Preventive and Predictive Maintenance

Preventive/Predictive Maintenance

The guiding principle of PPM is the regular and systematic application of engineering knowledge and maintenance attention to equipment and facilities to ensure their proper functionality and to reduce their rate of deterioration. In addition to dedicated engineering, PPM encompasses regular examination, inspection, lubrication, testing and adjustments of equipment without prior knowledge of equipment failure. PPM also provides the framework for all planned maintenance activity, including the generation of planned work orders to correct potential problems identified by inspection. The result is a proactive (rather than a reactive) environment, optimizing equipment performance and life.

Properly developed PPM programs are engineered efforts, which optimize the relationship between equipment ownership and operating profits by balancing cost of maintenance with cost of equipment failure, and associated production losses. Equipment ownership cost is a function of three factors: purchase price, equipment life and maintenance cost. Total maintenance cost is the sum of material and labor cost required to repair the item, the cost of preventive maintenance to avoid repairs, plus the cost of lost production while the unit is out of service for repairs. PPM includes actions which extend the life of equipment and avoid unnecessary failures by substituting selective programmed effort for “fix it when it fails” maintenance.

Actions that extend the life of equipment include: lubrication, cleaning, adjusting and the replacement of minor components like drive belts, gaskets, filters, etc. Actions that avoid unnecessary failure include timely, consistent equipment inspection and the aggressive use of nondestructive testing techniques such as vibration analysis, infrared testing, oil analysis and other techniques.

Predictive maintenance is the complement of *preventive maintenance*. Through the utilization of various nondestructive testing and measuring techniques, predictive maintenance determines equipment status before a breakdown occurs. With predictive devices currently available, it is incumbent upon maintenance organizations to include the process of predictive maintenance in their maintenance programs.

A total PPM program is absolutely essential to an efficient, reliable and safe production process. Benefits are direct and substantial, including: high product quality, long machine life, avoidance of work stoppage, high safety, high morale and fewer frustrations. There are five essential requirements:

1. Top management leadership and absolute commitment.
2. Compliance and discipline. PPM must be a normal part of schedule and capacity determination.
3. Process operators should be involved and perform daily maintenance checks.
4. The “true cost of poor maintenance,” which is several times initial estimates must be thoroughly understood by all.
5. Good PPM practices must be instituted immediately to enable the facility to achieve an efficient production system that delivers high quality goods on time, every time.

Although treated as separate elements, *preventive/predictive maintenance, Reliability Engineering, equipment history* and *functional pride* and *quality assurance* are inextricably supportive—each to the others. Success of the preventive/predictive maintenance program is dependent upon the existence of the other three elements. While planning and scheduling assure the effective utilization of resources to sustain an established proactive maintenance program, it is these four elements working in concert that define the proactive program.

Logically, an effective maintenance program, supported by these four essential elements, begins with equipment history. Then, based upon this factual information foundation, Reliability Engineering begins the development and subsequent refinement of a preventive/predictive maintenance program. An effective scheduling function assures that PPM routines are punctually performed as they become due, as follows:

A. The planning and scheduling program provides a structure into which PPM routines are woven. If PPM routines are continually shoved to one side, a proactive environment will never become reality.

   As scheduling contributes to the success of preventive maintenance so preventive maintenance contributes to the success of scheduling. The greatest obstacle to effective scheduling is the spasmodic occurrence of emergency breakdown repairs. Through scheduled inspections of equipment and repairs during scheduled downtime, emergency breakdowns can be nearly eliminated; thus the cause of interruptions to the planned schedule is removed or reduced to a minimum.

B. Program consistency and punctuality is a must. PPM must be viewed and conducted as an ongoing and controlled experiment to be continually nurtured and refined. It requires dedicated, uniquely talented effort (the maintenance engineer).

Program results will carry to the bottom-line in the form of:

1. Reductions in the total cost of maintenance
2. Fewer urgent and emergency interruptions to operations due to equipment breakdowns
3. Level workloads and a stabilized work force
4. Reductions in the total labor needed to maintain facilities in the required condition
5. Controlled reductions in the inventory of materials and spare parts
6. Increases in the volume of work that can be planned and scheduled repetitively, and a decrease in high priority, randomly occurring and unscheduled work
7. Reduced unnecessary damage to equipment

Preventive/Predictive Maintenance

Indicators of Ineffective PPM

1. Low equipment utilization due to unscheduled stoppages
2. High wait or idle time for machine operators during outages
3. High scrap and rejects indicative of quality problems
4. Higher than normal repair costs due to neglect of proper lubrication, inspections or service.
5. Decrease in the expected life of capital investments due to inadequate maintenance

Effective PPM Requires:

1. Top management understanding of the *true cost of poor maintenance*, which is several times initial estimate
2. Sustained management leadership and absolute commitment
3. Knowledge of equipment/process conditions required to yield quality, output, safety, and compliance standards

   A. One cannot determine what problems exist until knowing what conditions are proper
4. PPM and other programmed maintenance must be a normal part of schedule and capacity determination. Management must insure that PPM is never delayed.

