



# Property Risk Consulting Guidelines

XL Risk Consulting

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PRC.1.3.0.1

## MAINTENANCE PROGRAM ELEMENTS

### INTRODUCTION

Maintenance is the most important factor in equipment availability and reliability. Equipment can and should be properly designed for its purpose; carefully built, installed and protected; and skillfully operated. However, the day that equipment is installed, it begins to age. Foundations settle. Corrosion occurs. Ambient temperature changes loosen connections. Oxygen, humidity, heat and light degrade electrical insulation and other organic components. Placing equipment in service provides other stresses that accelerate aging.

Effective maintenance manages the aging process. Some maintenance activities, like cleaning and painting, lubricating, aligning and balancing, help slow aging by minimizing wear and corrosion. Other maintenance activities, like vibration and wear particle monitoring and analysis, on-site and replication metallography, and all forms of nondestructive testing, help detect the effects of aging. Still other maintenance activities, like repair and restoration, seek to reverse aging. A successful maintenance program minimizes aging-related costs.

PRC.1.3.0 describes maintenance philosophies that include breakdown, scheduled and predictive methods and describes how these philosophies might be applied in a complete maintenance program. This section discusses 21 maintenance program elements and characteristics that are found in successful maintenance programs in a variety of industrial facilities. It describes and supports functions that will deliver state-of-the-art maintenance, but it does not provide guidelines for specific facility types.

Maintenance program elements that loss investigations regularly find lacking are further discussed. To fully develop specific program elements, users will need more information. Sources for this information include textbooks, courses and consultants on principles of management and on maintenance.

Be skeptical and carefully examine resources before investing in them. Effective maintenance is not an easily-installed feature that will deliver immediate cost savings. Although names and buzzwords are generally public property, resources that espouse “total quality maintenance” (TQM), “reliability-centered maintenance” (RCM), “total productive maintenance” (TPM) and “planned and predictive maintenance” (PPM) tend to be safer choices than those that offer to immediately cut your maintenance budget.

Although buildings and other structures also age, this section does not deal directly with their maintenance needs. However, a soundly conceived and rigorously executed maintenance program can effectively and efficiently maintain structures as well as equipment.

Remember that maintenance excellence is not the ultimate goal. The ultimate goal is a loss-free, safe and profitable facility. In the present business environment, achieving that goal means competing

successfully with every similar facility in the world. A world-class facility cannot make world-class product unless it has a world-class maintenance program, because maintenance is a key contributor to quality as well as to reliability, availability and loss prevention. In addition, formal quality certification programs such as ISO 9000 require documented procedures for all activities, including maintenance.

## **POSITION**

Loss prevention and control programs cannot succeed without effective maintenance. Maintenance is Section 3 of *OVERVIEW*, the AXA XL Risk Consulting management program for loss prevention and control and PRC.1.3.0. Most losses, and also most accidents, happen during startups, shutdowns, upsets and emergencies. Effective maintenance helps minimize the number of startups, shutdowns and upsets and helps enable a facility to deal with emergencies. AXA XL Risk Consulting encourages effective maintenance because maintenance is a powerful loss control and safety-enhancing tool, however, effective maintenance is also a key to effective resource use. A facility with poor maintenance that wishes to upgrade its program may initially spend more on maintenance, however, good maintenance will in the long run save money.

Good maintenance is local. Although a good corporate maintenance program can greatly help an individual facility have good maintenance, local maintenance program effectiveness depends upon the skills and enthusiasm of the facility management or, in facilities with decentralized maintenance programs, upon the skills and enthusiasm of each production unit management or team. Therefore, maintenance program evaluation can be an important part of maintenance management. Maintenance program evaluation is further discussed in PRC.1.3.0.2.

## **Maintenance Decision Making**

Some facilities are new and have unlimited maintenance resources; others are not so new but have always had unlimited maintenance resources. Some corporate cultures explicitly embrace the long view and a proactive stance, and value maintenance people just as much as production people (all the time, not just when they respond effectively to a breakdown). Such facilities have no maintenance decision-making problems. However, equipment aging, shifting markets and competition or management changes might force hard choices upon them. Most facilities already have limited maintenance resources. All facilities should use risk-based analysis to help guide and support maintenance decisions.

## **Proactive vs. Reactive Maintenance**

Maintenance should be proactive. A typical standard for a well-maintained facility is for 85% of work to be performed proactively. Reactive or breakdown maintenance or “run to failure” does have a place, but in a well-maintained facility, that place is strictly limited to equipment that a formal risk analysis has identified as having acceptable business interruption and direct damage risks.

## **Deferred Maintenance And Maintenance Backlog**

Deferred maintenance is controlled in a well-run facility. A well-maintained facility will have at least 85% maintenance schedule compliance overall and at least 95% schedule compliance on preventive and predictive maintenance tasks. A well-run maintenance department will always hold its backlog within established lower and upper control limits, typically two and four weeks.

## **Contractors**

Thoroughly train contractors in and require that they comply with all facility loss prevention programs, such as hot work permitting and control, system isolation and inerting, confined space entry and lockout/tagout. Ensure that training costs and compliance requirements are part of the contract.

## **Maintenance Program Elements**

A maintenance program that is integrated with the facility mission, actively participates in that mission, and is proactive contains certain sub programs or elements. Not all of the listed elements will

be discreetly identifiable in every effective maintenance program, however, careful examination of any state-of-the-art maintenance program will reveal that all the elements are there. In small facilities, many people serving the maintenance function will necessarily “wear more than one hat.” All facilities, but especially smaller ones, need careful planning and carefully written procedures and job descriptions to avoid a slide into deferred maintenance and a purely reactive operational mode.

