TOTAL PRODUCTIVE MAINTENANCE
PLANNED MAINTENANCE
STEP 2

your partner in becoming GLOBALLY COMPETITIVE
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1. Introduction

Planned maintenance (PM) is the third pillar of Total Productive Maintenance (TPM). Its purpose is to improve the effectiveness of operational equipment, in terms of increasing its reliability, maintainability and performance and reducing maintenance costs and equipment failures, through scheduled maintenance tasks. These tasks are based on predicted and/or measured failure rates.

In order to implement planned maintenance successfully, support is required from both Maintenance and Production personnel, in the execution of the planned maintenance pillar. The benefits of introducing a planned maintenance system are described in the section following, as an incentive to working together as a team in its implementation.

A series of steps make up the planned maintenance pillar, with this module focusing on step two – reversing equipment deterioration and correcting weaknesses. Each step contributes to the reduction and prevention of unforeseen equipment failures and breakdowns.

This module is aimed at describing the activities required for implementing step two of planned maintenance.
2. Planned maintenance benefits

The benefits of planned maintenance are depicted below:

- a) The quality of the part is maintained,
- b) Increase in production up-time,
- c) Reduced cost of operations,
- d) Reduction in the number of machinery required,
- e) Improving equipment capability and reliability – increasing the mean-time-between-failures (MTBF),
- f) Improving equipment maintainability by reducing sporadic maintenance time – reduction in the mean-time-to-repair (MTTR),
- g) Establishing/improving predictive maintenance,
- h) Reduced maintenance costs.
Consequently, poor maintenance activities have a negative effect on operational activities and are listed in figure 1 below:

![Figure 1: The effect of poor maintenance activities](image)

**3. Planned maintenance responsibilities**

The implementation of planned maintenance activities requires the commitment and support of both Production and Maintenance. Each play a role in ensuring the planned maintenance activities are followed through, thereby improving the reliability, maintainability and availability of equipment, as well as reducing costs as a result of these improvements.

The crucial roles played by each of these parties, is described in the sections following and summarised in an illustration.

**3.1 The role of the production department**

The role of production entails the support for steps 0 to 3 of autonomous maintenance (this is known as planned maintenance step 0, as explained in the PM
step 0 module), segregated into three categories: preventing deterioration, measuring deterioration and rectifying deterioration.

**Preventing deterioration** requires the following:

- The up-keep of equipment through cleaning, oiling, tightening and routine inspections of equipment conditions, to avoid forced deterioration,
- Operating equipment correctly and making adequate adjustments during operation and setups,
- Recording data on breakdowns and other malfunctions,
- Collaborating with the maintenance department to study and implement improvements.

**Measuring deterioration** involves daily/periodic inspection of the equipment, to ensure its reliability and avoid unforeseen failures.

**Rectifying deterioration** includes the following:

- Minor maintenance on equipment to ensure its up-time,
- Developing countermeasures for causes of forced deterioration on the equipment,
- Reporting on breakdowns and malfunctions promptly and accurately.
Summary – Roles of the production department tabled in figure 2:

<table>
<thead>
<tr>
<th>Maintenance Classification</th>
<th>Preventing Deterioration</th>
<th>Measuring Deterioration</th>
<th>Rectifying Deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Operation</td>
<td>Correct operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Setup and adjustment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Routine Maintenance</td>
<td>Cleaning and Countermeasures of defects</td>
<td></td>
<td>Minor maintenance</td>
</tr>
<tr>
<td></td>
<td>Oiling</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Tightening</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Routine inspection of conditions of use and deterioration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periodic Maintenance</td>
<td>Periodic inspection</td>
<td></td>
<td>Early Detection of situation and speedy countermeasures</td>
</tr>
<tr>
<td>Breakdown Maintenance</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrective Maintenance (Reliability)</td>
<td>Enhancement of material strength</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Reduction of load</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhancement of accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrective Maintenance (Maintainability)</td>
<td>Development of condition monitoring</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: The roles of the production department

3.2 The role of the maintenance department

As is required of production, the role of maintenance includes the support for steps 0 to 3 of autonomous maintenance (AM), as well as support of planned maintenance activities. The maintenance activities to be performed are segregated into three categories: preventing deterioration, measuring deterioration and rectifying deterioration.

