1. MAINTENANCE ENGINEERING: INTRODUCTION

1.1 Meaning and Value of Maintenance

1.1.1 Overview

Maintenance of an instrument or system should ensure that it is operating within its normal operating parameters. Some describe maintenance as "fix what is broken." *The preferred definition describes maintenance as activities that are intended to keep equipment in satisfactory working condition, including tests, measurements, replacements, adjustments, and repairs*. This can involve preventive, predictive, and curative measures and requires technical knowledge of the system and some knowledge of past, present, and future states of the system as well as the skills to apply the knowledge. Some of this knowledge is very specific, while other knowledge is more generic but can be used to logically deduce more specific knowledge. The key is the acquisition, distribution, and utilization of the necessary knowledge and skills. Due to the many different types of instruments and systems available, basic technical knowledge and skills as well as specific knowledge and skills are necessary to maintain them.

This course addresses some of this knowledge and skills. We shall look at the various failures modes that are common in various types of machines i.e. mechanical, electrical, etc. The various forms of maintenance that can be applied to different machinery to abate failure will be examined. Furthermore, the course will also look at the planning of the maintenance activities, personnel involved, costs and how the maintenance activity can be computerised. The maintenance discipline is meant to meet the following objectives:

- To optimise the reliability of equipment and infrastructure,
- To see, on an on-going basis, that equipment and infrastructure are kept in good working condition,
- To ensure prompt emergency repair of equipment and infrastructure so as to secure the best possible availability for production,
- To enhance, through the study of modifications, extensions, or new low-cost equipment, the productivity of existing equipment or production capacity,
- To ensure operation of the equipment for production and for the distribution of energy and fluids,
- To improve works safety,
- To train personnel in specific maintenance skills,
- To advise plant management as well as production, purchasing, engineering ´and R & D departments in the fields of acquisition, installations and operation of machinery,
- To play an ongoing role in guaranteeing finished products quality,
- To ensure environmental protection.

1.1.2 Maintenance

Maintenance is *any activity intended to keep equipment in **satisfactory working condition**, including testing, measuring, repair, replacing, and adjusting. Routine operations require keeping equipment functional. There are two categories/types of maintenance: scheduled and unscheduled maintenance*

Scheduled maintenance is planned. It includes preventive, predictive, corrective, modification, upgrading or retrofitting and calibration.

Unscheduled maintenance or non-scheduled maintenance must be done immediately when an emergency affects the productivity of the plant. This is maintenance to "fix what is broken" or provide a work–around so the operation that was started can be finished. Unscheduled maintenance is an urgent need for repair or upkeep that was unpredicted or not previously planned and must be added to or substituted for previously planned work.

1.1.3 Importance of Maintenance

The function of maintenance is to keep equipment in a safe operating condition. It also must ensure that all instrumentation works when it is required to work. Emergency shutdown systems should be checked regularly as they must work every time. Improper maintenance could cause harm to personnel and the environment.

Maintenance aims at ensuring that the product functions as required during its utilization phase and at the same time prolonging this phase of life. The product life cycle follows through 8 steps as indicated in the **Figure 1-1**. An objective of a sound maintenance management program must be customer satisfaction, making sure customers have the equipment and systems needed to perform the production function in the most efficient manner possible within the limits of the equipment and systems under their control. The bottom line is profit. Sound maintenance practices, driven by a well organized maintenance management program, will contribute to profitability. Good maintenance and good service to the customer are not accidental. Planning is the key, and it is required.

