CHAPTER 59

Maintenance Management and Control

Ralph W. "Pete" Peters
Tompkins Associates, Inc.

Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.
Edited by Gavriel Salvendy

1. OBJECTIVES AND CONTENT OF THE CHAPTER

The key objectives of this chapter are to provide a firm understanding of the importance of the physical asset management and maintenance process, to review the key requirement for maintenance success, and to review some of today's best maintenance practices. This chapter includes how the results of continuous maintenance improvement can be measured, the methods to use for measurement, and how the results and ROI can be validated. The IE principles and practices that can support maintenance process improvement will be highlighted. Current strategies and trends in computerized maintenance management systems (CMMS) and enterprise asset management (EAM) systems technology to support physical asset management will also be covered.

An important look at maintenance management for the new millennium and the emerging role of a chief maintenance officer (CMO) and new technologies, will be presented. The chapter will help the new and experienced IE, the engineering manager, the operations manager, as well as the CEO, to understand better their own maintenance operation. It will outline specific methodologies to help improve mission-essential maintenance operations. It will also help all to view the maintenance process as a profit center and key contributor to total operations success

2. INTRODUCTION

2.1. The Maintenance Process: A Key Element of Plant and Facilities Engineering

The maintenance process is one of the most important elements within the overall scope of plant and facilities engineering function. It is a broad-based technology area for the industrial, commercial, institutional, and business communities. As covered within a previous chapter, the broad scope of plant and facilities engineering is continuously changing and growing in importance as a key contributor to the success of a total operation. Elements within it, such as maintenance, energy management and regulatory compliance, have all evolved to new levels of importance for the total operation.

Plant and facilities engineering is a multidisciplinary field of engineering concerned with the physical infrastructure of industrial, commercial, institutional, healthcare, and business facilities. It embraces the design, installation, operation, maintenance, modification, construction, modernization, and protection of physical facilities and equipment used to produce a product or provide a service (Dunn 1997). It includes, but is not necessarily limited to, the following areas of physical asset management:

- Design of facilities and systems
- Construction of facilities and systems
- Installation of facilities and systems
- Start-up of systems
- Operation of systems
- Maintenance of facilities and systems
- Retrofit of facilities and systems
- Environmental controls
- Safety and health
- Security and fire protection
- Production processes and equipment (in industry)
- Regulatory compliance (local, state, and federal)
- Energy management and building control
- Administration, supervision, organization, planning
- Other support functions as required by the enterprise owner or manager

2.2. The Scope of Maintenance and Physical Asset Management

Maintenance is about the care of physical assets: production equipment, plant facilities, office buildings, hospitals, trucks, cars, forklifts, and computers. It is very important to understand fully the scope of the maintenance management process because maintenance is much more than just the care of physical assets used in a production operation. The maintenance management and control functions, operations, and activities that may be required within a maintenance operation are very broad. Likewise, the application of the actual maintenance process—the hands-on, wrench time of doing the work—applies to many different types of operations. The maintenance processes in discrete manufacturing, continuous processing equipment, facility and building systems, property management, and fleet operations maintenance all have uniquely different challenges and types of assets. There are other unique applications of the maintenance process in areas such as health care, research facilities, and pharmaceutical operations. Physical assets, whether production equipment, a health care facility, or the assets that make up a trucking fleet or an airline, all have maintenance requirements to perform their primary function at a reasonable cost over their expected economical life. A maintenance operation may include, but also is not limited to, the following (Dunn 1997):

- Installation and maintenance of all utilities systems and components for electricity, water, steam, gas, oil, compressed air, communications, data networks, etc.
- Provision of services for construction, maintenance, and repair of buildings and structures
- Provision of services for alterations and modifications of buildings, structures and manufacturing type assets
- Installation, operation, and maintenance of all heating, ventilating, air conditioning, and refrigeration systems and components
- Installation, relocation, modification, maintenance, and repair of other equipment and systems, as determined by coordination with tenants
- Testing of electrical systems and backup utilities
- Maintenance of appropriate equipment records and histories
- Management of maintenance planning, scheduling, and work execution
- Implementation of preventive and predictive maintenance strategies and practices
- Management of spare parts and materials storerooms and inventories
- Coordination of federal, state, local, and insurance licensing inspections and compliance
- Management of special projects as required
- Provision of housekeeping, janitorial, and custodial services
- Preparation and control of budgets
- Control of maintenance contracts
- Maintenance of reports from inspectors and insurance carriers
- Work management: processing of work requests; preparation of project cost estimates; planning and scheduling of work; provision of required parts, materials, and equipment; and maintenance of all related labor and equipment records

- MRO materials management: management of maintenance repair operations (MRO) parts, materials, and special equipment for which the maintenance operation is held accountable
- Preparation of appropriate reports, statistics, and recommendations on activities
- Planning, coordination, and scheduling of predictive, preventive maintenance and other asset reliability programs.
- Maintenance of appropriate records pertaining to labor, MRO items, and asset history
- Ensuring compliance with all applicable life safety, building codes, and regulatory items
- Ensuring maintenance of all fire protection and security systems
- Operation and maintenance of all utilities systems and equipment
- Operation and maintenance of backup utility systems.
- Maintenance of environmental monitoring systems
- Organization, administration, and supervision of safety activities in accordance with all federal, state, and local requirements
- Initiation of safety-related work requests
- Compliance with all safety procedures.

2.3. Effective Maintenance Management Requires Industrial Engineering Principles

The maintenance process should be viewed as an internal business opportunity. Since Tompkins Associates introduced the concept of ‘‘maintenance as a profit center’’ (Tompkins 1999), this modern view of maintenance has emerged in literature and in practice. Business process continuous improvement (BPCI) and most of the traditional IE principles have application to maintenance operations. When we consider that there are countless contract service providers for all types of maintenance services competing to replace or supplement internal maintenance departments, it becomes apparent that internal maintenance with the help of IE techniques can be improved.

2.4. Maintenance as an Internal Business Opportunity and Profit Center

Traditional thinking about maintenance has changed dramatically. Maintenance was once considered a necessary evil, but it is now being viewed as a key contributor to profit in a manufacturing or service providing operation. For example, what if the net profit ratio of an operation is 4%? What does a 4% net profit ratio mean in terms of the amount of equivalent sales needed to generate profits? A net profit ratio of 4% requires $25 of equivalent sales for each $1 of net profit generated. Therefore, when we view maintenance in these terms, we can readily see that a small savings in maintenance can mean a great deal to the bottom line and equivalent sales. From Table 1, maintenance as a profit center is illustrated, showing that only a $40,000 savings is required to translate into the equivalent of $1,000,000 in sales. There are many more areas, such as the value of increased asset uptime, increased net capacity and just-in-time throughput, increased product quality and increased customer service, that all contribute to the bottom line and subsequently to profit (Peters 1994a).

3. THE 25 REQUIREMENTS FOR EFFECTIVE MAINTENANCE MANAGEMENT

When an organization prepares for business process continuous improvement and the application of IE technology and techniques, it should include the evaluation and improvement of the current maintenance processes. A number of key principles and practices that are fundamental to the BPCI journey.

TABLE 1 Maintenance as a Profit Center

Maintenance Savings to Impact Net Profit	Equivalent Sales Required for Generating Net Profit
$1	$25
$1,000	$25,000
$10,000	$250,000
$20,000	$500,000
$30,000	$750,000
$40,000	$1,000,000
$80,000	$2,000,000
$120,000	$3,000,000
$200,000	$5,000,000

They provide the foundation upon which to develop improvements. It is important to understand the requirements for maintenance success because they in turn provide the foundation for today's best maintenance practices.

These fundamental principles become the cornerstone for achieving, maintaining, and continually improving the maintenance process. Organizations that are establishing best practices for world-class maintenance will be actively pursuing the following 25 requirements for effective maintenance management (Peters 1994b).

1. *Priority:* The process of performing maintenance and managing physical assets will be recognized as a top priority within successful organizations.
   - Maintenance will be viewed as a top-priority operation, not as a necessary evil. It will be viewed as another area that contributes directly to the bottom line when a strategy for continuous maintenance improvement is adopted. The future capable leader will have identified top priority areas for improvement, based upon a total benchmark evaluation of the maintenance operation, and investments will be made to implement best practices.
2. *Leadership and understanding:* Maintenance leaders must understand the challenges of maintenance and provide effective maintenance leadership with a vision of continuous maintenance improvement.
   - Maintenance leadership must continually develop the skills, abilities and attitudes to lead maintenance into the future. Maintenance leaders must completely understand the 25 requirements for effective maintenance management and develop priorities for action. Maintenance leaders must create understanding within the organization about maintenance and develop a vision of continuous maintenance improvement shared throughout the organization.
3. *PRIDE in Maintenance*. Maintenance operations in the future capable company will experience fundamental improvements in work ethic, attitude, values, job performance, and customer service to achieve real pride in maintenance excellence.
   - Tangible savings and improvements will occur as a result of continuous maintenance improvement. The successful maintenance operations will experience other fundamental improvements that develop more PRIDE: People Really Interested in Developing Excellence in Maintenance. Improvements in work ethic, performance, attitudes, teamwork, and concerns for customer service will occur. Successful maintenance operations will have leadership that instills PRIDE in maintenance with a vision of maintenance excellence that creates inspiration, cooperation, and commitment throughout the organization.
4. *Maintenance profession:* The profession of maintenance will gain greater importance as a key profession for success within all types of organizations as the role of chief maintenance officer becomes well established.
   - Maintenance leaders will be recognized as critical resources that are absolutely necessary for the success of the total operation. The chief maintenance officer (CMO) within large multisite operations will create and promote standard best practices. The complexity and importance of the maintenance and physical asset management will continue to grow. New technologies and added responsibilities will require a higher level of technical knowledge and skills.
5. *Maintenance personnel:* A significant upgrade in the level of personnel involved with maintenance will take place to keep pace with new technologies and responsibilities.
   - Maintenance operations within future capable companies will achieve a significant upgrade in the skill level of maintenance crafts people in order to keep pace with new technology and responsibilities. Successful maintenance operations will continually upgrade the skill level of crafts people through more effective recruiting with higher standards and through more effective craft training programs. Pay increases will be more directly linked to performance and demonstrated competency levels in required craft skills.
6. *Craft skills development:* Successful maintenance operations will continually assess craft training needs and provide effective skills development through modern technical learning systems.
   - A complete assessment of craft training needs will be accomplished to identify priority areas for skill development that is competency based, to provide demonstrated technical capabilities for each craft skill. The successful maintenance operations will develop an ongoing program for craft skill development. Continuous maintenance education, based on modern technical learning systems, will be viewed as a sound investment and an important part of continuous maintenance improvement.

7. *Adaptability and versatility:* The maintenance crafts person will become more versatile and adaptable by gaining value with new technical capabilities and multi-craft skills.
   - The development of more crafts people with multiskills will occur to provide greater versatility, adaptability, and capability from the existing workforce. Multiskilled personnel will have added value and will be compensated according to well-defined policies. Craftspeople will become more adaptable, versatile, and valuable as a result of ongoing programs for craft skill development.
8. *Teamwork:* Maintenance will be team players and maintain a leadership-driven, team-based approach to continuous maintenance improvement.
   - Maintenance leadership will accept its role as a top priority operation and will set the example as team players within the organization. The strategy for continuous maintenance improvement will be a leadership-driven, team-based approach that captures the knowledge, skills, and ideas of the entire maintenance workforce. Cross-functional teams with representatives from maintenance, operations, engineering, etc. will be formally chartered to address improvements in equipment effectiveness, reliability, and maintainability.
9. *Maintenance and operations:* Maintenance and operations will become integrated, and function as a supportive team through improved planning, scheduling, and cooperative team-based improvement efforts. Operations will be viewed as an important internal customer.
   - Improved planning and scheduling of maintenance work will provide greater coordination, support, and service to manufacturing type operations. Maintenance and operations of all types will recognize the benefits of working together as a supportive team to reduce unplanned breakdowns, increase equipment effectiveness, and reduce overall maintenance costs. Operations will be viewed as an important internal customer. Operations will gain greater understanding of the 25 requirements of effective maintenance management and accept its important partnership role in supporting maintenance excellence.
10. *Pride in ownership:* Equipment operators and maintenance will develop a partnership for maintenance service and prevention and take greater pride in ownership through operator-based maintenance.
    - Equipment operators will assume greater responsibilities for cleaning, lubricating, inspecting, monitoring, and making minor repairs to equipment. Maintenance will provide training support to operators to achieve this transfer of responsibility and to help operators with early detection and prevention of maintenance problems. Operators will develop greater pride in ownership of their equipment with their expanded responsibilities.
11. *Equipment effectiveness:* A leadership-driven, team-based approach will be used by maintenance and operations to evaluate totally, and subsequently improve all factors related to equipment effectiveness. The goal is maximum availability of the asset for performing its primary function.
    - Continuous improvement of equipment effectiveness will address major losses due to equipment breakdowns, set-up/adjustments, idling/minor stoppages, reduced speeds, process defects, and reduced yields. Equipment improvement teams will be established to meet on a regular basis to identify and resolve equipment-related problems. They will work constructively as cross-functional teams to exchange and implement ideas for improving equipment effectiveness. They will use techniques such as continuous reliability improvement (CRI) and reliability-centered maintenance (RCM). Chronic problems will be analyzed using tools such as statistical process control, graphs, process charts, and cause-and-effect analysis. Maintenance operations within successful future capable companies will use a total team effort by operators, engineering, operations staff, and maintenance to identify and resolve root causes of equipment problems.
12. *Maintenance and engineering:* Maintenance and engineering will work closely during systems specification, installation, startup and operation to provide maintenance with the technical depth required to maintain all assets and systems.
    - Engineering will provide technical resources and support to ensure maintenance has the total technical capability to maintain all equipment and systems. Engineering will play a key support role with maintenance in improving the effectiveness of existing equipment. Maintenance and engineering will work closely in developing specifications for new equipment. During installation and start-up, maintenance and engineering will also work closely to ensure operating specifications are achieved.
13. *Reliability and maintainability:* Machines and systems will be specified, designed, retrofitted, and installed with greater reliability and ease of maintainability.
    - Equipment design will focus on maintainability and reliability and not primarily on performance. Design for maintainability will become an accepted philosophy that fully rec-

ognizes the high cost of maintenance in the life-cycle cost of equipment. The causes for high life-cycle costs will be reduced through the application of good maintainability and reliability principles during design. Design will be focused on life-cycle reliability by identifying potential problems before they are designed into the equipment. Equipment design will include a higher level of internal diagnostic capabilities and provide for greater use of expert systems for troubleshooting. Maintenance will work closely with equipment designers to share information about problems with existing equipment and to provide possible maintenance-prevention solutions for new equipment.