   A. PPM must be conducted as a *Controlled Experiment*

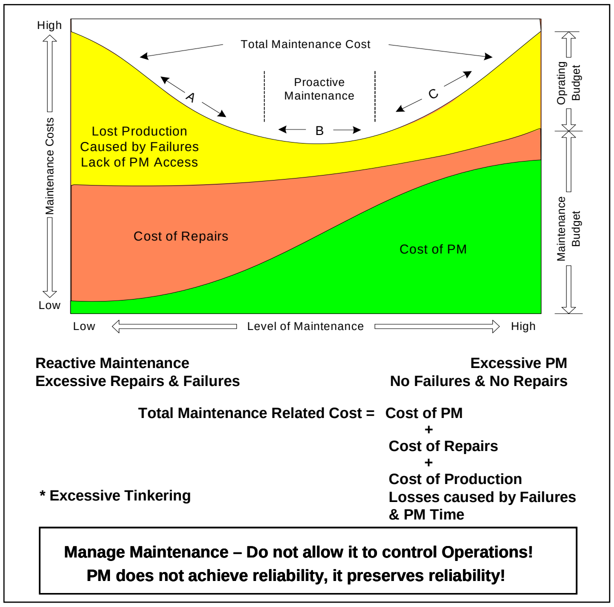
      1. Plan
      2. Do
      3. Evaluate
      4. Refine

   B. Weekly adherence to a balanced PPM schedule

The PM Program a "Controlled Experiment"

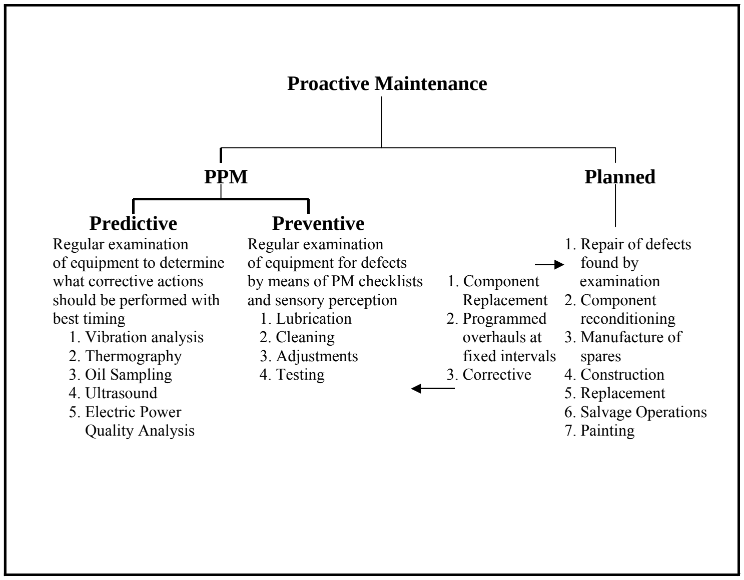
Maintenance Challenge (A Controlled Experiment)

Do not attempt to immediately PM everything
Apply A-B-C Analysis To Equipment Criticality
Build upon early successes.



5. Dedicated staffing is preferable
6. Operator should participate in daily machine checks
7. Efficient PPM routes
8. Effective PM checklists defining program required limits of equipment condition
9. Adequate Equipment Records and Equipment Histories
10. Three phases
    A. Detection—the key element
    B. Analysis—defines the specific problem from which the symptom originates
    C. Correction—the return of the PPM investment

Classification of Maintenance Work



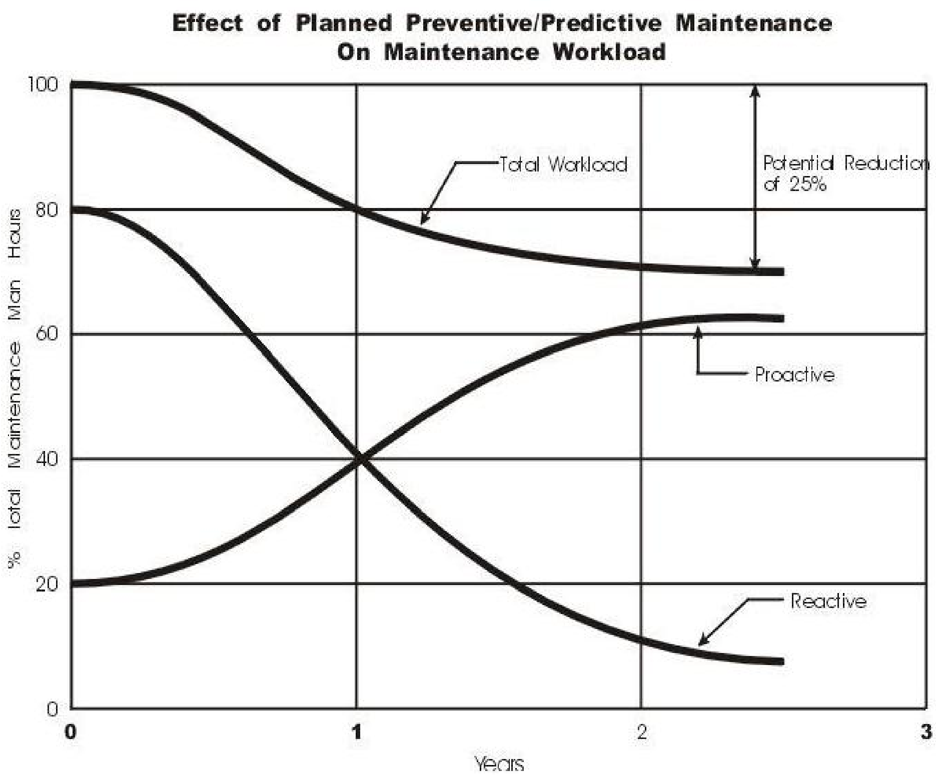
11. *A beginning*—Start PPM practices immediately if you expect to establish an efficient operating system. One that delivers high quality output, on time, every time.
    - A. Start small
    - B. Sell expansion upon early successes
    - C. Therefore select your early efforts wisely
    - D. Applied A-B-C analysis to selection of equipment
12. Focus On the Correction as well as The Inspection
    - A. Inspection Is The Investment
    - B. Correction Is The Return On The Investment
13. Management Follow-up