**Management Commitment**

Management commitment is the bedrock upon which any successful management program stands. Use an unequivocal statement of support signed by senior management to communicate this commitment throughout the facility. The statement of commitment may be part of the overall commitment to loss prevention and control described in *OVERVIEW* or it may be a free-standing document. Senior management must support the maintenance program not only in the material ways outlined in the following element descriptions but by regularly encouraging program efforts and by publicly recognizing maintenance’s role in the success of the facility mission.

**Cooperative Maintenance/Operations Partnership**

In recent years, an attitude has developed that maintenance exists to “serve” operations or production. This attitude cannot be tolerated in a well-managed facility. Senior management should treat maintenance and operations as equal partners in accomplishing the facility mission. Proactive maintenance depends upon operations to keep maintenance informed of its requirements and to bring problems to maintenance attention at the earliest manifestation. Operations need to trust maintenance to correct problems efficiently and in a timely manner; to “do the job right, the first time, on time,” consistently. Maintenance depends upon operations to make equipment available when proactive maintenance is needed. Operations depend upon maintenance to keep equipment capable of reliably producing quality product. None of this can happen except in a partnership.

Having a maintenance/production partnership clearly benefits quality. In a statistical quality control environment, product quality is maintained between upper and lower control limits. If there is a barrier between production and maintenance, whether because of management practice or because of production lack of faith in maintenance, problems are not reported to maintenance until quality degrades to the lower control limit. At that time, production effectively ceases and maintenance is faced with a reactive, or emergency job. In a proactive, partnering arrangement, operators bring quality problems to maintenance attention early enough in the aging/degradation process to allow maintenance to proactively correct the condition with minimal down time. The interfaces and responsibilities shown in Table 1 are typical for successful partnering arrangements.

**TABLE 1**  
**Typical Interfaces And Responsibilities**

Operations	Maintenance
Operate equipment properly	Provide effective support
Suggest and communicate priorities	Develop a responsive schedule
Anticipate repair work before jobs become emergencies	Develop a maintenance program that will address all levels of equipment needs
Have equipment ready for work when work is scheduled	Provide the labor, material, supervision and technical expertise to complete the job
Project future needs	Develop the master schedule
Assess the quality and timeliness of work performed	Feedback information on completed jobs

**Governing Principles and Concepts**

The maintenance department manifesto is the maintenance department mission statement; the commitment to act proactively, to be a full partner in the facility mission. The following statements should describe the facility approach to maintenance:

- The concept of operator custodianship is basic to facility philosophy.
- The maintenance department, through technically qualified knowledge and advice, is responsible for determining how to best satisfy maintenance needs.
- Process, equipment and facility maintenance responsibility is shared by all organizational units.
- Maintenance is a cornerstone of the operation. Management policy statements ensure that maintenance is an integral part of the operating strategy.
- Maintenance philosophies and functions, and information about how they support facility strategies, are communicated to all concerned departments.
- Operating and maintenance department primary and supportive responsibilities are clearly defined.
- Cooperation is excellent and mutual understanding is achieved. Important procedures, such as the work order system, welding and hot work authorization, fire protection and other protective equipment impairment reporting and management, and lockout/tagout are uniformly followed. (Section 1 of *OVERVIEW* [PRC.1.1.0]) describes a program for fire protection equipment impairment handling.)
- The proactive approach to maintenance is maintained, even when there is pressure to meet output targets.

### **Status Assessment**

The status assessment tells management how effectively maintenance programs are performing. The status assessment measures the maintenance function against concrete standards. It also needs to measure, against concrete standards, maintenance effectiveness in supporting the facility mission. This section provides a few suggested objective and subjective measures. PRC.1.3.0.2 contains more of these guidelines.

### **Objectives, Goals and Targets**

Maintenance objectives, goals and targets should be synchronized with the departmental mission statement and be consistent with the facility strategic and operational plans.

Objectives describe a desired state of organizational being. Some examples of maintenance department objectives:

- To continually reduce equipment downtime and increase equipment availability by establishing and implementing a preventive/predictive maintenance program designed, directed, monitored and continually enhanced by effective maintenance engineering.
- To ensure that work is performed efficiently through organized planning, optimal material support and coordinated work execution.
- To provide meaningful management reports that enhance control of maintenance operations and resource use.

Goals are quantitative, ultimate and strategic long-range aims. They must be attainable. Properly selected goals can be motivating as well as productive tools. In a team environment, goals should be set by the team.

Targets are short-term, quantitative milestones to be reached while progressing toward goals. Targets should be time-related, and should have defined individual or specified group responsibilities. For example, one measure of overall department effectiveness is “wrench time,” the percentage of time the average craftsperson spends productively working on an assigned job. A desirable target is 55%. Another measure is unscheduled equipment downtime. A suitable target is no more than 2%; significantly less for important equipment.

### **Master Plan**

The master plan defines the gap between the current conditions and the desired conditions and defines the short and long-range actions that are needed to close the gap. Master plan action items cover organizational, system, material, facility, equipment and procedural shortfalls.

Note that a large, effective and integrated management maintenance program requires about one year to install and another year or two of refinement and nurturing and continued pursuit of its ultimate goals and objectives before it is likely to be fully implemented and yielding its full potential.

The master plan should be acceptable to and adopted by all affected organizational units, and must have the active interest and support of the facility manager.

### **Budgetary Control**

Maintenance is neither a fixed nor a variable expense. It changes with volume in a stepwise pattern. This is because of the incremental nature of the staffing requirements of an effective maintenance department. Ironically, the maintenance staff percentage of total facility employment is likely to be largest, as high as 25%, in facilities that have up to 100 operating and maintenance employees. For facilities with 100 to 250 operating and maintenance employees, economies of scale drive the percentage down to about 12%. For larger facilities, the need for more specialized support staff brings the figure back up to the 18% range. Some details are provided in the discussion of organization.