14. *Modularity:* Physical assets and systems will be modularly designed so that failures can be easily identified and repaired quickly.

- Overall maintainability will be further improved through modular design of physical assets and systems. Highest-failure parts and components should be the most accessible, easily identified and designed for easy repair. Components should be designed for easy disassembly and assembly using the lowest skill level possible. Modularity of design will be an important part of the design for maintainability philosophy.

15. *Obsolescence:* The life-cycle costs of physical assets and systems will be closely monitored, evaluated, and managed to reduce total costs.

- Successful maintenance operations will achieve significant reductions in total life-cycle costs through an effective design process prior to purchase and installation. During the equipment's operating life, systems will be developed to monitor equipment costs continually. Information to identify trends will be available to highlight equipment with high maintenance costs. Action can be taken to address critical high-cost areas in order to reduce future costs. A complete equipment history of repair costs will assist maintenance in making decisions on equipment replacement, equipment overhaul/retrofit, and overall equipment condition.

16. *Redundancy:* Critical assets and systems will have backups provided so that if something fails, a secondary asset or system will take over.

- Critical operations will be identified where backup equipment or systems are economically justified. Redundancy of critical equipment and systems will ensure that continuous operation is achieved when something fails. Maintenance will focus attention on critical operations in order to increase equipment effectiveness, reduce unplanned breakdown and increase the effectiveness of preventive/predictive maintenance.

17. *Uncertainty:* Uncertainty will be minimized through effective preventive/predictive maintenance programs and through continuous application of modern predictive maintenance technology and expert systems.

- Effective preventive/predictive maintenance programs will be used to anticipate and predict maintenance problems in order to eliminate the uncertainty of expected breakdowns and high repair costs. Predictive maintenance will not be limited solely to the detection of failure but will proactively identify and eliminate the root causes of chronic problems. Preventive/predictive maintenance programs will be adequately staffed to cover all major assets within the operation. Maintenance will maintain current technical knowledge and experience for applying a combination of predictive technologies that is best suited for the specific application or system.

18. *Computerized maintenance management and enterprise asset management:* Systems that support the total maintenance operation will improve the quality of maintenance and physical asset management and be integrated with the overall business system of the organization.

- Computerized maintenance management systems (CMMS) will provide greater levels of manageability to maintenance operations. CMMS will cover the total scope of the maintenance operation, providing the means to improve the overall quality of maintenance management. Enterprise asset management (EAM) will provide a broader scope of integrated software to manage physical assets, human resources, and parts inventory in an integrated system for maintenance management, maintenance, procurement, inventory management, human resources, work management, asset performance, and process monitoring. Vast amounts of data associated with maintenance tasks will come under computer control and be available as key information for planning, scheduling, backlog control, equipment history, parts availability, inventory control, performance measurement, downtime analysis, etc.

19. *Maintenance information system:* The maintenance information system and database will encompass the total maintenance function and provide real-time information to improve maintenance management.

- The implementation of CMMS and EAM provides the opportunity for improved maintenance information systems. With CMMS and EAM, the maintenance information system can be developed and tailored to support maintenance as a true business operation. Information to support planning, scheduling, equipment history, preventive/predictive maintenance, storeroom management, etc. can be established to improve decision making and overall maintenance management. Improved maintenance information will allow for an open information flow to exist between maintenance, operations and all departments within the organization. Maintenance will become an important part of the overall information flow and be kept well informed about current and future operational plans.

20. *Maintenance storeroom:* The maintenance storeroom will be orderly, space efficient, labor efficient, and responsive and provide the effective cornerstone for maintenance excellence.

- The maintenance storeroom for maintenance repair operations (MRO) items will be recognized as an integral part of a successful maintenance operation. Initial storeroom design or modernization will include effective planning for space, equipment, and personnel needs while providing a layout that ensures efficient inventory control and includes maximum loss control measures. It will be professionally managed and maintained in a clean, orderly, and efficient manner. The trend will be towards larger centralized storerooms with responsive delivery systems to eliminate crafts people waiting or traveling to get parts. An effective maintenance storeroom catalog will be maintained to provide a permanent cross-reference of all storeroom items and serve as a tool for identifying and locating items.

21. *Maintenance inventory:* The proper quantity of the proper spare parts will be on hand due to progressive MRO procurement and internal storeroom controls, all to support maintenance excellence.

- The implementation of CMMS and EAM will include an inventory system that totally supports the requirements of maintenance and the storeroom. Maintenance inventory will be managed to ensure that the right part is available at the right time without excessive inventory levels. Information from all available sources will be used to determine optimum stock levels. A continuous review of stock levels will be made to eliminate excess inventory and obsolete parts. Inventory reductions will be achieved through more partnerships with suppliers and vendors that establish joint commitments to purchase based on responsive service and fast delivery. Positions within MRO material management and procurement will increase in their importance and level of technical knowledge to perform effectively

22. *Working environment:* Successful maintenance operations will be safe, clean, and orderly because good housekeeping is an indicator of maintenance excellence.

- Maintenance leaders will provide a working environment where safety is a top priority, which in turn allows maintenance to set the example throughout the organization. Maintenance shop and work areas will be clean and orderly. Good housekeeping practices in maintenance will provide the basic foundation for safety awareness. Maintenance will provide support throughout the organization to ensure that all work areas are safe, clean, and orderly.

23. *Environment, health, and safety:* Maintenance must provide proactive leadership and support to the organization's regulatory compliance actions.

- Maintenance leaders must maintain the technical knowledge and experience to support compliance with all state and federal regulations under OSHA, USEPA (Clean Air Act), the U.S. Department of Transportation, and the Americans with Disabilities Act. The issue of indoor air quality must receive constant attention to eliminate potential problems. Maintenance must work closely with other staff groups in the organization, such as quality and safety, to provide a totally integrated and mutually supportive approach to regulatory compliance.

24. *Maintenance performance and service:* Broad based measures of maintenance performance and customer service will provide a continuous evaluation of the value of maintenance.

- CMMS and EAM will allow for a broad range of measurement for maintenance performance and service. Investment in maintenance best practices will require valid return on investment. Projected savings will be established and results will be validated. Measures will be developed in areas such as labor performance/utilization, compliance to planned repair and preventive/predictive maintenance schedules, current backlog levels, emergency repair hours, storeroom performance, asset uptime and availability, etc. Leaders of successful maintenance operations will continuously evaluate performance and service in order to manage maintenance as a business. They will adopt the philosophy of continuous maintenance improvement and have a method to measure progress.

25. *Maintenance planning and scheduling:* Maintenance customer service and the utilization of available craft time will improve through more effective planning and scheduling systems.

- The development of more effective planning and scheduling systems will be a top priority for the future capable maintenance operation. As reductions in breakdown repairs occur through more effective preventive/predictive maintenance, the opportunity to increase planned maintenance work will result. Maintenance and operations work closely to schedule repairs at the most convenient time. Maintenance will become more customer oriented and focus on achieving greater customer service by completing scheduled repairs on time. The utilization of craft time will increase as levels of planned work increases and as the uncertainties and inefficiencies associated with breakdown repairs are reduced.

World-class maintenance starts with a total commitment to a strategy of continuous maintenance improvement with maintenance as a top priority within the organization. It is the realization that maintenance is a key contributor to profit. It is the realization that maintenance best practice, plus people assets, plus MRO assets and information technology asset, all combine for the success and improvement of the total maintenance operation. It is the application of business process improvement techniques such as industrial engineering that generates the results and enhances the improvement process. Section 7, A Review of Other Selected Maintenance Best Practices, will give the reader greater understanding of maintenance management technology, principles and practices.

4. BENCHMARKING THE TOTAL MAINTENANCE OPERATION

Benchmarking can be defined as the continuous process of measuring our products, services, and practices against our toughest competition. Often our toughest competitor is our own organization, which does not understand the true value of maintenance, the high cost of deferred maintenance, or the dangers of gambling with a run-to-failure strategy of continuous reactive maintenance. It is important to realize that there are two basic forms of benchmarking, internal and external, and to understand why both are essential during the journey to maintenance excellence.

4.1. Internal vs. External Benchmarking

External benchmarking within maintenance allows for taking the global view of identifying best practices and determining how they can be transferred and applied successfully within your own unique maintenance operation. External benchmarking provides for developing broad-based comparisons with other maintenance operations in terms of best practices, standard operating procedures, and industry-wide statistical data. *The Scoreboard for Maintenance Excellence*, reviewed within this chapter, is today's most comprehensive guide for external benchmarking. It covers 18 best practice categories and 200 evaluation criteria (Peters 1994).

Think global—start local: Internal benchmarking starts locally within the maintenance operation at the shop floor. It focuses on measuring the successful execution of best practices such as CMMS, preventive and predictive maintenance, maintenance planning and scheduling, and effective maintenance storeroom operations (Peters 1997).

Internal benchmarking is about developing specific internal metrics or performance indicators. It is about determining progress from an internal baseline or starting point and measuring the progress toward a performance goal specific to your type of maintenance operation. For example, an internal benchmark could be the current level of maintenance-related downtime hours for a critical asset or the maintenance cost per unit of output, such as cost per ton, cost per carton, or cost per equivalent standard hour if a standard cost system is in place (Peters 1998).

4.2. The Scoreboard for Maintenance Excellence

4.2.1. Global Best Practices as External Benchmarks

There are many maintenance best practices that can serve as the global external benchmarks. External benchmarking is about gaining the knowledge and understanding of best practices and then applying them within the maintenance operation to help pursue and gain a manufacturing or service edge. Today's best maintenance practices are in areas such as:

- Preventive/predictive maintenance
- Continuous reliability improvement
- Reliability-centered maintenance
- Maintenance parts/materials control
- Maintenance storeroom operations
- Work order and work control
- Maintenance planning/scheduling
- Maintenance budget and cost control

- Operator-based maintenance
- Team-based continuous improvement
- Improving and measuring equipment effectiveness and reliability
- Craft skills development
- Maintenance performance measurement
- Computerized maintenance management systems
- Continuous maintenance improvement

Effective benchmarking should start locally, with a total evaluation of current maintenance practices and procedures, and then lead to the development of a strategic maintenance plan. The strategic maintenance plan provides the road map for applying maintenance best practices through a long-term process of continuous maintenance improvement. Benchmarking at its best is when maintenance effectively measures its level of services and practices and develops its own unique benchmarking criteria with high standards for maintenance excellence.

4.2.2. Conducting an Assessment of the Total Maintenance Process

Today's most comprehensive benchmarking guide, *The Scoreboard for Maintenance Excellence*, has been discussed in this chapter to support external benchmarking of your maintenance operation. *The Scoreboard for Maintenance Excellence* includes 18 maintenance best practice categories and 200 benchmark evaluation items. It has been used by over 4000 international organizations of all types to include translations into a number of languages. A complete copy of this very comprehensive document, with a guide for doing a self-assessment, can be downloaded from *www.tompkinsinc.com*. A summary of the evaluation categories and the number of evaluation items per category is included in Table 2.

Table 3 provides a general assessment of the overall benchmark rating, which has a maximum point value of 2000 points; 10 points maximum for each of the 200 benchmark evaluation items. Overall ratings of excellent (90–100%), very good (80–89%), good (70–79%), average (60–69%), and below average (less than 60%) are defined with general assessment comments.

Using *The Scoreboard for Maintenance Excellence*: It is recommended that the benchmark evaluation be conducted through a team effort within an organization or through an outside resource that can provide an objective and unbiased evaluation. When using an outside consulting resource, it is important to select a firm with broad-based experience in maintenance management as well as knowledge and experience with CMMS implementation.

When using an internal team, it is important to select knowledgeable members from maintenance as well as representatives from the storeroom, purchasing, accounting, production, and engineering

TABLE 2 Maintenance Evaluation Summary

Section	Evaluation Category	Evaluation Items
A.	Maintenance and organization culture	10
B.	Organization and administration	12
C.	Work authorization and work control	10
D.	Budget and cost control	11
E.	Maintenance planning and scheduling	12
F.	Maintenance storeroom	16
G.	Preventive and predictive maintenance	22
H.	Lubrication program	11
I.	Overall equipment effectiveness	9
J.	Operator-based maintenance	8
K.	Engineering support	9
L.	Safety, housekeeping, and regularity compliance	12
M.	Craft skills development	9
N.	Maintenance performance measurement	9
O.	Maintenance supervision/leadership	6
P.	Computerized maintenance management systems (CMMS)	13
Q.	Maintenance facilities, equipment, and tools	7
R.	Continuous maintenance improvement	14
	Total evaluation criteria	200

TABLE 3 General Assessment of Overall Benchmark Rating

General Assessment of Overall Benchmark Rating	
Total Point Range	Overall Rating Summary
1800 to 2000 (90–100%)	*Excellent:* Practices and principles in place for achieving effective maintenance and world-class performance based on actual results. Reconfirm overall maintenance performance measures. Maintain strategy of continuous maintenance improvement. Set higher standards for maintenance excellence and measure results.
1600 to 1799 (80–89%)	*Very good:* Fine-tune existing operation and current practices. Reassess progress on planned or ongoing improvement activities. Redefine priorities and renew commitment to continuous maintenance improvement.
1400 to 1599 (70–79%)	*Good:* Reassess priorities and reconfirm commitments at all levels to maintenance improvement. Evaluate maintenance practices and develop and implement plans for priority improvements. Ensure that measure to evaluate maintenance performance and results are in place. Initiate strategy of continuous maintenance improvement.
1200 to 1399 (60–69%)	*Average:* Conduct a complete assessment of the maintenance operation and current practices. Determine total costs/benefits of potential improvements. Develop and initiate strategy of continuous maintenance improvement.
Less than 1200 (<60%)	*Below average:* Same as Average, plus depending on the level of the rating and major area that is Below average, immediate attention may be needed to correct conditions adversely affecting on life, health, safety, and regulatory compliance. Priority to key issues, major equipment, or increasing costs that are having a direct impact on the immediate survival of the business.

and computer systems. An outside consultant can also be used as part of the team approach to performing the benchmark evaluation. It is recommended that maintenance provide the team leader to support overall coordination of the benchmarking evaluation.