**Preventing deterioration** by improving the service life of the equipment, reducing its load or enhancing the material strength of the equipment, improves its reliability. The AM activities of production should be supported by maintenance to maintain the basic condition of the equipment.
Measuring deterioration involves periodic inspection and examination of the equipment, to monitor equipment conditions, as well as develop trends in downtime or failures. Maintenance is also involved in improving the methods for inspecting equipment.

Rectifying deterioration and restoring the basic conditions of equipment in the following ways:

- Defects, deterioration and weak points of machine design to be investigated,
- Conduct why-why analyses on breakdowns or failures, as well as developing and implementing countermeasures,
- Strengthen weak equipment/component design through improvements,
- Develop a maintenance prevention (MP) sheet for design changes, for future planning and design/development of new equipment,
- Kaizens for improvements in the reliability and maintainability of equipment.
Summary – Roles of the maintenance department tabled in figure 3:

<table>
<thead>
<tr>
<th>Maintenance Classification</th>
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<th>Rectifying Deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic Maintenance</td>
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<td>Periodic inspection</td>
<td>Periodic shutdown</td>
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<tr>
<td></td>
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<td>Periodic examination</td>
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<tr>
<td>Predictive Maintenance</td>
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<td>Trend control</td>
<td>Unscheduled shutdown</td>
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<tr>
<td>Breakdown Maintenance</td>
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<td>Early Detection of situation and speedy countermeasures</td>
</tr>
<tr>
<td>Corrective Maintenance (Reliability)</td>
<td>Enhancement of material strength</td>
<td>Development of condition monitoring</td>
<td>Improvement of maintenance work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of load</td>
<td>Improvement of maintenance work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enhancement of accuracy</td>
<td>Enhancement of maintenance quality</td>
</tr>
<tr>
<td>Corrective Maintenance (Maintainability)</td>
<td>Development of condition monitoring</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Improvement of inspection work</td>
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Figure 3: The roles of the maintenance department

4. Types of maintenance

There are four types of maintenance performed, namely breakdown maintenance, periodic maintenance, predictive maintenance and corrective maintenance. The applications of these are explained in the sections following:

4.1 Breakdown maintenance

Breakdown maintenance occurs after an equipment/component failure. It is used intentionally in cases where the costs and losses of breakdowns are smaller than that associated with preventing the failure. Inspection or the periodic replacement of
parts is not conducted at all. Because the parts are used until the end of its service life, maintenance and repair costs are lower.

4.2 Periodic maintenance
Periodic maintenance occurs at scheduled intervals or periods. It is based on a schedule as per the manufacturer’s recommendation or past experience and collected data. Time based maintenance (TBM) or Inspection and Repairs (IR) are methods used to conduct periodic maintenance.

Time based maintenance - The repair period is set based on the life-cycle of the component, taking into consideration productivity, the number of operations, etc. This reduces maintenance inspections and failures are infrequent.

Inspection and repairs - The equipment is inspected and disassembled regularly, with defective parts replaced based on its condition.

4.3 Predictive maintenance
Inspection is carried out to determine the state of the equipment or component deterioration and conduct repair based on the results of the inspection. Condition based maintenance (CBM) is a method used to conduct predictive maintenance. Technology can also be used to assess the condition of a component or equipment, to determine if maintenance or the replacement of parts is necessary.

Condition based maintenance - The deterioration of equipment is based on measurement data and the analysis thereof. Repair is carried out when the values measured reach pre-set deterioration standards set by the manufacturer or as a result of past experience. This can prevent the costs associated with over-maintenance.