Maintenance budgeting often requires more detailed information than the facility general accounting system can provide; therefore, coordination between the facility system and the work order system is needed. Historical data analyses modified to cover planned improvements and business volume changes will result in a realistic budget. Maintenance costs need to be segregated, by requesting production units to obtain volume variances, and by maintenance unit to obtain productivity variances, by equipment type and by cost center.

### **Management Reporting and Control**

Management uses maintenance reports to give direction, receive feedback, react and make corrections. Maintenance information includes decision-making information by which to manage the maintenance function as well as administrative information by which to handle personnel and accounting matters. Key maintenance reports include:

- Activity report — A weekly report of open work orders, sorted by priority and crew, which feeds the performance report, the backlog report and the work program. It also identifies departments that generate large numbers of urgent work orders.
- Distribution of labor by work type.
- Weekly performance report for each supervisor or crew.
- Weekly backlog report — Net remaining workload on all remaining work orders, sorted by crew and by originator.
- Work program — Compares the workload to the available labor resources; used to establish the overall work force level, balance crafts, plan for shutdowns, determine the available capacity to handle project work, and to decide if and when to use contract labor. Resources and work load must balance. If workload exceeds resources on an ongoing basis, the organization cannot become proactive.

Other typical reports include a schedule compliance report, predictive/preventive maintenance delinquency report, ratio of inspection to corrective maintenance, maintenance downtime by equipment, and administrative and budgetary reports.

### **Organization**

After the commitment to a proactive approach to maintenance, the maintenance organization and structure might be the single most influential factor in program success. An organization that is tacked as an afterthought low in the organizational chart is unlikely to ever obtain the respect and prestige

that it needs to deliver its promise. A poorly constructed organization will breed bureaucracy and frustration. A well-constructed organization will tend to synergise all that is positive. The following comments introduce a few key points.

The maintenance organization must address three essential functions: planned work preparation, supervised work execution and engineering dedication to repetitive failure elimination. There are several ways to organize a maintenance department that will deliver these functions, but AXA XL Risk Consulting recommends centralized maintenance leadership. A small portion of the resources can be assigned to specific production areas, but all maintenance personnel should remain under central leadership.

There are several reasons:

- The maintenance manager should be a dedicated professional, equal in status and level of authority to the production manager. This arrangement avoids having the maintenance manager routinely overruled by the production manager without equal access to senior management for appeal and adjudication.
- A centralized maintenance department is more likely to deliver uniform quality maintenance throughout the facility. When maintenance is decentralized, uneven levels of service often result. It is not very useful to have state-of-the-art maintenance in one step of an operation if another part of the same operation is always broken down. Poor maintenance in one of several linked facilities or in one unit of a single facility drags down the whole. No amount of quality on the part of the good performers can drive any more product through the bottleneck formed by the poor performer. Worse, the poor performer, by regularly providing unscheduled outages, deprives the good performers of any motivation to improve.
- If all maintenance is decentralized, vital central services, such as the main electrical distribution system, fire protection systems, and the plant air and water system, are easily neglected.

Another reason lies in the typical staffing ratios listed in [Table 2](#). A centralized department can much more easily justify and support the specialized staff needed by a large facility than can several decentralized units, all of which lack the essential critical mass. Specialized crafts may also be more easily supported and balanced when there is a large organization within which to work.

Regardless of the organization used, there should always be a current and complete organizational chart that clearly defines all maintenance department reporting and control relationships, and any relationships to other departments. The organization should clearly show responsibility for the three basic maintenance responses; routine, emergency and backlog relief.

### **Training**

A carefully planned and thoroughly documented continuous program of training is another key element in a successful management loss prevention program. Training is addressed by Section 4 of *Overview* (PRC.1.4.0) Here are a few key points and ideas specific to maintenance department needs:

Operators cannot possibly handle modern, complex equipment unless they are thoroughly trained and drilled in normal and emergency procedures. They cannot have the necessary awareness of off-normal and potentially dangerous conditions unless they are trained to recognize and report those conditions. Craftworkers are not kept up-to-date without training in the latest technologies. Vibration analysts, infrared thermographers, electrical insulation test apparatus operators — none of these become skillful and effective without training and practice. Planners and schedulers cannot provide sound estimates and ensure all resources are available for all jobs without training. Supervisors and managers cannot be effective leaders and motivators without training. And contractors cannot work safely in a complex facility without training, including site-specific procedures and rules.

Anyone who does maintenance work needs at least an indoctrination or awareness-level training course in safety-related matters such as hot work, proper mechanical and electrical isolation procedures, and lockout/tagout. The course could also address initial response procedures for

dangerous conditions such as fires and leaks or spills of any hazardous materials present at the facility. See *OVERVIEW* Section 7 (PRC.1.7.0), “Pre-Emergency Planning,” for more information.

**TABLE 2**  
**Typical Maintenance Department Span Of Control Ratios**

Support Staff	Ratio to Mechanics (range)
Supervisors	1:10 (8 to 15)
Planner/schedulers	1:20 (12 to 30)
Maintenance Engineers	1:40 (40 to 70)
Maintenance Clerks	1:40 (20 to 55)
Training Coordinator	1:80
Composite	1:5
Planner, contract administrator or project engineer	Each \$1,000,000 of outside contracts

Everyone in the maintenance organization needs general instruction in the organizational structure and in its mission, targets, goals and objectives. Each functional and organizational unit needs in-depth instruction in its specific mission. Operating and support management, supervisors and personnel need a course in maintenance appreciation and in any specific maintenance tasks in which they share responsibility.