A self-assessment will provide benefits; however, an assessment conducted by an outside resource provides a greater sense of the big picture in terms of objectivity and completeness. Should you want to begin with an internal study of maintenance, here are some guidelines to consider when using *The Scoreboard for Maintenance Excellence.*

- *Obtain Leadership Buy-in:*
  - Establish a firm commitment from company leadership to take action based upon results of the assessment.
  - Gain commitment from company leadership for the necessary resources.
- *Charter maintenance excellence team:*
  - Establish a maintenance excellence strategy team to guide and promote improved maintenance practices within the operation.
  - Utilize a team-based approach with a cross-functional assessment team specifically chartered for conducting and preparing the results of your assessment.
  - Have at least one team member with solid background in each of 18 evaluation categories.
- *Define and weight benchmarking criteria:*
  - Gain complete understanding of each evaluation criterion (200 total).
  - Modify existing evaluation criteria as required.
  - Add evaluation criteria as required.
  - Ensure that all team members understand the scoring process and develop consistency in scoring each area.
- *Develop action plan:*
  - Determine information required, persons to interview, and observations needed prior to start of assessment.
  - Develop schedule and implementation plan for the assessment.

- *Conduct assessment:*
  - Assign team members to specific evaluation categories (ideally, in two-person teams for each category).
  - Conduct kickoff meeting, firm up schedules, etc.
  - Conduct the assessment, record observations, and assign scores to each evaluation criteria.
- *Analyze and review results:*
  - Review all scoring for consistency.
  - Develop final results of the assessment and document in a written report.
  - Determine strengths/weaknesses, priorities for action, and benefits.
  - Present results to company leadership, define benefits and get commitment for investments.
- *Develop path forward for maintenance excellence:*
  - Develop a strategic maintenance plan (SMP) and implement best practices.
  - Measure benefits and validate ROI.
  - Maintain a continuous maintenance improvement process (i.e., repeat assessment process).

Each of the 200 benchmark items will include evaluation criteria to provide a means to rate each item with up to 10 points maximum. Examples from *The Scoreboard for Maintenance Excellence* are shown in Tables 4 and 5 to illustrate the two methods for establishing benchmark rating values. Ratings are established as follows:

- *Based on point value:* The benchmark item is rated as excellent (10 or 9 points), very good (8 points), good (7 points), average (6 points), below average (5 points) and poor (4 points or less), as shown in the example in Table 3. This method of rating requires that a consistent judgment be made on assigning point values, particularly in the areas rated average and below average.
- *Based on specific conditions:* The benchmark criteria will describe a number of specific conditions that are assigned point values. Table 4 provides two examples of this type of rating from the maintenance storeroom category. For example, benchmark item 6 rates whether storeroom inventory accuracy is being measured and is over 95% for a score of 10. In turn, inventory accuracy levels within 90–95%, 9 points, 80–89%, 8 points, 70–79%, 7 points, and below 70%, 5 points.

The benchmark evaluation score: As the benchmark evaluation is completed, it is important to realize that the total point value is not an absolute value but represents an important baseline value unique to your maintenance operation. It provides a baseline value as to where you are with best

TABLE 4 Example for Benchmark Rating Based on Point Values

Item #	Benchmark Item	Benchmarking Criteria	Rating
A.	Maintenance and Organization Culture		
1.	The organization's vision, mission, and requirements for success include physical asset management and maintenance as a top priority.	The organization has written mission statement/goals that include maintenance and/or preventive maintenance as a top priority and key goal. Rated as: Excellent—10 or 9, Very good—8, Good—7, Average—6, Below average—5, Poor—4 or less.	
2.	Senior management is visible and actively involved in continuous maintenance improvement and is obviously committed to achieving maintenance excellence.	Management commitment is rated as: Excellent—10 or 9, Very good—8, good—7, Average—6, Below average—5, Poor—4 or less.	

TABLE 5 Example for Benchmark Rating Based on Specific Conditions

Item #	Benchmark Item	Benchmarking Criteria	Rating
F. Maintenance Storeroom			
5.	Inventory accuracy is determined by an effective cycle-counting program.	• Cycle counting used—10 • Count once per year—7 • Count occasionally—5 • Do no inventory counts—0	
6.	Inventory accuracy is regulary measured and is 95% or above.	Inventory accuracy 95% or above—10 90%–95%—9 80%–89%—8 70%–79%—7 <70%—5	

practices from *The Scoreboard for Maintenance Excellence.* In Section 5, very specific metrics for internal benchmarking and measurement of progress will be reviewed.

At this point, the benchmarking process has helped define current strengths and weaknesses within a maintenance process. Benchmarking helps to identify where we are with best practices that are essential to an effective asset management. By using a benchmarking guide such as *The Scoreboard for Maintenance Excellence*, you can easily see the status of current practices:

- Work order/work management
- Equipment/asset management
- Preventive/predictive maintenance
- Planning and scheduling
- Parts inventory management/purchasing
- Budgeting and cost control

The benchmark evaluation may reveal weaknesses related to the primary CMMS modules. A wide range of scores have come from the benchmark assessments conducted by Tompkins Associates and others using *The Scoreboard for Maintenance Excellence*. The important point was not the numeric score but that each organization had taken the first step with a total benchmark evaluation of their maintenance operation and used the results to develop and implement a strategic plan for improvement.

4.2.3. Internal Benchmarking: The Key to Validation of Results and ROI

Measurement of improvement internal to a maintenance operation is the real value of internal benchmarking. It's knowing exactly where we are with applying best practices, gaining a commitment from the organization to implement those needed, and then measuring the results. Internal benchmarking provides the means to validate results of maintenance improvement, define the ROI, and manage and control maintenance as a business.

It makes little sense to develop and worry about industry-wide benchmark statistics when, for example, an operation does not measure its own maintenance-related downtime. Industry-wide benchmark statistics can be very misleading when we try to compare our maintenance operation to them. On the other hand, when we understand today's best practices for effective maintenance, apply them, and measure the results, we are providing real value (Peters 1998).

5. PERFORMANCE MEASUREMENT: KEY TO MAINTENANCE CONTROL

5.1. Techniques for Measuring Maintenance Activities

Maintenance work, by its very nature, seldom follows an exact pattern for each occurrence of the same job. Traditional work-measurement techniques are not readily adaptable to maintenance-type work. Therefore, exact methods and exact times for doing most maintenance jobs cannot be established as they can for discrete manufacturing-type work. However, the need for having reliable performance measures for maintenance planning becomes increasingly important as the cost of maintenance labor rises and the complexity of production equipment increases.

Various methods for establishing maintenance performance standards have been used, including:

- *Reasonable estimates:* A knowledgeable person, either a supervisor or planner, uses his or her experience to provide their best estimate of the time required. This approach does not scope out the job in much detail to determine method or special equipment needed.
- *Historical data:* The results of past experience are captured via the CMMS or other means to get average times to do a specific task. Over time, a database of estimated time is developed that can be updated with a running average time computed for the tasks.
- *Predetermined standard data:* Standard data tables for a wide range of small maintenance tasks have been developed. A standard data example is shown for one task for the pipefitting craft of cutting with a pipe machine. Standard data represent the building blocks that can then be used to estimate larger, more complex jobs. Each standard data table provides what the operation is, what is included in the time value, and the table of standard data time for the variables that are included. The variables for the example standard data sheet is the size of the pipe from ½ in. diameter up to 8 in. diameter.

Example: Maintenance Standard Data—Pipefitting

Code PF-2-1

SKILL: Pipefitting

OPERATION: Pipe—Cut with Pipe Machine

Includes:

1. Pick up pipe, place in chuck, and tighten chuck jaws.
2. Measure pipe for cut and position carriage.
3. Hand feed parting tool to cut piece off pipe.
4. Hand feed parting tool to remove burrs.
5. Loosen chuck jaws, remove pipe from chuck, and set aside.
6. Dispose of scrap or set aside unused piece.

The three techniques described previously require that an outside party establish the standards that are then imposed upon the maintenance force as an estimated time on the work order. These approaches to craft performance measurement often bring about undue concern and conflict between management and the maintenance workforce over the reliability of the standards. Rather than progressing forward together in a spirit of continuous improvement, the maintenance workforce in this type environment often works against management's program for maintenance improvement. Some other very progressive options to the challenging task of work measurement within nonrepetitive maintenance operations are available.

5.2. The ACE Team Benchmarking System

As a means to overcome many of the inherent difficulties associated with developing maintenance performance standards, the ACE (A Consensus of Experts) team benchmarking system relies primarily on the combined experience and estimating ability of a group of skilled crafts personnel. The objective is to determine reliable planning times for a number of selected benchmark jobs. This system places a high emphasis on continuous maintenance improvement and the changing of planning times to reflect improvements in performance and methods as they occur.

Generally, the ACE team benchmarking system parallels the UMS (universal maintenance standards) approach in that the range of time concept and slotting are used once the work content times for a representative number of benchmark jobs have been established. The ACE team benchmarking system focuses primarily on the development of work content times for representative benchmark jobs that are typical of the craft work performed by the group (Peters 1996a).

Once a number of benchmark job times have been established, these jobs are then categorized onto spreadsheets by craft and task area and according to work groups which represent various ranges of times. A spreadsheet is then set up for four work groups, such as for jobs in the E, F, G, and H time slots. In this case, work group E would be for benchmark jobs ranging from 0.9 hr up to 1.5 hr and assigned a standard time (slot time) of 1.2 hr. Likewise, work group F would be for benchmark jobs ranging from 1.5 hr up to 2.5 hr and assigned a standard time of 2.0 hr. This spreadsheet would

TABLE 6 Standard Data: Pipe Size ½ in. to 8 in.

Pipe Size	Normal Minutes per Cut
1/2 in.	0.9
3/4 in.	1.0
1 in.	1.1
1-1/4 in.	1.2
1-1/2 in.	1.3
2 in.	1.4
2-1/2 in.	1.6
3 in.	1.8
3-1/2 in.	2.2
4 in.	2.5
5 in.	3.4
6 in.	4.4
8 in.	6.2

also include brief descriptions of the benchmark jobs that have work group times of 1.2 (E), 2.0 (F), 3.0 (G), and 4.0 (H) hr respectively. All of the work groups, and their respective time ranges, are shown in Table 7.

Spreadsheets provide the tool: After spreadsheets have been prepared based on the representative benchmark jobs from various craft/task areas, a planner/analyst now has the means to establish planning times for many different maintenance jobs using a relatively small number of benchmark jobs as a guide for work content comparison. By using work content comparison combined with a good background in craft work and a knowledge of the benchmark jobs, a planner now has the tools to establish reliable performance standards consistently, quickly, and with confidence. The ACE team benchmarking system allows a wide range of tasks to be estimated with a 95% confidence level by using work content comparison to a small but representative sample of well-defined benchmark jobs.

TABLE 7 ACE System Time Ranges and Work Groups

	Time Range		
Work Group	From	Standard Time (Slot time)	To
A	0.0	0.1	0.15
B	0.15	0.2	0.25
C	0.25	0.4	0.5
D	0.5	0.7	0.9
E	0.9	1.2	1.5
F	1.5	2.0	2.5
G	2.5	3.0	3.5
H	3.5	4.0	4.5
I	4.5	5.0	5.5
J	5.5	6.0	6.5
K	6.5	7.3	8.0
L	8.0	9.0	10.0
M	10.0	11.0	12.0
N	12.0	13.0	14.0
O	14.0	15.0	16.0
P	16.0	17.0	18.0
Q	18.0	19.0	20.0
R	20.0	22.0	24.0
S	24.0	26.0	28.0
T	28.0	30.0	32.0

Since the actual times assigned to the benchmark jobs are so critical, it is very important to use a technique that is readily acceptable. The ACE team benchmarking system provides such a technique, since it is based on the combined experience of a group of skilled crafts personnel, and their consensus agreement on the range of time for the benchmark jobs. The following is a recommended approach for using the ACE team benchmarking system (Peters 1996a).

1. *Select benchmark jobs:* Review past historical data from work orders and select representative jobs that are normally performed by the craft groups. Special attention should be paid to determine the 20% of total jobs (or types of work) that represent 80% of the available craft manpower. Focus on determining repetitive jobs where possible in all craft areas.
2. *Select and train experts* (*ACEs*): It is important to select experienced crafts people and/or supervisors who, as a group, have had experience in the wide range of jobs selected as benchmark jobs. All craft areas should be represented in the group. In order to ensure that this group understands the overall objectives of the maintenance planning effort, special training sessions should be conducted to cover the procedures to be used, reasons for establishing performance measures, etc. A total of 6 to 10 craft people is the recommended group size.
3. *Develop major elemental breakdown for benchmark job:* For each benchmark job that is selected, a brief element analysis should be made to determine the major elements of the total job. This listing of the major steps of the job should provide a clear, concise description of the work content for the job *under normal conditions*. It is important that the work content for a benchmark job be described and viewed in terms of what is a *normal* repair and not what may occur as a rare exception.

   An excellent resource to consider for doing the basic element analysis for each benchmark job is the crafts (ACEs) that are selected for doing the estimating. Brief training on methods/operations analysis can be included in the initial training for the ACEs. This process leads to the question "Are we using the best method, equipment, or tools for the job?" Often significant methods improvements are discovered and implemented as a result of this step.

   Major exceptions to a routine job should be noted if they are significant; generally an exception will be analyzed as a separate benchmark job, along with an estimate of time required for such repair. This portion of the procedure ensures that the work content of each benchmark job is clearly defined so that each person doing the estimating has the same understanding about the nature and scope of the job. When the benchmark jobs are finally categorized into spreadsheets, the work content description developed in this step is used as key information about the bench job on the spreadsheet.
4. *Conduct first independent evaluation of benchmark jobs:* Each member of the group is now asked to review the work content of the benchmark jobs and to assign each job to one of the UMS time ranges or slots. Each member of the group provides an independent estimate that represents an unbiased personal estimate of the pure work content time for the benchmark job.