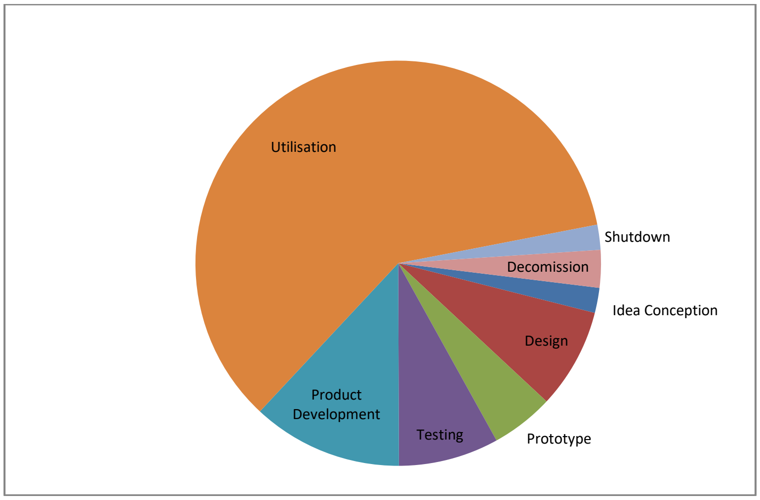


Figure 1-1: Life Cycle of a Product

A machine is designed and built once but must be serviced many times. Engineering creates the design, the design is constructed, the plant organization accepts the design and construction, and then the maintenance organization comes into the loop because it is expected to keep the system going at peak performance. Some maintenance organizations come into the loop early in the design phase, which is a good practice and pays dividends in the long run. Other maintenance organizations do not come into the loop until the plant is built and operating, which results in very slow acclimatization to the plant's operations.

Excellent reliability built into instrumentation today has shortened maintenance time, compared to even a decade ago. Meanwhile, the skill set needed to work with today's computerized automation equipment has changed significantly. Maintenance personnel have needed to undergo considerable training to keep abreast of the new and emerging instrumentation and control technologies.

1.2 Historical Evolution of the Maintenance Discipline

Since the 1930's, the evolution of the maintenance discipline can be traced through three generations with varying expectation as highlighted in **Figure 1-2**.

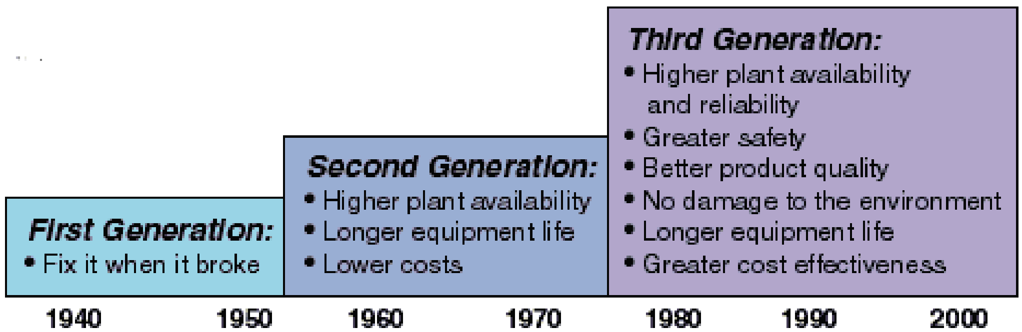


Figure 1-2: Growing Expectations of Maintenance

The First Generation

The First Generation covers the period up to World War II. In those days, industry was not very highly mechanised, so down time did not matter much. This meant that the prevention of equipment failure was not a very high priority in the mind of most managers. At the same time, most equipment was simple and some of it was over-designed. This made it reliable and easy to repair. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing and lubrication routines. The need for skills was also lower than it is today.

The Second Generation

Things changed drastically during World War II. War time pressures increased the demand for goods of all kinds while the supply of industrial man power dropped sharply. This led to increased mechanisation. By the 1950's machines of all types where more numerous and more complex. Industry was beginning to depend on them.

As this dependence grew, downtime came into sharper focus. This led to the idea that equipment failure could and should be prevented, which led in turn to the concept of *preventive maintenance*. In the 1960's, this consisted mainly of equipment overhauls done at fixed intervals.

The cost of maintenance also started to raise sharply relative to other operating costs. This lead to the growth of maintenance planning and control systems. These have helped greatly to bring maintenance under control, and are now and established part of the practise of maintenance.

Finally, the amount of capital tied up in fixed assets together with a sharp increase in the cost of that capital led people to start thinking of ways in which they could maximise the life of the assets.

