Chapter 5 Types of Maintenance Programs

5.1 Introduction

What is maintenance and why is it performed? Past and current maintenance practices in both the private and government sectors would imply that maintenance is the actions associated with equipment repair after it is broken. The dictionary defines maintenance as follows: "the work of keeping something in proper condition; upkeep." This would imply that maintenance should be actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. Unfortunately, data obtained in many studies over the past decade indicates that most private and government facilities do not expend the necessary resources to maintain equipment in proper working order. Rather, they wait for equipment failure to occur and then take whatever actions are necessary to repair or replace the equipment. Nothing lasts forever and all equipment has associated with it some predefined life expectancy or operational life. For example, equipment may be designed to operate at full design load for 5,000 hours and may be designed to go through 15,000 start and stop cycles.

The need for maintenance is predicated on actual or impending failure – ideally, maintenance is performed to keep equipment and systems running efficiently for at least design life of the component(s). As such, the practical operation of a component is time-based function. If one were to graph the failure rate a component population versus time, it is likely the graph would take the "bathtub" shape shown in Figure 5.1.1. In the figure the Y axis represents the failure rate and the X axis is time. From its shape, the curve can be divided into three distinct: infant mortality, useful life, and wear-out periods.

The initial infant mortality period of bathtub curve is characterized by high failure rate followed by a period of decreasing failure. Many of the failures associated with this region are linked to poor design, poor installation, or misapplication. The infant mortality period is followed by a nearly constant failure rate period known as useful life. There are many theories on why components fail in this region, most acknowledge that poor O&M often plays significant role. It is also generally agreed

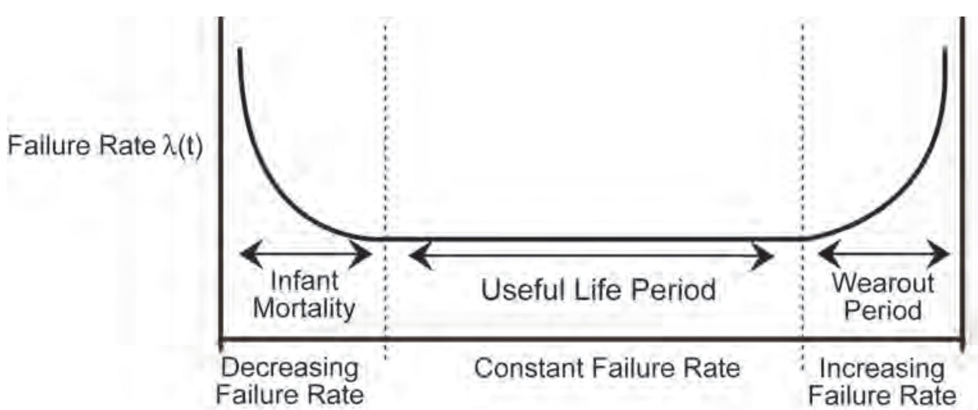

Figure 5.1.1. Component failure rate over time for component population

that exceptional maintenance practices encompassing preventive and predictive elements can extend this period. The wear-out period is characterized by a rapid increasing failure rate with time. In most cases this period encompasses the normal distribution of design life failures.

The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, proper lubrication on rotating equipment is required, and so on. In some cases, certain components need replacement, (e.g., a wheel bearing on a motor vehicle) to ensure the main piece of equipment (in this case a car) last for its design life. Anytime we fail to perform maintenance activities intended by the equipment's designer, we shorten the operating life of the equipment. But what options do we have? Over the last 30 years, different approaches to how maintenance can be performed to ensure equipment reaches or exceeds its design life have been developed in the United States. In addition to waiting for a piece of equipment to fail (reactive maintenance), we can utilize preventive maintenance, predictive maintenance, or reliability centered maintenance.

5.2 Reactive Maintenance

Reactive maintenance is basically the "run it till it breaks" maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached. Studies as recent as the winter of 2000 indicate this is still the predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance program as follows:

- >55% Reactive
- 31% Preventive
- 12% Predictive
- 2% Other.

Advantages

- Low cost.
- Less staff.

Disadvantages

- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Cost involved with repair or replacement of equipment.
- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

Note that more than 55% of maintenance resources and activities of an average facility are still reactive.