4.4 Corrective maintenance
Corrective maintenance is carried out after a breakdown occurs. It is used in cases where trends in deterioration are not clear and inspection of the equipment is difficult. It is also used to improve or modify equipment to reduce failures and make maintenance easier, thereby increasing the reliability and maintainability of the equipment, as well as improving the mean-time-between-failures (MTBF) and
mean-time-to-repair (MTTR). Steps are also taken to extend the service life of equipment and reduce the cost of maintenance.

5. PM Step 2: Reverse deterioration and correct weaknesses

Step 1 of planned maintenance involved the evaluation of equipment failure/breakdown status and understanding the current situation. This described the current state of the equipment and provided a baseline for data collection and future improvements.

Step 2 involves reversing deterioration to the equipment and restoring it to its basic condition, as well as correcting the weaknesses observed, to strive for zero failures.

Figure 4 describes the process to be followed for PM step 2. These steps will be explained in further detail in the sections following.

Process for planned maintenance step 2:

![Figure 4: Process for planned maintenance step 2](image-url)
5.1 Reverse deterioration and establish basic conditions

In the second step of planned maintenance, the aim is to reverse forced deterioration and bring the equipment back to its basic condition. This is achieved by carrying out the autonomous maintenance activities of cleaning, lubrication and inspection (AM steps 0 to 3).

It requires the effort of both production and maintenance, as stated earlier in the module. The roles required of each party in bringing the equipment back to its basic condition and reducing deterioration is tabled in figure 5 and 6.

Production requirements (for PM step 2):

1. **Deterioration prevention:**
   - Operate equipment correctly
   - Maintain basic equipment conditions (cleaning, lubrication)
   - Make adequate adjustments (during operation and setup)
   - Record data on breakdowns and other malfunctions
   - Collaborate with maintenance department to study and implement improvements

2. **Deterioration measurement** (using the 5 senses)
   - Conduct daily inspections

3. **Equipment restoration**
   - Make minor repairs (simple parts replacement and temporary repairs)
   - Report promptly and accurately on breakdowns and other malfunctions

*Figure 5: Roles of production for PM step 2*
Maintenance requirements (for PM step 2):

1. **Autonomous maintenance**
   - AM activities of production should be supported by maintenance.

2. **Restore deterioration**
   - Inspection using optimal condition check sheets / manufacturer specification sheets.

3. **Countermeasures for deterioration and restoration of basic conditions**
   - Defects, deterioration and weak points of design to be investigated,
   - **Why-why analysis**: countermeasures to be developed and implemented,
   - Improvements to strengthen weak design,
   - A **Maintenance Prevention (MP) sheet** can be developed for part design changes – for future planning and design of new equipment,
   - Kaizens for improvements in **reliability and maintainability**.

Figure 6: Roles of maintenance for PM step 2

The following tools and templates are used in developing countermeasures for deterioration, improving the condition of equipment and reducing breakdowns/failures.

a) **Why-why analysis**

The why-why analysis is used to determine the root cause of a breakdown, as well as that of defects, equipment deterioration and weak points of equipment design. Countermeasures for the causes and source of the failure are to be brainstormed and the most effective solution implemented. Improvements can be made to strengthen the design of equipment, or its reliability and maintainability.

The why-why analysis is constructed by maintenance personnel and can include support from the focused improvement (FI) team, to determine the root cause of the problem. An example of a why-why analysis is shown in figure 7.
Example: Why-why analysis

![Image of why-why analysis]

Figure 7: Example of why-why analysis

The why-why analysis consists of the following information:

- **Breakdown** – the description of the breakdown
- **Repair action** – the countermeasure performed to correct the failure
- **Asking why** – Each reason for the failure is broken down until the root cause of the failure is found

**b) Maintenance prevention sheet**

Improvements in equipment design weaknesses can be recorded on a maintenance prevention (MP) sheet for future use. This provides useful information to manufacturers, for the planning and design of new equipment. It ensures that the improvements made on the current equipment are aligned to the plans of the new equipment, thereby avoiding defects or weak points built into the design. An example of an MP sheet is shown in figure 8.
Example: Maintenance prevention sheet