PPM Increases

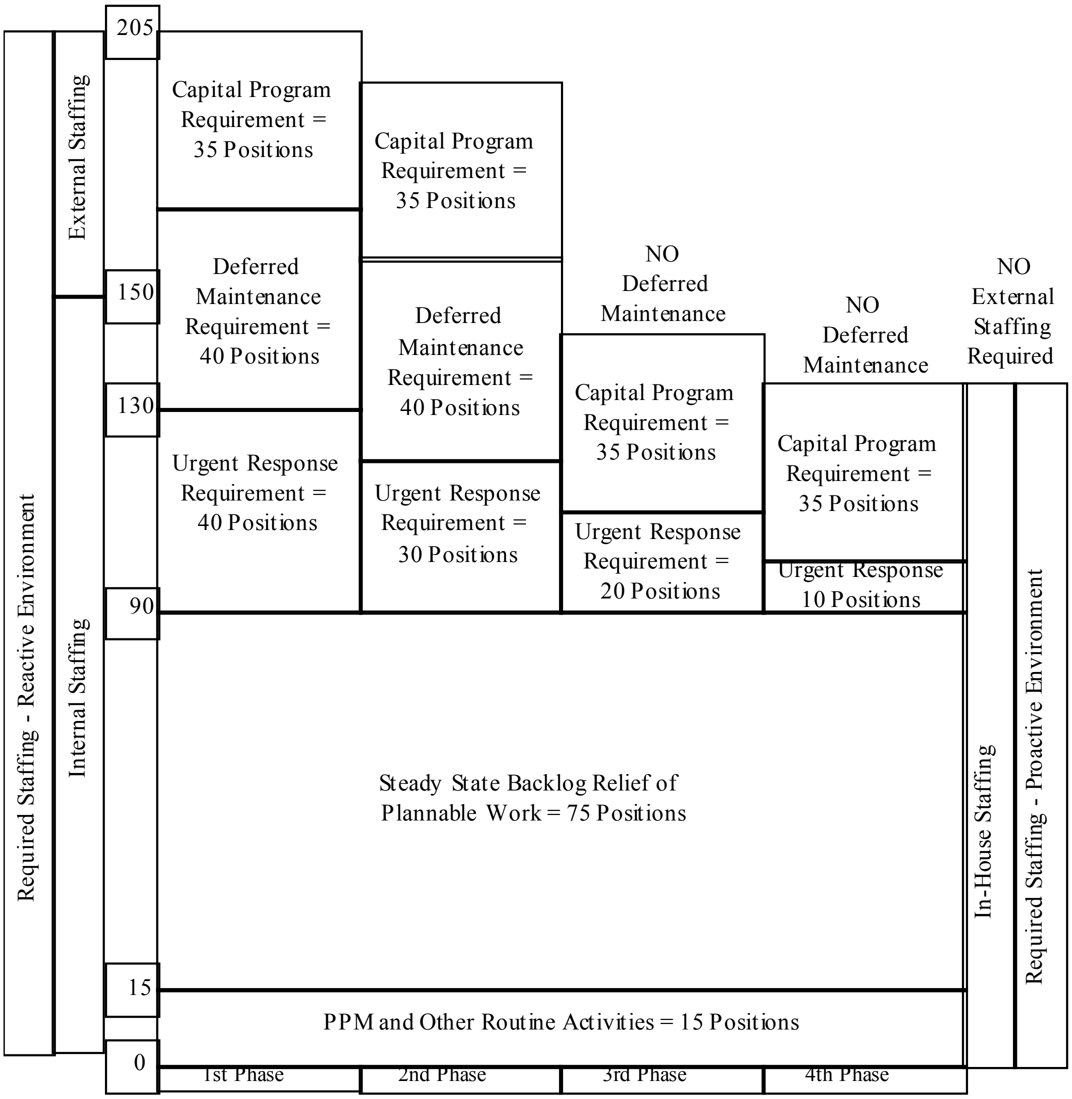
1. Maintenance staffing
2. Repair parts costs
    - A. Preventive tends to increase parts cost
    - B. Predictive reduces parts cost
3. Volume of work that can be planned and scheduled repetitively
4. Work load leveling
5. Equipment reliability and uptime