Advantages to reactive maintenance can be viewed as a double-edged sword. If we are dealing with new equipment, we can expect minimal incidents of failure. If our maintenance program is purely reactive, we will not expend manpower dollars or incur capital cost until something breaks. Since we do not see any associated maintenance cost, we could view this period as saving money. The downside is reality. In reality, during the time we believe we are saving maintenance and capital cost, we are really spending more dollars than we would have under a different maintenance approach. We are spending more dollars associated with capital cost because, while waiting for the equipment to break, we are shortening the life of the equipment resulting in more frequent replacement. We may incur cost upon failure of the primary device associated with its failure causing the failure of a secondary device. This is an increased cost we would not have experienced if our maintenance program was more proactive. Our labor cost associated with repair will probably be higher than normal because the failure will most likely require more extensive repairs than would have been required if the piece of equipment had not been run to failure. Chances are the piece of equipment will fail during off hours or close to the end of the normal workday. If it is a critical piece of equipment that needs to be back on-line quickly, we will have to pay maintenance overtime cost. Since we expect to run equipment to failure, we will require a large material inventory of repair parts. This is a cost we could minimize under a different maintenance strategy.

5.3 Preventive Maintenance

Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.

Advantages

- Cost effective in many capital-intensive processes.
- Flexibility allows for the adjustment of maintenance periodicity.
- Increased component life cycle.
- Energy savings.
- Reduced equipment or process failure.
- Estimated 12% to 18% cost savings over reactive maintenance program.

Disadvantages

- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance.

The U.S. Navy pioneered preventive maintenance as a means to increase the reliability of their vessels. By simply expending the necessary resources to conduct maintenance activities intended by the equipment designer, equipment life is extended and its reliability is increased. In addition to an increase in reliability, dollars are saved over that of a program just using reactive maintenance. Studies indicate that this savings can amount to as much as 12% to 18% on the average. Depending on the facilities current maintenance practices, present equipment reliability, and facility downtime, there is little doubt that many facilities purely reliant on reactive maintenance could save much more than 18% by instituting a proper preventive maintenance program.

While preventive maintenance is not the optimum maintenance program, it does have several advantages over that of a purely reactive program. By performing the preventive maintenance as the equipment designer envisioned, we will extend the life of the equipment closer to design. This translates into dollar savings. Preventive maintenance (lubrication, filter change, etc.) will generally run the equipment more efficiently resulting in dollar savings. While we will not prevent equipment catastrophic failures, we will decrease the number of failures. Minimizing failures translate into maintenance and capital cost savings.

5.4 Predictive Maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of system degradation (lower functional state), thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. Results indicate current and future functional capability.

Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule. You will recall that preventive maintenance is time-based. Activities such as changing lubricant are based on time, like calendar time or equipment run time. For example, most people change the oil in their vehicles every 3,000 to 5,000 miles traveled. This is effectively basing the oil change needs on equipment run time. No concern is given to the actual condition and performance capability of the oil. It is changed because it is time. This methodology would be analogous to a preventive maintenance task. If, on the other hand, the operator of the car discounted the vehicle run time and had the oil analyzed at some periodicity to determine its actual condition and lubrication properties, he/she may be able to extend the oil change until the vehicle had traveled 10,000 miles. This is the fundamental difference between predictive maintenance and preventive maintenance, whereby predictive maintenance is used to define needed maintenance task based on quantified material/equipment condition.

Advantages

- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.
- Improved worker and environmental safety.
- Improved worker morale.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

Disadvantages

- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

The advantages of predictive maintenance are many. A well-orchestrated predictive maintenance program will all but eliminate catastrophic equipment failures. We will be able to schedule maintenance activities to minimize or delete overtime cost. We will be able to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs. We can optimize the operation of the equipment, saving energy cost and increasing plant reliability. Past studies have estimated that a properly functioning predictive maintenance program can provide a savings of 8% to 12% over a program utilizing preventive maintenance alone. Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30% to 40%. In fact, independent surveys indicate the following industrial average savings resultant from initiation of a functional predictive maintenance program:

- Return on investment: 10 times
- Reduction in maintenance costs: 25% to 30%
- Elimination of breakdowns: 70% to 75%
- Reduction in downtime: 35% to 45%
- Increase in production: 20% to 25%.

