DEPARTMENT OF PRODUCTION ENGINEERING

MAINTENANCE ENGINEERING AND MANAGEMENT

BPE 412: MAINTENANCE ENGINEERING & MANAGEMENT (3-1-0)

Module-I

Importance of maintenance, Objectives of maintenance, Types of maintenance, Maintenance systems, Planned and unplanned maintenance, Breakdown maintenance, Corrective maintenance, Opportunistic maintenance, Routine maintenance, Preventive maintenance, Predictive maintenance, Condition based maintenance systems, Design-out maintenance, Selection of maintenance systems. [10]

Module-II

Maintenance planning and scheduling, establishing a maintenance plan, Safety precautions Characteristics of items to be maintained, Classification of items, Maintenance procedure, Guidelines for matching procedures to items, Maintenance organization, Resource characteristics, Resources structure, Maintenance control, Administrative structure, Training of maintenance personnel. [10]

Module-III

System operations and documentation, Documenting maintenance operations, Record keeping, Data collection and analysis, Failure statistics, Planning and scheduling plant shutdowns, Depreciation and Machine Life, Replacement policies, Spares and types of spares, spares planning. [10]

Module-IV

Network techniques in maintenance activities, Evaluation of maintenance performance. Total productive maintenance – development and scope, Basic systems of TPM, Procedures and steps. Productivity circles, TPM as a part of TQM, benefits of TPM. [10]

TEXT BOOK(S):

1. Maintenance Planning and Control- A. Kelly, East West Press.

2. Mechanical Fault Diagnosis- R.A. Collacott, Chapman and Hall.

REFERENCE(S):

1. Managing Maintenance Resources- A. Kelly, Butterworth-Heinemann.

2. Handbook of Maintenance Management- Levitt Joel, Industrial Press.

1. Introduction

Maintenance Engineering is the discipline and profession of applying engineering concepts to the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment.

-Maintenance engineering is the occupation that uses engineering theories and practices to plan and implement routine maintenance of equipment and machinery. This must be done in conjunction with optimizing operating procedures and budgets to attain and sustain the highest levels of reliability and profit.

-Maintenance engineers are often required to have knowledge of many types of equipment and machinery. A person working in the field of maintenance engineering must have in-depth knowledge of or experience in basic equipment operation, logistics, probability, and statistics.

-Experience in the operation and maintenance of machinery specific to a company's particular business is also frequently required. Since the position normally requires oral and written communications with various levels of personnel, excellent interpersonal communication and participatory management skills are also desirable.

-Maintenance engineering positions require planning and implementing routine and preventive maintenance programs .In addition, regular monitoring of equipment is required to visually detect faults and impending equipment or production failures before they occur.

- These positions may also require observing and overseeing repairs and maintenance performed by outside vendors and contractors.In a production or manufacturing environment, good maintenance engineering is necessary for smooth and safe daily plant operations.

-Maintenance engineers not only monitor the existing systems and equipment, they also recommend improved systems and help decide when systems are outdated and in need of replacement. Such a position often involves exchanging ideas and information with other maintenance engineers, production managers, and manufacturing systems engineers.

-Maintenance engineering not only requires engineers to monitor large production machine operations and heavy duty equipment, but also often requires involvement with computer operations.

-Maintenance engineers may have to deal with everything from PCs, routers, servers, and software to more complex issues like local and off-site networks, configuration systems, end user support, and scheduled upgrades. Supervision of technical personnel may also be required.

-Good maintenance engineering is vital to the success of any manufacturing or processing operation, regardless of size. The maintenance engineer is responsible for the efficiency of daily operations and for discovering and solving any operational problems in the plant.

1.1. Maintenance

Definition:-“Maintenance is a routine and recurring activity of keeping a particular machine or facility at its normal operating condition so that it can deliver its expected performance or service without causing any loose of time on account of accidental damage or breakdown”.

- Once equipment is designed, fabricated and installed, the operational availability of the same is looked after by the maintenance requirement. The idea of maintenance is very old and was introduced along with inception of the machine. In the early days, a machine was used as long as it worked. When it stopped working, it was either repaired/serviced or discarded.

- The high cost sophisticated machines need to be properly maintained/serviced during their entire life cycle for maximizing their availability. The development of mechanization and automation of production systems and associated equipment, with the accompanying development of ancillary services and safety requirements, has made it mandatory for engineers to think about proper maintenance of equipment.
- Maintenance function also involves looking after the safety aspects of certain equipment where the failure of component may cause a major accident. For example, a poorly maintained pressure vessel such as steam boiler may cause a serious accident.

1.2. Objectives of maintenance

The objectives of maintenance should be formulated within the framework of the overall organizational setup so that finally the goals of the organization are accomplished. For this, the maintenance division needs to ensure that:

(a) The machinery and/or facilities are always in an optimum working condition at the lowest possible cost
(b) The time schedule of delivering to the customers is not affected because of non -availability of machinery /service in working condition
(c) The performance of the machinery /facility is dependable and reliable.
(d) The performance of the machinery /facility is kept to minimum to the event of the breakdown.
(e) The maintenance cost is properly monitored to control overhead costs.
(f) The life of equipment is prolonged while maintaining the acceptable level of performance to avoid unnecessary replacements.

Maintenance is also related with profitability through equipment output and its running cost. Maintenance work enhances the equipment performance level and its availability in optimum working condition but adds to its running cost. The objective of maintenance work should be to strike a balance between the availability and the overall running costs. The responsibility of the maintenance function should, therefore, be ensure that production equipment /facilities are available for use for maximum time at minimum cost over a stipulated time period such that the minimum standard of performance and safety of personal and machines are not sacrificed. These days therefore, separate departments are formed in industrial organizations to look after the maintenance requirements of equipments and machines.

1.3. Effects of maintenance

Maintenance, being an important function in any production system, has far reaching effects on the system. If the right practice of maintenance is not established for a particular environment, it may lead to serious problem of either over maintenance or under maintenance. The selection of a particular maintenance policy is also governed by the past history of the equipment. Cost effective maintenance will help in enhancing productivity. It is therefore, is important for the team associated with maintenance work, to know how much to maintain.
The nature of the maintenance function affects the life of equipment. It is known from experience that optimum maintenance will prolong the life of the equipment, and on the other hand, carelessness in maintenance would lead to reduced life of the equipment and in some cases an early

failure as well. Further, proper maintenance will help to achieve the production targets. If the availability of the equipment in good working condition is high, the reliability of the production will also be high. Another important effect of the maintenance function is the working environment. If the equipment is in good working condition, the operator feels comfortable to use it otherwise there is a tendency to let the equipment deteriorate further. To get the desired results in maintenance operations, there should be selective development of skilled, semiskilled, and unskilled labour. And also proper job description is required for the jobs in order to make full use of skilled workforce available.

1.4. Types of maintenance systems

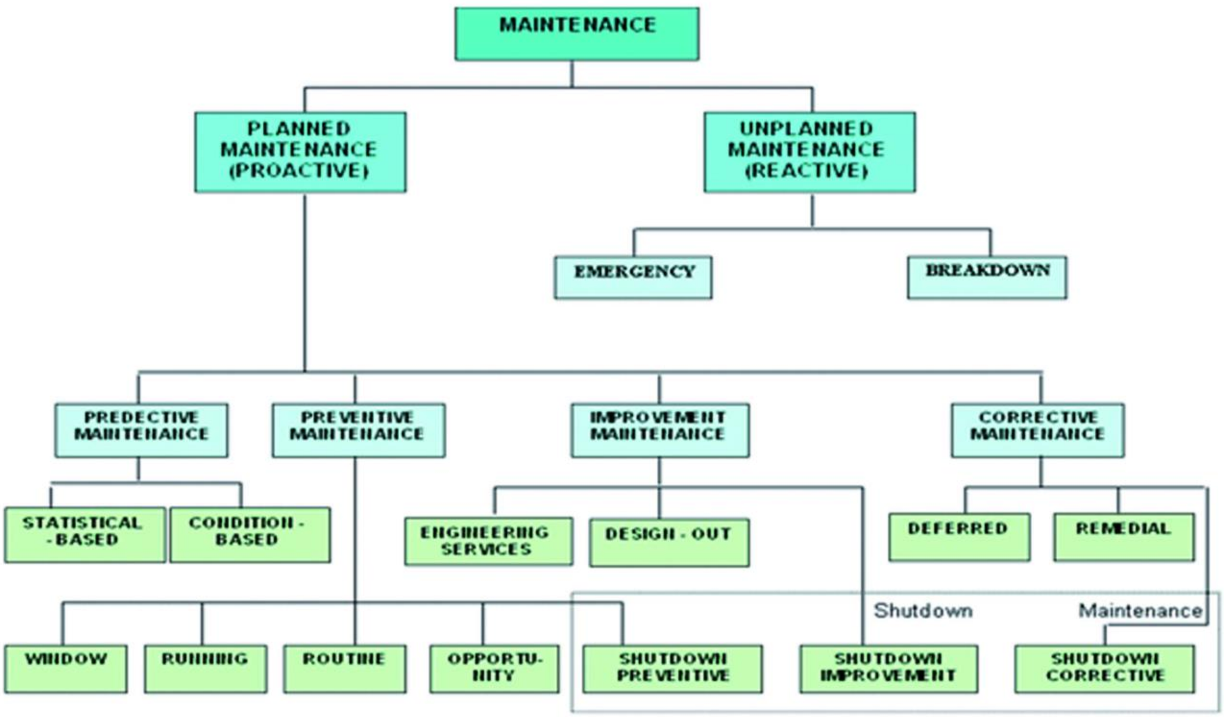


Fig.-1.1

Planned Maintenance: "The maintenance organized and carried out with forethought, control and the use of records to a predetermined plan."