PPM Decreases

1. Scrap and reject costs
2. Downtime costs
3. Cost of lost sales volume
4. Total cost of maintenance
5. Urgent or emergency interrupts due to breakdowns
6. Unnecessary damage to equipment
7. High priority, randomly occurring unscheduled work
8. Material and spare parts inventories
9. Total labor required to maintain the facility



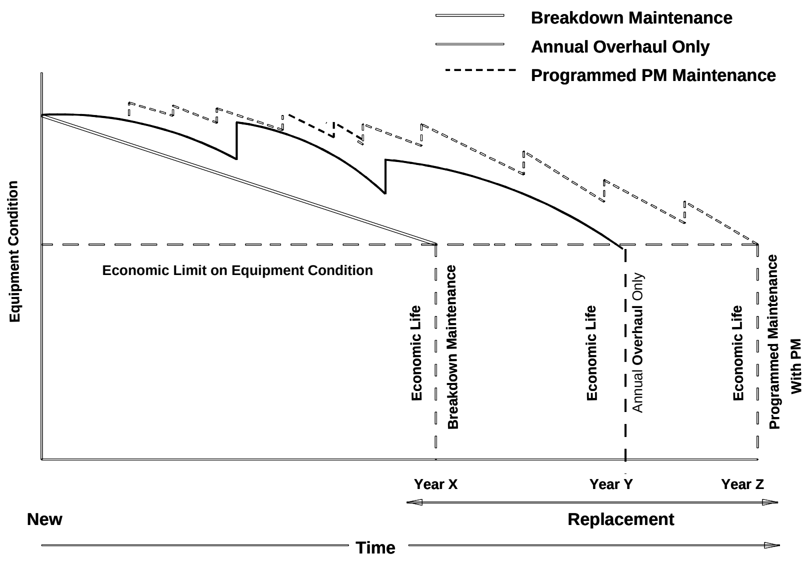
Proper Staffing is Dependent Upon Workload



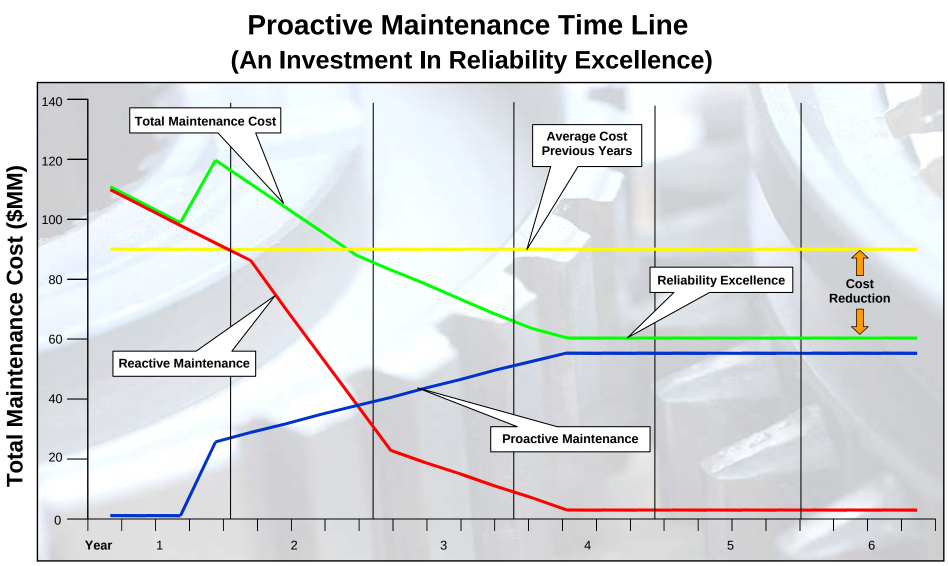
PPM Is Comprised Of

1. Proper organization
2. Proper operation of equipment
3. The proper lubricants, in the right quantities, in the right location, at the proper time
4. Predicting wear and deterioration by regularly checking, measuring and adjusting
   A. Regular inspection to identify small repairs before they become major repairs
   B. Predictive techniques to replace components just before they fail
      a. Vibration monitoring and analysis
      b. Infrared inspection
      c. Sound detection
      d. Lubrication and oil sampling
      e. Etc.
5. Replacement of components on a regular basis before they fail
6. Correction of potential failures when inspection indicates the need
7. Overhauling equipment periodically to upgrade general equipment condition
8. Reliability engineering to reduce or eliminate repetitive failures
9. Reliability engineering to minimize failures through adjustments to the PPM program

Preventive Maintenance Impact



Proactive Maintenance



Solid solutions require time foresight patience sacrifices and discipline. But they have large long-run payoffs. The basic difference between solid solutions and quick fixes is the difference between investing in the future and mortgaging it. To invest too little in the pursuit of "Reliability Excellence" only leads to failure. Like any investment, the Maintenance Investment precedes the Proactive Return.