The Third Generation

Since the mid1970's, the process of change in the industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research and new techniques.

1. <u>New Expectations</u>

Reliability and Availability; Downtime has always affected the productive capability of physical assets by reducing output, increasing operating cost and interfering with customer service. By the 1960's and 1970's this was already a major concern in the mining, manufacturing and transport sectors. In the manufacturing, the effect of downtime where being aggravated by the worldwide move towards just-in-time systems, where reduced stocks of work-in-progress mean that quite small breakdowns are now much more likely to stop a plant.

Quality Standards; Greater automation also means that more and more failures affect our ability to sustain satisfactory quality standards. This applies as much to standards of services as it does to product quality. For instance, equipment failure can affect climate control in buildings and the punctuality of transport networks as much as they can interfere with the consistent achievement of specified tolerances in manufacturing.

Environmental Consequences; More and more failure have serious safety or environmental consequences, at a time when standards in these areas are rising rapidly. In some parts of the world, the point is approaching where organisations either conform to society's safety and environmental expectations or they cease to operate. This adds an order of magnitude to our dependence on the integrity of our physical assets – one which goes beyond cost and which becomes a simple matter of organisational survival.

Return on Investment (ROI); At the same time as our dependence on physical assets is growing, so too is their cost - to operate and to own. To secure the maximum ROI which they represent, they must be kept working efficiently for as long as we want them to.

2. <u>New Research</u>

Quite apart from greater expectations, new research has changed many of the most basic beliefs about age and failure. In particular, it is apparent that there is less and less connection between the operating age of most assets and how likely they are to fail. The earliest view of failure was simply that as things got older, they were most likely to fail. A growing awareness of "burn-in" led to the widespread Second Generation belief in the **"bath-tub"** curve.

However, Third Generation research has revealed that not one or two but six failure patterns actually occur in practice. This will be discussed in detail later.

3. <u>New Techniques</u>

The new developments include:

- Decision support tools, such as hazard studies, failure modes and effects analyses and expert systems,
- New maintenance techniques such as conditions monitoring,
- Designing the equipment with a much greater emphasis on reliability and maintainability,
- A major shift in organisational thinking towards participation, team working and flexibility.

A major challenge facing maintenance people nowadays is not only to learn what these techniques are, but to decide which are worthwhile and which are not in their own organisations. If we make the right choices, it is possible to improve asset performance and at the same time contain and even reduce the cost of maintenance.

1.3 Failure Patterns

To adequately describe failure modes of a plant or machinery, six (6) patterns are normally used as shown in **Figure 1-3**. These patterns provide an indication of the *machines probability of failure with time*. Depending on the type of failure pattern, maintenance strategies such as condition monitoring may be useful or completely irrelevant. Thus, by pursuing a correct approach to the management of failure, an appropriate maintenance strategy may be adopted. The patterns are illustrated below.