Preventive Maintenance: "The maintenance carried at predetermined intervals or corresponding to prescribed criteria and intended to reduce the probability of failure or the performance degradation of an item."

Breakdown Maintenance: – Repair is undertaken only after failure of system. Equipment is allowed to run till it fails. Lubricating and minor adjustments are done during the period.

- Small factories where equipment are very small and doesn't use special tools

- Isn't suitable for big industries

Opportunistic Maintenance: – In multi component system, several failing components, often it is advantageous to follow opportunistic maintenance. When an equipment or system is taken down for maintenance of one or few worn out component, the opportunistic maintenance can utilize for maintaining or changing other wear out components, even though they are not failed.

-It is actually not a specific maintenance system, but its a system of utilizing an opportunity which may come up any time.

Corrective Maintenance – Maintaining action for correcting or restoring failed unit.

- Very vast scope for small actions like adjustment, minor repairs to redesign of equipments

- Generally once taken and completed fully

Usually carried out in four steps :

1st step : collection of data, information and Analysis
2nd step : identifying the causes
3rd step : find out the best possible solution to illuminate likely causes
4th step : Implement those solutions

Emergency maintenance: It is carried out as fast as possible in order to bring a failed machine or facility to a safe and operationally efficient condition.

Routine maintenance which includes those maintenance activities that are repetitive and periodic in nature such as lubrication, cleaning, and small adjustment.

Running maintenance which includes those maintenance activities that are carried out while the machine or equipment is running and they represent those activities that are performed before the actual preventive maintenance activities take place.

Opportunity maintenance which is a set of maintenance activities that are performed on a machine or a facility when an unplanned opportunity exists during the period of performing planned maintenance activities to other machines or facilities.

Window maintenance which is a set of activities that are carried out when a machine or equipment is not required for a definite period of time.

Shutdown preventive maintenance which is a set of preventive maintenance activities that are carried out when the production line is in total stoppage situation.

Remedial maintenance which is a set of activities that are performed to eliminate the source of failure without interrupting the continuity of the production process.

Deferred maintenance which is a set of corrective maintenance activities that are not immediately initiated after the occurrence of a failure but are delayed in such a way that will not affect the production process.

Shutdown corrective maintenance which is a set of corrective maintenance activities that are performed when the production line is in total stoppage situation.

Design-out maintenance which is a set of activities that are used to eliminate the cause of maintenance, simplify maintenance tasks, or raise machine performance from the maintenance point of view by redesigning those machines and facilities which are vulnerable to frequent occurrence of failure and their long term repair or replacement cost is very expensive.

Engineering services which includes construction and construction modification, removal and installation, and rearrangement of facilities.

Shutdown improvement maintenance which is a set of improvement maintenance activities that are performed while the production line is in a complete stoppage situation.

Predictive maintenance is a set of activities that detect changes in the physical condition of equipment (signs of failure) in order to carry out the appropriate maintenance work for maximising the service life of equipment without increasing the risk of failure.

It is classified into two kinds according to the methods of detecting the signs of failure:

  – *Condition-based predictive maintenance*
  – *Statistical-based predictive maintenance*

- *Condition-based predictive maintenance* **depends on** continuous or periodic condition monitoring equipment to detect the signs of failure.
- *Statistical-based predictive maintenance* **depends on** statistical data from the meticulous recording of the stoppages of the in-plant items and components in order to develop models for predicting failures.

❖ *The drawback of predictive maintenance is that it depends heavily on information and the correct interpretation of the information.*
❖ *Some researchers classified predictive maintenance as a type of preventive maintenance.*
❖ *The **main difference** between preventive maintenance and predictive maintenance is that predictive maintenance uses monitoring the condition of machines or equipment to determine the actual mean time to failure whereas preventive maintenance depends on industrial average life statistics.*

1.5. Challenges in Maintenance

The maintenance function of a modern industry faces a number of challenges attributable to:

❖ Rapid growth of technology resulting in current technology becoming obsolete. Such a challenge is a frequent one in Information and Communications Technology (ICT) industry where computers and computers based system (hardware and Software) is the main component.
❖ Advent of new advanced diagnostic tools, rapid repair systems, etc.
❖ Advance store management techniques to incorporate modular technologies.

- Requirements of keeping both outdated and modern machines in service. For example, many industrial organizations have a combination of the old machines working on obsolete technology and new systems utilizing the latest technology and equipment.
- The effective management of maintenance aspects under such challenging circumstances is often a difficult job. Besides the rectification of the faults in the equipment, the activities of the maintenance department include:
- Up gradation of the existing plants and equipments and training maintenance personnel to attend the required technical skills.
- Effective maintenance of the old equipment for higher availability
- Cost optimization of all maintenance functions
- Improvement of maintenance activities in the areas of tribology and terotechnology
- Reconditioning of used /unserviceable spare parts.
- Development of indigenous sources for parts for import substitution
- Setting up of an effective maintenance information management systems (MIMS).
- Effective utilization of the maintenance workforce
- Setting up of in house R&D activities for effecting improvements in maintenance practices.

1.6. Reliability Centered Maintenance

It is used to identify the maintenance requirements of equipment. The RCM establishes the functional requirements and the desired performances standards of equipments and these are then related to design and inherent reliability parameters of the machine.
For each function, the associated functional failure is defined, and the failure modes and the consequences of the functional failures are analyzed.
The consequences of each failure are established, which fall in one of the four categories: hidden, safety or environmental, operational, and no operational. Following the RCM logic, preemptive maintenance tasks which will prevent these consequences are selected, provided the applicability and effectiveness criteria for preventive maintenance are satisfied.
The applicability requirements refer to the technical characteristics and effectiveness criteria for preventive maintenance tasks and the frequency at which these should be carried out.
Effectiveness criteria depend on the consequences of the failure; probabilities of the multiple failures for hidden failure consequences, acceptable low risk of failure for safety consequences, and nonoperational consequences. When the requirements for planned maintenance (PM) are not fulfilled, default tasks include failure finding (for hidden failure, possible redesign of equipment, procedures and training processes) and no-schedule maintenance.

2.1. Maintenance Planning and Scheduling

Having known the fault lists, result of condition monitoring and having decided the type/ strategy of maintenance, the next step is to plan and schedule the maintenance jobs so that the jobs can be executed properly and desired results can be obtained in time. Planning and scheduling functions are the key deliverables of the planning role. This is where the most gains in execution have the potential to be made and acted upon. In some larger organizations these are split, allowing more adequate resources for each role, but often planning and scheduling is done by same person or group. Often problem arises in that case, as the maintenance planner does not do much planning and jumps to scheduling. Very often, the planner bogs down to work as expedite material, work on tools, plan emergency work or work as relief supervisor and gives very little thought to work-order planning. The two, planning and scheduling have to have completely different approach. The role of the planner needs to cover the full range of the work order system, from input into coding, prioritization and a degree of autonomy in execution.

2.2. Planning

Planning of jobs or Job-planning can occur at any stage during the life of a works order or maintenance job. An indicator (electronic or otherwise) in the work-order systems needs to be able to identify the work-order by status of planning. In this manner works orders requiring parts, procedures, documents, skills or equipment can easily be focused upon. A work order cannot be considered planned until all of these have been considered. However, detailed manpower planning/ deployment is not done at this stage.

Planning of maintenance jobs basically deals with answering two questions, "**what**" and "**How**" of the job; i.e. "what jobs/ activities are to be done" and "how those jobs and activities are to be done". While answering these two questions, many supplementary questions are to be answered, e.g. "Where the job is to be done" and "Why the job is to be done" etc, but all these will be helping in developing "what" and "how" of the job. As such, it is very essential that engineering knowledge must be applied extensively to maintenance jobs for development of appropriate job plans using most suited techniques, tools, materials and special facilities etc.

As the job planning forms the basic foundation, over which the efficiency and cost of further actions (e.g. scheduling, execution and control etc) depends, persons responsible for job planning should have adequate qualities/ capabilities, such as, knowledge about jobs and available techniques facilities and resources, analytical ability, conceptual logical ability and judgmental courage etc.

2.2.1. Steps of job planning

The main steps to be followed for proper job planning are, generally, as follows—

1. ***Knowledge Base-*** It includes knowledge about equipment, job, available techniques, materials and facilities etc. The planner should have through understanding of workorder requirement and should know and refer to—

- Correct equipment number and code,
- Work description request or equipment symptom and failure analysis reports etc,
- Refer to CMMS for details and previous history of the job, if any,
- Drawings, instruction manuals and Maintenance Manuals, including assembling, Dismantling and packing instructions etc,
- Job Manuals,
- Experience of same or similar machines,
- Departmental maintenance workshop and that of other departments,
- Plant's Captive or centralized workshops or repair cells,
- Nearby ancillary industries, etc.

2. ***Job Investigation at Site-*** It gives a clear perception of the total job and also helps in ascertaining the followings—

- Physical access and space limitation- This may call for jobs like removing covers, guards, stoppers or cutting a portion machine housing etc for better approach,
- Assessing if available lifting and handling tackles/ facilities are enough or special cranes/ facilities are to be brought; also helps in deciding scaffolding etc.
- Facilities for disposal of water, oil, gases and hazardous materials which may leak or come out during dismantling,
- Space for keeping the dismantled parts and safety enclosures for machine under repair.
- Proximity of other jobs, going on at potentially the same time,
- Safety issues, e.g. requirement of permits, clearances, putting danger tags, any hot or cold or wet situation there, etc,
- Identify any reference point or benchmark or match-mark, for ease of assembly,
- Take necessary photographs before dismantling, for checking later-on.

