average split of 85-15% between non-value-added and value-added work. In areas where Lean has been applied, there is an estimated 70–75% reduction in waste. Savings are difficult to assess quantitatively, as many involve defining avoided cost.

Company B

Company B has not sought to establish Lean metrics. There are, however, common business metrics and performance indicators that Lean is used to help achieve. Maintenance costs are not tracked separately, but in combination with overall operations and maintenance. Estimates of savings also include other elements of the OS program, such as the reliability improvement initiative.

Estimated cost savings associated with the Lean efforts are reportedly in the hundreds of millions over the life of their Lean journey. They are mostly made up of increased reliability and lower operations and maintenance costs. In summary, Lean is closely aligned with and instrumental in achieving the key corporate goals of improving reliability at lower operating costs.

7 CONCLUSIONS AND RECOMMENDATIONS

This report has provided a description of Lean maintenance and Kaizen continuous improvement from the perspective of fossil power generation. Companies considering introduction of new initiatives to lower maintenance costs, improve work quality, and improve the balance of preventive to corrective maintenance will find this information to be a useful starting point. The following paragraphs summarize the key conclusions and recommendations derived from this research.

Conclusions

- Lean and Kaizen principles can be adapted from their well-established roots in the manufacturing sector and applied to maintenance of power generating stations. Early adopters have shown success by embedding key elements of Lean and Kaizen into broader business improvement initiatives that are corporatewide.
- Maintenance budget-cutting directives that are not supported by a formal program involving Lean and continuous improvement will not be sustainable and will contribute to an increasingly reactive maintenance style.
- Lean and Kaizen challenge the traditional command and control style of management. Success is derived from empowering workers to identify and remove all forms of waste. Management's new role is to support culture change by providing continued program support, process facilitation, training resources, and sustained executive endorsement.
- Lean and Kaizen do not conflict with existing equipment reliability initiatives. They share a common philosophy that waste is reduced when an organization moves toward more proactive and less reactive maintenance. Organizations adopting Lean should continue to emphasize development of their maintenance basis and improvement of their corrective action program. There is increased focus in Lean initiatives on removal of failure modes through design improvements.
- Investment in a Lean initiative primarily includes the costs of consultants, additional staff training, and hiring of dedicated staff with specific training in Lean and continuous improvement tools. The break-even point for this investment will not occur in the first year. Management must have the patience to stay the course and allow the necessary culture change to take place over the first 2–3 years. Significant gains will then be realized once the Lean and continuous improvement program is mature and part of the way the company does business.

- Early adopters of Lean and Kaizen techniques in the power industry have linked their initiatives to the strategic issue of workforce planning. Productivity improvements will be an important element of the overall strategy required to meet future needs for reduced staffing levels.
- Employee training is a key element of Lean and Kaizen. First, program success is dependent on all employees acquiring a good understanding of basic Lean principles. Second, a limited number of in-house experts dedicated to Lean and Kaizen implementation will require more in-depth training. Third, cross-training of maintenance staff in multiple skill areas is a key element of Lean maintenance and should be encouraged.

Recommendations

- Start the Lean initiative with small-scale projects such as those in the area of work execution. Focus initially on employee engagement and culture change. Do not expect or demand an immediate return on investment.
- Promote "waste awareness" and "problem awareness" by employees. Back this up by instituting a formal employee suggestion program that includes incentives for participation and executive involvement in the award process.
- Share successes as the Lean program begins to identify and reduce waste. Include recognition by management, regular reporting at executive briefings, and publicity in corporate newsletters.
- Incorporate Lean principles into any future initiatives relating to improved planning and scheduling and/or CMMS upgrades. After achieving initial success in the area of work execution, maintenance planning and scheduling should be the next focus. Planning and scheduling is an existing area of weakness in fossil power generation. Lean principles offer the potential for significant gains if applied in an integrated manner that includes enhancements to the CMMS tool.
- The key organizational change recommended in Lean and Kaizen implementation is the creation of dedicated positions for staff with expertise needed to start and sustain the program. This staff should operate in a cross-functional arrangement with the line organization, but maintain tight integration with their day-to-day activities. The cross-functional relationship can be described as partnering to achieve the corporate goals.
- Avoid "initiative overload" that leads to employee disenfranchisement. If there is an existing corporate initiative that is already focused on continuous improvement, consider expanding or refining this program to include Lean and Kaizen rather than abandoning it for a new program with a new name. Seek endorsement for the new initiative at the highest corporate level, to avoid the potential for initiatives to be tied to specific executives. It is noted that early adopters have instituted a position at the vice-president level specifically to manage, direct, and sustain the corporate Lean and continuous improvement program.