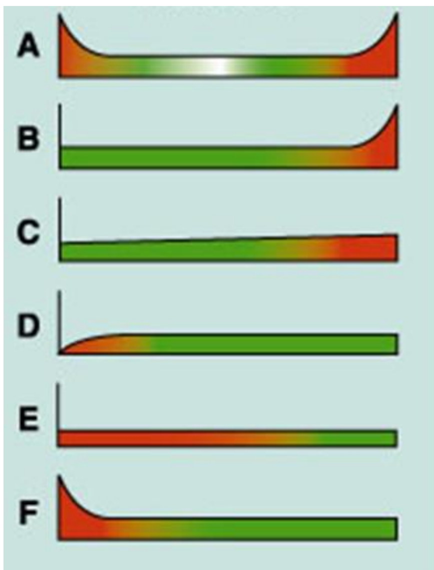


Figure 1-3: The 6 Failure Patterns

A. *<u>The Bath-tub Curve Failure pattern</u>*

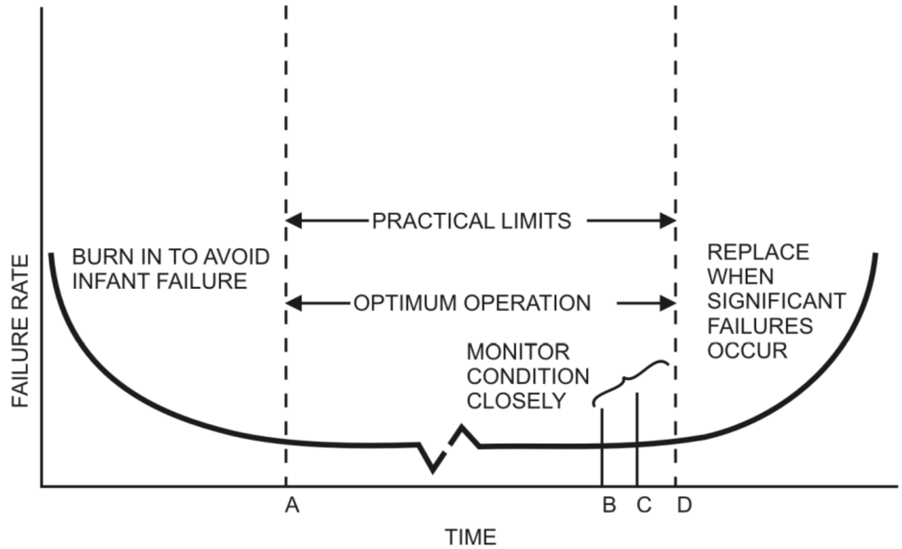


Figure 1-4: The Bath-tub Curve

The condition monitoring concept is founded on an assumption that plant or machinery degradation/failure mode follows the classic ‘bath-tub’ curve failure pattern.

A newly commissioned machined would experience a short period of *mechanical running-in*, which period would be exhibited as one of high wear rate. This could be due to a number of reasons including among others, poor installation, inexperienced workers, poor design, adjustment to working conditions, etc. This period is also critical because it brings out to the fore any design and manufacturing defects. In fact if these are excessive, *infant mortality may occur*. Commissioning engineers often pay particular attention to this period. During running-in, if parameters such as vibrations are measured, they are expected to be high.

After this period, the vibrations are expected to be lower and stable – with stable operating conditions. This is the normal running period. Some machine vendors ensure that their warranty is within this period.

As the machine parts begin to wear and faults begin to develop with time and age, the vibrations begin to increase too, in proportion to the severity of the wear or the fault. This if left unchecked would continue till the machine fails. Through the use of condition monitoring principles and techniques such as vibration monitoring, the onset of the wear period can be easily noted and the trend established. Thus, failure time may be predicted and subsequently avoided by scheduling machine shutdown and correction at the right time.

It is important that the right parameters are selected for monitoring so that not only is early detection of incipient failure possible but also providing adequate lead - time - to - failure.

B. *<u>Final Wear-out Pattern</u>*

This shows a constant or gradually increasing probability of failure, with time, finally culminating into wear-out. This is true for machine components with a finite life such as bearings.

C. No Wear-out Pattern

This shows a failure probability which is slowly increasing but without a defined wear-out stage, especially true for 1st generation machinery – heavily designed (overdesigned) and built.

D. Low Infant Mortality

The failure probability is low during the infancy stage, but after that assumes a constant level.

E. Random Failure Pattern

This illustrates a failure probability that is constant throughout the age of the machine or equipment. Failure may be seldom but certainly random during the life of such machinery/equipment.

F. High Infant Mortality

Illustrates a high failure probability in the infancy stage of machinery/equipment. This may be due to very stringent or faulty design, manufacturing, installation or commissioning. Most *electronic equipment* today tend to follow this failure pattern.

1.4 Challenges of the Maintenance Discipline

The key challenges facing modern maintenance managers can be summarised as follows:

1. Selecting the most appropriate maintenance techniques,
2. Dealing with each type of failure,
3. Fulfilling all the expectations of the owners of the assets, users and the society as a whole,
4. Carrying out the maintenance activity in the most cost-effective and enduring fashion,
5. Getting the active support and co-operation of all the people involved.