**Supervision and Practices**

Good supervision, the art of getting average people to do superior work, is an essential part of maintenance. Whether within a traditional organization or one oriented toward self-directed teams, certain supervisory functions need attention in any successful maintenance department. Some of those key functions are:

- Point contact for production; an easily contacted, good communicator who is receptive to suggestions and new ideas, and has an appreciation for urgent needs yet has the vision to understand conflicting needs and the wisdom to balance them.
- Jobsite safety monitor, counselor, arbitrator, quality control monitor and troubleshooter.
- “Learning leader;” able to recognize and arrange to correct any skill-level deficiencies and to recognize the need for and to implement any developing needs for new skills and techniques.
- Shift-change coordinator and management point contact.
- Planning and scheduling coordinator; ensures that the planners receive the feedback needed to continuously refine and improve the planning process; ensures no changes are authorized without proper management-of-change procedures.

**Pride, Quality and Workmanship**

No facility can afford to take quality product for granted; neither should it assume quality maintenance will occur unless management takes positive action to ensure it. The pride and workmanship that make good product also make good maintenance. Pride, quality and workmanship flow from concerned and responsive management, good organization and properly trained and motivated people working in a smoothly operating facility. Management needs to address pride and workmanship problems on a case-by case basis; quality assurance often requires a free-standing program of its own, such as ISO 9000.

Good housekeeping is both a cause and a symptom of pride and quality. Doing the job right includes jobsite cleanup. Proud mechanics will generally keep their equipment in good order if allowed; they certainly will if management expects good order. The loss prevention aspects of housekeeping are further discussed in *OVERVIEW* Section 14 (PRC.1.14.0).

## Facilities and Equipment

The old adage, “It’s a poor worker who blames the tools” is only true for a worker who has the correct tools. No craftsperson can do quality work without the right tools and equipment and a well-located and equipped shop. Facilities and equipment involve other considerations than tools and a shop, though:

- Hot work is less likely to be done in the wrong places if the right place is properly located and equipped. See Section 9 of *OVERVIEW* (PRC.1.9.0) for more information.
- Many lubricants, fluids and other materials are flammable, combustible or otherwise hazardous. Personnel need to know the hazards and how to control them; properly designed storage, dispensing and disposal facilities are needed. See *OVERVIEW* Section 8 (PRC.1.8.0) for more information.
- Machines will eventually need to be dismantled and moved. When installing machines, plan ahead; if there is a crane in the area, make it strong enough; if this is not practical, provide portable crane access, and ensure management-of-change procedures will not allow a later project to block the access.
- Maintenance tools require maintenance. See, for example, that standard gauges and other test equipment are kept calibrated and that rigging equipment is regularly inspected and proof tested.
- Maintenance training often needs shop facilities. If a dedicated training shop is not practical, provide training space and resources in the main shop.

## Work Order System

The work order system must efficiently handle huge amounts of information and many kinds of input and output, yet be understandable at its interface by the least-skilled operator, clerk and maintenance worker. In other words, the internal complexity of a good work order system is transparent to its users.

Work order systems should control three basic functions:

- Authorize and define work: Provide information about work type and scope, location, urgency and cause.
- Plan and control work: Measure and record the amount of incoming work; assign priorities; provide the information that is needed to plan; schedule and coordinate methods, materials and labor; supply supervisors and technicians with instructions and time estimates; accumulate job progress information; and record and measure the amount of completed work.
- Accumulate maintenance history: Collect the time, cost and performance data from which time estimates and cost, performance and schedule compliance measures can be developed and improved.

Elements of a typical work order include:

- Work order number: Must be unique; may or may not have any coded meaning.
- Work type: Breakdown/emergency, general repair or maintenance, preventive maintenance (PM) inspection, corrective repair work from PM inspection, operator support and modifications, etc. Provides meaningful expenditure division for budgeting, control, and variance calculation and for PM effectiveness analysis.
- Priority: Separates plannable from unplannable work, indicates available lead time for planning, facilitates work order execution sequencing. Easily abused if not well-defined, audited and controlled.
- Crafts/skills needed and crew to which the job is assigned.
- Status: Waiting to be planned, waiting for engineering/design, waiting for materials, waiting for downtime, scheduled, completed but awaiting materials rebuilding or print revision, closed, etc.



- Failure cause: Entered by the assigned craftperson or by a root cause analyst upon job completion.
- Authorization: Screen unnecessary work, approve scope, authorize resources, control priority system use. Special authorizations for repairs, alterations, modifications, improvements (management-of change) and capital expenditures.
- Condition(s) found.
- Action(s) taken.
- Component(s) involved.
- Time and materials.

A superior craftperson might “make do” with inferior tools, but no maintenance organization will succeed without a good work order system. Work order systems can be home grown, using available literature and consultants for assistance when needed, or they can be purchased and modified. In all cases, consider the following:

- The system must be user-friendly. Unique jobs need separate work orders that can be initiated easily and correctly by anyone, including operators, housekeepers and inspectors who are responsible for identifying maintenance needs. Standing work orders may be useful for ongoing and routine jobs having known content and frequency, such as: machine lubrication and adjustment; relamping; housekeeping and custodial work; transportation; and fire prevention inspections. Work order logs might be used for jobs scheduled within a short time frame that are too simple to benefit from planning. However, in general, less than 20% and preferably less than 10% of work should be on nonstandard work orders.
- Emergency work should be entered into the work order system during or after the fact.
- All work orders must be reviewed to ensure that management-of-change procedures are followed as appropriate. See PRC.1.0.2.
- Regularly audited priority assignment procedures should ensure the lowest priority consistent with the job is assigned. Job priority should automatically increase as jobs age. Operating departments should periodically justify their requested level of emergency work.