Figure 8: Example of MP sheet

The MP sheet should be developed by maintenance and include the following information:
A description of the problem,

- The root cause determined by the why-why analysis or other quality control tool,
- A drawing depicting the problem before and the improved state due to modifications or design changes,
- The positive effect of the design change on the equipment or process.

c) Kaizens for reliability and maintainability

Improvements in the reliability and maintainability of equipment, increases the up-time of the machine and thereby reduces losses. Kaizens for reliability (shown in figure 9) ensures the machine is available for use when required (during production) and Kaizens for maintainability (shown in figure 10) improves the time and effort taken to rectify failures when they do occur or during planned maintenance.

These Kaizens are to be developed by maintenance personnel, with the support of the FI team and should include before and after drawings or photos of the improvements, as well as the benefits associated with each improvement.
Example: Kaizen for reliability

Figure 9: Kaizen for reliability
Example: Kaizen for maintainability

![Kaizen Sheet](image)

**Figure 10: Kaizen for maintainability**

### 5.2 Eliminate environment causing forced deterioration

Using the breakdown sheets developed in step one of planned maintenance (shown in 4.1 and 4.2 of the PM step 1 tutor manual), the nature of failures should be investigated. Is the failure natural or forced? Forced deterioration can be remedied using autonomous maintenance activities (cleaning, lubrication and inspection), as well as focused improvement activities (Kaizens) to reduce and eliminate sources of contamination causing a harmful environment.

Failures that are natural and due to weak design can be improved through focused improvement Kaizens for design improvements.

Examples in eliminating forced deterioration caused by the environment:

- Set loading limits to eliminate excess loading and excessive stresses,
- Standardise equipment operation methods,
✓ Countermeasures for eliminating dust, humidity, vibration, shock and high temperatures.

5.3 Forecast problems (failures)

The purpose of planned maintenance is to schedule maintenance tasks and thereby avoid unscheduled down time. This requires measured failure rates, in order to predict breakdowns in the future and prevent identical or similar major breakdowns from reoccurring.

In order to schedule maintenance tasks, the prediction of failures is required and the following tools can be used to detect deterioration, before a failure occurs.

a) Mean time between failures and Mean time to repair

The mean time between failures measures the reliability of the equipment, by determining how long a machine runs for, before a breakdown or failure occurs. The longer the period between failures, the longer the machine is running for. This provides higher machine reliability and availability.

The formula for calculating MTBF is shown in figure 11:

\[
MTBF = \frac{\text{Total Operating Time}}{\text{Total Failures}}
\]

MTBF is calculated by adding the total operating time for a period and dividing it by the total number of failures within that period. This provides the average time a machine runs for, before a failure occurs and provides a forecast for when a scheduled maintenance task should take place, to prevent that failure.

The mean time to repair measures the average time taken to repair a machine/component failure and is an indicator of the maintainability of the equipment. The shorter the repair time, the smaller the machine down-time, thereby providing higher machine availability.
The formula for calculating MTTR is shown in figure 12:

![MTTR formula](image)

Figure 12: MTTR formula

MTTR is calculated by adding the total repair time for a period and dividing it by the total number of failures within that period. This provides the average time taken to repair a machine/component failure.

Knowing the MTTR, allows the maintenance department to accurately allocate the time required for the scheduled maintenance task to take place and the downtime required from production or overtime required for the task.

An example of a MTBF and MTTR calculation is shown in figure 13.

Example of MTBF and MTTR:

![MTBF and MTTR calculation example](image)

Figure 13: MTBF and MTTR calculation example

- The total operating time in green = 270min
- The total repair time in red = 45min
- The total number of failures = 3 (in red)

Therefore: \( MTBF = \frac{270}{3} = 90 \text{min of operating time before a failure occurs (average)} \)

\[ MTTR = \frac{45}{3} = 15 \text{min to repair a failure when it occurs (average)} \]
Ideally, the MTBF should be as long as possible and the MTTR as short as possible, to maintain the up-time of the machine.