Predictive Maintenance

Predictive Maintenance (PdM) monitors the performance and condition of equipment or systems to detect/trend degradation. Techniques include:

1. Vibration monitoring
2. Thermographic inspection
3. Oil analysis
4. Visual inspection
5. Shock pulse
6. Ultrasonic leak detectors
7. Electrical insulation
    A. Megger tests
    B. Surge comparison
8. Performance testing
9. Wear and dimensional measurements
10. Signature analysis, time and frequency domain
11. Nondestructive testing
    A. Ultrasonic
    B. Borescope inspections
    C. Eddy current

Why perform predictive maintenance?

1. Monitoring detects degrading conditions
2. Most cost failures result from degrading conditions
3. Trending degradation permits planning for repair
4. Trending degradation permits scheduling repair

What are the concerns of predictive maintenance?

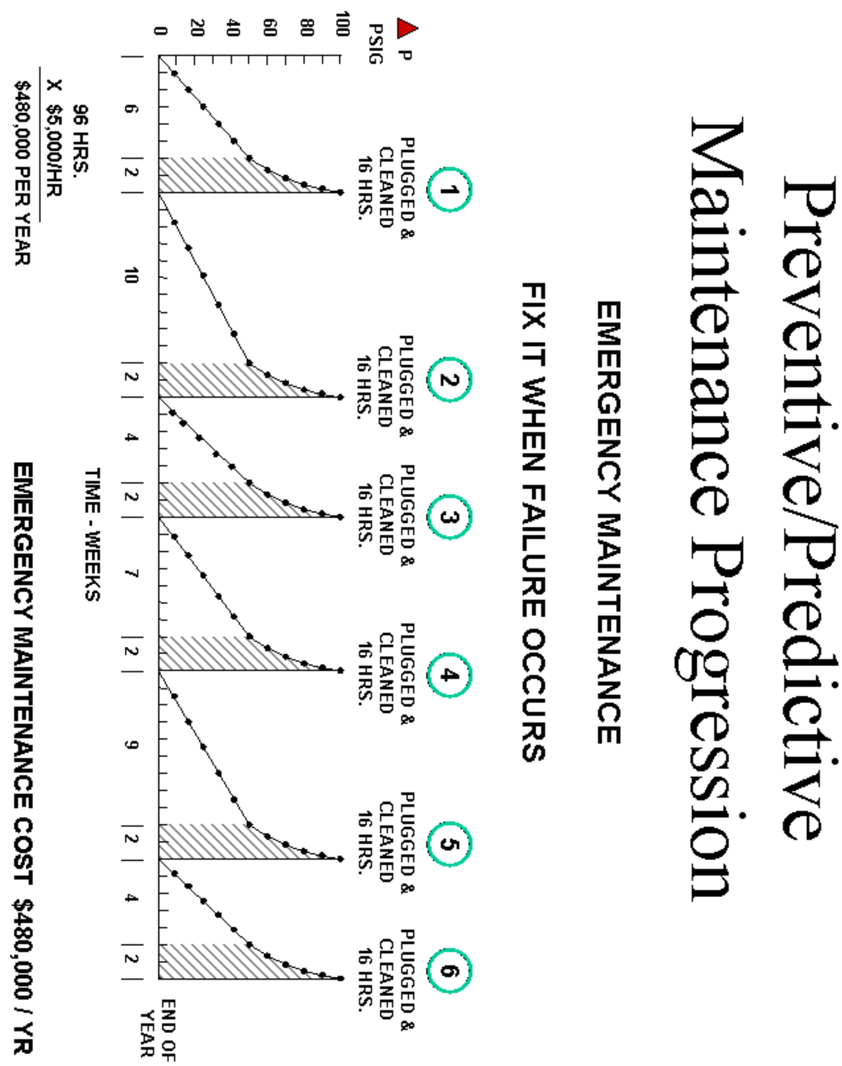
1. Doing only predictive maintenance is living close to the edge
2. Takes courage to make the initial calls for repairs
3. Must be an adjunct to a sound preventive maintenance program

When should you consider a predictive maintenance program?