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A
TOOLS FOR CONTINUOUS IMPROVEMENT PROJECTS

This appendix contains a synopsis of commonly used tools for use in continuous improvement projects [22]. Their applications include eliciting ideas, solution implementation, process data analysis, and working with teams. Tables A-1 through A-3 list the tool name and a brief description. Readers are encouraged to purchase books for more detailed information on how to apply the tools.

Table A-1
Continuous Improvement Tools Used to Analyze Data

Tool Name	Description
Check sheet	Tabular listing of historical process data presented in a manner that makes patterns and trends identifiable; helps promote fact-based problem analysis
Control charts	Plots of process data shown against control limits that help people understand process variation
Histogram	Bar charts showing how distribution of process values falls within various data ranges about the mean value
Pareto chart	Bar chart used to show the cumulative relationship between two variables arranged in decreasing order of effect
Process capability	Distribution plot of observed process variation shown against the customer-required limits on variation
Run	Chart of observed process data over a specific time duration used to look for trends or patterns
Scatter plot	Plot used to show changes observed between two different sets of data to assess a potential relationship between the variables

Table A-2
Continuous Improvement Tools Used to Generate Ideas

Tool Name	Description
Activity network diagram	Essentially a process flow diagram, with focus on task sequence, timing, and criticality; useful as a starting point for process improvement; usually arranged in time sequence with parallel processes stacked
Affinity	Method of breaking down analysis of a single large problem or potential solutions into a number of natural subcategories
Brainstorming	Process of eliciting ideas that fosters contributions by removing constraints such as criticism and judgment by others
Cause-effect and fishbone diagram	Analysis tool used to systematically diagram, in increasing detail, all the possible root causes of a problem, failure, or condition
Flowchart	Process diagram that depicts actual flow and sequence of process elements; it is not task-specific and does not include timing like activity network diagrams, but can highlight and diagnose problems
Force field	Simple listing of both positive and negative attributes associated with a decision or solution; helps develop success strategy
Gantt chart	Project scheduling tool that shows task interrelationships and timing on a common time scale on horizontal axis
Interrelationship diagram	Cause-effect analysis tool that diagrams relationships among key drivers
Nominal group technique and multivoting	Process of group ranking of issue importance or potential solutions in which each group member individually force-ranks the list, and then these are summed to achieve the group consensus
Prioritization matrices	Decision process that involves two steps: first, development of a list of criteria and importance ranking, and second, the assessment of the various options against the list of weighted criteria
Process decision program chart	Tool used in implementation planning that analyzes potential problems so that effective countermeasures can be developed
Radar	Polar plot used in organizational performance assessments that shows the strength rating of each process category
Tree	Diagram used to map tasks required for implementation in increasing levels of detail

Table A-3
Continuous Improvement Tools Used in Working with Teams

Tool Name	Description
Storyboarding	The integration of all elements of the Plan-Do-Check-Act cycle into a single package (document, presentation, and so on) that describes all information using the common continuous improvement tools
Starting teams	The process of developing effective teams for problem identification and solution that uses specific predefined expectations around team behavior, purpose, and metrics
Maintaining teams	A set of strategies used to keep team performance at high levels; can involve use of facilitators, conflict management, recognition of agreement, and encouragement of fair participation
Ending teams and projects	Stresses the importance of proper project close-out and completion of team effort; key element of this tool is to revisit the previously defined list of goals and assess success of completion; other elements include a discussion of ideas for improving future team efforts and official recognition of the team and accomplishments
Effective meetings	A set of guidelines for conducting meetings that increase chances of project success; includes specific to-dos in five categories: preparation, beginning, etiquette, ending, and next steps

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