In developing Kaizens for increasing MTBF and reducing MTTR, parts are to be prioritised according to their importance in attaining the goal of improving MTBF and MTTR.

Figure 14 displays a summary for selecting priority parts to improve MTBF and MTTR:

- Selecting parts to improve MTBF
  - Select equipment whose failure will result in serious production losses
  - Use a pareto chart of replacement parts history to choose the important parts
  - Analyze individual parts to determine if the failures are initial failure, random failure, or wear-out failure

- Selecting parts to shorten MTTR
  - Parts which are expensive or require many maintenance-hours to replace
  - Parts requiring advanced skills
  - Parts with long lead times
  - Parts that require long downtime

Figure 14: Selecting priority parts to improve MTBF and MTTR

b) Time based maintenance and Condition based maintenance

Time-based maintenance entails the performance of maintenance activities, based on a schedule. The schedule for the replacement or maintenance of a component/equipment is based on the manufacturer’s recommendation or on past experience and collection of breakdown data. This allows down time to be planned, preferably during non-production hours, thereby maintaining equipment up-time and avoiding losses.
The time-based maintenance schedule is developed by the maintenance team and includes the parts to be replaced/checked, as well as specific times during the year in which to do planned maintenance.

An example of a TBM schedule is shown in figure 15 below:

![Figure 15: TBM schedule example](image)

**Condition based maintenance** is based on equipment conditions, including the operating environment. It is performed after one or more indicators (pre-set deterioration standards) show that the equipment is going to fail or that the equipment performance is deteriorating.
It is aimed at extending machine health, as well as correcting equipment at the right time, thereby preventing the costs associated with over-maintenance. CBM forecasts potential failures, by assessing the condition of components/equipment and carrying out repairs when its condition reaches a certain level.

The replacement or maintenance of a component/equipment is based on the manufacturer's recommendation or on past experience and collection of breakdown data by maintenance personnel.

Examples of CBM include vibration analysis, Thermography surveys and oil analysis. These are explained further in the sections following.

**Vibration analysis**

![Vibration Analysis](image1.png)

**Figure 16: CBM - Vibration analysis**

Vibration analysis (figure 16) can detect problems early and before a breakdown occurs. The advantages of vibration analysis include:

- Decreases in repair and production costs due to early detection,
- Maintenance tasks scheduled and planned conveniently,
- Increases in the reliability of equipment,
- Reductions in production down time and costs,
- Reductions in large scale repairs and failures.

**Thermography**

**What can Thermography find?**

- Overheating electrical connection indicates a serious fire hazard.
- Indication of bearing overheating, will eventually cause failure

**Figure 17: CBM - Thermography**

Infrared Thermography detects temperature disparities that could indicate problems such as loose electrical connections or excessive friction in machinery and mechanical systems. Infrared emissions are displayed visually, as shown in figure 17, while the equipment remains in operation, thereby avoiding production interruptions. “Hot spots” can be identified quickly, saving labour and cost, while planned maintenance can be targeted where it is required.

The three common uses of infrared Thermography are listed below:

- Electrical — faulty connections can be detected in its early stages, so possible breakdowns can be avoided,
Mechanical — infrared Thermography can help detect problem areas (such as excessive friction from insufficient lubrication) in motor bearings, gears, couplings, pulleys, conveyors and chain drive systems,

Refactory/Insulation — this detects hidden losses of heat that can drain performance and increase costs. Thermal images of walls, ceilings and roofs can be evaluated for signs of heat escaping from those areas or entering the insulated space.

Oil analysis

Figure 18: CBM - oil analysis

Oil analysis (figure 18) helps identify lubrication-related failures, before significant machine wear has occurred. It determines the condition of the oil and thus the condition of the machine’s internal components to some extent.