3. ***Identify and document the work-*** Knowing earlier two steps and knowing the needs of preventive, predictive and other maintenance jobs, a complete job/ work list is made. Pending and leftover jobs from previous schedules may also be included. The planner often consults concerned operating and maintenance personnel and PdM and CBM inspectors also for any special problems and cross-checking. A trained planner may review the inspection results for common problems (e.g. misalignment, imbalance etc) and also not so common problems (e.g. resonance etc).

4. ***Development of Repair Plan-*** Preparation of step-by-step procedures which would accomplish the work with the most economical use of time, manpower and material. It may include making of sketches, line diagrams and rough networks etc. For first time jobs, provision of still and video photography can also be planned before starting the job and during critical dismantling. Weight of each item to be determined/ estimated before hand and planning should be done to avoid double or multiple handling of the same item. The total job should be broken in small measurable activities at this stage.

5. *Preparation of Tools, Tackles and Facilities List-* In smaller plans, like Fig.7.1, this can be done in the plan sheet itself, but for bigger jobs, a separate list may be attached indicating the needs of special tools, tackles and facilities needed, with sketches etc, such as special porter bar and other lifting tackles, arranging special long boom crane and transfer cars, special torque wrenches and big spanners etc. Advance action has to be taken for most of these. Surveying equipments may also have to be arranged to mark the level of machine foundations (if earlier markings are not seen), before dismantling.

6. *Estimation of Time Required to do the Job-* For smaller jobs, as shown in Fig 7.1, it is easier, but for bigger jobs it may need knowledge of "work simplification", "work measurement" and Critical path analysis etc.

7. *Work-order Feedback forms/ plan-* Two types of feedback forms are used; one for supervisor of planner to approve the plan and other for scheduler to report after completion.

Fig. 7.1 shows a sample plan for a small job of changing V belt of blower- X. In the figure SH-1 means Store House No. 1. Cost column can be filled at initial planning stage or, better, at review stage, after knowing exactly the number of parts changed.

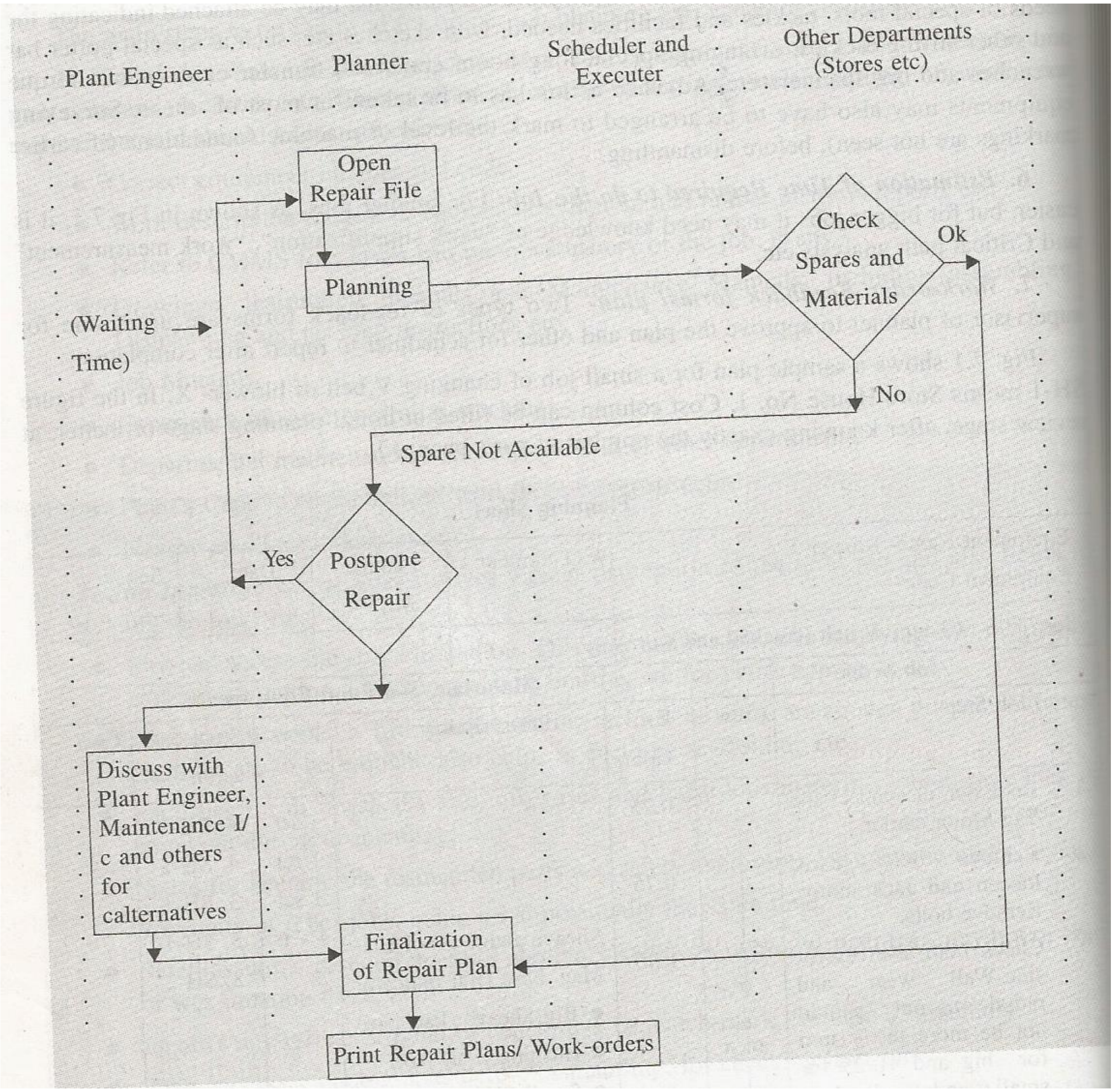
Planning Sheet

Equipment Name- Blower X Equipment Code—	W.O.Number —	Planner Mr, —	Date —	Seq. —
Job Title- Change V belt (cracked and worn)				

Job Scope			Materials, Tools and Equipments			
Job Steps	Crew	Est. Hours	Description	Qty	Stock as on——	Cost
1. Look out, disconnect and Tag Motor starter,		0.25		1 set 1 set	4, SH-1 4, SH-1	
2. Remove belt guard, loosen and Jack motor, Remove bolts,		0.75		1 set 4 sets	3, SH-1 3, SH-1	
3. Check both sheaves for side-Wall wear and radial run-out (should not be more the +1mm for big and +0.25 for small ends), Replace worn-out sheaves if needed,	2 men	1.00	Sheave gauge (Tool kit) Mag. base Dial Indicator • Big Sheave (Part No.) • Bushing (Part No.) • Small Sheave(Part No) • Bushing (Part No.) Bolts—— (Part No)		8, SH-2	
4. Install new bolts, align sheaves, tighten motor bolts.		1.0				
5. Tension belts, using force deflection method, recheck alignment,		0.5	Belt alignment tool Belt tension gauge			
6. Reinstall guards, remove locks, clean up and release for operation		0.75				
Drawing No–	Total Time——		Total Cost——			

Fig. 7.1 Changing V belt of Blower-X

The previous page table 2.1 show a sample plan of a small job of changing V bolt of Blower X in a planning sheet.



The above figure 2.2 shows a planning process , indicating connection with different agencies.

2.2.2. Planning techniques

There may be numerous methods/ techniques, a planner may use to plan and putdown that on paper or computer etc. Few of those are mentioned below–

1. Work breakdown structure– This involves breaking the total job down into lower and lower levels of tasks that have to be carried out. A good test is, can you easily estimate how long the task will take and who will be required. There is never a wrong or a right answers to how you do a Work Breakdown Structure. It is for the planner or planning manager to come up with what they consider the best solution. The lowest levels of the tasks should be capable of being clearly defined. The pre-requisite for a planner is–

- should be able to estimate resources (time, people material etc),
- should be able to assign work and
- should think about reporting cycle.

2. Work Measurement—It is the careful analysis of a task, its size, the method used in its performance, and its efficiency. The objective is to determine the **workload** (the amount of work assigned to or expected from a worker in a specified time period) in an operation, the time that is required, and the number of workers needed to perform the work efficiently.

The purpose of measurement is to collect real data about actual events.

Components– A work measurement system has three components– 'preferred methods', 'time values', and 'reporting'. Preferred methods are not always the most efficient or fastest way to do a task. This should enhance safety, quality, and productivity.

The time (Time value), that a job should take, is determined not on the basis of speeding up the motions a worker normally makes but on the normal pace of the average worker, taking into consideration allowances for rest periods, coffee breaks, and fatigue.

A reporting system is important to the success of any work measurement method. Supervisors and managers must have access to labor-management information that is both timely and complete. Timely information can be used to manage and shift labor hours to areas where they are needed and to correct problems or at least prevent them from becoming a crisis.

Work Measurement Methods— All work measurement systems are based on the same, simple three-stage procedure— 'analysis', 'data collection and measurement', and 'synthesis'. They differ in the nature and degree of analysis, the nature and level of data collection and measurement, and the nature of the synthesis process.

There are four work measurement methods— historical data, work sampling, time study and predetermined motion/time systems. Each of the four methods have their strengths and weaknesses.

Work Simplification technique can also be used, but that is used more for mass production operations.

3. Work Packages– It involves details of what work is required and when it is to be delivered, negotiation to agree for the work with the line manager and for necessary clearances, arranging the broken down works in some logical sequence, determining what works can be done in parallel and putting them on paper or computer etc. A sample shown below–

Task/ work/ activity	Start time	Duration	Agency	Note

3. Gantt Chart— Though these are basically planning technique, these are extensively
4. PERT and CPM— used in scheduling and monitoring, as such are discussed later.