1.5 Maintenance Levels

In order to set-up an efficient maintenance organisation, and to take management decisions such as the degree of subcontracting, the investment in maintenance workshops, the recruitment of appropriate personnel, etc maintenance activities have been analysed in relation to their complexity.

Five levels of maintenance can be discerned, according to the complexity of work and the urgency of action to be taken.

1.5.1 Level 1

Simple adjustments anticipated by the manufacturer, by means of accessible components, requiring no disassembling or opening of the equipment, or completely safe replacement of accessible consumable components, such as signal lights or some types of fuse.

Servicing of this type can be performed by the equipment operator on site, without tools and by following the instructions for use. The stock of consumable parts required is very small.

1.5.2 Level 2

Troubleshooting by means of exchange units designed for this purchase, and minor preventive maintenance operations such as greasing or checking for proper functioning.

Servicing of this type can be performed by an authorised technician with average qualifications, on site, with the portable tools specified in the maintenance instructions and help of the fore mentioned instructions. The transportable spare parts required can be easily procured without delay in the immediate area of the place of use.

NB: A technician is authorised when he has received training enabling him to work safely on a machine which could be potentially dangerous, and with full awareness of the problem.

1.5.3 Level 3

Identification and diagnosis of breakdowns repair by replacement of components or working parts, minor mechanical repairs, and all routine preventive maintenance operations, such as general adjustment or recalibration of measuring instruments.

Servicing of this type can be carried out by a specialised technician, on site or in the maintenance workshop. This is done with the aid of the tools specified in the maintenance instructions and measuring or calibration equipment, and if need be test benches, using all the documentation necessary for maintenance of the equipment, as well as store supplied parts.

1.5.4 Level 4

All major corrective and preventive maintenance jobs except modernisation and rebuilding. This level also includes gauging of the measuring equipment used for maintenance, and may also include calibration by specialised organisations.

Service of this type can be carried out by a team which includes highly skilled technical specialists, in a specialised workshop fully equipped with tools (mechanical tools, for cabling, cleaning, etc) and if need be with measuring benches and the necessary callipers for the work, using all the general and specific documentation.

1.5.5 Level 5

Modernising, rebuilding or execution of major repairs, entrusted to a central workshop or an outside workshop. It involves spare parts manufacturing.

By definition, work of this type is thus carried out by the manufacturer or the rebuilder, with resources specified by the manufacturer, and therefore very similar to those used in the original manufacturing. It may also be carried out by a fully equipped central workshop.

1.6 Types of Maintenance and Strategies

The maintenance activity follows mainly into two major types viz; scheduled/planned and unscheduled/unplanned maintenance. Under these two types are various strategies as indicated in **Figure 1-5**.

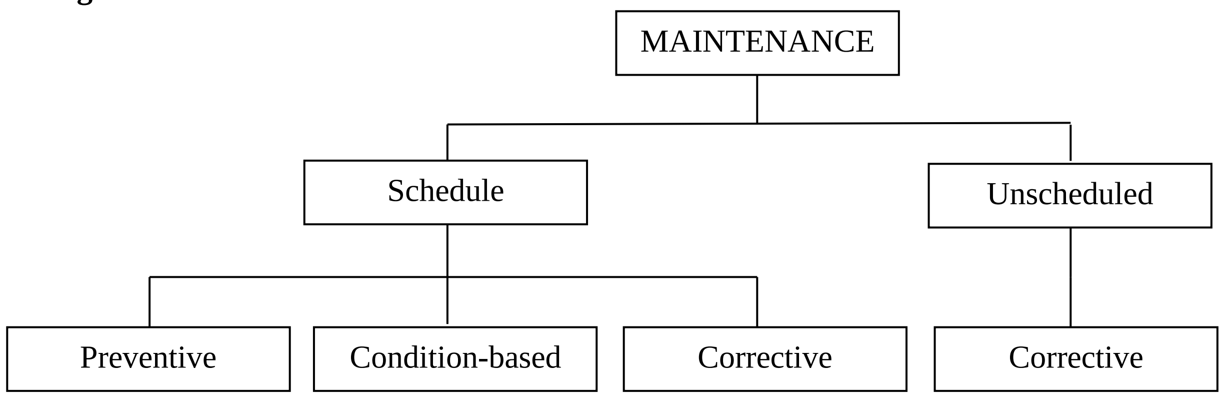


Figure 1-5: The maintenance types and strategies

1.6.1 Types of Maintenance

1.6.1.1 Scheduled Maintenance

Scheduled maintenance is planned. It includes the following:

1. Preventive maintenance, which is specifically intended to prevent faults from occurring during subsequent operation.
2. Predictive maintenance, which uses special measurements to indicate equipment or a device is beginning to go out of specified limits and if not corrected may fail completely.
3. Corrective maintenance, which can be scheduled when equipment is not being used.

1.6.1.2 Unscheduled Maintenance

Unscheduled or nonscheduled maintenance must be done immediately when an emergency affects the productivity of the plant. This is maintenance to "fix what is broken" or provide a work-around so that the operation that was started can be finished. Unscheduled maintenance generally has to be acted upon quickly.

1.6.2 Strategies of Maintenance

1.6.2.1 Preventive Maintenance

Preventive maintenance (PM) consists of scheduled inspection and upkeep that is specifically intended to prevent faults from occurring during subsequent operation. Inept PM, however, can also cause problems. Whenever any equipment is touched, it is exposed to potential damage. It is economically unwise to replace components prematurely. A good preventive maintenance program is the heart of effective maintenance, and inspection is the key to detecting the need for it. A PM program requires an initial investment of time, parts, people, and money.

Most preventive maintenance is scheduled; that is, maintenance is carried out in accordance with an established plan. Preventive maintenance may be scheduled by hours, uses, sequences, or the calendar. The use of performance intervals is itself a step toward basing PM on actual need instead of on a generality.

Inspection is a key to detecting the need for PM. It should be non-destructive so that it will not harm the equipment. The two main elements of fixed-interval PM are **procedure** and **discipline**. **Procedure** means that the correct tasks are done, the right lubricants are applied, and consumables are replaced at the best interval. **Discipline** requires that all the tasks be planned and controlled so that everything is done when it should be done.

Most PM programs are based on the fact that certain equipment or systems can be taken out of operation for the time required to give them a good check-up. Sometimes this is not practical. Seasonal equipment, such as air conditioners and heaters, require special maintenance care at the end of each season in order to clean and refurbish them when they are not being used so they will be ready for the next season.

If a failure occurs before the scheduled maintenance or preventive maintenance is performed, the maintenance supervisors and maintenance engineers should investigate. The investigation should determine a plan to ensure that the equipment will continue to operate until the equipment is replaced or retrofitted. This information should be passed on to management personnel. If a malfunction is found during PM, plant policy will determine if corrective action should be accomplished as corrective maintenance or as a repair utilizing the Preventive Maintenance Work Order (PMWO).

1.6.2.2 Condition-based Maintenance

This is a strategy of maintenance program that anticipates failures that can be corrected before total failure. This helps to determine that a failure is about to occur. For example, vibration analysis determines the normal vibration that is acceptable; when the vibration starts to exceed this point, maintenance can be scheduled when the equipment is not being used in order to prevent a complete failure during operation. Maintenance activities are done on and only on the fore-known condition of the plant or machinery. By monitoring the plant or machine systems, any material degradation can be measured and trended to predict possible time of failure, which can then be avoided by scheduling maintenance shutdown.

Noise, oil samples, additional heat, intermittent diagnostic errors, data highway retries, and unexplained glitches are other examples of warning signs for predictive maintenance. Most of the above can be measured, recorded, and annunciated.