Reliable maintenance cost reporting depends upon effective systems that charge labor, material and service costs to individual work orders and then in turn to items of equipment, cost centers, accounts and budgets. Maintenance management needs cost distribution information to calculate or detect:

- Total equipment repair cost by type of work, labor and parts.
- Above-average maintenance costs for groups of similar equipment.
- Comparative maintenance costs among like pieces of equipment.
- Maintenance cost trends that facilitate rebuild/replace decisions.
- Purchase cost versus maintenance cost for selected similar pieces of equipment, or life cycle costs.
- Reports by failure type.

### **Computer Support**

A large industrial facility can have hundreds of machines, thousands of components and possibly a million parts, any of which can shutdown or seriously inconvenience the facility by catastrophically failing. No person and no paper system can possibly manage the maintenance information that such a facility place requires. Collecting and effectively analyzing maintenance information for even a large office building, hospital or university campus requires a computer-based maintenance information system.

The computer database needs to be intelligently designed, with limited options allowed for most entries. For example, “air tank,” “air tnk,” and “air tk.” are all different to a computer. Uncontrolled data

entry results in chaos and a failed system. Plain-text entry should be minimized and carefully controlled.

In addition to managing and analyzing maintenance-based information, the maintenance information system needs to communicate with the systems used by stores, purchasing, payroll and the facility cost distribution and budgeting systems. Implementing such a system is a major undertaking, however, when functional, the system should perform the following functions and analyses:

- Planning and work measurement
  - Work order generation
  - Work measurement (to established job standards)
  - Backlog management
  - Preventive maintenance scheduling
  - Weekly master scheduling
  - Major project scheduling
  - Daily job scheduling
  - Personnel deployment
  - Labor planning, forecasting and balancing with the workload
  - Material planning, forecasting and allocating
  - Component maintenance forecasting
  - Critical path scheduling
- Scheduling and work assignment
  - Job loading
  - Job scheduling
  - Equipment access
  - Labor assignment
- Equipment History
  - Job costs
  - Materials usage history
  - Labor usage history
  - Payroll linkage
- Control reports
  - Work program, to keep resources balanced with workload
  - Work-in-progress status
  - Inventory status
  - Labor efficiency
  - Materials trends
  - Actual versus planned status
  - Equipment performance
  - Overtime control
  - Vendor analysis
- Control accounting
  - Maintenance indices
  - Budgets
  - Payroll

- Labor and material allocation by equipment
- Plant property database
- Facilities cost forecasting
- Engineering Calculations
  - Simulations
  - Mean time between failure
  - Statistical evaluations

Using a fully integrated computer-based maintenance information system can benefit the loss control program in several ways. For example:

- The system can be linked to up-to-date drawings and procedures, and can be arranged to automatically provide these items as part of the work order package.
- Hot work permits and authorization, required isolation and lockout/tagout instructions, pre-and post-maintenance valve and switch lineups and other safety-related items can also be incorporated.
- Feedback from previously-performed jobs can be provided almost automatically, thereby avoiding repeated errors.

### **Work Planning**

Each dollar invested in planning saves three to five dollars during work execution. A planned job typically requires only half as much time during execution as does an unplanned job. No organization would survive very long if it regularly sent production crews into the facility and, without the right materials, the appropriate mix of skills, the right tools or enough time, expected the crews to produce product. Planning pays; the need for planning should be obvious, yet, the planning function seems to be one of the first to disappear during corporate reengineering and downsizing efforts. A stable facility with a substantial inventory of previously-planned job packages that cover all its essential tasks might be able to do without; but any other facility needs planners.

Maintenance is managed by managing the backlog. It is impossible for a facility to be proactive if resources are not kept in balance with the workload. If the overwhelming majority of jobs are not planned, there is no effective way to know what the backlog is; therefore it cannot be managed. Two to four weeks of planned backlog is considered the norm, based upon 80 to 90% of jobs being planned.

Planning is critical to loss prevention, because the planning stage is the time to incorporate safety program support into the job package, before the pressure to finish the job begins.

### **Work Measurement**

Work measurement systems support planning. Work measurement and analysis produces maintenance labor and resource estimates that are essential to the entire planning, scheduling and control process. In order of increasing sophistication, work standards and estimates may be produced by:

- Supervisor or planner estimates
- Historical averages
- Averages or estimates adjusted by work sampling
- Analytical estimates (based upon job element computations)
- Engineered job standards

### **Material Support and Control**

This element is intended to get the right materials to the right place, at the right time, at the lowest cost; avoid excess inventories; charge stock and direct-purchased items directly to jobs; and be accessible to supervisors, planners and craftspeople.

Inventory management is a management specialty for which numerous resources are available, however, it is important to consider that maintenance stores pose special problems. Expensive items that do not move are anathema to scientific inventory control systems, and yet, failing to stock large spare motors, spare rotating elements for turbomachines, spare rolling mill gears and the like can impose a heavy penalty in downtime and expediting expenses should a failure occur. Risk-based analysis should be incorporated into stocking decisions for such major items. Also, proper preservation of major spare parts is a specialized task that requires maintenance and store room coordination.

Finally, the normal business reflex to seek the lowest cost needs to be tempered by performance feedback from the maintenance department and by the need to follow management-of-change procedures whenever material substitutions are considered.

### **Scheduling and Coordination**

Scheduling is the marketing arm of the successful maintenance organization. If maintenance does not schedule effectively, it will not consistently do jobs right, the first time, on time. If maintenance cannot produce an acceptable schedule and live by it, the maintenance department is likely to see nothing but emergency jobs and be forced into a reactive posture.

Maintenance staff who know what they are going to do before they are expected to do it have time to prepare mentally and otherwise and are therefore likely to be more effective, and safer.

### **Equipment History and Records**

This a fundamental maintenance management element and the primary maintenance engineering tool. Maintenance departments that do not study equipment history are more likely to suffer repeated failures. Equipment history helps:

- Identify equipment that requires abnormally high maintenance levels
- Analyze repetitive failures
- Compare projected maintenance cost with replacement cost
- Justify and refine the overall program

Equipment records include up-to-date drawings and specifications for all equipment and systems. A facility that cannot provide an up-to-date electrical distribution system drawing cannot be considered highly protected.