2.2.3. Planner's Tool Kit

For field inspection and notes, a planner should have a note book for writing (and or a digital voice recorder), a small digital camera 9for taking pre-dismantling photos), a strong torch light, a marker and a measuring tape etc. In the office, he/she should have computer, printer and other essential things.

2.3. Job Manuals

Job Manuals are almost permanent about methodologies, tools, tackles and facilities for all maintenance jobs, which may have to be done in future. This involves saving the different plans and modifying and expanding those plans for other similar machines. Generally following steps are involved in preparing Job Manuals—

1. Make a list of all major and medium jobs of the plant (preferably equipment. Shop wise) and codify (numerical codes) for proper identification.
2. For each coded job, a separate job manual is to be made in the form of job plan, indicating job steps, tools, tackles, spares, consumables and facilities needed and also indicating safety and statutory clearance etc.
3. Each job manual, thus prepared, should be cross checked and cleared by Maintenance I/c.
4. Different Job manuals should be bunched and sent to respective potential users.
5. Necessary updation of job manuals, as needed, in consultation with respective users.

These job manuals are quite useful for maintenance organization and plant. Few main uses are—

- For actual planning and scheduling of any job, the job manuals provide ready information for use as it is or for further micro-planning.
- The executing agencies refer to the job manual before starting the job, to ensure that they follow correct procedures and to take necessary tool and spares etc to avoid frequent visits to stores and thus save time.
- Material Department may also use job manual for better material procurement strategy.

2.4. Scheduling

Scheduling is the function of coordinating all of the logistical issues around the issues regarding the execution phase of the work. This can also uncover some areas of planning deficiency, which needs to be addressed. Scheduling is best performed in a capacity-scheduling manner. Most modern systems have the capacity to output data to spreadsheets or in similar forms. Only planned job can be scheduled properly. A schedule without a planned job is like "wish list".

Scheduling of maintenance jobs basically deals with answering two questions—**"Who"** and **"When"** of the job, i.e. "who would do the job" and "when the job would be started and done".

Effective scheduling essentially needs realistic thinking, based on substantial data and records. However, majority of scheduling work needs to occur in areas such as –

- Overhead labour hours (such as safety and toolbox meetings, break times and training times etc) are to be gathered, along with holidays and off-days and scheduled as standing works orders for future analysis of these,
- Hours for PM completion to be deduced form data in the CMMS. This focuses on ensuring the equipment is maintained to its best levels,
- Addition of corrective and approved improvement actions as dictated by the prioritization system and operations plan. These are to be planned works orders only. A guide could be "Age of works orders against priority (As a measure of the priority systems effectiveness)".
- The combination of corrective, preventative and improvement work needs to total the levels set for planned / scheduled work. However, a workable level may be 70%- 80% in the initial stages; etc.

2.4.1. Pre-requisites for Schedules

A scheduler should also have knowledge about job, techniques, facilities, analytical ability and judgmental courage. The scheduler must obtain knowledge/ information about following facts/ aspects, before starting his job—

1. Manpower availability by trade, location, shift, crew arrangement and permissible overtime limit etc.
2. Man-hour back log on current or unfinished jobs.
3. Availability of the equipment or area where the work has to be performed.
4. Availability of proper tools, tackles, spares, consumables, structural and other required materials.
5. Availability of special equipments, jigs/ fixtures, special lifting and handling facilities and cranes etc. This should also include labour and time saving devices like pneumatic hammers and excavators etc.
6. Availability of external manpower and their capabilities; these may be from other shops/ departments of the plant or from contractors (local, nearby, ancillary etc).
7. Starting date of the job; also often completion time of total job is predetermined and, in that case, resources are to be arranged accordingly.
8. Past schedules and charts (updated) if the same job has been done earlier; etc.

2.4.2. Scheduling techniques

Following principles greatly contribute to the success of scheduling, especially in a bigger organization–

1. Job plan should provide number of workmen required with the lowest required skill/ craft level and the job duration.

2. Entire plant must respect the importance of schedules and job priorities.

3. Special or heavy demand jobs can not be scheduled unless backlog is addressed by providing additional resources or by relaxing/ reassigning priorities.

4. Lobs will not be scheduled unless all the planned materials (parts, tools, special facilities etc) are available in time and in required quantity.

5. Each available maintenance trade must be scheduled for a full day of productive work for every day of availability.

6. Scheduler should develop a one week schedule for each crew based on craft hour available forecast that shows highest skill level available and job priorities. Consideration is also given for multiple jobs on the same equipment or system and of proactive versus reactive work available.

7. The one week schedule assigns work for every available work hour. The schedule allows for emergencies and high priority, reactive jobs by scheduling a reasonable amount of work hours on easily interruptible tasks. Preference is given for completing higher priority work by even underutilizing available skill level over completing lower priority work.

8. The crew supervisor develops a daily schedule, one day in advance, using current job progress, the one week schedule and new high priority reactive job as a guide. The crew supervisor handles the current day's work and problem, even to the extent of rescheduling the entire crew for emergency works.

9. **Wrench Time** (It is a measure of crafts personnel at work, using tools, in front of jobs. Wrench time does not include obtaining parts, tools or instructions, or the travel associated with those tasks or traveling to or from jobs etc) is the primary measure of workmen's efficiency and of planning and scheduling efficiencies. Again, schedule compliance is the measure of adherence of one week schedule and its effectiveness. Wrench time can't improve if the crew is not given enough work.

10. **Advance Scheduling**- It is actually more of an allocation of work and may not be a detailed schedule of exact personnel and time assignment. Advance scheduling provides enough work for the entire crew and sets goal for maximum utilization of available craft hours.

Scheduling differs from 'Job Loading'. **Job loading** is the jobs listed in sequence of agreed upon importance during the weekly or other coordination meetings. This sequence may not be chronological within the week or that period.

2.4.3. Schedule types and techniques

Different types of schedules are made suiting the respective job plans and different techniques are used for making and following those schedules. The first step of all scheduling is to break the job into small measurable elements, called activities and to arrange them in logical sequences considering the preceding, concurrent and succeeding activities so that a succeeding activity should follow preceding activities and concurrent activities can start together.

Arranging these activities in different fashion makes different types of schedules. The schedules may be Weekly General Schedule, Daily Schedule, Gantt Chart, Bar Chart, PERT network and CPM or CPA schedules etc.

2.4.3.1. Weekly General Schedule

This is made to provide weeks worth of work for each employee in an area. The shutdown (S/D) date column indicates the best day in the week to perform some job. As such, operation should also get a copy of this schedule to help arrange shutdown. However, maintenance supervisor has to be attentive for individual's deployment. Table 7.1 shows a portion of one such schedule

Schedule of work, beginning Sept. 7, 2004				
Area-D. Available Hours- 180 Hrs + 52 PM Hrs.= 232 Hrs.				
W.O.No.	**Equip. No.**	**Description**	**Est. Hrs.**	**S/D date**
P 14351	26C420	PM, Compressor, Quarterly	4	Sep. 9
P14318	Gen.	Greasing, Route D-4	11	
P14321	Gen.	Oil, Route D-5	16	
P14322	MOB23	PM, Pickup Truck Safety Check	2	
P14324	Gen.	PdM, Vibration Monitoring, Week 27	7	
P14326	37T910	PM, E-13 D Transmitter Calibration	4	Sep.11
03426	47R200	Repair Minor Leak at Reactor Seal	14	
03398	37R907	Replace Rupture Disc with low pressure	7	Sep.11
03369	05T905	Replace Frayed Hose	6	
03414	26B501	Increase fan speed, Change sheave and motor	11	Sep.9
03415	10B501	Replace fan bearings, per vibration analysis	9	Sep.8
—	—	— —	—	—

The above table 2.3 shows a weekly schedule technique.

2.4.3.2. Daily Schedule

Daily schedule is developed to free maintenance supervisor from some of the coordination problems. Effort is made by the scheduler to provide a day's work for each maintenance employee of the area. Using the CMMS, the scheduler lists the number of times each job has been placed on schedule. It is normally the responsibility of team leader or maintenance supervisor to assign the right person or persons to each job. The job that is not completed in a day, may be placed on schedule of next day or left for another suitable day of week. Table 7.2 shows one such sample schedule. The table shows original estimated time just for reference. It can be deleted or, additionally, one more column can be introduced showing least time taken in past for the same job.

Table 7.2 Sample Daily Schedule

Daily Schedule											
Area- D	Day- Tuesday	Date- 7. Sept. 2003					(Unit- Hrs.)				
WO No.	Equip. No.	Description	Mr A	Mr B	Mr C	Mr D	Mr E	Mr F	Org Est.	Actual Hrs.	
03415	10B601	Replace Fan Bearings				4.5		4.5	7.0		
03403	10M210	Replace worn mixer blades			5.5		5.5		8.0		
P1432	Plant	Oiling, Route 06			2.5		2.5		7.0		
03465	37T973	Relocate Level Controls				3.5		3.5	8.0		
P1431	Plant	Grease, Route 04		x					2.0		
03464	37P101	Replace Guards and Nipples	6.0						8.0		
03481	35P201	Emergency- Replace pump seals	10								
03480	37M120	Emergency, Replace Valve	2.0								
		Straight Time Hrs.	8.0	8.0	8.0	8.0	8.0	8.0			
		Overtime Hours	0	2.0	0	0	0	0			

2.4.3.3. Gantt Chart and Bar chart

Gantt charts are, normally, a project planning tool that can be used to represent the timing of tasks required to complete a project. Because Gantt charts are simple to understand and easy to construct, they are used by most project managers for all but the most complex project and are also used by maintenance engineers for scheduling bigger maintenance jobs. In a Gantt chart, each task/activity takes up one row. Dates run along the top in increments of days, weeks or months, depending on the total length of the work. The expected time for each task is represented by a horizontal bar whose left end marks the expected beginning of the task and whose right end marks the expected completion date. Tasks may run sequentially, in parallel or overlapping. As the work progresses, the chart is updated by filling in the bars to a length proportional to the fraction of work that has been accomplished on the task. This way, one can get a quick reading of project progress by drawing a vertical line through the chart at the current date. Completed tasks lie to the left of the line and are completely filled in. Current tasks cross the line and are behind schedule if their filled-in section is to the left of the line and ahead of schedule if the filled-in section stops to the right of the line. Gantt charts made with Microsoft Excel are easy to update and maintain.