   It is important here for each member of the group to remember that only the work content of the benchmark job description is to be estimated, and not the make ready and put away activities associated with the job. This part of the procedure is concerned only with estimating the pure work content, *excluding* things such as travel time, securing tools and parts, delays, and personal allowances.

   The estimate should be made for each job under these conditions:

   (a) An average skilled craftsman is doing the job giving 100% effort, i.e., a fair day's work for a fair day's pay.

   (b) The correct tools are available at the job site or with the craftsman.

   (c) The correct parts are available at the job site or with the craftsman.

   (d) The machine is available and ready to be repaired.

   (e) The craftsman is at the job site with all of the above and proceeds to complete the job from start to finish without major interruption.

   The work accomplished under these conditions therefore represents the pure work content of the job to be performed. Establishing the range of time estimate for this pure work content is the prime objective of the first evaluation. It is important for each estimator to remember that to develop a planning time requires pure work content time plus additional time allowances to cover make ready and put away-type activities associated with each job.

5. *Summarize first evaluation:* Results of the first evaluation are then summarized to check the agreement among the group as to the time range for each benchmark job. A coefficient of concordance can be computed from the results. A value of 0.0 denotes no agreement, while a value of 1.0 denotes complete agreement, or consensus among the ACEs.

   Group members who are significantly higher or lower than the rest of the group for a particular benchmark job are asked to explain their reasons for their high or low estimates. This information will then be used during the second evaluation to refine the next estimates from the entire group.
6. *Conduct second independent evaluation of benchmark jobs:* A second evaluation is conducted using the overall results from the first evaluation as a guide for the group. Various reasons for high or low estimates from the first evaluation are provided to the group prior to the second evaluation. This allows for adjustment to individual estimates if the other experts' reasons are considered to be valid.
7. *Summarize second evaluation:* Results of the second evaluation are then summarized to evaluate changes or improvements in the agreement or consensus among the ACEs as to the time range for each benchmark job. This evaluation should produce improved agreement among the group. If an extreme variance in time range estimates still exists, further information regarding the work content of the job may be needed.
8. *Conduct third independent evaluation if required:* This evaluation is required only if there remains a wide variance in the estimates among the group.
9. *Conduct group session to review final results:* This session serves to finalize the results achieved and to discuss any of the high or low estimates that have not been resolved completely. A final group consensus on all time ranges is the objective of this session.
10. *Develop spreadsheets:* The benchmark jobs with good work content descriptions and agreed-upon time ranges can now be categorized onto spreadsheets. From these spreadsheets, which give work content examples for a wide range of typical maintenance jobs, a multitude of individual maintenance performance standards can be established by the planner through the use of work content comparison. The basic foundation for the maintenance planning system is now available for generating consistent planning times that will be readily acceptable by the maintenance work force that developed them.

The ACE Team Benchmarking System approach combines the DELPHI technique for estimating along with the inherent and inevitable ability of most people to establish a high level of performance measures for themselves. As used in this application, the objective is to obtain the most reliable, reasonable estimate of maintenance-related work content time from a group of experienced crafts personnel.

This approach allows for independent estimates by each member of the group, which in turn builds into a consensus of expert opinion for a final estimate. The final results are therefore more readily acceptable because they were developed by skilled and well-respected crafts people from within the work unit. Application of the ACE team benchmarking system promotes a commitment to continuous maintenance improvement and provides reliable planning time for a wide range of maintenance activities.

5.3. Establishing Key Performance Indicators

This section will outline and describe key performance indicators that can be used to measure the overall effectiveness of a maintenance operation.

- *Percent craft utilization* (*CU*): Evaluates actual wrench time (hands-on time) for craft labor. Provides one of the two key elements for measuring the overall craft effectiveness (OCE). Measures the overall increase in craft labor wrench time due to a proactive, planned maintenance strategy with effective planning and scheduling, positive impact from the PM/PdM program, effective MRO materials management service, and improved CMMS.
- *Percent craft performance* (*CP*): Evaluates actual craft performance against a reasonable/reliable planned time for a planned repair job or task such as PM inspections. Where craft labor utilization measures effectiveness, this measure addresses the efficiency factor for overall craft effectiveness (OCE). This measure is improved by having effective craft skills to do the job, along with the motivation to work efficiently. It is directly impacted by shop working areas, having the right personal and special tools available, and safe working conditions.
- *Overall equipment effectiveness* (*OEE*): A world–class metric that originated from the total productive maintenance (TPM) movement, which evaluates critical equipment in terms of equip-

ment availability, equipment performance, and the quality of output. Improving OEE focuses on eliminating the six major losses:

Availability issues:	1. Breakdowns
	2. Set-up and adjustments
Performance issues:	3. Idling and minor stoppages
	4. Reduced speed
Quality Issues:	5. Process defects
	6. Reduced yield

The average OEE factor is in the 40–50% range before an improvement process starts. A world-class OEE factor is around 85%, which means that all three elements must be around 95%, i.e. 0.95 (availability) $\times$ 0.95 (Performance) $\times$ 0.95 (Quality) = 0.857 $\times$ 100 = 85.7% OEE factor.

$$\text{The OEE factor} = \text{availability \%} \times \text{performance \%} \times \text{quality \%}$$

- *The overall craft effectiveness (OCE) factor:* The OCE factor relates to craft labor assets, as compared to the metric for OEE, which measures the combination of equipment asset availability, performance, and quality output. The OCE factor focuses upon measuring and improving the value-added contribution that people assets make to total asset management. Section 7.5 includes more detailed information about the OCE factor.
- *Number of call-backs (or percentage of craft rework)*: Measures the quality of maintenance repair work and provides one key indicator for maintenance customer service. It helps focus on doing the repair right the first time.
- *Schedule compliance (percent jobs completed as scheduled)*: Evaluates the overall effectiveness of executing the planned work on the agreed-upon schedule by the craft workforce.
- *Percent planned work:* Measured by either the percent work orders planned or percent actual craft hours on planned work. This metric evaluates the overall effectiveness of the planning process as well as the impact of all maintenance best practices to promote a proactive maintenance repair strategy, i.e., PM, PdM, reliability improvement actions, effective MRO support, etc.
- *Percent work orders with planned time:* Provides one very key measure for the maintenance planner position. Evaluates the ability and effectiveness of the maintenance planner/coordinator position to establish reliable planning times, using maintenance standard data or other available data for determining planning times. The objective for the planning process is to have as many jobs scoped and planned as possible, to the level that reliable estimates are established.
- *Percent planned work orders generated from PM/PdM program:* Provides valuable feedback that the PM/PdM effort is helping avoid catastrophic failure and is truly providing benefits. Measures how well PM/PdM program is detecting deficiencies before catastrophic failure or downtime occurs. The reliability improvement goal, however, is not to continue to fix before failure but to eliminate root causes of failure and in turn the failure rate. However, this is an important metric as a client's PM/PdM program is reinforced or renewed and in turn begins to provide measurable results.
- *Percent PM/PdM compliance:* Measures the execution and compliance to completing scheduled PMs, PdM data collection, lube services, scheduled structural/process inspections, calibrations, etc. Typical completion of scheduled PM/PdM actions required within a week's window of time is used as criterion for compliance. This metric can also apply to instrumentation calibration and to any regulatory inspections such as crane, fire protection testing/PM, etc.
- *Number of stock outs:* Evaluates the MRO inventory/materials management process capability to have the on-hand quantities needed for stock items that are normally stocked in the maintenance storeroom. Provides an excellent countermeasure to ensure planned inventory reduction goal is not detrimental to storeroom customer service. Does not measure nonstock items that require requisitioning/purchasing as direct purchases or availability of project-related items.
- *Percent inventory accuracy:* Maintains accurate fiscal accountability of stocked items to ensure total confidence in current inventory levels and dollar value of MRO inventories. Measures the effectiveness of the cycle-counting process and storeroom control.

- *Dollar value of MRO inventory reductions:* Helps to ensure that proactive MRO inventory management practices and those well-planned MRO inventory reductions are given proper credit and recognition within the organization. This reduction may also serve to offset additions to inventory of more useful items and critical spares.
- *Percent asset utilization:* A good metric that evaluates how well the overall capacity of an asset is being used in the operation. It should be supplemented by measurement of overall equipment effectiveness (OEE).
- *Maintenance cost per unit of output:* Measures bottom-line maintenance cost per unit of output and evaluates net improvements related to maintenance improvements on total operation costs. Excellent metric for process-type industries and/or for discrete manufacturers with major single product output and a strong standard cost and production-reporting system.
- *Maintenance cost as percent of total operations cost:* Provides an overall comparison of how maintenance cost impacts total cost.
- *Other metrics to consider:*
  - Overtime
  - Craft time charged to work orders
  - Overdue work orders
  - Emergency craft hours

TABLE 8 Sample Maintenance Excellence Index

MAINTENANCE EXCELLENCE INDEX

Performance Measurement Categories

	Craft Productivity			Cost	Planning & Scheduling		MRO Mat'l Management		PM Compliance			Asset Uptime		
A. Performance Metric	Craft Utilization	Craft Performance	% Job Completed as Scheduled	Maintenance Cost Per Carton	% Planned Hours	% Work Orders with Standard Time	$ of Stockouts	% Inventory Accuracy	Mobile PM Compliance	Conveyor PM Compliance	Bldg Sys PM Compliance	Sorter % Utilization	Forklift % Utilization	
B. Current Month Performance	55	75	85	0.106	70	80	6	85	90	80	95	98	96	Performance Level
C. Performance Goal	80	95	95	0.082	85	90	2	95	100	100	100	100	98	10
	75	90	90	0.086	80	85	3	90	95	95	95	98	95	9
	70	85	85	0.090	75	80	4	85	90	90	90	96	92	8
	65	80	80	0.094	70	75	5	80	85	85	85	94	89	7
	60	75	75	0.098	65	70	6	75	80	80	80	92	86	6
	55	**70**	70	0.102	60	65	7	70	75	75	75	90	**83**	5
	50	65	65	0.106	55	60	**8**	**65**	**70**	70	**70**	**88**	80	4
D. Baseline Performance in **BOLD**	45	60	**60**	**0.110**	**50**	55	9	60	65	65	65	86	77	3
	40	55	55	0.114	45	50	10	55	60	**60**	60	84	74	2
	35	50	50	0.118	40	45	11	50	55	55	55	82	71	1
	30	45	45	0.122	35	40	12	45	50	50	50	80	68	0
E. Current Performance Scores	5	6	8	4	7	8	6	8	8	6	9	9	9	SCORES X WEIGHT
G. Weighted Value of Performance Metric	12	8	6	14	8	6	8	10	5	7	2	9	5	
H. Performance Value, *Score (F) x Weight (G)*	60	48	48	56	56	48	48	80	40	42	18	81	45	= 670
J. Total MEI Values Over Time	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99	Jun 99	Jul 99	Aug 99	Sep 99	Oct 99	Nov 99	Dec 99	
	490	510	525	539	550	570	585	590	630	649	650	690	646	

F. PERFORMANCE LEVEL SCORES

I. TOTAL MEI PERFORMANCE. VALUE: January 2000 — 670

MAXIMUM POSSIBLE MEI PERFORMANCE VALUE 1000 TOTAL POINTS

- PM/PdM coverage, i.e., the equivalent craft hours invested in PM/PdM tasks, which can also be shown as equivalent crafts people
- Response time to priority jobs
- Closed work orders without time
- Craft hours charged back to customers
- Jobs by one-person crew
- Percent craft hours by work order type
- Percent craft hours by work/cost center

5.4. Developing a Maintenance Excellence Index

Often performance measurement is something new to the maintenance operation, but it is highly recommend that a performance-measurement system be put in place. Justification for investments in maintenance best practices must be validated. One approach used by Tompkins Associates has been to help clients create a maintenance excellence index (MEI) that includes 10–15 key performance indicators. These metrics, with agreed-upon weighted values, are developed into a composite total performance value (Peters 1998). The metrics that are selected should cover areas such as:

√ Craft Productiivty
√ Budget/cost
√ Planning and scheduling
√ Parts inventory management
√ PM compliance
√ Asset uptime/OEE
√ Asset utilization
√ Customer service

- *The Maintenance Excellence Index* (*MEI*): The sample MEI shown in Table 8 provides a composite index that integrates a number of key metrics. Each metric can also be monitored and trended individually. The MEI helps keep in focus the fact that the success of maintenance operations depends on many factors. Therefore, one or two metrics can't provide the total performance picture. The MEI concept provides a complete approach to maintenance performance measurement. If a maintenance process improvement has been justified on craft productivity increases, parts inventory reduction, maintenance cost per unit of output reduction, or value of increased asset uptime, the original projection of benefits and savings can be validated with the MEI.
- *The basic format of the MEI calculations:* The total MEI performance value is the composite score of all metrics, considering current performance of each metric as compared to the goal and the weighted value of each individual metric. The total possible score for the total MEI performance value is 1000. The key steps in developing and using the MEI are as follows:

Step	Description	Comments
A	Performance metrics	From 10 to 15 metrics are selected and agreed upon by the organization.
B	Current month performance	This is the acutal performance level for the metric for the reporting month. This value will also be noted in one of the incremental values blocks below the performance goal. This value will correspond to a value for F, the performance level scores which go from 10 down to 1.
C	Performance goal	This is the preestablished performance goal for each of the MEI metrics. For example, if the current month's performance is at the performance goal level, the performance level score for that goal will be a 10, the maximum score.
D	Baseline performance	The baseline performance level prior to start of MEI performance measurement

Step	Description	Comments
E	Current performance score	Depending on the current month's performance, a performance level score (F) will be obtained. This value then goes to the current performance score row and serves as the multiplier for (G) the weighted value of the performance metric.
F	Performance level score	Values from 10 down to 1, denote the level of current performance compared to the goal. If current performance achieves the predetermined goal, a performance value of 10 is given. Each metric is broken down into incremental value, from the baseline to the goal. Each incremental value in the column corresponds to a performance level value. This value becomes the current performance score.
G	Weighted value of the performance metric	The values along this row are the weighted value or relative importance of each of the metrics. These values are obtained via a team process and a consensus on the relative importance of each metric that is selected for the MEI. All of the weighted values sum to 100.
H	Performance value score	The weighted values (G) are multiplied by (E) the current performance scores to get the performance value score (H).
I	Total MEI performance value	The sum of the performance value scores for each of the 15 metrics and the composite value of monthly maintenance performance on all MEI metrics.
J	Total MEI performance values over time	Location for tracking total MEI performance values over a number of months

Investments in maintenance and total operations improvements should be measured and bottom-line return on investment validated. The proven methodology of the MEI utilizes existing data to provide a very effective multifactored system to measure mission-critical maintenance and its contribution to total operation performance and success. Organizations will make a wise decision to start this process, for example, as a new CMMS system is purchased and begins implementation. Positive trends on the Maintenance Excellence Index will validate the projected results: tangible benefits and savings that were used to justify the capital investment for this and many other types of maintenance-improvement projects.