1.6.2.3 Corrective Maintenance

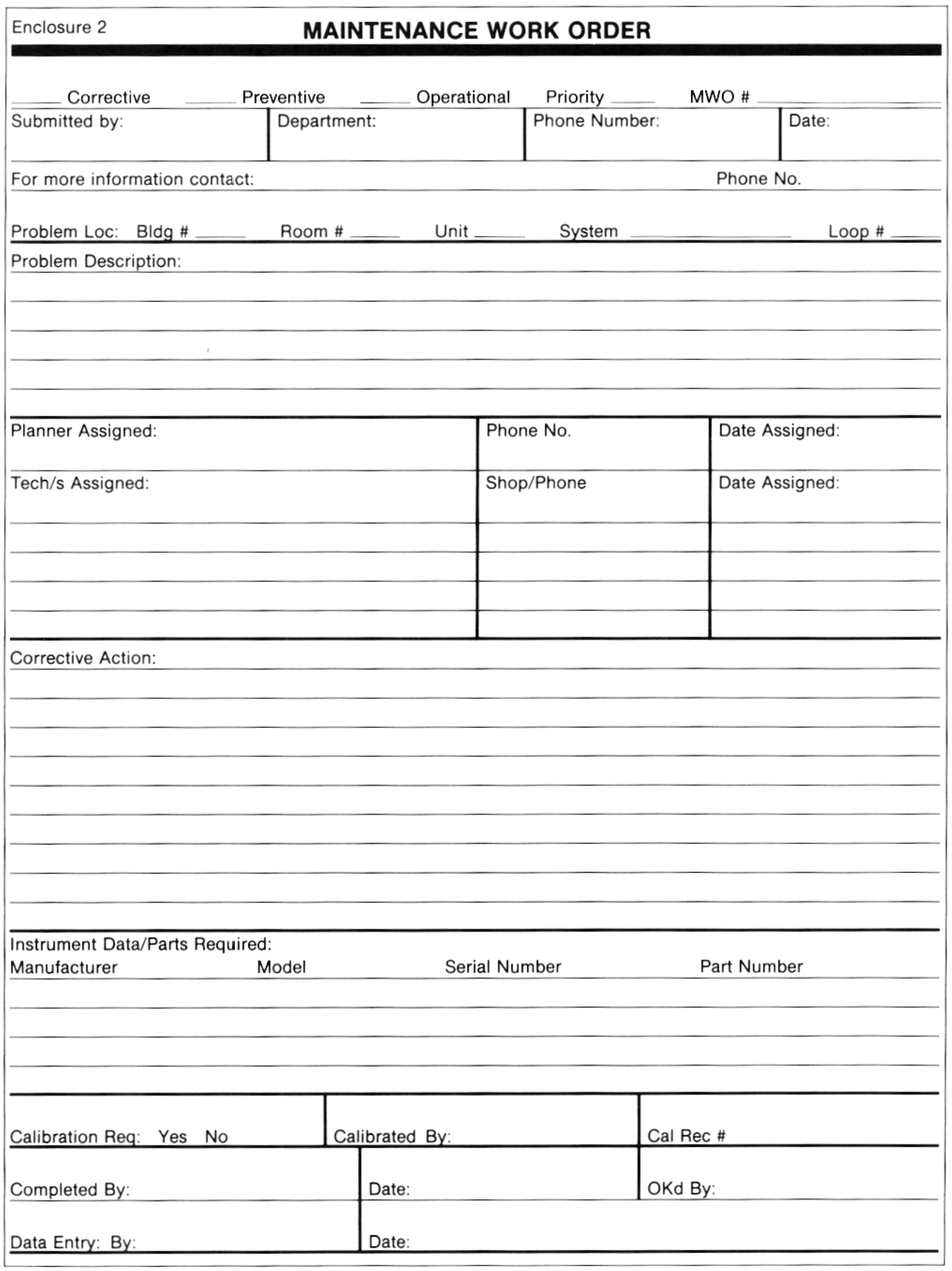
Corrective maintenance is an activity that is carried out to restore the condition of the equipment or system to the normal operating level. It is expected to be performed by qualified personnel who are aware of the hazards involved. Such activities typically include locating causes of faulty performance, replacement of defective components, adjustment of service controls, or the like.