Bar chart can be defined as a graphical comparison of several quantities in which the lengths of the horizontal or vertical bars represent the relative magnitude of the values. It is the type of chart most commonly used by technical analysts. The horizontal scale on the bottom of the chart indicates the passage of time. The time scale is usually shift-wise, daily, weekly or monthly. Bar chart is concerned with two major tasks. Firstly, it visualizes the time flow of the individual processes for all project workspace members. The second task of the bar chart is to provide the project manager or maintenance personnel with functionalities for individual processes.

Bar Charts are of different types for different applications. In maintenance scenario, Bar Chart is a Gantt Chart on slightly lower scale for scheduling maintenance jobs and employing the same principles as Gantt Chart. Maintenance Bar Charts are of two types—

1. Overall Chart—This broadly shows all the jobs /activities of a repair plan in one chart. However for a big repair plan, this may become confusing.
2. Individual Charts—This, again, can be of two types—
   - Individual section/ area/ execution agency wise; such as separate charts for shop maintenance crews, heavy maintenance crews, contractors and captive shops etc.
   - Individual crew or workmen wise chart within each individual section agency.

Individual workman chart is also called **Manpower Chart.**

Fig.7.3 shows a portion of Bar Chart for 900 Mill shutdown. In the chart, A,B C are the three working shifts of a day, HM means heavy maintenance, "Opr" means operation and "Contr" means contractor. The duration of each activity is shown by the lower portion of each bar. The portion above each bar in the same row is used to fill up during review/ follow-up, indicating the actual time taken.

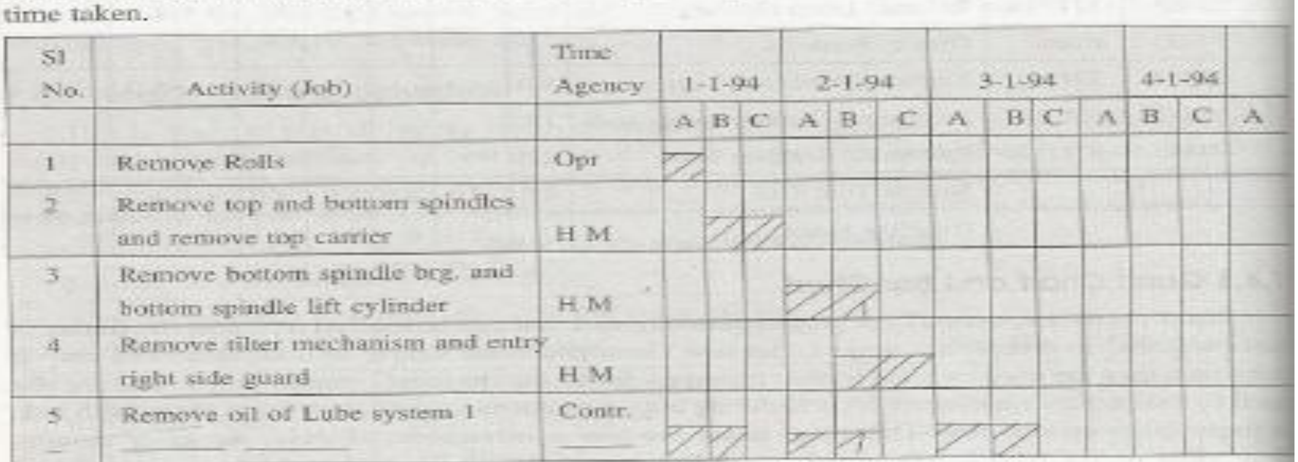


Fig 7.3 Bar Chart for 900 Mill Shutdown Repair

Limitation of Gantt Chart- Though Gantt charts are very useful for maintenance activities it has some limitations or disadvantages, such as—

1. They can become quite unwieldy for major repairs or projects with more than about 3[illegible] activities. Larger Gantt charts may not be suitable for most computer displays.

2. Gantt charts communicate relatively little information per unit area of display. That is major repairs or projects are often considerably more complex than can be communicated effectively with a Gantt chart.

3. Gantt charts do not represent the size of the total job or the relative size of work elements therefore the magnitude of a behind-schedule condition is easily miscommunicated.

2.4.3.4. PERT, CPM and CPA networks

Though Bar Charts /Gantt Charts have lot of merits, one big demerit is that they do not clearly define interdependencies of activities, i.e. which activity must precede and which activity must succeed concerned activities and how much delay in one activity actually affects other activities. To overcome this demerit, many **Network Techniques** have come up, like **PERT (Programme Evaluation and Review Technique), CPM (Critical Path Method) or CPA (Critical Path Analysis)** etc. Though most of these were developed for monitoring big project works, they are equally suitable for maintenance jobs.

All these Network Techniques have common methodologies and approach. The networks are made of "Activities" and "Events". Activity tells the actual job to be done and is in the form of straight line. Event tells the actual beginning or ending of an activity (job) and is designated by a circle, or sometimes a square. Events do not consume any time but activities do consume time. All events are numbered and an activity is indicated by two connecting events. For plotting a network, following guidelines are followed—

1. Total Repair/ Shutdown job is broken into small measurable activities. Occasionally a Work Breakdown Structure (WBS) is used for that. WBS is a hierarchic decomposition or breakdown of a major activity into successive levels, in which each level is a finer breakdown of the preceding one.
2. All activities and events are arranged in logical sequence and plotted on paper so that succeeding activity and event must follow the preceding activity and event, i.e. succeeding activity must be on the right side of preceding activity.
3. The network is not drawn on time scale, but it has time-sense; i.e. each event, starting earlier than few events, must be on left (west) side of those events. Similarly, an event, finishing later than few events, must be on right (east) side of those events.
4. From one event many activities can start (including concurrent activities) and many activities can end at one event.
5. There can be only one activity between two events. If there is an activity between two events, they may be connected by dummy activity (dotted line) to show the time-sense.
6. The activity line may or may not have arrow head. In case arrow head is indicated, it must be from left to right (West to East).
7. Based on the activity time, the "Earliest Start Time, T_{ES}" and "Latest Finish Time, T_{LF}" is calculated and indicated on network (at least for smaller networks). Similarly "Latest Start Time, T_{LS}" and "Earliest Finish Time, T_{EF}" are also calculated. Based on these, the "**Slack Time**" for each activity (amount of time that the activity can be delayed past its earliest start time or earliest finish time, without delaying the job/ project) and "**Float**" for each event (the amount of time an activity can be delayed without affecting subsequent activities) are calculated. Float is, also called **node** by some users. Event number, earliest finish time (T_{EF}) and latest finish time (T_{LF}) are either written inside the event (if the event size is big to accommodate, as shown in Fig 7.5) or on the top of the event.
8. Each network will have at least one critical path, having zero slack and zero float. These critical paths are specifically marked on the network.
9. The total duration of Repair job is, thus, obtained by adding all the activity times on the critical path.

PERT vis-à-vis CPM- CPM and CPA are same with little different emphasis and both would be taken as CPM. PERT is used for bigger works, involving some uncertainties and first time jobs. It is a network model that allows for randomness in activity time. As such PERT uses three time estimates: "Optimistic", "Most-likely" and "Pessimistic" and based on these, Expected Activity Time is calculated—

Exp. Activity Time = [Optimistic Time + 4(Most Likely Time) + Pessimistic Time] / 6

CPM charts are similar to PERT charts and are sometimes known as PERT/CPM. CPM is a deterministic method that uses a fixed time estimate for each activity. While CPM is easy to understand and uses, it does not consider time variations that can have a great impact on completion time of a complex project or Repair Plan. In most maintenance application we use PERT/CPM model networks.

CPM may be considered as a smaller PERT and is more often used in maintenance.

Advantages (PERT/ CPM)	Disadvantages
1. Very effective tool for monitoring any repair plan or project.	1. Costly
2. Helps in understanding and communication amongst involved personnel/ agencies.	2. Time consuming.
3. Highlights activities important to complete the total job on time.	3. Poor estimates in activity times in PERT.
4. Shows interrelationship in workflow and is useful in determining labour and resources needs in advance.	4. Inclination to use pessimistic time estimates for activity time (in PERT)
5. An effective tool in controlling the cost and can easily be computerized.	
6. Helps in avoiding duplication and omissions and determining the total job duration systematically.	

2.5. Maintenance Organisation

2.5.1. Definition and Purpose

Organization means a group of people who work together in a structured way for a shared purpose. In any industry, the various maintenance functions are planned and executed by workmen of different trades/ disciplines/skills and of different levels (workmen/ employees, supervisors, executives and engineers etc) and they have to be arranged/ grouped/ organized in such a way that they have to work as a team towards the common goal of improving maintenance effectiveness/ efficiency and for improving equipment availability and reliability. Such grouping and arranging of maintenance personnel, with their interlinking and relationships, is generally termed as maintenance organization. (Maintenance organization, as in the case of other organization, requires delegation of authority and span of control, with necessary feedback and control system.)