6. INFORMATION TECHNOLOGY TO SUPPORT MAINTENANCE MANAGEMENT AND CONTROL

6.1. Introduction to Computerized Maintenance Management Systems/Enterprise Asset Management

The purchase of information technology in the form of a CMMS/EAM system is not a quick fix or a panacea. Many excellent systems are available, but surveys have consistently shown that only 80% of CMMSs are actually being used. In turn, typically only 30% of CMMSs functional capabilities are being used. Expenditures for CMMSs were $553 million in 1995 and have grown to over $1 billion in 2000. Therefore, gaining full value from your CMMS investment should be a top priority.

Basically, CMMS/EAM provides computer software programs designed to assist in the planning, management, and administrative procedures required for an effective maintenance process. The need for a maintenance management system, whether manual or computerized, is determined by the need to perform effective maintenance on assets, equipment and facilities. We can think of CMMS/EAM as providing the business system for maintenance operations.

Choosing a CMMS/EAM and determining how it will operate and what it will do should occur only after recognizing that a system is needed or that an existing system needs improvement. The need for, and use of a CMMS/EAM is not specific to any one industry or type of application. Anyplace where maintenance is done is a candidate user, and all users have the same basic system needs as dictated by the maintenance process itself. The scope of maintenance is broad and technically challenging. Likewise, the scope of today's CMMS/EAM is broad based to include a number of integrated modules to manage the maintenance process.

- *CMMS/EAM facilitates best practices:* Implementation of a CMMS is most successful in an organization that has committed to a total reevaluation and internal benchmarking of current practices and procedures, as reviewed previously in this chapter. Organizations should realize that lack of a CMMS is never the main problem. The main problem is the lack of best practices. A CMMS provides the framework to fully integrate best practices into the maintenance process; to provide the systems, procedures, and information to manage maintenance as a business. The effective use of a CMMS is important, but it is only part of the process for improving maintenance management. The maintenance organization plays a big part; it needs to be refined before a CMMS is put in to support it. Successful implementation of a CMMS will facilitate applying best practices discussed previously, and will provide tangible benefits and savings. Improved performance of the following maintenance activities can be expected to support justification of a CMMS/EAM (Peters 1999):
- *Improved work control:* The work order module is the heart of any CMMS. It provides the basis for work management, cost tracking, equipment history, and performance reporting. Effective CMMS supports improved control of work requests by craft, monitoring backlogs, determining priorities, and scheduling of overtime.
- *Improved planning and scheduling:* Unplanned maintenance work typically costs two to three times as much as planned work. A CMMS provides the systems and procedures to establish a more effective maintenance planning and scheduling function, which is a key contributor to improved craft labor utilization.
- *Enhanced preventive and predictive maintenance* (*PM/PdM*): Automatic scheduling of repetitive PM activities is possible through CMMS. PM tasks and inspection frequencies can be documented on the PM module and printed as part of the PM work order. A CMMS enhances PM by providing a method to monitor failure trends and highlight major causes of equipment breakdowns and unscheduled repairs.
- *Improved parts availability:* A well-organized stockroom with accurate inventory records, stock locator system, stocking levels, and a storeroom catalog can significantly improve the overall maintenance operation. Having the right part at the right time is the key to effective maintenance planning and increased maintenance customer service.
- *Reduced storeroom inventory:* A CMMS provides the means for more effective management and control of maintenance parts and material inventories. Information for decisions on inventory reduction is readily available to identify parts usage, excess inventory levels, and obsolete parts.
- *Improved failure and repair analysis:* A CMMS provides the means to track work order and equipment history data related to types of repairs, frequencies, and causes for failure. It allows maintenance to have key information on failure trends that leads to eliminating root causes of failures and improving overall equipment reliability.
- *Increased budget accountability:* A successful CMMS requires greater accountability for craft labor and parts/materials through the work order and storeroom inventory modules. This increased level of control provides greater accountability of the overall maintenance budget by individual pieces of equipment and by using department or work center.
- *Increased capability to measure performance:* The CMMS database provides a vast source of maintenance information to allow more effective measurement of maintenance performance and service. Successful CMMS applications will establish internal benchmarks to provide a measurement for improvements in the areas of craft labor utilization, PM/PdM compliance, downtime, store inventory control, backlog, level of planned maintenance, etc.
- *Increased level of maintenance information:* A major benefit of a CMMS comes from developing the historical database that becomes readily available as critical maintenance information. Many types of maintenance data are normally available, but it is often not in the form that helps manage and control maintenance operations. Now such data can be turned into valuable maintenance information with an effective CMMS.

6.2. Overview of CMMS/EAM System Functionality

This section provides an introduction to the overall scope, functionality summaries, and the primary CMMS modules that make up a typical integrated system. Many other system functions are available.

The modules described here are provided in various levels of functionality by over 100 CMMS/EAM vendors. These modules and the respective functionality they provide to the user comprise the basic elements needed for effective management of the maintenance process (Peters 1999).

- *Work order/work management module:*
  - Manages and controls approvals of work requests for correcting faults or improving an asset's condition. May be configured to require that certain types of work requests go through a review or approval cycle before they are submitted to maintenance.
  - Opens, edits, and records work orders as history. Basic work order information on the work request might include the equipment/asset number to be worked on, a description of the problem or work to be done, who requested the work, when they wanted it completed, the priority of the work, and the date the request is made.
  - This module records the basic work order information and supports editing the details on the work needed, parts and materials required, sequence of work, job steps, and other pertinent data.
  - Planning and scheduling of work orders may be available to associate each step with specific equipment, craft foreman, estimated and standard duration, lists of tasks, and special tools and equipment required.
  - Provides linking of craft resources, parts requisitions, bill of materials, routes and checklists, safety documentation/permits, material, and labor costing to a job step.
  - Work order completion is recorded with final information and closed to work order history file.
  - Reporting may be available to work orders in current backlog as well as in the work order history file.
- *Equipment/asset management module:*
  - Provides listing and basic data for equipment/assets owned and maintained. May include breakdown of asset information related to hierarchies of system/subsystems.
  - Information recorded may include equipment/asset number, location, maintenance priority, cost, manufacturer, model and serial numbers, and the dates of purchase and installation.
  - Defines assemblies and spare parts lists and supporting information, such as calibration data, which may also be kept in this module.
  - May include detailed support documentation associated with the asset: drawings, specifications, technical reference manuals, performance standards, extended descriptions, etc. Can be referenced for presentation on screen or printed on demand.
  - Support documentation data may be stored as free text, formatted, or a combination of both.
  - Parts lists usually are formatted and within an integrated system are linked with the inventory management module for data validation.
  - Operational data such as hour meter or temperature readings may be captured in this module to allow usage information to trigger the need for maintenance work or inspection.
  - Tracks failure information at the asset system/subsystem level through information entered when closing work orders and provides capability to compute various key performance indicators.
  - Tracks detailed cost history data by type of cost associated with asset system/subsystems.
- *Planning and scheduling:*
  - Manages the detailed planning of the labor, materials, and all other resources needed to complete a work order.
  - Permits defining and sequencing the specific job steps, identifying the required craft labor types, determining estimated times, as well as all other resources, such as special tools and equipment, contract services, etc.
  - Planned work orders for which all planned resources are available may then be scheduled. This may be a separate module or part of the work order/work-management module.
  - Provides ability to allocate and level craft resources for individual jobs as well as larger projects.
  - Supports building a schedule that includes corrective, preventive, and predictive work in a future period. Allows performing availability check on one or more work orders before issuing a final schedule.
- *Preventive maintenance/predictive maintenance (PM/PdM) module:*
  - Manages work orders for predefined repetitive and rigidly scheduled PM tasks to preserve good equipment condition.

- Opens and edits work orders and automatically schedules and records when jobs are completed. Jobs done under PM usually include inspections, lubrications, and changes of finite-lifetime items such as filters or seals.
- An important assignment of PM is discovering needed corrective work, which results in writing the required work order and creating a planned job to make the correction.
- PM may exist as a separate module or be a subfunction within the work order module.
- Allows for links to process control or PdM systems to obtain critical readings and determine current conditions that initiate actions such as an inspection work order or a troubleshooting call.
- Predictive readings are interpreted by software/hardware devices to determine whether a problem exists and what is its nature. If a problem is found, a corrective work order is written for the needed work. Any or all parts of this process may be automated.

- *Inventory management module:*
  - Manages MRO parts and materials inventory with the necessary record keeping of items received, stocked, and dispersed as well as their locations in the stockroom.
  - This module provides the information needed for managing the stock of parts and materials used in performing maintenance work in multiple stockrooms.
  - Provides data showing what items are to be ordered, what are available, and what are on order. Data in this module are directly supportive of the planning and scheduling effort.
  - This module is typically integrated with the purchasing module to fully support MRO procurement.
  - Warranty information and records may be included as a separate module or within this module, coded by vendor with description of warranties and warranty coverage. May include printing of exception reports, warranty claims and follow-up information.
- *Procurement/purchasing module:*
  - This module provides the mechanism to ensure that proper resources of stock material, non-stock items, raw materials, and outside services are available in an adequate manner to ensure adequate planning of maintenance work.
  - Provides for the creation and processing of purchase orders. This module manages the purchasing function, beginning with the automatic creation of a purchase order when the reorder point of a stock item is reached.
  - Data include a list of primary and alternative vendors and prior purchase history information along with vendor performance.
  - Reports available would include current items on order, delivery status, and vendor status and history.
  - May include processes to manage quotations, provide invoice matching, and manage blanket orders and service contracts.
- *Budgeting and cost:*
  - Development and management of cost estimates and budgets for maintenance projects and their distribution to various other operating departments.
  - Data managed in this module would include the details of the maintenance budget and provide current cost experience at cost center, project number, equipment location, system/subsystem level, etc.
  - Reports would be designed and used for control of maintenance expenses, charge-backs to customers, and/or activity codes, variance reporting, etc.
  - This module may be structured for easy linkage and distribution of applicable costs to the general ledger.
- *Project management:*
  - Typically works in conjunction with the work management module for grouping of work orders into specific projects. Where more than one work order is needed to describe a job, grouping as a project is convenient and helps to ensure that all jobs will be done.
  - May offer the ability to time-phase a job and to do sophisticated interactive planning for needed resources such as labor, materials, and production facilities.
  - Provides ability to manage projects from a capital project or a larger-scale construction management point of view.

- *Standard maintenance procedure/job library:*
  - A compilation of standard maintenance repair procedures to be used on work orders for specific jobs. The sequence of job step activities, labor requirements, parts, and materials required are listed, along with special permitting and safety requirements.
  - Serves as a valuable guide to work order planning for larger jobs and is updated whenever a standard repair procedure is changed or created.
  - May include a library of standard times needed to perform specific maintenance tasks. This can be used in planning the estimated time to perform the repair job steps.
- *Personnel:*
  - Provides complete management of in-house crafts personnel as well as contract individuals.
  - Maintains a roster of available employees, their skills, and their training for job-assignment purposes.
  - Maintains a history of where employees have worked for compliance with quality and safety programs.
  - Union agreement restrictions on assignments and past assignment histories, would also be used for scheduling of the work force.
- Data within the personnel module could be shared with, and in some cases updated by, other enterprise systems, such as payroll, labor reporting, safety, and contract management.

These basic modules provide the foundation for an effective maintenance management system. Many other system functions are offered, depending on the CMMS sophistication and intended application. CMMS software packages are now being sold by more than 300 vendors for applications on personal computers, minicomputers, and mainframes.

It is very important that a CMMS/EAM be viewed as an information technology tool for more effective maintenance management and not as a panacea that provides a quick fix. Effective installation of a CMMS/EAM is a maintenance best practice that must be tailored to the specific needs of each unique maintenance operation. Implementing a CMMS/EAM also forces the issue for applying other maintenance best practices.

An effective CMMS/EAM requires that a work order system be in place for control of work requests, monitoring of backlogs, control of maintenance labor, maintaining equipment history, and so on. Full utilization of the basic CMMS/EAM modules requires a sound commitment to establishing best practices for PM/PdM, maintenance planning and scheduling, and maintenance storeroom inventory management.

6.3. Benchmarking the CMMS/EAM Installation

Today's information technology for computerized maintenance management offers the maintenance leader an exceptional tool for managing and controlling the maintenance process as an internal business and profit center. However, maintenance surveys and benchmark evaluations conducted by Tompkins Associates and others validate that poor utilization of existing CMMS/EAM systems is a major improvement opportunity.

6.3.1. The CMMS Benchmarking System

To help improve utilization of this information technology for maintenance, many things were needed, especially a tool for benchmarking the actual CMMS/EAM installation. There was a real need to see how well the systems were working, and being utilized in the real world of maintenance management and control. There was also the requirement to validate benefits expected to reach the projected ROI. These needs, in turn, led to the development of the CMMS Benchmarking System by Tompkins Associates in 1997. It is designed as a methodology for developing a benchmark rating of an existing CMMS (Class A, B, C or D) to determine how well this tool is supporting best practices and the total maintenance process. The system is not designed to evaluate or rate levels of CMMS functionality or to compare vendors of various systems (Peters 1999).

The CMMS Benchmarking System can also be used as the process to benchmark the future success of a CMMS system that is now being installed. It can be very easily tailored to include more advanced CMMS functionalities included with a large, multisite installation. By benchmarking an existing CMMS/EAM installation, it can be determined if the operation is receiving the maximum benefits possible from their investment.