Maintenance personnel should have sufficient documentation to understand and repair the problem. After logical troubleshooting procedures have determined the faulty component, repair can be completed. After the repair, the operation and calibration are checked and documentation of the repair activities and parts used is made.

Another name for corrective maintenance is remedial maintenance, which is defined as the maintenance performed following equipment failure, as required, on an unscheduled basis.

Nonscheduled, unscheduled, or emergency maintenance is an urgent need for repair or upkeep that was unpredicted or not previously planned and must be added to or substituted for previously planned work — maintenance specifically intended to eliminate an existing fault.

Corrective maintenance is generally considered non-scheduled, unscheduled, or emergency maintenance if it affects the productivity of the plant. Normally, an emergency maintenance work order, **Figure 1-6**, is written to document the parts and labour hours used and to be added to the history file. Corrective maintenance can be scheduled maintenance when the device or system does not affect the productivity of the plant.



Enclosure 2

MAINTENANCE WORK ORDER

____ Corrective ____ Preventive ____ Operational Priority ____ MWO # ____

Submitted by:	Department:	Phone Number:	Date:

For more information contact: Phone No.

Problem Loc: Bldg # ____ Room # ____ Unit ____ System ____ Loop # ____

Problem Description:

Planner Assigned:	Phone No.	Date Assigned:
Tech/s Assigned:	Shop/Phone	Date Assigned:

Corrective Action:

Instrument Data/Parts Required:

Manufacturer Model Serial Number Part Number

Calibration Req: Yes No	Calibrated By:	Cal Rec #
Completed By:	Date:	OKd By:
Data Entry: By:	Date:	

Figure 1-6: Typical Maintenance Work Order

Corrective emergency maintenance could generate a scheduled maintenance activity for example, replacement of a whole unit or device to get the line or system working, followed by repair of the failed unit or device at a scheduled time (e.g an engine knock or blowing up of a transformer). Care must be taken to ensure that the failed unit or device is either replaced or repaired for use at a later time.

Corrective maintenance includes logical troubleshooting, which is a search for the cause of a malfunction or erroneous behaviour, in order to remove the malfunction. Knowledge and experience are necessary to find the root problem. Qualified instrument technicians and instrument mechanics use logical troubleshooting concepts to ensure that the unit, device, or subassembly needs to be replaced and that the replacement corrects the problem.

1.6.3 Caution on Carrying out the Maintenance Activities

Production pressures to hurry and correct the problem should not cause the maintenance personnel to shortcut safety procedures. Maintenance is not complete until the system has been repaired, reworked, or replaced and calibrated, tested, and, logged into the equipment history files.

Repair
The word "repair" in a maintenance sense means to restore an item to serviceable condition following a failure or malfunction.

Rework
Restoring an item to a condition that exactly conforms to original design specifications is called rework. This word is usually applied to corrective action taken when an item has failed an inspection but requires a relatively simple operation, such as replacing a part or component, to enable the item to pass an identical inspection

Replacement
When an item fails or malfunctions, a decision must be made to repair or to replace it. If it is to be repaired, the proper maintenance work order and schedule must be submitted. If it is to be replaced, the proper material requisition must be submitted, and the malfunctioning item must be discarded if it cannot be repaired. The component or spare part may be replaced by a design equivalent replacement that is at least equivalent in performance to the item being replaced. It must also meet the requirements of form, function, and fit.

Calibration
To ascertain outputs of a device that correspond to a series of values of the quantity that the device is to measure, receive, or transmit is called calibration. The output must be adjusted to bring it to the desired value within a specified tolerance, and the error must be ascertained by comparing the device output reading to a standard.

Testing
Testing consists of checking out a system to determine the attributes or performance characteristics. The operators should verify that the malfunction has been removed and that no additional malfunctions exist.

Recording
The corrective action, parts used, and hours spent in repair must be recorded on the maintenance work order.

Input

This information must be input into the maintenance management system (MMS) files. The service life of the equipment can be determined by the history files of the equipment in the MMS. Service life is the length of time a mechanism or piece of equipment can be used before it becomes either unreliable or economically impractical to maintain in good working order.