On the down side, to initially start into the predictive maintenance world is not inexpensive. Much of the equipment requires cost in excess of $50,000. Training of in-plant personnel to effectively utilize predictive maintenance technologies will require considerable funding. Program development will require an understanding of predictive maintenance and a firm commitment to make the program work by all facility organizations and management.

5.5 Reliability Centered Maintenance

Reliability centered maintenance (RCM) magazine provides the following definition of RCM: "a process used to determine the maintenance requirements of any physical asset in its operating context."

Basically, RCM methodology deals with some key issues not dealt with by other maintenance programs. It recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others. It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both need to be prioritized and optimized. In a nutshell, RCM is a systematic approach to evaluate a facility's equipment and resources to best mate the two and result in a high degree of facility reliability and cost-effectiveness. RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a reactive maintenance approach. The following maintenance program breakdowns of continually top-performing facilities would echo the RCM approach to utilize all available maintenance approaches with the predominant methodology being predictive.

Advantages

- Can be the most efficient maintenance program.
- Lower costs by eliminating unnecessary maintenance or overhauls.
- Minimize frequency of overhauls.
- Reduced probability of sudden equipment failures.
- Able to focus maintenance activities on critical components.
- Increased component reliability.
- Incorporates root cause analysis.

Disadvantages

- Can have significant startup cost, training, equipment, etc.
- Savings potential not readily seen by management.

- <10% Reactive
- 25% to 35% Preventive
- 45% to 55% Predictive.

Because RCM is so heavily weighted in utilization of predictive maintenance technologies, its program advantages and disadvantages mirror those of predictive maintenance. In addition to these advantages, RCM will allow a facility to more closely match resources to needs while improving reliability and decreasing cost.

Table 5.5.1 below highlights guidance on RCM development by equipment application (adapted from NASA 2000). It is important to both define the equipment criticality and cost of down-time when determining the optimal mix of maintenance elements. Once defined, the equipment can be prioritized in the developing a functional RCM program.

Table 5.5.1. Reliability centered maintenance element applications

Reliability Centered Maintenance Hierarchy		
Reactive Element Applications	*Preventive* Element Applications	*Predictive* Element Applications
Small parts and equipment	Equipment subject to wear	Equipment with random failure patterns
Non-critical equipment	Consumable equipment	Critical equipment
Equipment unlikely to fail	Equipment with known failure patterns	Equipment not subject to wear
Redundant systems	Manufacturer recommendations	Systems which failure may be induced by incorrect preventive maintenance

5.6 How to Initiate Reliability Centered Maintenance

The road from a purely reactive program to a RCM program is not an easy one. The following is a list of some basic steps that will help to get moving down this path (NASA 2000).

1. Develop a Master equipment list identifying the equipment in your facility.
2. Prioritize the listed components based on importance or criticality to operation, process, or mission – see text box highlighting priority scheme.

Maintenance Priority Matrix for RCM Development

Priority Weighting	Description	Application
1	Emergency	Life, health, safety risk-mission criticality
2	Urgent	Continuous operation of facility at risk
3	Priority	Mission support/project deadlines
4	Routine	Prioritized: first come/first served
5	Discretionary	Desired but not essential
6	Deferred	Accomplished only when resources allow

Comparison of Four Maintenance Programs (Piotrowski 2001)

Reactive Maintenance (Breakdown or Run-to-Failure Maintenance)

Basic philosophy

- Allow machinery to run to failure.
- Repair or replace damaged equipment when obvious problems occur.

Cost: $18/hp/yr

This maintenance philosophy allows machinery to run to failure, providing for the repair or replacement of damaged equipment only when obvious problems occur. Studies have shown that the costs to operate in this fashion are about $18 per horsepower (hp) per year. The advantages of this approach are that it works well if equipment shutdowns do not affect production and if labor and material costs do not matter.

3. Assign components into logical groupings.
4. Determine the type and number of maintenance activities required and periodicity using:
    a. Manufacturer technical manuals
    b. Machinery history
    c. Root cause analysis findings - Why did it fail?
    d. Good engineering judgment
5. Assess the size of maintenance staff.
6. Identify tasks that may be performed by operations maintenance personnel.
7. Analyze equipment failure modes and impacts on components and systems.
8. Identify effective maintenance tasks or mitigation strategies.