### **Maintenance Engineering**

This is the maintenance program central intelligence. Maintenance engineering uses the information that is collected and managed by the other elements to refine and continuously improve the facility and equipment reliability. Maintenance engineering:

- Administers and applies equipment history; analyzes the data to ensure maintenance program effectiveness.
- Defines, develops, administers and refines the PPM program; adjusts intervals and procedures to optimize maintenance resource use.
- Manages lubrication programs (PRC.6.0.8.3), vibration monitoring programs (PRC.6.0.8.1.1) and infrared inspection programs (PRC.1.3.1).
- Manages transformer oil testing programs (PRC.5.4.5) and other electrical preventive maintenance programs (PRC.5.0.5).
- Writes work and safety procedures.
- Analyses proposed new equipment and facilities for life-cycle cost and maintainability.
- Uses accumulated information to identify modifications that cost-effectively maximize equipment reliability and minimize maintenance and its associated downtime.
- Performs remaining life and life extension analysis (PRC.1.3.2).

- Checks out new installations and approves them for maintenance acceptance.

Maintenance engineering needs access to the facility hazard analysis to ensure all process hazards are considered and, where possible, reduced or eliminated. Section 13 of *OVERVIEW* (PRC.1.13.0) discusses hazard identification and evaluation. Maintenance engineering is also a good place to assign management of loss prevention recommendations. See Section 6 of *OVERVIEW* (PRC.1.6.0).

If the same engineers are responsible for project work or for production engineering and also for maintenance engineering, they are likely to be consumed by the other demands. A dedicated maintenance engineering staff is more likely to be proactive in its approach to problems and responsive to requests for assistance.

### **Preventive/Predictive Maintenance**

This element is often poorly understood. Worse, the terms are victims of ever-changing fads and buzzwords.

NFPA 70B describes preventive maintenance for electrical equipment as “any managed program of inspecting, testing, analyzing and servicing electrical systems and equipment for the purpose or maintaining safe operations and production.” PRC.5.0.1 expands that definition. But other reputable groups define the term differently. Some limit preventive maintenance to actions performed on fixed schedules. These groups often coin new terms to suggest newer, better programs.

This section uses the term “preventive/predictive maintenance (PPM)” to avoid confusion with any currently-existing fads or buzzwords. PPM refers to the subset of maintenance activities that inspect, test and measure equipment to detect adverse conditions in advance of failure. PPM is not intended to endorse any specific concept or philosophy.

As a stand-alone program, PPM is worthless. As one element of a complete management maintenance program, it is the program keystone. However, PPM only identifies conditions for the other elements to correct.

Effective PPM must be conducted as a controlled experiment. This means a schedule compliance of at least 90%; better 95%. Most PPM provides data points that mean very little individually. These points acquire high value when aggregated and their trends and patterns studied. If, for example, lubricant wear particle samples are not collected in a consistent manner under proper conditions on a regular frequency, they will provide little or no indication of a problem until failure is eminent. Properly conducted lubricant wear particle analysis can be a more sensitive early warning system than vibration analysis. Lubricant wear particle analysis teamed with vibration analysis in a controlled and coordinated PPM program can precisely monitor the aging process.

Routine, scheduled or planned maintenance has traditionally referred to maintenance performed on a time schedule. It can effectively manage failure mechanisms that are real-time or operating-time dependent. Sliding surfaces, such as sleeve bearings, piston rings, cams and followers, and some gears; and eroding or corroding surfaces such as vessel internals, pump impellers and wearing rings, and turbine blades were candidates for time-based procedures. While performance-based and predictive tools have been developed that can better measure the actual condition of many of these components without an overhaul, time-based maintenance is still the only way to control aging of some components, for example, those in combustion turbine hot gas paths.

Predictive maintenance refers to tools and techniques that directly measure machine or component condition. These tools include vibration monitoring and lubricant wear particle analysis.

Some components, such as gears and electrical insulation, have both measurable and random failure modes. These components require careful maintenance engineering study, to establish baseline data for all the available tests that can detect the random modes and to ensure sufficient physical inspections or overhauls early in life to obtain confidence in an estimated wear rate for the linear modes.

Various techniques have developed that allow confidence-improving inspections without overhauls. For example, flexible borescopes, or endoscopes, can partially inspect properly-equipped turbines without lifting the casings.

Some equipment, because of its particular design, failure modes, accessibility, environment or other factors defy cost-effective maintenance. This equipment, if its associated risk is low enough, might be allowed to run to failure. Otherwise, installed duplicate or standby equipment might be the only way to manage the risk.

All equipment needs to be maintained. New equipment does not have a “honeymoon period” during which no maintenance is required. Assuming that it does squanders the opportunity to collect baseline data; it also allows a random failure event, which might have been proactively detected, to cause an unscheduled outage. Further, it could allow the equipment to deteriorate to the point that a major overhaul is needed before PPM can be effective.

The PPM program must also address fire protection equipment inspection, which is further discussed in Section 12 of *OVERVIEW* (PRC.1.12.0).

## DISCUSSION

### Risk-Based Methods

Risk is a two dimensional combination of failure probability and consequence. A risk-based analysis starts by defining systems and their success criteria. It continues by breaking the systems into components and using the system success criteria to define component success criteria. Then, for each system and component, it defines the risk of failure. Once risk values have been assigned or calculated, components are sorted by risk level, or risk-ranked. Then, inspection and maintenance programs are designed that focus resources on the highest risk components.