There are almost infinite numbers of organizational structures in use but many of those are not configured to provide effective utilization of workforce and have unbalanced indirect (clerical, administrative and other support) personnel. Maintenance organization (or for that reason, even corporate organization) is both science and art. The science of the organization lies in different dimensions (e.g. different categories of workmen, supervisors, staff and support personnel, contractors, vendors, sophistication, prevailing cultures and regulations etc) on which they are designed. How these dimensions are coordinated, interlinked and governed is more of an art than science. Again, the total number of workforce in an organization may not be a mere addition of persons needed for different trades or dimensions but a judicious balance is to be arrived. Organization, like individual, must preserve their integrity. It must be a balance between policy and practice; between philosophy and performance; between decisions and deeds.

In 1986, the Society of Manufacturing Engineers, USA, examined the balance between the current level of manufacturing technology and of company's organization and the conclusion of the study was that, 'American industries, in its drive to become more competitive, is attempting to put fifth generation technology into second generation plant organization'. Thus the maintenance organization should also correspond to the advancement of maintenance practices in use.

Employees' involvement, to a reasonable extent, may also be considered in deciding maintenance organization through suggestion system, information sharing and survey feedback etc. However, while doing this, care should be taken not to increase the staff un-necessarily or not to create additional management structure.

2.5.2. Basic concepts for Maintenance Organization

Followings are the basic concepts

(*a*) Establish reasonably clear division of authority, with minimum overlap—Authority can be divided functionally, geographically, on the basis of expediency or it can be on some combination of all the three. But there must always be clear definition of the line of demarcation to avoid confusion and conflict. The over lap should be bare minimum.

(*b*) Keep vertical line of authority and responsibility as small as possible— Unclear or many levels of intermediate supervision or over-application of specialized functional employees must be minimized. Whenever such practices are felt to be necessary, clear division of duties must be established.

(*c*) Maintain an optimum number of people reporting to one individual— In a good organization, number of people reporting to one individual may vary from 3 to 6, depending on the type of job. When a job requires a fairly small amount of supervision, one man can direct the activities of 12 or more persons.

(*d*) The total maintenance workload should be reasonably distributed amongst all concerned persons to avoid conflicts amongst workers.

(*e*) Maintenance is not subordinate to operation. Again, difference between 'supportive service' and 'subordinate service' should be kept in mind.

2.5.2.1. Factors governing Maintenance Organization

Even with the above concepts in mind, decision of maintenance organization will vary as per the following local factors of the organization

1. Type of operation: e.g. buildings, machine tools, process equipments, manufacturing facilities, piping, mining machineries, electrical equipments etc—each will affect the character of organization and supervision required.

2. Continuity of operation: e.g. if the operation is 5/6 days a week, single shift one or a 7 days a week, round the clock (3 shift) one or others— considerable differences may be in these on how the maintenance engineering department may be structured and how many personnel may be needed.

3. Geographical location: The maintenance that may be needed in a compact plant will vary considerably from the one that is dispersed through several buildings or over a larger area. The later often leads to area maintenance shops and additional layers of intermediate supervision at local centres.

4. Equipment's age and condition: Older the equipment, more maintenance and supervision may be needed (for older plants).

5. Size of plant/ industry: Here also the actual size of plant/ industry and its volume of business will dictate the number of maintenance employees needed and amount of supervision for those. Many more subdivisions in both, the line and staff personnel, can be justified since the overheads can be distributed amongst more departments.

6. Scope of Plant maintenance engineering department: This scope is a direct relationship of management policy. Inclusion of responsibilities for a number of secondary functions means additional manpower and supervision.

7. Employees level of training and reliability: This highly variable factor has a strong impact on the maintenance organization because it dictates how much work can be done and how well it can be performed. In industries where sophisticated equipments predominates, with a high wear or failure incidences, more monitoring systems and more employees and supervisors may be needed. Higher need of reliability of equipments may need bigger maintenance organization.

8. Complexity of business and machines and extent of automation and built-in test and monitoring equipments provided: This may lead to less frequent physical check and correspondingly less manpower.

9. Prevailing maintenance types/ systems of the industry (for older plants).

10. Extent of out-sourcing available or permissible: Availability of highly competent maintenance contractors around the industry may dictate out-sourcing some maintenance jobs (intermittent or continuous) and correspondingly reduce the industry's maintenance organization.

11. Local labour laws and prevailing industrial culture and practices.

2.5.3. Aims / Objectives of Maintenance Organisation

Much of these have been discussed along with its purpose in previous section. The basic objective/ aim of any maintenance organization or department is to ensure that production plants and equipments are available, at minimum cost, for production for scheduled hours and quantity, operating to agreed standards, safely and with minimum waste.

There must be recognition at the top management level and at all other levels of the vital need for maintenance organization and an understanding of its aims and objectives. It should be clear that maintenance department/ organization exists only by virtue of it being necessary for plant's operation and upkeep. It is not a self sufficient or self contented unit. It is a part of team that can perform satisfactorily only when firmly cooperating with others.

In order to develop an effective maintenance organization, following features must be kept in mind:

1. Maintenance is basically a teamwork activity; still the individuals should be able to work reasonable freedom for the specific/ defined job.
2. The jobs/ trades/ crafts of individuals should be so interlinked that they are supporting to each other and pulling towards a common goal. This is very essential as maintenance department consists workers of very many trades/ crafts; few of those are given below.

Main disciplines	Trades/ crafts	
Mechanical	1. Fitters,	2. Welder/ Gas-cutters
	3. Riggers	4. Plumbers/ pipe fitters
	5. Lubricators	6. Mechanics (esp. automobile mechanics)
	7. Machinists	7. Blacksmiths
	8. Markers	9. Millwrights (combined fitter, rigger, welder)
	10. Utility operator (for running pumps, compressors, boilers etc) Etc.	
Electrical	1. Armature winder	2. Electrician
	3. Switchmen	4. Electrician technicians
	5. Electrical inspectors	6. Electrician and cable jointer; Etc
Instrumentation	1. Instrumentation technician	
	2. I and C (Instrumentation and controls) technician	
	3. I and E (instrumentation and electrical) technician; Etc.	
Civil	1. Mason,	2. Surveyor
	3. Carpenter	4. Structural fabricator
	5. Overseers	6. Landscaper; Etc.
Others	1. AC and Refrigerator mechanic	2. Draftsmen (Drawing Office)
	3. Tool and Die technician; Etc.	

2.5.4. Types of maintenance organization

One way of classifying any organization is

- Formal and
- Informal

Though this is not a popular way of classifying, with respect to maintenance organization, it can be said that 'Formal Maintenance Organization' means a separate distinctive maintenance department within an industry or plant, whereas 'Informal Maintenance Organization' means that maintenance jobs are clubbed with operation jobs and same personnel do the operation as well as maintenance jobs as per need and help of external agencies may be taken for heavier jobs, as per need.

As a more popular way, maintenance organization may be classified in following ways—

- Line and staff organizations,
- Functional organizations
- Centralized/ decentralized organizations

2.5.4.1. Line Staff organization

In the line organization, top management has complete control, and the chain of command is clear and simple. Examples of line organizations are small businesses in which the top manager, often the owner, is positioned at the top of the organizational structure and has clear "lines" of distinction between him and his subordinates. A line position is directly involved in the day-to-day operations of the organization, such as producing or selling a product or service. Line positions are occupied by line personnel and line managers. Line personnel carry out the primary activities of a business and are considered essential to the basic functioning of the organization. Line managers make the majority of the decisions and direct line personnel to achieve company goals. This is called **'Line Authority'**. However, two important clarifications should be considered, however, when discussing line authority

(1) line authority does not ensure effective performance, and

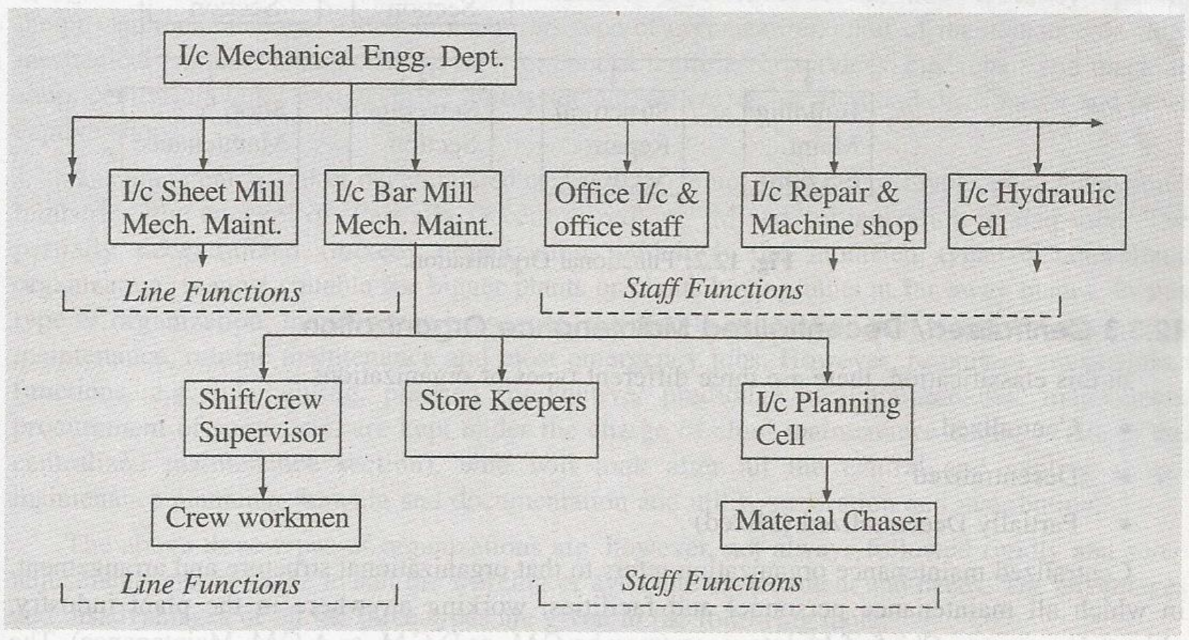
(2) line authority is not restricted to line personnel. The head of a staff department has 'line authority' over his or her employees by virtue of authority relationships between the department head and his or her directly reporting employees.

