

# Predictive Maintenance

## Overview



Predictive maintenance programs come in all shapes and sizes, depending on a facility's size, equipment, regulations, and productivity goals.

This overview:

- Outlines some of the most common predictive maintenance methods
- Explains how to determine the potential cost savings of maintenance improvements
- Walks through a predictive maintenance process
- Lists the relevant standards

For more specific cost calculations or measurement guidelines, reference the other application notes in this series.

## Maintenance methods

### Reactive Maintenance

Run-to-failure approach: letting a system run until something breaks. Maximum cost in terms of revenue lost and equipment replacement.

### Preventive Maintenance (PM)

Maintenance repairs performed on a regular schedule to minimize component degradation and extend the life of equipment. Preventive maintenance is performed after a set amount of elapsed calendar time or machine run time, regardless of whether the repair is needed. While more cost-effective than reactive maintenance, preventive maintenance still requires substantial human resources and replacement parts inventories.

### Predictive Maintenance (PdM)

Tracking key indicators over time to predict when equipment needs repair. Predictive maintenance programs measure equipment on a regular basis, track the measurements over time, and take corrective action when measurements are about to go outside the equipment operating limits. Repairing equipment as-needed requires fewer man-hours and parts than preventive maintenance. However, tracking the measurements requires new tools, training, and software to collect and analyze the data and predict repair cycles.

### Reliability-Centered Maintenance (RCM)

Prioritizing maintenance efforts based on equipment's importance to operations, its downtime cost in revenue and customer loss, its impact on safety, and its cost of repair. Reliability maintenance depends on the same measurements used in predictive maintenance, but saves additional maintenance resources by spending less effort on less important machinery. RCM also requires more training and software than PdM.

### Maintenance software: CMMS and AMS

Most facilities practicing predictive maintenance purchase or develop a specialized database, commonly referred to as either an asset management system (AMS) or a computer managed maintenance system (CMMS). To track trends, a database system should be able to store:

- List of critical equipment
- Maintenance and measurement procedures for each type of equipment
- Maintenance schedule
- A history for each measurement
- Limits for each measurement (maintenance alarm trigger)

Many systems also track warranty status, depreciation records and purchasing information, and can generate works orders, manage schedules, and track employee training histories and related skills.

## Cost analysis

There is plenty of evidence that careful, well-planned maintenance prolongs the life of equipment and prevents costly downtime. Insurance data referenced in NFPA 70B indicates that roughly half of the damages associated with electrical failures alone could be prevented by regular maintenance.

To determine the investments to make in your system, you need to know two things: the probability of a failure and the cost of the failure. By multiplying these two figures, you can estimate a level of investment in your infrastructure, including maintenance.

### Probability of failure

The IEEE 493 standard contains useful data on the failure rates of electrical equipment and techniques for determining the probability of downtime for any given load. For each facility, also incorporate operator knowledge, maintenance history and manufacturers specifications, as well as the failure analysis provided by PdM software tools.

### FMEA: Failure Modes and Effects Analysis

Used in reliability-centered maintenance, FMEA is a method for analyzing how a system can fail, the impact of the failure, the frequency of failure and the probability of the failure being hidden. The FMEA method assigns risk priority to assemblies based on:

- Severity of impact
- Probability of occurrence
- Probability that a failure will remain hidden

For example, for a critical three-phase motor, over-current trip due to phase loss would be failure mode. The probability of phase loss remaining hidden can be high, since the motor may continue to run. To bring hidden failures to the surface, take measurements that are closely correlated to the failure mode. In the motor example, current monitoring will quickly uncover loss of a phase on a three-phase motor.

### Cost of failure

Unplanned downtime cost variables:

- Lost revenue during downtime – especially critical if the plant is running at or near capacity, or in highly competitive markets. Measured in dollars per hour.
- Lost revenue due to loss of customer confidence – how many customers will leave you.
- Replacement cost of damaged electrical or production equipment
- Repair costs, especially labor
- Cost of scrap
- Cost to clean and restart production
- Insurance premium reductions

To build a case for preventive maintenance, estimate the cost of failure and compare that to the cost of a maintenance program.

1. Calculate net income per hour of output for your production line or other critical process.

**Sample = \$5,000/hr.**

2. Calculate average downtime for each equipment failure and number of events per year.

**Sample = Failed motor repair requires avg 5 hrs; 2 motors fail annually.**

3. Multiply the results of #1 by both values in #2.

**Sample: \$5,000 x 5 x 2 = \$50,000 in lost revenue.**

4. Estimate labor and equipment repair cost.

**Sample: \$50/hr x 5/motor + \$3,000/motor = \$6,500.**

5. Add #3 and #4. This is your avoidable annual cost in lost revenue + repair.

**Sample: \$50,000 + \$6,500 = \$61,500.**

6. Repeat cost calculation based on planned downtime where no revenue loss is incurred.

**Sample: \$50/hr x 5/motor + \$3,000 for 1 new motor + \$1,500 for 1 repaired motor = \$5,000.**

Utilizing scheduled downtime, the maintenance cost is \$5,000 annually with no revenue loss, compared to \$61,500 in lost revenues and unexpected downtime costs.