Risk-based decision making can be qualitative or quantitative. Qualitative methods rank failure probability and consequence in broad categories, such as “very high,” “high,” “medium,” “low” and “very low.” The analyst plots the items being ranked on a grid like the one shown in [Figure 1](#), in which the highest-risk items fall in the upper right-hand corner of the plot. Quantitative risk-based methods base ranking and other decisions upon calculated or estimated failure probabilities multiplied by consequence costs. Qualitative methods are much more easily applied, and are suitable for preliminary risk analyses in all cases. They are often used to “pre-screen” major facility units. Such methods may also provide enough analytical depth for uncomplicated facilities or for moderate-risk facilities. Quantitative methods are needed for complex and high-risk facilities. They are also required when risk-rankings from dissimilar facilities need to be compared.

The formal risk-based method is a living process. When maintenance activities reduce risk on the first cut of high-risk components, the focus naturally shifts to another set of components. The risk-reduction process continues until all components meet management-defined acceptable risk criteria.

Basing maintenance programs on properly calculated failure risk is the only safe and effective way to achieve the optimum maintenance level. When there is a high level of maintenance, maintenance costs are high, but operating costs are reduced, and at some extreme maintenance level, repair costs disappear. When maintenance costs are reduced, operating and repair costs increase. Efforts to optimize the balance by looking only at maintenance, operating and repair costs fail because of the way these costs are often calculated. Reducing maintenance reduces direct costs such as labor, overtime, contract services, overhead and benefits, and maintenance materials. However, avoiding failures also reduces indirect costs that are not normally considered as maintenance costs. Using a formal risk basis for maintenance decision-making brings into the equation costs associated with:

- Unnecessary startups, shutdowns and equipment failures in service, with their associated higher probability of:
  - fire, explosion and injury;
  - unnecessary cleanup,

- waste disposal and environmental damage costs
- and regulatory fines;
- Excess downtime,
- Missed schedules,
- Lost good will and business opportunities,
- Unnecessary production of defective goods, seconds and scrap,
- Customer complaints and
- Product liability exposures.

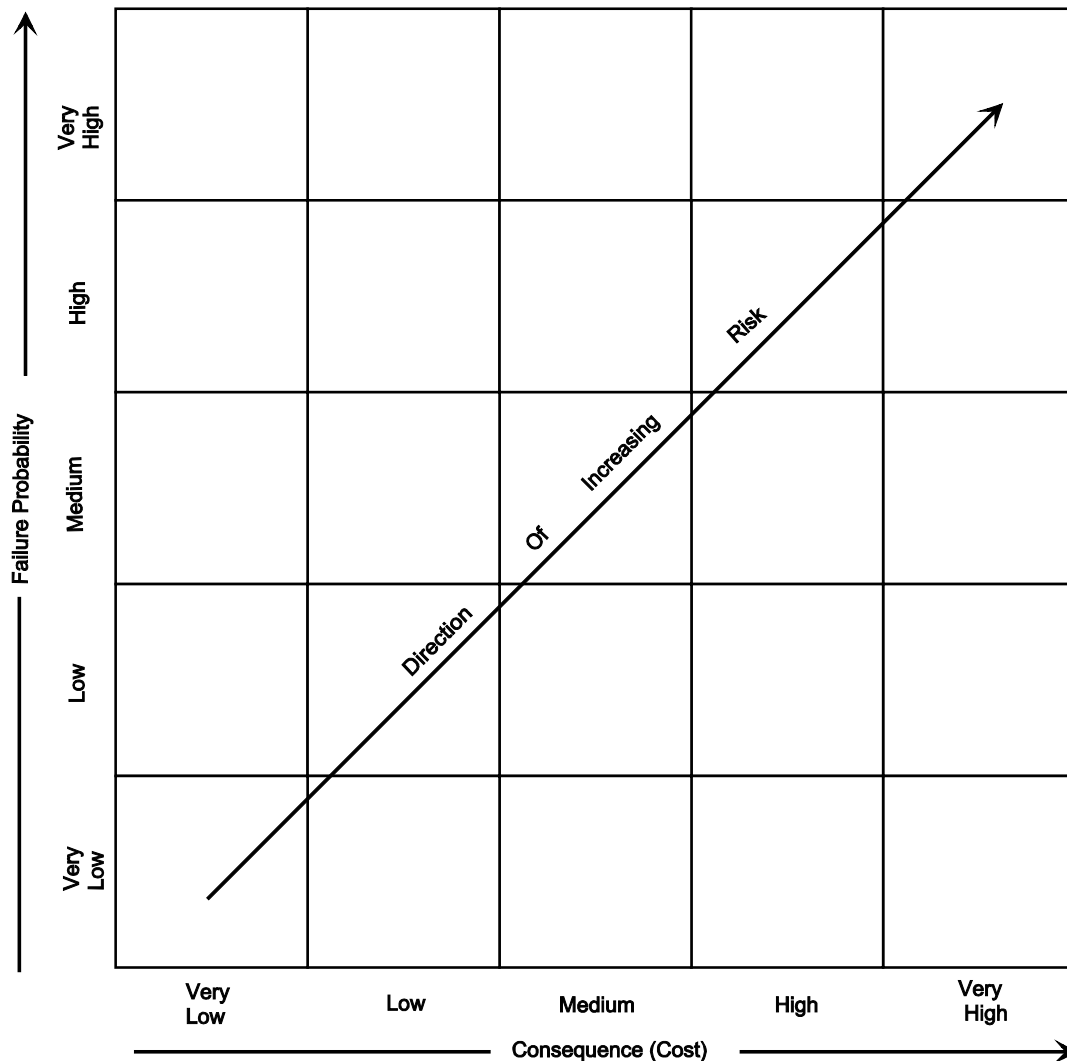


Figure 1. Matrix For Qualitative Risk Plot.