1. After the preventive maintenance program is established
2. Only with corporate/management support

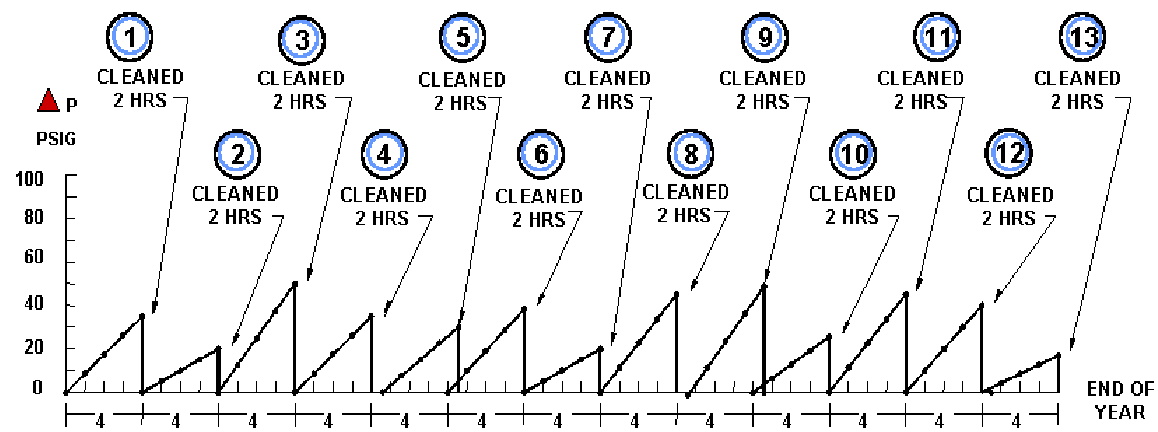
Typical Predictive Techniques

Monitoring Techniques	Use	Problem Detection
Vibration	Rotating machinery, e.g., pumps, turbines, compressors, internal combustion, gear boxes	Misalignment, imbalance, defective bearings, mechanical looseness, defective rotor blades, oil whirl, broken gear teeth
Shock Pulse	Rotating machinery	Trends of bearing condition
Fluid Analysis	Lubrication, cooling, hydraulic power systems	Excessive wear of bearing surfaces fluid contamination
Infrared Thermography	Boilers, steam system components, electrical switchboards and distribution equipment, motor controllers, diesel engines, power electronics	Leaky steam traps, boiler refractory cracks, deteriorated insulation, loose electrical connections, hot or cold firing cylinders
Performance trending	Heat exchangers, internal combustion engines, pumps, refrigeration units and compressors	Loss in efficiency, deteriorating performance trends due to faulty components
Electrical insulation tests, e.g., megger tests, polarization index, surge comparison testing, rotor impedance testing, DC high potential testing	Motor and generator windings, electrical distribution equipment	Trends of electrical insulation condition, turn-to –turn and phase-to –phase short, grounds, reversed coils or turns
Ultrasonic leak detectors	Steam hydraulic and pneumatic system piping	Leaking valves, system leaks
Fault gas analysis and insulating liquid analysis	Circuit breakers, transformers and other protective devices	Overheating, accelerated deterioration, hostile dielectric
Protection relay testing and time travel analysis	Circuit breakers, transformers and other protective devices	Deteriorating or unsafe performance
Stereoscopic photography, hull potential measurements, diving inspections.	Underwater hull	Corrosion, fatigue cracking trends, hull fouling trends
Material (non-destructive) testing, e.g., ultrasonic, eddy current, borescopic inspections	Hull structure, shipboard machinery and associated piping systems and mechanical components	Corrosion, erosion, fatigue cracking, delaminations, wall thickness reduction
Signature analysis, time domain and frequency domain	Rectifiers, power supplies, inverters, AC and DC regulators, generators	Degraded solid state circuits and other electrical components
Wear and dimensional measurements	Sliding, rotating and reciprocating elements	Excessive wear and proximity to minimum acceptable dimensions which affect performance


Preventive/Predictive Maintenance Progression
EMERGENCY MAINTENANCE
FIX IT WHEN FAILURE OCCURS
▲P PSIG
100
80
60
40
20
0
1 PLUGGED & CLEANED 16 HRS.
2 PLUGGED & CLEANED 16 HRS.
3 PLUGGED & CLEANED 16 HRS.
4 PLUGGED & CLEANED 16 HRS.
5 PLUGGED & CLEANED 16 HRS.
6 PLUGGED & CLEANED 16 HRS.
6
2
10
2
4
2
7
2
9
2
4
2
END OF YEAR
TIME - WEEKS
96 HRS.
X $5,000/HR
$480,000 PER YEAR
EMERGENCY MAINTENANCE COST $480,000 / YR