The CMMS Benchmarking System includes a total of nine evaluation categories, along with 50 specific evaluation items. The major categories and evaluation items per category are as follows:

Benchmark Evaluation Category	Evaluation Items
CMMM data integrity	6
CMMS education and training	4
Work control	5
Budget and cost control	5
Planning and scheduling	7
MRO materials management	7
Preventive and predictive maintenance	6
Maintenance performance measurement	4
Other uses of CMMS	6
Total evaluation items	50

6.3.2. The CMMS Benchmarking System Rating Process

Each evaluation item that is rated as being accomplished satisfactorily receives a maximum score of 4 points. If an area is currently being "worked on," a score of 1, 2, or 3 points can be assigned, based on the current level of progress being achieved. For example, if spare parts inventory accuracy is 92%, compared to the target of 95%, a score of 3 points is given. A maximum of 200 points is possible. A CMMS rating of "Class A" is within the 180–200-point range, or 90% + of total possible points. The complete CMMS Benchmarking rating scale is shown below:

CMMS Benchmarking Rating Scale	
Class A	180–200 points (90% +)
Class B	140–179 points (70%–89%)
Class C	100–139 points (50%–69%)
Class D	0–99 points (up to 49%)

6.3.3. Conducting the CMMS Benchmark Evaluation

The CMMS Benchmark Evaluation can be conducted internally by the maintenance leader or via an internal team effort of knowledgeable maintenance people. Other options include using support from consultants as an independent and objective maintenance benchmarking resource. Used by over 4000 operations, the Tompkins Associates *Scoreboard for Maintenance Excellence has* proven to be today's most comprehensive benchmarking tool for evaluating the total maintenance process. In combination with a complete CMMS Benchmark Evaluation and implementing results from *The Scoreboard for Maintenance Excellence,* maintenance leaders in all types of operations can move toward greater value-added service to the customers of maintenance.

Complete copies of the CMMS Benchmarking System, along with *The Scoreboard for Maintenance Excellence,* are available for download from www.tompkinsinc.com or by calling 1-800-789-1257.

7. A REVIEW OF OTHER SELECTED MAINTENANCE BEST PRACTICES

Previous sections reviewed a number of best practices such as performance-measurement techniques, internal benchmarking, selection of metrics, assessment of the total maintenance operation and CMMS/EAM. This section will review eight more best-practice areas. Readers must remember that the scope of plant and facilities engineering is very broad and technical. The material presented in this chapter is the maintenance management piece; how to lead, manage and control the execution of maintenance. The sciences and technologies that underlie the practice of maintenance are found in publications such as the Maintenance Engineering Handbook (Higgins 1995) and in many other handbooks specifically related to mechanical, electrical and reliability engineering. The following best-practice areas can all contribute significantly to bottom-line results.

7.1. Continuous Reliability Improvement (CRI)

Continuous reliability improvement is the application of the traditional reliability centered maintenance (RCM) processes, using the best from total productive maintenance (TPM) and going beyond these traditional approaches to include all maintenance resources: equipment / facility, craftspeople / operators, MRO material management, and maintenance information resources. CRI includes effective team processes to create synergy and serve as people asset multipliers. CRI also includes maximizing the capability of the asset through comprehensive asset facilitation.

CRI, developed by Tompkins Associates, is a total maintenance operations improvement process to support the total operation. The CRI approach to leadership driven teams is defined in Tompkins (1998). CRI focuses team processes on continuous reliability improvement opportunities, considering:

- *Physical asset:* Use of reliability improvement technologies; reliability-centered maintenance, preventive / predictive maintenance, and knowledge-based / expert systems for maintenance of the physical asset. Asset facilitation to gain maximum capacity at the lowest possible life-cycle cost.
- *MRO material resources:* Effective maintenance repair operations (MRO) parts, supplies and materials for quality repair with effective storeroom and procurement processes.
- *Information resources:* Quality information resources for maintenance management and control from CMMS, EAM, ERP, vendor and customer.
- *Craft resources:* Quality skill improvement by people assets for the maintenance process to support customer service to the total operation.
- *Operator resources:* The added value of equipment operators instilled with pride in ownership at the most important level—the shop floor.
- *Synergistic team processes* as multipliers of people assets.

7.1.1. Asset Facilitation

This very comprehensive process is a component of CRI. It is conducted for critical assets and, typically, discrete manufacturing equipment. The objective is to maximize the capability of the asset to perform its primary functions. It takes a complete look at the requirements for maintenance, set-up, operations, changeover and shutdown, and documents these into standard operating and maintenance procedures. The results of a typical asset-facilitation process would include the following:

- Development of a quality operations and maintenance guide for the asset that provides complete operating and maintenance guidelines, procedures, and documentation for:
  - Equipment safety and housekeeping requirements
  - Defining operator and extrusion departmental requirements for the 5S Process
  - Defining requirements for subsequent 5S evaluations and ratings
  - Asset documentation references and drawings, either manual or electronic medium, using electronic document imaging capabilities.
  - Preventive and predictive maintenance requirements
  - Setup / validation / changeover / operator inspection procedures
  - Start-up, operating, and shutdown procedures for the asset
  - Quality control requirements
  - Operator-based maintenance (OBM) tasks with details on:
    - Recommended operator-level PM tasks and lubrication services
    - Other well-defined maintenance tasks to be performed by the operators
    - Operator training and certification requirements; production; related tasks
    - Operator training and certification requirements for maintenance related (OBM) tasks
    - Develop visual management to support OBM and production operation tasks
    - Quality requirements for ISO / QS compliance

7.2. Preventive Maintenance

Preventive maintenance is an interval-based surveillance method in which periodic inspections are performed on equipment to determine the progress of wear in its components and subsystems. When wear has advanced to a degree that warrants correction, maintenance is performed on the equipment to rectify the worn condition. The corrective maintenance work can be performed at the time of the inspection or following the inspection as part of planned maintenance. The decision of when to perform the corrective repair related to PM inspections depends on the length of shutdown required for the repair (Tompkins 1998).

Consideration is given to the impact of the shutdown on the operation caused by the repair vs. how immediate is the need for repair. If it is judged that the worn component will probably continue to operate until a future repair can be scheduled, major repairs are postponed until they can be planned and scheduled.

Periodically, a preventive maintenance inspection is made. If the inspection reveals serious wear, some maintenance operation is performed to restore the component or subassembly to a good state of repair, and reduce the probability of failure. A PM system increases the probability that the equipment will perform as expected without failure until the next inspection due date.

Determining the interval between inspections requires considering the history of maintenance for the equipment in each unique operation. Time between PM inspections (intervals) will ultimately be guided by a number of resources. These include manufacturer's recommendations, feedback information from repair history of breakdowns, and the subjective knowledge of the maintenance craftsmen and supervisors who daily maintain the asset. Equipment operators may also be a good source of information in some operations.

A central characteristic of preventive maintenance is that in most major preventive maintenance applications, the asset must be shut down for inspection. For example, a heat exchanger must be shut down and isolated when a nondestructive eddy current inspection is made on its tubes. The inspection process would require a discrete amount of downtime for the unit, which is typical for preventive maintenance.

The loss of operational time when significant preventive maintenance inspections are made is one of the reasons PM programs are often less than successful. This is especially true in applications where there are few redundant units and equipment must operate at 100% of capacity. In some situations the loss form shutdown is considered too high a penalty and preventive maintenance inspections are resisted.

7.3. Predictive Maintenance (PdM)

In contrast to preventive maintenance, predictive maintenance is a condition-based system. PdM measures some output from the equipment that is related to the degeneration of the component or subsystem. An example might be metal fatigue on the race of a rolling element bearing. The vibration amplitude produced by the rolling element as it passes over the degenerating surface is an indicator of the degree of severity of wear. As deterioration progresses, the amplitude of vibration increases. At some critical value, the vibration analyst concludes that corrective action should be taken if catastrophic failure is to be avoided.

Predictive maintenance usually permits discrete measurements that may be trended compared to some predefined limit (baseline) or tracked using statistical control charting. When an anomaly is observed, warning is provided in sufficient time to analyze the nature of the problem and take corrective action to avoid failure. Thus, predictive maintenance accomplishes the same central objective as preventive maintenance (Higgins 1995).

Confidence in the continued on-specification operation of the asset is increased. By early detection of wear, you can plan for and take corrective action to retard the rate of wear or prevent or minimize the impact of failure. The corrective maintenance work restores the component or subassembly to a good state of repair. Thus, the equipment operates with a greater probability of trouble-free performance.

The enhanced ability to trend and plot numbers collected from PdM measurement gives this method greater sensitivity than traditional preventive maintenance methods. The technique yields earlier warning of severe wear and thus provides greater lead-time for reaction. Corrective actions may be scheduled so that they have minimum impact on operations.

A principal advantage of predictive maintenance is the capability it offers the user to perform inspections while the equipment is operating. In particular, in order to reflect routine operating conditions, the technique requires that measurements be taken when the equipment is normally loaded in its production environment. Since the machine does not need to be removed from the production cycle, there is no shutdown penalty. The ability to conduct machine inspections while equipment is running is especially important in continuous operations such as in utilities, chemical, and petrochemical manufacturing.

Another advantage of predictive maintenance is that the cost of surveillance labor is much less than the cost of preventive maintenance activities. Although the technical knowledge required for predictive maintenance inspections is usually higher than that for preventive maintenance, the inspection time required per machine is much less. With predictive maintenance, the machines do not have to be disassembled for inspection. For example, with vibration analysis, 50 to 60 machines may be inspected in a single day using modern computer data collectors. When comparing cost advantages of predictive maintenance over preventive maintenance, consider production downtime costs, maintenance labor costs, maintenance materials costs, and the cost of holding spare parts in inventory.

If predictive maintenance methods are superior to preventive maintenance, why use preventive maintenance at all? The answer is simple. The nature of your operation will determine which methods are most effective. In actual practice, some combination of preventive and predictive maintenance is required to ensure maximum reliability. The degree of application of each will vary with the type of equipment and the percent of the time these machines are operating.

Pumps, fans, gear reducers, other rotating machines, and machines with large inventories of hydraulic and lubricating oils lend themselves to PdM surveillance methods. On the other hand, machines such as those that might be involved in high-speed packaging may be better inspected using traditional preventive maintenance methods. Machines that have critical timing adjustments, which tend to loosen and require precision adjustments, or that have many cams and linkages that must be reset over time lend themselves to preventive maintenance activities.

The strategy for selecting the appropriate or predictive approach involves the following decision process:

- Consider the variety of problems (defects) that develop in your equipment.
- Use the predictive method if a predictive tool is adequate for detecting the variety of maintenance problems you normally experience. One or a combination of several predictive maintenance methods may be required.
- Use preventive maintenance if it is apparent that predictive maintenance tools do not adequately apply. Inspection tasks must be developed that reveal the defects not adequately covered by preventive maintenance.
- After you have decided the combination of inspection methods, determine the frequency at which the particular inspection tasks must be applied.

Some equipment will be satisfactorily monitored using only predictive maintenance. Other equipment will require preventive maintenance. Ultimately, some combination of methods will provide the required coverage for your operation to assure reliable performance. In most operations, it is wise to apply a combination of methods to ensure that equipment defects do not go undetected. The following provides a brief summary of some of the leading predictive maintenance technologies.

7.3.1. Vibration Analysis

Today, electronic instrumentation is available that goes far beyond the human limitations with which the old time craftsmen had to contend when trying to interpret vibration signals with a screwdriver-handle-to-the-ear method. Today's instruments can detect, with accuracy and repeatability, extremely low-amplitude vibration signals. They can assign a numerical dimension to the amplitude of vibration and can isolate the frequency at which the vibration is occurring. When measurements of both amplitude and frequency are available, diagnostic methods can be used to determine the magnitude of a problem and its probable cause. When you use electronic instruments in an organized and methodical program of vibration analysis, you are able to:

- Detect machine problems long before the onslaught of failure
- Isolate conditions causing accelerated wear
- Make conclusions concerning the nature of defects causing machine problems
- Execute advance planning and scheduling of corrective repair so that catastophic failure may be avoided
- Execute repair at a time that has minimum impact on operations

7.3.2. Shock Pulse

Shock pulse is a method of surveillance that is specific to rolling element bearings. Since rolling element bearings (sometimes referred to as antifriction bearings) are so common in machines, the method has many applications. A secondary but important feature of the shock pulse method is that it permits maintenance workers to judge the adequacy of the lubrication program applied to this type of bearing.

7.3.3. Spectrometric Oil Analysis

Oil in machines carries the products of deterioration resulting from wear and mechanical failure. Analyzing the oil resident in a machine or the debris the oil carries allows predictions to be made about the state of health of the machine. The critical measurement reflecting the condition of machine wear is the number of microscopic metal wear particles that are suspended in the oil system of the machine. The spectrometric oil analysis process is a laboratory technique that uses various instruments to analyze a used oil sample from a machine. The spectrometric result is compared to a baseline level of metal found to be typically suspended in the oil under normal operating conditions. When the wear is meaningful, the sample will show high levels (in parts per million) of wear metals compared to the baseline oil sample.

7.3.4. *Standard Oil Analysis*

In addition to the spectrometric analysis, the oil laboratories also check the oil using common oil-analysis techniques. For example, the oil is usually checked for viscosity. Other types of standard oil analysis might include total acid number, percent moisture, particle count (for hydraulic systems), total solids, or percent silicon (representing dirt from the atmosphere in the form of silicon dioxide or perhaps just from an additive).

7.3.5. *Ferrographic Oil Analysis*

Ferrography provides the maintenance manager with two critical sets of decision support information: condition monitoring, which prevents unnecessary maintenance, and precise trend information, which allows maintenance to initiate repairs before equipment failure. This is accomplished by the analysis of wear particles in lubricants to determine their size, distribution, quantities, composition, and morphology (form and structure).

Ferrography is a technique that provides microscopic examination and analysis of particles separated from fluids. Developed in the early 1970s as a predictive maintenance technique, it was initially used to precipitate ferrous wear particles from lubricating oils magnetically. This technique was used successfully to monitor the condition of military aircraft engines. That success has led to the development of other applications, including testing of fluids used in vacuum pumps within the semiconductor industry.

7.3.6. *Infrared Thermography*

The use of infrared thermography has grown significantly in the past 10 years. Equipment is easier than ever to use and more effective. The real power of thermography is that it allows quick location and monitoring of problems. It then presents critical decision-making information in *visual* form, making it easy for management to understand. Infrared imaging systems, as they are generally called, produce a picture, either black and white or color, of the invisible thermal patterns of a component or process. These thermal patterns, when understood, can be used to monitor actual operating conditions of equipment or processes.