Failure to consider all these costs will make maintenance cost reduction look more attractive than it really is.

**Proactive vs. Reactive Maintenance**

Proactive maintenance is work that is planned and scheduled and is completed at a time in the aging process when the condition being corrected can be restored with a minimum investment. Consider a rolling-element (anti-friction) bearing in an important piece of equipment. Proactive maintenance

lubricates the bearing to ensure that it ages as slowly as possible and monitors it to detect the onset of failure as early in the failure process as possible. Proactive maintenance then schedules bearing replacement at an early opportunity, before the bearing fails. The proactive approach has several clear advantages:

- The probability is maximized that only the bearing needs replacement, and not the shaft, rotating components, bearing housing and possibly the casing.
- Engineering has time to determine what other work should be done at the same time. Engineering also has time to study the machinery history and, while the bearing is being replaced, implement other changes that could improve overall performance and reduce future maintenance needs.
- Planning can ensure that the procedures, parts, tools and skills needed to do the job right the first time will be available.
- Management, not the machine, decides when to do the job.

Reactive maintenance might or might not lubricate the bearing, but otherwise takes no action until intolerable performance or breakdown occurs. The reactive approach has several clear disadvantages:

- More, possibly much more, than the bearing will probably require attention.
- Opportunistic work probably cannot be arranged.
- The required parts and other resources may or may not exist, much less be available at the facility.
- The necessary people will almost certainly have to be pulled off other jobs to perform what will be an emergency job.
- The machine, which has no respect for production schedules or anything else, decides the scope of work and schedules the job. Management is a guilty bystander.

Breakdowns will occur; legitimate emergencies will arise. However, the immediate reaction to a breakdown signals very strongly the facility commitment to proactive response. If restoring production is the only consideration, commitment to proactivity is lacking. A proactive approach will first determine the root cause of failure so that maintenance engineering can, during the restoration or later if absolutely necessary, eliminate the cause of failure.

### **Deferred Maintenance and Maintenance Backlog**

Deferred maintenance is the best way to move further into the reactive mode. Deferred maintenance spends down the capital invested in equipment. Consider an automobile. It will probably run for some time, possibly a long time, beyond the recommended oil change interval. However, the probability steadily increases that, when maintenance is finally performed, an engine change will be needed as well as an oil change. Short of that extreme is the probability that the deferred maintenance will unnecessarily age the engine.

The maintenance backlog is the work, measured in craft hours, that has been requested but not yet performed. Too little backlog means that the maintenance staff does not have enough work to stay effectively employed; too much backlog means that maintenance is being excessively deferred. For example, facilities have been surveyed in which maintenance on the most important machinery had been deferred for years because it was the most difficult machinery on which to work. An efficient priority system with an automatic job aging feature will prevent individual items in the backlog from being indefinitely deferred.

### **Maintenance Job Types**

Maintenance departments must respond to three distinct types of maintenance request:



- **Routine maintenance** includes preservation activities such as cleaning, lubrication, visual inspection and testing and also planned and preventive maintenance activities such as taking vibration readings and lubricant samples for analysis.
- **Backlog relief** is the bulk of the maintenance department work. It is the investigation, repair and restoration activity the need for which is identified by operators or by persons performing routine maintenance work.
- **Emergency response** takes immediate action to address breakdowns and other suddenly-developing conditions.

Traditionally, the emergency response has consumed excessive maintenance resources. Although absolutely necessary, emergency response is a wholly reactive function. Proper attention to the routine work and timely backlog relief will minimize the demand for emergency response.

### The Role of Contractors

Contracted service use is growing for several good reasons. Payroll and its associated costs are reduced. Specialty skills and equipment are not “carried” during the intervals between use. New or different technologies can be tested without equipment purchase or training costs and without risk of being stuck with unsatisfactory equipment following an unsatisfactory trial. However, contractors have played a significant role in several major losses. Some factors to consider:

Contractors must be thoroughly trained in and comply with all facility loss prevention programs, such as hot work permitting and control, system isolation and inerting, and lockout/tagout. Training costs and compliance requirements must be part of the contract.

Contractors are often used for routine maintenance. This has certain management advantages; this work is by definition predictable and is often specialized. However, persons performing routine maintenance can provide important “sensory input” to the maintenance program. If the routine maintenance providers are not wholly invested in the facility mission, they are unlikely to report adverse conditions that are outside their assigned scope of work. For example, the person taking vibration readings can also detect and report leaks and abnormal noises. If contractors are doing a lot of routine maintenance, the added burden on the facility loss prevention inspection program needs to be addressed. See Chapter 10 of *OVERVIEW* (PRC.1.10.0) for more information.

Contractors can obviously help with timely backlog relief. The jobs in the backlog are planned and therefore fairly easy to specify and schedule; however, management needs to control job performance and ensure that correct procedures are followed, nondestructive testing methods are used, and that any conditions requiring attention that are outside the job scope are detected and addressed.

Contractors are seldom used for emergency work; the facility emergency response is often looked upon with pride. This attitude needs further thought. Emergency maintenance is often specialized. It is not planned by the facility, but it could be work that has been previously well-planned and performed by an available contractor. Emergency work is the enemy of proactivity. Therefore, once the root cause of failure has been determined and any necessary engineering input made to scope the corrective work, “jobbing out” emergency response work might make sense.

The final consideration is responsibility. The attitude occasionally becomes evident that, because a contractor is doing a job, “It’s not management’s problem.” This attitude is dangerous. Management is always responsible for the facility. Suppose that a contractor could be assigned legal liability for a fire or for a post-job failure. Few contractors, if any, have the financial resources to rebuild a multi-million dollar facility or to make good several hundred thousand dollars per day of business interruption costs, lost orders and goodwill and the rest. Contractor activities in some ways require more management oversight than in-house activities may require.