# Predictive maintenance program steps

## Setup

1. Develop a list of critical processes, applications and equipment and prioritize each item based on the impact a failure would have. High priority equipment:
  - Directly impacts safety, the environment, revenue, or customer relations
  - Is unique or costly to replace, or used constantly (24x7)
  - Is difficult to find spare parts for or has a long lead time for repair
2. Determine how likely your equipment is to fail, using PdM software, operator knowledge and maintenance history.
3. Combine those two pieces of information – failure probability and impact – and create an inspection schedule (see sample at right).
4. Set up a database to store measurement results for each piece of equipment. Incorporate baseline data, repair histories, manufacturer recommendations and operator knowledge: when units broke/ how often, why, and what they cost to fix.

## Test

5. Test the equipment with the appropriate predictive technologies and record the measurements in the PdM database.

## Monitor

6. Analyze and monitor your measurements for signs of change in operating conditions: vibration measurements trending up, increased current draw for the same process, current lead to ground, increasing bearing temperatures, and so forth.

## Repair

7. Investigate any warning signs and determine if repairs are necessary.
8. Determine the length of time before failure occurs. Again, if you lack the PdM tools to determine this, rely on technician experience and manufacturer data.
9. Schedule repair before failure. One of the powerful PdM paradigms is not to repair equipment too early or too late. You don't want equipment to go down, but you also don't want to replace equipment if it will continue to run for a year or more.
10. Use your lead-time to properly align resources, check for spare parts, and choose a shutdown time that minimizes the down condition in the plant.

11. Make the repair. Document the results and if appropriate, try to determine the root cause of the failure of the equipment.
12. Take new baseline readings for the repaired/replaced equipment.

## Inspection schedules

Frequency of inspection is based on a number of factors, including safety, the criticality of the equipment, the expense of a failure, and the frequency with which problems impact production and/or maintenance. As assets age, are heavily loaded, or are poorly maintained, inspections may become more frequent. When repairs or modifications are made to equipment, conduct a follow-up inspection.

Equipment Type	Max. Time Between Inspections
Transformers	1 year
440V Motor Control Centers	
Air conditioned	6-12 months
Non-air conditioned or older	4-6 months
Electrical distribution equipment	4-6 months
Large motors*	1 year
Smaller motors	4-6 months

\*Assumes vibration analysis, machine circuit analysis, lube analysis and thermography are being used.

## General equipment list

- Rotating machinery/loads
  - Motors
  - Generators
  - Pumps
  - A/C units
  - Fans
  - Gearboxes
  - Chillers
- Motor controls & adjustable speed drives
- Lighting systems
- Electrical system
  - Switchgear
  - Transformers
  - Cables/wiring
  - Switches
  - Circuit breakers
  - Metering
  - Grounding systems
  - Ground fault protection
  - Surge arrestors
  - Power Factor Correction
  - Filters and reactors
  - Outdoor bus structures
  - Emergency systems
    - UPS
    - Generators
    - Transfer Switch

## Standards

Reference these standards when creating safe standard work procedures for your PdM program.

*International Electrical and Electronic Engineers standard IEEE-90* describes the elements of an EPM program, including safety, while 1584™-2002 provides a guide for arc flash hazard calculations and *ANSI/IEE C2-81 National Electrical Safety Code* governs heavy industrial installations.

*MTS-2001 Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems* from the International Electrical Testing Association (NETA), [www.netaworld.org](http://www.netaworld.org), contains set of step-by-step standard procedures for inspecting, testing and evaluating system components and an appendices that recommends maintenance intervals for various components.

*Standard NFPA 70B Recommended Practice for Electrical Equipment Maintenance* from The National Fire Protection Association provides a PdM program overview, as well as an appendix with sample tests and record forms. For each component of the electrical system, it describes how you should inspect and test each sub-element. For example, in the section on rotating machinery it covers stator and rotor windings, then goes into brushes, collector rings, commutators, and then bearings and lubrication.

*NFPA 70B* also includes a section on test methods, including insulation testing, transformer turns-ratio testing, circuit breaker testing and ground impedance testing, and power quality issues such as harmonics, transients, unbalance, sags and swells.

Also refer to *NFPA 70E Standard for Electrical Safety in the Workplace* for safety training, procedures, personal protective gear (PPE) requirements, and lockout/tagout procedures.

Occupational Safety and Health Administration *OSHA 29 CFR, 1910 Subpart S Electrical and Subpart I Personal Protective Equipment Safety* standards for electrical systems, safe work practices, maintenance requirements.

*ISO 6781* International Standards Organization (ISO) (American National Standards Institute) discusses thermal insulation, qualitative detection of thermal irregularities in building envelopes, and infrared methodology.

ASTM International <http://www.astm.org> *ASTM E 1934, 1213, 1311, 1316, and 1256 Standard guide for examining electrical and mechanical equipment with infrared thermography*, plus additional thermography references in ASTM 1060 and 1153.