For instance, viewing a thermogram (heat picture) can clearly show the heat of a failing bearing or a pitted contact on a disconnect switch. Today's sophisticated imaging equipment is capable of acquiring a thermal video. This allows us to see *dynamic* thermal patterns of a casting process or a belt wear pattern in real-time, for instance. When teamed with the power of computer-based analysis systems, it can go one step further to compare and trend the critical thermal changes that often precede equipment failure or loss of production quality.

Thermography can be used to quickly locate and prevent recurrence of many equipment and process problems, such as:

- Catastrophic electrical failures
- Unscheduled electrical outages or shutdowns
- Chronic electrical problems in a piece of equipment or process
- Excessive steam usage
- Frozen or plugged product transport lines
- An inability to predict failures accurately
- Inefficient use of downtime maintenance opportunities
- Friction failures in rotating equipment
- Poor product quality due to uneven heating or cooling or moisture content
- A fire in a wall or enclosed space
- Inability to locate or verify a level in a tank
- Replacement of refractory in a boiler, furnace, or kiln
- A leaking flat roof
- Uneven room temperatures affecting product quality or employee productivity
- Trouble locating underground water, steam, or sewer lines

7.3.7. *Ultrasonic Detection*

A variety of tools using airborne ultrasound technology (commonly called ultrasound) have revolutionized many maintenance programs, allowing inspectors to detect deteriorating components more accurately before they fail. Ultrasound, by definition, is beyond the limits of normal human hearing, so an inspector uses a sophisticated detector to transpose ultrasonic signals to the range of human hearing.

Fluid and gas systems and other working machinery have constant ultrasound patterns. Changes in the "sonic signatures" can be recognized as wear in components. An ultrasonic detector senses such subtle shifts in the signature of a component and pinpoints potential sources of failure before they can cause costly damage.

7.4. Maintenance Storeroom Operations and MRO Materials Management

Maintenance repair operations (MRO) parts, materials, and supplies are the key material resources necessary for the execution of the maintenance process. Often the physical storage, control, and procurement of MRO items is never recognized for its value to the total operation. The effective operation of a maintenance storeroom is a cornerstone for maintenance excellence, but it is often a neglected area for management attention.

Best practices for maintenance storeroom operations parallel those for a finished goods warehouse in some cases but nonetheless are distinctively different. For more information on storage and warehousing, material and information handling systems, and warehouse management, readers should also refer to the respective chapters for these best practices that have general application to the maintenance storeroom operation. The following key strategies should be applied to the maintenance storeroom operation (Newhouse 1999):

- *Professionalism:* The company needs to view the maintenance storeroom as an important activity and not as a necessary evil. Both the dollars invested in maintenance storeroom materials and the impact of downtime have highlighted the need for a more professional approach to maintenance storerooms.
- *Customer awareness:* Successful maintenance storerooms will have a high regard for the customer, will know the customer requirements, and will consistently meet these requirements. The right materials will be available at the right time, in the right quantity, at the right location.
- *Measurement:* The maintenance leader will establish storeroom standards, performance will be measured against these standards, and timely actions will be taken to overcome any problems. Performance reports will be distributed to management on a monthly basis.
- *Operations planning:* Systems and procedures will be put into effect that allow the storeroom manager to plan the storeroom operations proactively as opposed to responding reactively to external circumstances.
- *Materials planning:* Systems and procedures will be put into effect that will assure having the right materials on hand in the right quantity at the right time. The materials-planning systems will provide for good inventory rotation, a minimum of stock outs, the elimination of obsolete materials, and the addition of new items, when new equipment and systems are installed.
- *Centralization:* The trend will be towards larger, centralized storerooms with responsive material-delivery systems instead of smaller, decentralized storerooms to which people travel and where they wait for required materials.
- *Adaptability:* Maintenance storeroom facilities, operations and personnel must become more adaptable. The pace of the storeroom will continue to increase: reduction of lead times, shorter equipment lives, increased inventory turns, more SKUs, and more customer demands require that storeroom adaptability be present to satisfy customers.
- *Uncertainty:* All uncertainty must be minimized; all interactions with the maintenance storeroom must be based on meeting expectations. No surprises.
- *Integration:* The activities within the maintenance storeroom will be integrated (from storeroom item identification to item issue), and the maintenance storeroom will be more integrated with the overall organization.
- *Material control:* Maintenance storeroom facilities, procedures, and systems will be designed to provide for the control of all materials. The importance and enforcement of maintenance storeroom security will be widely understood and accepted.
- *Maintenance information system:* The maintenance information system will support exceeding customer expectations. The information system will include the maintenance catalog system and the management of inventory.
- *Inventory accuracy:* Cycle counting will be used to manage inventory accuracy, and accuracy above 98% will be the norm.
- *Space utilization:* Space will be more efficiently and effectively utilized.
- *Housekeeping:* Quality housekeeping will be a priority. There will be an acceptance of that fact that there is efficiency in order.
- *Human resources:* A priority in the maintenance storeroom will be establishing a positive culture and the training and education required to achieve quality maintenance.

- *Team players:* Everyone associated with the maintenance storeroom and MRO procurement functions within the organization must be integrated into a single service-providing activity.

7.4.1. Storeroom Inventory Management

It is also important to establish an inventory planning methodology. As part of this, a determination must be made of what to stock, what the inventory policy will be, and how the inventory will be managed. A bar coding system could be just the solution for improving accountability and accuracy. This would be just one part of a strategic plan to introduce many new technologies for a major upgrade of the maintenance storeroom.

Inventory accuracy is a must for a maintenance storeroom. It must have 98% or better accuracy. If not, the craftspeople will bypass the storeroom to order a new part. It is critical that they have confidence in the accuracy. In order to attain this level of accuracy, it is necessary to cycle count. Timely detection of errors and correction of causes for the errors are essential to good control. All storerooms must have a proper cataloging system as a permanent record of all storeroom items and as a tool for identifying and locating items.

A maintenance storeroom strategic master plan is a prerequisite for success. There is efficiency in order. We must know what is to be done and what is the proper order to do it. It all starts with a plan, and successful planning requires teamwork.

7.5. Planning and Scheduling

Planning for maintenance excellence requires planning at the strategic level and the shop-floor level. This section introduces the need for implementing the maintenance best practice for planning and scheduling at the operational, shop-floor level. Surveys consistently show that only about 30–40% of an eight-hour craft day is devoted to actual hands-on wrench time. Without effective planning and scheduling, maintenance operations continue to operate in a reactive, fire-fighting mode, wasting their most valuable resource: craft time. Gambling with maintenance costs is not an option for today's organization that wants long-term survival and profitability. Achieving world-class status requires a world-class maintenance operation. World-class maintenance requires strategic planning, especially at the shop-floor level. The effective planning and scheduling of the most valuable maintenance resource, craft skills and labor, can provide an important step forward in a strategic maintenance plan.

Effective planning and scheduling improves the overall craft effectiveness (OCE) factor, which focuses upon measuring and improving the value-added contribution that people assets make to total asset management. There is also a very real concern within many areas of the United States and the world about the availability of craft skills. Technical resources and craft skills are terrible things to waste because they are so hard to find and keep. A review of the three key elements for measuring OCE shows how they very closely align with the three elements for determining the OEE factor for equipment assets.

7.5.1. The Overall Craft Effectiveness (OCE) Factor

Measuring and improving overall craft effectiveness (OCE) is one of the key benefits from maintenance planning and scheduling. The OCE factor includes three key elements very closely related to the three elements of the OEE factor.

Overall Craft Effectiveness (OCE)	Overall Equipment Effectiveness (OEE)
Craft utilization (CU)	Availability/utilization
Craft performance (CP)	Performance
Craft methods and quality (CM&Q)	Quality

7.5.1.1. Craft Utilization The first element of the OCE Factor is craft utilization, which measures how *effective* we are in planning and scheduling craft resources so that these assets are doing value-added, productive work. Craft utilization is about wrench time. Effective planning/scheduling within a proactive maintenance process is key to increased wrench time and craft utilization. It's having the right part at the right place in time to do scheduled work with minimal nonproductive time on the part of the craftsperson or crew assigned to the job. Craft utilization is expressed simply as the ratio of:

$$\frac{\text{total productive (wrench time)}}{\text{CU\%} = \text{total craft hours available/paid} \times 100}$$

Improving craft utilization provides additional craft capacity in terms of total productive craft hours available It is gained value and additional equivalent hours that can be used to reduce overtime, devote to PM/PdM, reduce the current backlog, and attack deferred maintenance, which doesn't go away.

Even if an operation does nothing to improve the other two elements of OCE (craft performance and the craft methods and quality level), significant tangible benefits can be realized with improving wrench time and craft utilization. An improvement of from 20–30% in craft utilization can typically be expected from effective maintenance planning and scheduling.

For the 30-person craft workforce, operating at 40% craft utilization, a 10% gain in wrench time hours represents a 25% increase in craft labor capacity from baseline performance. With only a 10% increase in craft utilization for a 30-person craft workforce, more than a 5:1 return can be achieved to offset a maintenance planner position, and implementation of planning and scheduling.

7.5.1.2. Craft Performance The second key element affecting overall craft effectiveness is craft performance. This element relates to how *efficient* we are in actually doing hands-on craftwork when compared to an established planned time or performance standard. Craft performance is directly related to the level of individual craft skills and overall trades experience, as well as the personal effort of each craftsperson or crew. Effective craft skills training and technical development contribute to a high level of craft performance. Craft performance (CP) is expressed as the ratio of:

$$\frac{\text{total planned time (hours)}}{\text{CP\%} = \text{total actual craft hours required} \times 100}$$

An effective planning and scheduling function requires that reasonable estimates and planning times be established for as much maintenance work as possible. Since maintenance work is not highly repetitive, the task of developing planning times is more difficult. However, there are a number of methods for establishing planning times for maintenance work, as outlined in Section 5.

Planning times are essential. They provide a number of key benefits for the planning function. First, they provide a means to determine existing workloads for scheduling by craft areas and backlog of work in each area. Planning times allow the maintenance planner to balance repair priorities against available craft hours, and to establish repair schedules realistically that can be accomplished as promised. Secondly, planning times provide a target or goal for each planned job, that allows for measurement of craft performance. Here we are not as concerned with measuring individual craft performance but rather with the overall performance of the craft workforce as a whole. Individual craft performance can be determined by comparing the group performance to individual performance over a period of time. Training needs are normally identified when individual craft performance is consistently below the group norm.

7.5.1.3. Craft Methods and Quality Level The third element affecting overall craft effectiveness relates to the relative level of the methods being used, considering personal and shop tools, special shop equipment, shop work areas, repair methods, and so on, as compared to current state-of-the-art methods. This element can include call-backs, where the poor quality of the initial repair requires another trip to fix it right the second time. Typically, the CM&Q element is a more subjective value, and is not determined based on actual data such as craft utilization and performance. However, the craft methods and quality level do affect overall craft labor productivity. The overall craft effectiveness factor is determined by multiplying each of these three elements:

$$\begin{array}{lccccc} \text{OCE} = & \text{CU\%} & \times & \text{CP\%} & \times & \text{CM\&Q\%} \\ & \text{craft} & \times & \text{craft} & \times & \text{craft methods and quality} \\ & \text{utilization} & & \text{performance} & & \text{level} \end{array}$$

Due to the subjective nature of determining the value of craft methods and quality, this element is typically not used, but it is still an important part of effective planning and scheduling. One key part of planning is determining the scope of the repair job and the special tools or equipment that might be required. A continuing concern of the maintenance planning function should be on improving existing repair methods, whether by using better tools, repair procedures, or diagnostic equipment. Providing the best possible tools, special equipment, shop areas, and repair procedures is a key contributor to improving craft performance and craft morale. It should be recognized that the value for craft methods and quality is subjective. The overall craft effectiveness Factor is best determined by:

$$OCE = \text{craft utilization} \times \text{craft performance}$$

7.5.2. Getting Started with Planning and Scheduling

Select from within the maintenance workforce the best-qualified candidate possible. Normally 1 planner per 25–30 craft personnel is sufficient. The planner position requires knowledge of existing equipment repair needs and a strong craft skill background. It also requires new skills for planning/scheduling, estimating, parts coordination, computer use, personal relations, customer service, and so on. Sufficient time must be invested in formal training of the planner(s), and for on-the-job training to get the planning function off to a smooth start. Since the planning function is often the focal point for successful CMMS utilization, planners must understand all functions of the CMMS and be capable of helping to train others in the organization.

7.5.3. Focus on Customer Service

The ultimate success of maintenance planning and scheduling will be determined by whether or not the customer is satisfied. All preliminary work to develop a plan and coordinate the scheduled repairs is wasted if execution of the schedule does not occur as promised. The customer (operations) will determine the true success of the planning process. The entire maintenance workforce must understand their service role to operations. As a formal planning process is implemented, an increased focus on customer service must be established. Operations will expect better service and maintenance must commit to providing it.

7.5.4. Measure Effectiveness of the Planning Function

The planning function should provide the focal point for measuring overall maintenance performance. However, the measurement process should start within the planning function. Planning requires an investment in staff resources. Develop and use performance measures to evaluate the return on investment and the effectiveness of the planning function.

7.6. Reliability-Centered Maintenance

7.6.1. The Evolution of Reliability-Centered Maintenance

In the early 1960s, the developmental work for reliability-centered maintenance was done by the North American civil aviation industry. During that period, the airlines began to see that many of their maintenance philosophies were not cost effective. But most importantly, they did not achieve the best possible conditions for safety. The airline industry then put together a series of Maintenance Steering Groups (MSGs) to reexamine all aspects of their aircraft maintenance operation. Representatives from the aircraft manufacturers, the airlines, and the Federal Aviation Authority were members of the MSG team. The Air Transport Association completed the first attempt at formulating maintenance strategies in 1968. Known as MSG 1, this document was later refined to MSG 2 in 1970.

In the mid-1970s, the U.S. Department of Defense commissioned a report by Stanley Nowlan and Howard Heap of United Airlines (Nowlan and Heap 1978) to define state-of-the-art strategies for maintenance within the airlines industry. It is still one of the most important documents in the history of physical asset management.