The results of an oil analysis can determine component wear, bearing wear, additive depletion / fuel dilution, coolant leaks, contamination, ingress of dirt, deterioration of internal seals, etc. The results of oil samples taken from the same machines over a period of time can be trended to gain an insight into the machine’s operating condition.
Some of the benefits of oil analysis are listed below:

- Maximises the life cycle of oil by only replacing lubricants when necessary,
- Prevents breakdowns by early identification of deteriorating machine components,
- Planned downtime can be scheduled to maintain machines,
- Reduction in lubrication and maintenance expenses,
- Reduction in environmental impacts due to reduced oil wastage.

### 5.4 Reduce failures through Kaizens (focused improvement)

Equipment deterioration and failures are reduced through focused improvement activities. Correct weaknesses and lengthen equipment life spans by developing countermeasures and implementing design changes to improve excessive stresses and environment causing deterioration.

Countermeasures for reducing failures can be developed using five categories, namely:

1. Establishing the basic conditions of the equipment,
2. Maintaining the operating conditions,
3. Restoring equipment deterioration,
4. Improving the weak points of equipment design,
5. Preventing human errors.

Figure 19 explains these in further detail:
Establish basic conditions
- Equipment cleaning – countermeasures to eliminate sources of dirt
- Retightening countermeasures, to prevent loosening
- Lubricating – identifying lubricating points & improving lubrication methods
- Preparation of cleaning and lubrication standards

Maintain operating conditions
- Setting design capability & loading limit countermeasures to improve weaknesses in excessive load conditions
- Standardisation of equipment operation methods
- Setting & improving operating conditions for components

Restore the deterioration
- Detection or prediction of deterioration
  - Inspection of equipment components through senses & detection of deteriorated portions
  - Preparation of daily inspection standard
  - MTBF analysis & estimation of service life & setting previous change over criteria
  - Study on finding abnormality signs
  - Study parameters for predicting deterioration & measuring methods

Improve the weak points in design
- Countermeasures to improve design strength, to extend service life, mechanism structure, materials, shape & dimensional accuracy, asm strength, wear resistance, anticorrosion, surface roughness capacity, etc

Prevention of human mistakes
- Prevention of operation mistakes
  - Analysis of causes for improper operation
  - Improving control panel design
  - Countermeasures for error-free operation
  - Visual controls
  - Standardise operation & adjustment methods

Prevention of improper repair
- Analysing causes of improper repair
- Improving the shape & installation methods for spare parts which are hard to identify
- How to store spare parts
- Improve tools & jigs
- Develop a troubleshooting procedure
- Study methods to conduct visual controls

Establishing good working environment countermeasures to prevent dust, high temperatures, humidity, vibration & shock

Establishing repair method
- Standardisation of disassembly, assembly, measurement & replacement methods
- Standardise components/parts
- Make tools & jigs for special repair
- Improve equipment structures for ease of repair
- Establish criteria for storing spare parts

Design to release excessive stresses

Prevention of improper repair
- Analysing causes of improper repair
- Improving the shape & installation methods for spare parts which are hard to identify
- How to store spare parts
- Improve tools & jigs
- Develop a troubleshooting procedure
- Study methods to conduct visual controls
5.5 Maintenance and control

To sustain planned maintenance, support is required from both production (performing AM steps 0 to 3) and maintenance. The implementation of each step needs to be maintained and controlled, to continue reversing the deterioration of equipment, maintaining its basic conditions and reducing unscheduled down time. All of which is aimed at increasing the up-time of equipment.

Increasing the up-time of equipment requires improvements in the maintenance and control of a machine’s MTBF and MTTR.

Improvements in MTBF are accomplished through the support of AM activities and the implementation of the four maintenance types discussed previously in the module:

- Breakdown maintenance,
- Periodic maintenance,
- Predictive maintenance,
- Corrective maintenance.

Improvements in MTTR are accomplished through improvements in maintenance skills, as described below:

- Specialised maintenance skills,
- Equipment repair skills,
- Inspection and measurement skills,
- Equipment diagnostic skills,
- Developing new maintenance technologies,
- Developing work instructions for maintenance jobs.
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