Transition To Preventive Maintenance

PREVENTIVE MAINTENANCE
USING A CLEANING CYCLE OF 4 WEEKS

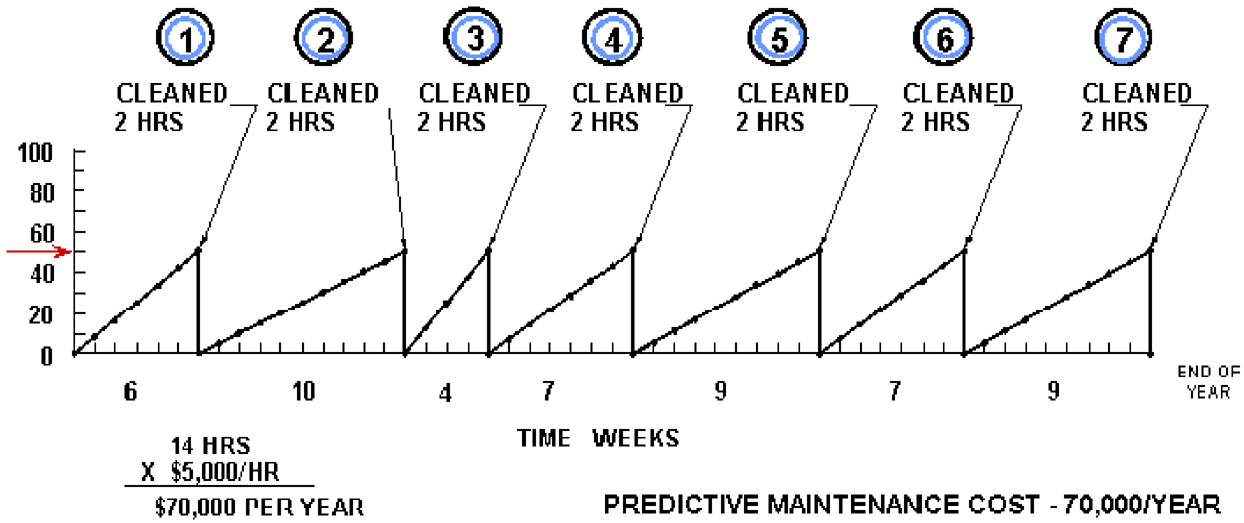


26 HRS
X $5,000/HR
$130,000 PER YEAR

PREVENTIVE MAINTENANCE COST $130,000 / YEAR

Preventive Maintenance is <u>time</u> based and uses personal sensory perception.

PREDICTIVE MAINTENANCE
USING AN ENGINEERING LIMIT OF 50 PSIG ΔP



Predictive Maintenance is condition based using advanced technology and instrumentation. It represents the application of JIT (Just In Time) philosophy to the maintenance function.

** Assumes installed indicators; read and reported by operators. Therefore, the savings need not be partially offset by routine maintenance inspection tours.*

Setting Up a Preventive/Predictive Maintenance Program
(Sequence of Major Steps)

1. Assess the Need
   A. Analyze equipment history
   B. Review available records
      a. Downtime
      b. Defects
      c. Yield Losses
      d. Energy Losses
      e. Regulatory Fines
      f. Work Place Accidents
   C. Establish definitions, principles and concepts
   D. Build a Case
2. Educate Management and Obtain General Commitment
   A. No sense expending the effort on hope of support
   B. Make it clear that PPM is an investment. Payback is excellent, but does not occur over night.
   C. Obtain approval for sufficient, dedicated and qualified Reliability Engineering resource for program design, installation and continuing refinement.
3. Inventory Equipment
   A. Establish a plant-wide equipment identification system
4. Appraise Equipment Condition
   A. Can it be easily maintained in its present condition? *If not;*
   B. Can it be upgraded to maintainable condition? *If it can;*
   C. How can it be taken out of service and how much will it cost? *If it cannot be;*
   D. What alternatives are there to choose from?
5. Choose Equipment to Be Included in the Initial Program
   A. Start small. Build as you go. Use early successes to justify and sell program expansion. Progressive improvement is better than delayed perfection.
      a. Apply the Pareto Principle in selecting initial equipment to be included (A-B-C Analysis)
   B. Select critical items. Those where failure to maintain properly results in serious consequences, such as:
      a. Excessive out-of-service time
      b. Excessively high maintenance cost
      c. Serious equipment deterioration

d. Conditions endangering employee safety or health

e. Variations in product beyond quality items

f. Insufficient dependability to support JIT

C. Consider Alternatives. Decide whether, or not, to PPM.

a. Is the equipment critical to the operating plan?

b. Does normal equipment life without PPM equal or exceed operating needs?

c. Will the cost of PPM exceed the cost of all losses incurred within a reactive maintenance mode (repair only upon failure)?

d. Will failure cause a major shutdown, create a hazard, or cause costly damage?

D. When possible, select members of a large class of identical items—compounded benefits.

6. Define the Program in General Terms

A. Establish Principles, Concepts, Objectives, Scope, Definitions, Goals, and Interim Targets (milestones)

7. Develop System Details by Individual System/Component

A. Gather source documents

B. Perform Failure Mode and Maintenance Analysis (FMMA) to establish the mechanisms and conditions to be monitored

a. Analyze equipment history

b. Analyze downtime records

c. Conduct design review to identify functional failure modes

C. Evaluate existing PPM's

D. Determine the most suitable type of system

a. Component vs. Process

b. Inspection vs. Programmed Change Out/Overhaul

c. Avoid Over-Inspection! It is expensive!

d. Prevention vs. Predictive vs. Combination Inspections

E. Determine what to inspect for

a. A few questions are in order

1. What symptoms indicate the pending failure under review?

2. How can the symptom be detected?

3. Which methods of detection might be useful?

4. How long is the anticipated failure development period?

5. What does this suggest about inspection interval?

b. Prepare and code written standard practices, instructions, and check sheets for all PPM work (inspections, lubrications, adjustments, and part replacements)

1. Be specific
2. Apply machine condition maintenance
   - Establish acceptable criteria for each monitored condition
   - Quantify acceptable conditions/limits
   - General directions such as "check belt tension" should be improved to read:
     - "Check belt tension using tensioning tools #1432"
     - "Retention belt if deflection is greater than one-half inch"

c. Do not neglect inactive equipment

d. Determine which PM's can be performed by equipment operators

F. Utilize operation's statistical process/quality control charts as predictive maintenance vehicles

G. Consider alternatives

a. Is it more economical to operate with installed, standby (spare, redundant) equipment?

- Is it available?

b. Can the equipment be made reliable through programmed change outs/overhauls without interim inspections?