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

An Introduction to Reliability and Maintainability Engineering
By: Charles E. Ebeling
Published by: McGraw Hill College Division
Publication date: September 1996

Maintenance Engineering Handbook
By: Lindley R. Higgins, Dale P. Brautigam, and R. Keith Mobley (Editor)
Published by: McGraw Hill Text, 5th Edition
Publication date: September 1994

Condition-Based Maintenance and Machine Diagnostics
By: John H. Williams, Alan Davies, and Paul R. Drake
Published by: Chapman & Hall
Publication date: October 1994

Maintenance Planning and Scheduling Handbook
By: Richard D. (Doc) Palmer
Published by: McGraw Hill
Publication date: March 29, 1999

Maintainability and Maintenance Management
By: Joseph D. Patton, Jr.
Published by: Instrument Society of America, 3rd Revision
Publication date: February 1994

Reliability-Centered Maintenance
By: John Moubray
Published by: Industrial Press, 2nd Edition
Publication date: April 1997

Reliability-Centered Maintenance
By: Anthony M. Smith
Published by: McGraw Hill
Publication date: September 1992.

Preventive Maintenance (Time-Based Maintenance)

Basic philosophy

- Schedule maintenance activities at predetermined time intervals.
- Repair or replace damaged equipment before obvious problems occur.

Cost: $13/hp/yr

This philosophy entails the scheduling of maintenance activities at predetermined time intervals, where damaged equipment is repaired or replaced before obvious problems occur. When it is done correctly, studies have shown the costs of operating in this fashion to be about $13 per hp per year. The advantages of this approach are that it works well for equipment that does not run continuously, and with personnel who have enough knowledge, skills, and time to perform the preventive maintenance work.

Predictive Maintenance (Condition-Based Maintenance)

Basic philosophy

- Schedule maintenance activities when mechanical or operational conditions warrant.
- Repair or replace damaged equipment before obvious problems occur.

Cost: $9/hp/yr

This philosophy consists of scheduling maintenance activities only if and when mechanical or operational conditions warrant-by periodically monitoring the machinery for excessive vibration, temperature and/or lubrication degradation, or by observing any other unhealthy trends that occur over time. When the condition gets to a predetermined unacceptable level, the equipment is shut down to repair or replace damaged components so as to prevent a more costly failure from occurring. In other words, "Don't fix what is not broke." Studies have shown that when it is done correctly, the costs to operate in this fashion are about $9 per hp per year. Advantages of this approach are that it works very well if personnel have adequate knowledge, skills, and time to perform the predictive maintenance work, and that it allows equipment repairs to be scheduled in an orderly fashion. It also provides some lead-time to purchase materials for the necessary repairs, reducing the need for a high parts inventory. Since maintenance work is only performed when it is needed, there is likely to be an increase in production capacity.

Reliability Centered Maintenance (Pro-Active or Prevention Maintenance)

Basic philosophy

- Utilizes predictive/preventive maintenance techniques with root cause failure analysis to detect and pinpoint the precise problems, combined with advanced installation and repair techniques, including potential equipment redesign or modification to avoid or eliminate problems from occurring.

Cost: $6/hp/yr

This philosophy utilizes all of the previously discussed predictive/preventive maintenance techniques, in concert with root cause failure analysis. This not only detects and pinpoints precise problems that occur, but ensures that advanced installation and repair techniques are performed, including potential equipment redesign or modification, thus helping to avoid problems or keep them from occurring. According to studies, when it is done correctly, operating in this fashion costs about $6 per hp per year. One advantage to this approach is that it works extremely well if personnel have the knowledge, skills, and time to perform all of the required activities. As with the predictive-based program, equipment repairs can be scheduled in an orderly fashion, but additional improvement efforts also can be undertaken to reduce or eliminate potential problems from repeatedly occurring. Furthermore, it allows lead-time to purchase materials for necessary repairs, thus reducing the need for a high parts inventory. Since maintenance work is performed only when it is needed, and extra efforts are put forth to thoroughly investigate the cause of the failure and determine ways to improve machinery reliability, there can be a substantial increase in production capacity.

5.7 References

NASA. 2000. *Reliability Centered Maintenance Guide for Facilities and Collateral Equipment*. National Aeronautics and Space Administration, Washington, D.C.

Piotrowski, J. April 2, 2001. *Pro-Active Maintenance for Pumps*, *Archives*, *February 2001*, **Pump-Zone.com** [Report online]. Available URL: **http://www.pump-zone.com**. Reprinted with permission of Pump-Zone.com.