A considerable advance in thinking, well beyond MSG 2, was achieved in Nowlan and Heap's report. It was used as a basis for MSG 3 in 1980, which was revised in 1998 (Rev 1) and in 1993 (Rev 2). It is still used to develop prior-to-service maintenance programs for new aircraft types such as the Boeing 777 and the Airbus 330/340.

Nowlan and Heap's report and MSG 3 have since been used as a basis for various military RCM standards and for nonaviation-derivative programs with acronyms such as FMECA, MSG3, TPM, RCA, RBI, and RCM2. Continuous reliability improvement (CRI), developed by Tompkins Associates, uses the best from RCM, TPM and the total operations approach to leadership-driven teams, as defined in Tompkins (1998).

7.6.2. Overview of the RCM Process

The key elements of the RCM process include the following:

- Analysis and decision on what must be done to ensure that any physical asset, system, or process continues to do whatever its users want it to do. Includes essential information gathering.
- Define what users expect from their assets in terms of primary performance parameters such as output, throughput, speed, range, and carrying capacity.

- As applicable, the RCM 2 process defines what users want in terms of risks, process and operational safety, environmental integrity, quality of the output, control, comfort, economy of operation, customer service, etc.
- Identify ways in which the system can fail to live up to these expectations (failed states) and failure consequences.
- Conduct failure modes and effects analysis (FMEA) to identify all the events that are reasonably likely to cause each failed state.
- Identify a suitable failure management policy for dealing with each failure mode in the light of its consequences and technical characteristics. Failure management policy options include:
  - Predictive maintenance
  - Preventive maintenance
  - Failure finding
  - Changing the design or configuration of the system
  - Changing the way the system is operated
  - Run-to-failure (if preventive tasks not found)

7.7. Total Productive Maintenance

Total productive maintenance (TPM) is a maintenance-improvement program concept and philosophy that resembles total quality management (TQM). The TPM movement has excellent objectives:

- Zero unplanned downtime
- Zero defects
- Zero machine capacity losses
- Zero accidents
- Minimum life-cycle asset care cost

It requires a total commitment to the program by upper-level management and employees to be empowered to initiate corrective action. It is a long-term strategy, so a long-range outlook must be accepted. TPM may take more than a year to implement and is an ongoing process. Changes in employee mindset toward their job responsibilities must take place as well. TPM brings maintenance into focus as a necessary and vitally important part of the business. It is no longer regarded as a nonprofit activity.

To successfully apply TPM concepts to plant maintenance activities, the entire workforce must first be convinced that upper-level management is committed to the program. Typically, a TPM coordinator is hired or recruited to sell the TPM concepts to the workforce through an extensive training program. To do a thorough job of educating and convincing the workforce that TPM is just not another "program of the month" will take time, perhaps a year or more. Once the coordinator is convinced that the workforce is sold on the TPM program and that they understand it and its implications, the first study and action teams are formed. These teams are usually made up of people who directly have an impact on the problem being addressed. Operators, maintenance personnel, shift supervisors, schedulers, and upper management might all be included on a team. Each person becomes a stakeholder in the process and is encouraged to do his or her best to contribute to the success of the team effort. Usually, the TPM coordinator heads the teams until others become familiar with the process and natural team leaders emerge. The action teams are charged with the responsibility of pinpointing problem areas, detailing a course of corrective action, and initiating the corrective process. Recognizing problems and initiating solutions may not come easily for some team members. They will not have had experiences in other plants where they had opportunities to see how things could be done differently. In well-run TPM programs, team members often visit cooperating plants to observe and compare TPM methods and techniques and to observe work in progress. Publicity of the program and its results is one of the secrets of making the program a success. The initial stages of TPM will include taking the machine out of service for cleaning, painting, adjustment, and replacement of worn parts, belts, hoses, and so on. As a part of this process, training in operation and maintenance of the machine will be reviewed. A daily checklist of maintenance duties to be performed by the operator will be developed. Factory representatives may be called in to assist in some phases of the process. After success has been demonstrated on one machine and records begin to show how much the process had improved production, another machine is selected, then another, until the entire production area had been brought into a world-class condition and is producing at a significantly higher rate. This is one of the basic innovations of TPM. The attitude of "I just operate it!" is no longer acceptable. Routine daily maintenance checks, minor adjustments, lubrication, and minor parts change become the responsibility of the operator. Extensive overhauls and major breakdowns are handled by plant maintenance personnel, with the operator assisting in some cases.

7.8. Operator-Based Maintenance

Pride in ownership and the process of operator-based maintenance started early in American history. It is also a key element of TPM called autonomous maintenance. Operator-based maintenance is also a key element in the very successful and effective maintenance program of the U.S. armed services.

Operator-based maintenance began with the entrepreneurial spirit of the cottage industry in the U.S. free enterprise system. In most cases, the owners fixed the sawmills, the cotton gins, the printing presses, and the wagon wheels. Owners were the skilled crafts people working within a free enterprise culture and system. For many Americans, OBM started with Henry Ford's Model T, which came with tools—a crescent wrench, slip-joint pliers, screwdriver, and hammer, and so on—for the do-it-yourself repairs.

Early American culture did not normally employ the philosophy of ''I own—you fix—you operate.'' Back then it was an attitude of ''We are all responsible for the equipment.'' However simplistic it may have been prior to the industrial revolution, it was a matter of necessity and survival, just as it is in a combat zone.

Ironically, we have returned to the world-class attitude toward maintenance in many organizations, that being ''We are all responsible for our equipment.'' The key word in the TPM world-class attitude is ''our'': *our* equipment, not *the* equipment. These objectives can and will be achieved in varying degrees for organizations that include OBM as part of the total operations/maintenance strategy. The following is a basic strategy for developing successful operator-based maintenance:

- Start with an overall strategic maintenance plan, and include defined goals/objectives for OBM within this plan.
- Understand that OBM is a deliberate process for gaining commitment by operators toward:
  - Keeping equipment clean and properly lubricated
  - Keeping fasteners tightened
  - Detecting symptoms of deterioration
  - Providing early warning of catastrophic failures
  - Making minor repairs and being trained to do them
  - Assisting maintenance in making selected repairs
- Start with the first things first. Provide the necessary communication between maintenance operations and the rest of the total operation to gain the commitment and internal cooperation needed to start OBM.
- Clean the equipment to like-new condition, make minor repairs, and develop a list of major repairs for the future.
- Utilize leadership-driven, self-managed teams with whatever team names that evolve. For example, ''equipment improvement team,'' ''SWAT Team,'' or ''continuous reliability improvement team.''
- Develop a written and specific team charter.
- Avoid use of self-directed teams with no technical leadership ''driver'' for the process.
- Have teams evaluate/determine the best methods for operator cleaning, lubrication, inspection, minor repairs, and level of support during major maintenance repairs.
- Develop standard written OBM procedures for operators and include them in the quality operations and maintenance guide.
- Evaluate your current predictive and preventive maintenance procedures and include those that the operator can do as part of OBM.
- Document start-up/operating/shut-down procedures along with set-up/changeover practices.
- Consider quality control and safety requirements.
- Document operator training requirements and what maintenance must do for support.
- Develop operator certification to validate operator-performed tasks.

There are many organizational roadblocks to effective OBM. However, the roadblocks to the world-class attitude ''We are all responsible for our equipment'' exist only by self-imposed limitations we create by our attitude toward maintenance.

8. MAINTENANCE MANAGEMENT FOR THE NEW MILLENNIUM

A number of positive trends will occur within maintenance operations of the future. Just as the last 10 years of the 20th century saw extraordinary technological advances related to the physical asset, the use of CMMS/EAM, and the use of the computer and the Internet, the new millennium will see extraordinary advances. There will be a positive revolution within maintenance management, based upon four key principles from Tompkins (1998):

1. "Revolution is never a spur-of-the-moment decision. It is a process, and in a true scenario, a continuous process." Continuous reliability improvement and leadership-driven, self-managed teams will enhance the application of emerging new technologies.
2. "Although revolution is a grassroots effort, it is characterized by its leaders." Maintenance leaders will emerge to support the continuous improvement process at the grass-roots, shop-floor level. There will be a progression from maintenance manager to true maintenance leadership.
3. "A revolution cannot be managed, it must be led." An individual who is profit-centered yet understanding of the fact that people assets are the most important assets will lead new millennium maintenance. The evolution of a chief maintenance officer (CMO) will occur in both large and small operations. Successful maintenance leaders will be profit centered, establish strategic maintenance plans that are integrated with the business plan, and validate return on investment with effective measurement processes.
4. "A Revolution cannot be carried out by individuals, it must be a collaborative effort." The maintenance leader of the new millennium will recognize needs of the customer, serve the customer, and bring together all maintenance resources to maximize the value of maintenance. The synergistic effect of teams and collaborative interactions among individuals will be an additional resource and measurable gain in productivity.

8.1. The Emergence of the Chief Maintenance Officer (CMO)

The chief maintenance officer (CMO) will emerge as a recognized corporate leadership position. The CMO (or an equivalent) will be absolutely essential for long-term profitability in the new millennium and will eventually evolve into a recognized corporate position. The CEO/COO of a multisite operation that does not have a CMO accountable for physical asset management will be gambling with stockholder's equity. The small single-site operation without a CMO equivalent will realize the high cost of bad maintenance. The CEO must understand the state of maintenance in the operation and the physical asset management process. The emerging CMO with profit ability and effective leadership and technical skills will facilitate this process in larger multisite operations. The future capable company will require a proactive, capable CMO just as it needs a CFO, CIO and CEO.

8.2. Growth of Reliability-Improvement Technologies

New reliability-improvement technologies will continue to evolve and greater use of existing tools will occur. Greater use of radio frequency (RF) technology to support condition-based monitoring will occur. RF technology will enable mobile, timely, and vital communications with the mobile workforce of craftspeople.

Process-control systems will become more integrated with condition-based monitoring systems that in turn link to CMMS/EAM systems or even back to the condition-based equipment suppliers for real-time troubleshooting. Condition-based monitoring systems will eventually link data collection directly back to suppliers such as CSI, ENTEK, SKF, and others via the Internet or RF. Reliability data analysis by off-site reliability experts providing contract services will be as close as e-mail.

Information technology for the life-cycle information loop will be available. for critical assets from the internet, Intranets, and real-time data collection. The result will be "real information" on the shop floor. Information will be available to take life-cycle costing, equipment design/redesign, reliability improvement, and execution of maintenance to new levels. The craftsperson doing the repair will be in the life-cycle information loop with the OEM, subsystem and MRO providers, the asset designers, local engineering, the local asset-documentation sources, and the customers of maintenance.

A new generation of handheld computers, personal digital assistants (PDAs), and smart phones give the craftspeople their own terminal and will link them firmly to the network. Advances in voice recognition will make data collection on the shop much easier. All the necessary components are falling into place: price, performance, and communications. Since these devices are Internet capable, they will be much easier to integrate into a Web-based EAMS/CMMS package than earlier generations of handheld computers that required proprietary software.

8.3. The Role of the Internet

The use of the Internet will expand exponentially. Client/server solutions that became main stream in the 1990s have their drawbacks. From an IT standpoint, their "thick" client software is costly to deploy and support. They are difficult to integrate with other external applications. Their client software also tends to run on only one type of device, a desktop PC. Using development tools like

Java, software vendors are starting to provide solutions featuring "thin" client software or web browsers as their front end. These solutions draw their application services from centralized servers instead of megabytes of software installed on the desktop. Since they utilize the Web as a transport medium, they are much easier to integrate with the outside world. They can also support nondesktop PC devices such as handheld PDAs.

The top-tier EAMS/CMMS vendors will complete the process of developing new versions of their software, featuring a Web-centric architecture. Most of the industry will follow their lead in the coming years. They will do so because of the benefits that the technology has to offer.

8.4. MRO Materials Management

E-commerce will continue to expand, and direct links to the overall supply chain will enhance procurement of MRO parts/materials and services. E-procurement over the Internet with electronic purchasing is just too cost effective for both buyers and suppliers for it not to become the dominant MRO procurement method.

An integrated MRO supply chain management process began with MRO vendor websites as the start of this process. The creation of large trading networks of hundreds of vendors and the provision of EAMS/CMMS packages access to these networks will complete the equation. True point-and-click MRO purchasing, from requisition generation to order fulfillment, is going to be commonplace in both large and small organizations. Top-tier EAMS/CMMS vendors are now releasing e-procurement solutions and developing or joining the trading networks (Singer 2000).

8.5. The Growth of Contract Maintenance

Contract maintenance will continue to grow. The core requirement for maintenance will be even more important in the next millennium due to technology advances. Organizations will focus on core competencies. Some forget the core requirement for maintenance and also lose their core competencies to do effective maintenance. Profit-centered contract maintenance providers will consume internal maintenance operations that continue a cost-centered approach. In-house maintenance operations will continue to lose when they are unable to replenish and/or maintain their core competencies in maintenance.

Maintenance is forever. Maintenance of our bodies, minds, souls, cars, and computers and all physical assets providing products or services in today's global economy will always be required. Some organizations today have neglected maintaining their core competencies in maintenance to the point that they have lost complete control. The core requirement for good maintenance remains (forever), but the core competency to do good maintenance may be missing. In some cases, the best, and often only, solution is value-added outsourcing.

The neglect of the past and the future will be overcome by services from a growing number of profit-centered maintenance providers that clearly understand how to provide value-added maintenance service at a profit. Neglect of the past can also be overcome internally by the emergence of an internal CMO who can lead maintenance forward to profitability as if he or she owned the internal maintenance business.

9. CONCLUSION

This chapter helps to provide a firm understanding of the physical asset management and maintenance process and its important role. The contribution of maintenance to total operations success and profitability is now being more fully recognized. Effective maintenance and physical asset management are closely linked to enterprise wide performance success and profitability.

This chapter presented the 25 key requirements for maintenance success, as well as a review some of today's best maintenance practices. It outlined how the results of continuous maintenance improvement can be measured, reviewed methods for measurement, and showed how results and ROI can be validated.

There are many IE principles and practices that can support maintenance process improvement. The new and experienced IE, the engineering manager, the operations manager, and the CEO can now better understand the maintenance operation and how to improve mission-essential maintenance operations. The next step is to take action on the journey to maintenance excellence.

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