- A trend to programmed should be progressive as the knowledge base improves, allowing reliable prediction of wear-out.
- Should consideration be given to the installation of permanent predictive monitoring devices (vibration, temperature, pressure, etc.)?

H. Consider equipment status required for PPM performance

a. Can it be performed while equipment is in operation?

- predictive techniques increase likelihood

b. Is downtime required?

c. Is complete or partial teardown necessary?

I. Define PPM criticality

a. Critical

b. Essential

c. Preferred

d. Regular

J. Develop PM packages and inspection routes to gain the economies of logical groupings and sequencing

K. Establish frequency and schedule type

a. Fixed (balanced throughout the year)

- Delinquent if not completed by end of scheduled week

b. Floating (fixed interval)

c. Metered

L. Determine resource requirements

a. Labor (crew size, duration and labor-hours)

b. Materials, tools and equipment

c. Equipment access

M. Determine who is to perform each routine

a. Dedicated PPM crew or general crew

b. Maintenance or Operations

N. Prepare associated PPM work orders

O. Summarize on a component maintenance plan

8. Organize for a Successful Program

A. Develop a program plan establishing functions, responsibilities, training and equipment needs, budgetary requirements, etc.

a. Establish total PPM workload

b. Determine necessary PPM staffing

c. Decide upon Dedicated vs. Non-Dedicated PPM Crew

B. Tie PPM into the scheduling system

a. Establish PPM priority and placement upon schedules relative to other work

b. Balance weekly PPM resource requirements using calendar loading

C. Define the responsibility for writing corrective work orders stemming from PPM inspections

D. Avoid excessive and cumbersome administrative detail (paperwork).

E. Schedule compliance for preventive and corrective maintenance must be high (initially above 85%, eventually above 95%)

9. Sell the PPM Program to Management, Operations, and the Maintenance Tradespersons.

A. Obtain management approval . . . and commitment!!!

10. Upgrade Equipment to Maintainable Condition, as Defined in the Plan

A. Set priorities

B. Obtain vendor quotes

C. Obtain approval

D. Take equipment out of services by priority

E. Reinstall upgraded equipment

F. Immediately activate PPM inspections and corrective actions

11. Conduct Essential Training

12. Set up equipment history

A. Create permanent files and records on PPM work performed (including costs)

B. Develop files of completed PPM work orders and resultant corrective work orders

13. Create computerized program to fit needs of the PPM system

14. Put PPM scheme into operation

15. Activate reliability-engineering review

    A. Develop tests that establish operating parameters and gather data

    B. Analyze reports of completed PPM/Corrective work orders to determine high-cost areas

    C. Establish methodology for trending and analyzing data to make recommendations

    D. Focus reliability-engineering talent on essential areas

    E. Establish assessment process to fine tune the program

        a. Establish performance standards for each piece of equipment

        b. Adjust inspection frequencies based on experience

        c. Optimize inspection methods and introduce advanced inspection methods

        d. Conduct a periodic review of equipment on the PPM program and delete the equipment no longer requiring PPM

        e. Remove from or add to the PPM program equipment and items deemed appropriate

    F. Communicate problems and solution to involved personnel

    G. Control the direction and cost of the PPM program

Reasons for Failure

1. Preventive maintenance not properly sold or justified to top management
    A. Component-based rather than process-based
2. Preventive maintenance not sold to workers
3. Qualified engineering talent not assigned to provide Reliability Engineering and corrective maintenance on a continuing basis
4. Conflict between emergencies and PM's
5. Scope of the PM program too broad—tried to PM everything
6. Too much paper work
7. Frequencies established for PM work orders not followed as scheduled
    A. Not conducted as a "controlled experiment"
    B. Used as "fill in" only
    C. Lack of monitoring and refinement of the system
8. Inspection procedures inadequately defined
    A. Directions such as "check belt tension" should be improved to read:
        a. "Check belt tension using tensioning tool #1432"
        b. "Retention belt if deflection is greater than one-half inch"
9. Lack of follow-up information regarding corrective efforts (Deferred)
10. Equipment Failure Record not available
11. Lack of adequately trained labor resources to carry out scheduled inspections
12. Initial discouragement, accompanied by dwindling support
    A. Insufficient attention to corrective maintenance
13. Over-inspection resulting in higher costs than necessary
14. Equipment included in the PM program not maintainable in the sense required for PM
    A. No upfront equipment appraisal

To realize full potential from PPM the following requirements must be met:

A. Management commitment and involvement

B. Existence of a Reliability Engineering function to design, guide, apply and refine the program

C. A unified work order system to include all preventive maintenance services and inspections

D. An effective planning function and scheduling procedure

E. Full support of operations which, as custodian of the facilities, has the ultimate responsibility for its condition and operating efficiency

F. Provision of equipment maintenance history and PM reports

G. Systematic use of equipment history and other maintenance information by management and reliability engineers as a basis for developing and adjusting regular PM routines and correcting equipment defects.

Remember

1. PPM is not an end in itself—only one of the essential elements.
2. It is, however, one of the essential elements and is indeed the keystone of successful maintenance programs.
3. Consider the alternatives.