Staff positions serve the organization by indirectly supporting line functions. Staff positions consist of staff personnel and staff managers. Staff personnel use their technical expertise to assist line personnel and aid top management in various business activities. Staff managers provide support, advice, and knowledge to other individuals in the chain of command. Although staff managers are not part of the chain of command related to direct production of products or services, they do have some authority over personnel. **'Staff authority'** has the right to advise or counsel those with line authority. For example, a human resource development manager advises and aids a production manager or maintenance manager by training their workmen to improve their skill and capability. Therefore, staff authority gives staff personnel the right to offer advice in an effort to improve line operation.

The line-and-staff organization combines the line organization with staff departments that support the line departments. Most medium and large-sized firms exhibit line-and-staff organizational structures. The distinguishing characteristic between simple line organizations and line-and-staff organizations is the multiple layers of management within line-and-staff organizations.

An advantage of a line-and-staff organization is the availability of technical specialists. Staff experts in specific areas are incorporated into the formal chain of command. A disadvantage of a line-and-staff organization is conflict between line and staff personnel. Often, due to different positions and types of authority within a line-and-staff organization, conflict between line and staff personnel do occur, but a clear chain of command, which is a consistent characteristic among line-and-staff organizational structures, help minimize such conflicts.

Though maintenance as a whole is, often, considered as a staff organization (with production personnel as line organization), within the maintenance department, we have line organization and staff organization, thus terming the whole maintenance as a line and staff organization. Fig. 12.1 shows a typical line and staff organization of Mechanical maintenance department of Alloy Steels Plant (SAIL), Durgapur, W.Bengal, India. It shows the line and staff functions at two different levels. At first level, I/c Bar Mill Maintenance, I/c Sheet Mill Maintenance and I/c of other mills are line functions and Office staff, I/c Repair and Machine shop and I/c Hydraulic Cell are staff functions. At next level, Shift/ crew in-charge, along with crew workmen are line staff and store keepers and I/c Planning cell with material chaser etc are staff organization.

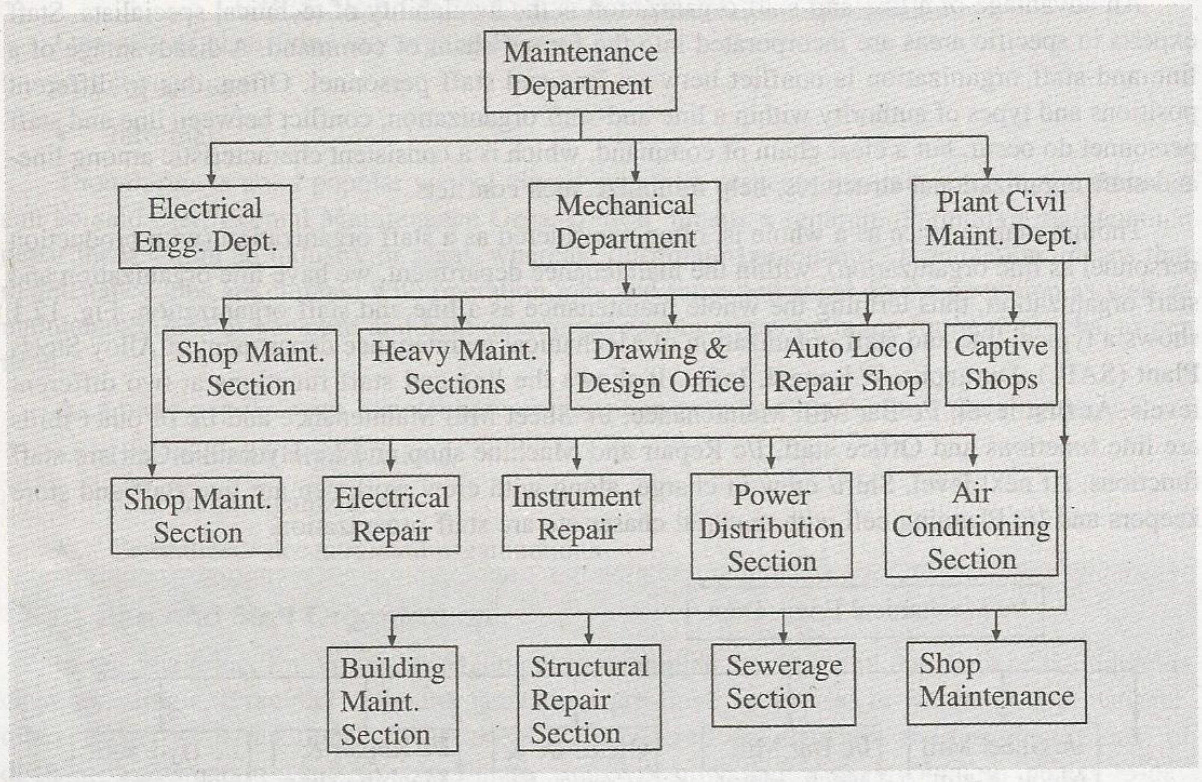


The above figure 2.4. is an example of line staff organization.

2.5.4.2. Functional Organisation

In this type of organization, the arrangement is not made by level, designation or hierarchy of maintenance personnel but by the type of functions they perform. Such organization is basically not individual based but is based on the functional areas, shops and sections. This only highlights the functional working arrangements in a plant/ industry.

Some experts/ writers on Maintenance Engineering may consider 'Functional Maintenance Organization' as a sort of 'Line Organization', but the author considers 'Functional organization' more appropriate as mentioned above.



The above figure 2.5. is an example of functional organization.

2.5.4.3. Centalized / Decentralized Organisation

In this classification, there are three different types of organizations

- Centralized
- Decentralized
- Partially Decentralized (Mixed)

Centralized maintenance organization refers to that organizational structure and arrangement, in which all maintenance personnel and facilities, working anywhere in the plant industry, ultimately report to Chief of Maintenance (may be G.M. or D.G.M. or A.G.M. Maintenance). The maintenance facilities may be located in the same shop or in different production shops or different maintenance workshops or captive shops and the maintenance personnel may be working in shifts round the clock or in single shift, but at no stage they directly to report to or directly responsible to production in-charge.

The centralized maintenance concept seems to promote harmony between the maintenance personnel because they are closer together. When area concept is used with centralized maintenance, a small area near the process or production is set aside for maintenance personnel. If needed, they can go to central shops or call additional crews from there to do the heavier or specialized work that can only be done in the larger and better equipped place or by more workmen.

Centralized maintenance organization may be of two types—pure and amalgamated. In **'pure centralized maintenance organization'**, the employees of individuals disciplines ultimately report to chief of that discipline (e.g. all mechanical workers and executives ultimately report to chief mechanical engineer, electrical employees should ultimately report to chief electrical engineer and so on) and these individual chiefs report to head of plant (e.g. GM-Works or Director-Works etc). In **'amalgamated type'**, the lower levels (crew in-charges or sub-area in-charges) of individual disciplines (mechanical, electrical, instrumentation etc) may report to area in-charge of maintenance (senior manager or other such high level), who may be of any of those disciplines and who, in-turn, will report to chief of plant maintenance (GM/ DGM- Maintenance and so on).

The decentralized maintenance organization may base on two concepts——the **discipline-wise decentralization** and **area-wise decentralization**. Discipline-wise means mechanical crafts/ trades may have separate shop/ department, electrical have separate shop/ department etc. Area-wise means separate composite group of maintenance personnel for maintaining separate system or physical area.

Normally, the decentralized maintenance organization refers to that organizational structure and arrangement in which all the maintenance jobs of a shop are also the responsibility of in-charge of production of that shop and the maintenance personnel of that shop ultimately report to the production in-charge of that shop. In this type of organization, chief of maintenance or chief mechanical engineer is responsible only for central facilities or services, e.g. repair and machine shop, central drawing/ design office, utility (steam, air etc) generation and distribution and other captive shops.

As either centralized or decentralized organization is not suited for all types of organizations/ industries, the concept of 'Partially Decentralized" or "Mixed" organization is also used. The partially decentralized (mixed) organization, which is the modified type of centralized organization, is most suitable for bigger plants or plants having units at far away places. In this type of organization, maintenance personnel, attached to production unit, carry out day-to-day maintenance, routine maintenance and most emergency jobs. However, important maintenance functions, e.g. overhauling, planned (preventive/ predictive etc) maintenance, major jobs, procurement of spares etc, are kept under the charge of chief maintenance engineer (I/c of the centralized maintenance section), who will look after all the central and captive shops, maintenance planning, drawing and documentation and utility generation and distribution.

The above three types of organizations are, however, not always followed rigidly and some adjustments can be made to suit the working or available environment and needs. The advantages and disadvantages of all the three types are given in the following table:

Type	Advantages	Disadvantages
Centralized organization	1. Skill and technology easily disseminated, 2. Problem easily investigated, 3. Easy deployment from a more diversified and specialized craft group. 4. Lesser duplicating of workers and facilities, thus lesser manpower and facilities needed, 5. Excel in planning, scheduling 6. Costly and specialized equipments can be procured and used more effectively, 7. More specialized supervision, when needed	1. Collaboration with operation departments difficult, 2. Incomplete collection of operating data, 3. Higher transportation cost, both for men and material, 4. More time getting to and from work area,

	8. Better standardization and variety reduction of spares and materials for industry, 9. Generally more cost-effective,	
Decentralized organization	1. Good communication with operating dept 2. Speedy maintenance response and reduced travel time. 3. Better familiarity with machines and Processes; more production mindedness. 4. Interchangeability of operation-maintenance workforce, even at managerial level, is possible 5. Conflict amongst workmen is reduced due to better coordination.	1. Difficult to share technology and skills, 2. Requires more people, 3. Non-availability or under-utilization of specialized tools and facilities, 4. Generally more costly, Because of duplication of tools and facilities,
Partially Decentralized organization	1. Good communication with operating Dept, 2. Skills and technology dissemination and problem investigation easier 3. Many of the other advantages of the above two types.	1. Management somewhat difficult 2. Job rotation requires ingenuity

2.5.5. Roles and Responsibilties of centralized maintenance groups

1 Planning and scheduling of all major repairs, shutdowns and overhauls etc, in consultation with shop maintenance and other agencies,

2. Planning of spares, tools, tackles, specific consumables and other necessary materials, in consultation with shop maintenance etc,

3. Preparation of annual maintenance budget and periodical reviews,

4. Manpower planning and their training and development, in consultation with personnel department and training department,

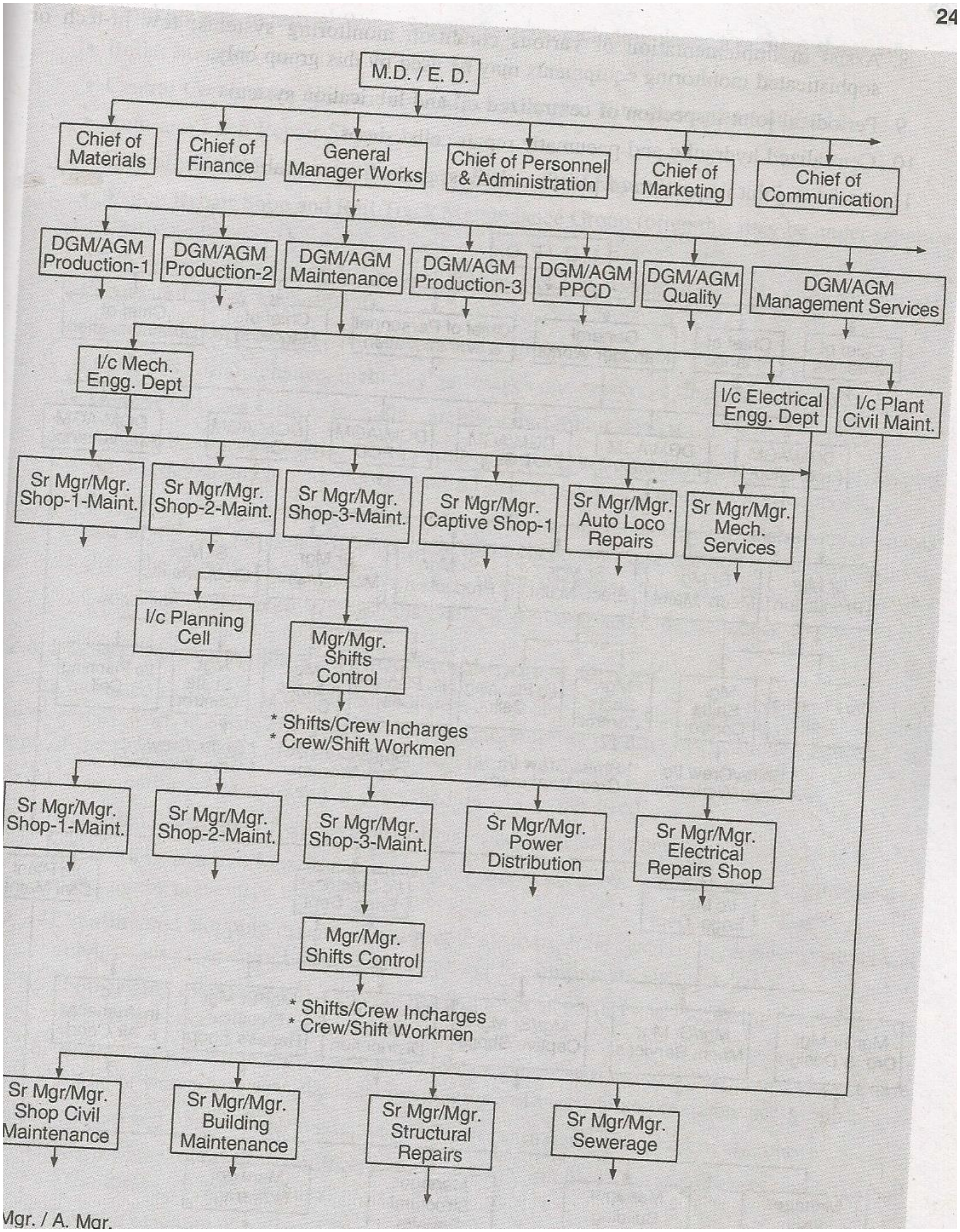
5. Execution and supervision of all heavy repairs and major overhauls,

4. Assistance and technical guidance on addition, modification and replacement (AMR) schemes pf the plant,

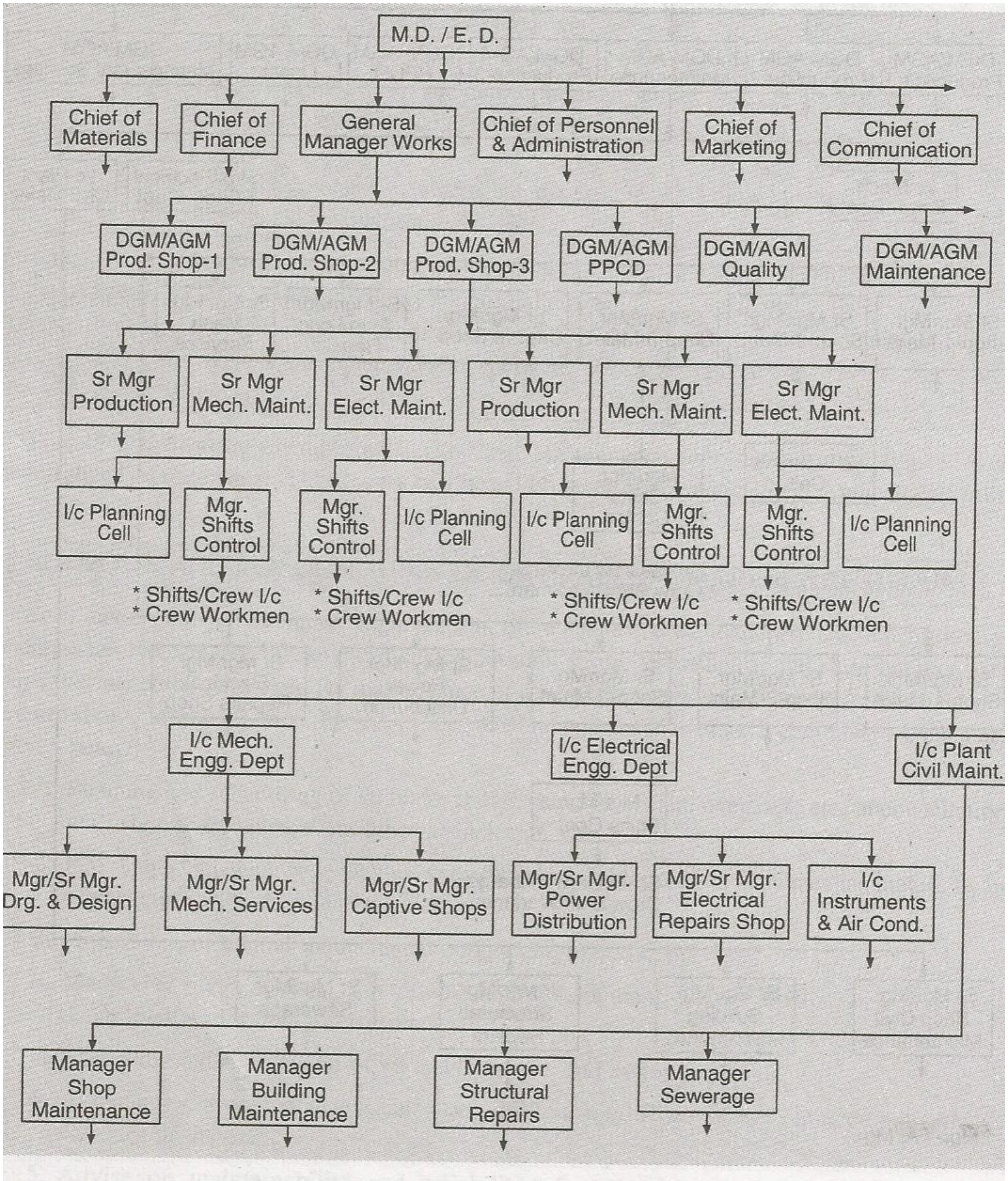
5. Advise on maintainability and reliability of equipments, before purchase and on improvement/ changes etc,

6. Assist shop maintenance personnel in repetitive failure analysis and analysis of other major defects and suggest suitable improvements/ changes,

The diagram 2.6 shows an example of centralized maintenance organization.



And the figure 2.7 shows the decentralized orgainsation



2.6. Training of maintenance personnel

Today many companies are finding it difficult to attract qualified technicians for manufacturing technology, maintenance, repair and service functions. The shortage can be attributed to many factors; one is that not enough young people pursuing careers in manufacturing/ maintenance technology-related fields as it appears little dirtier in nature and IT related jobs or other softer and glamorous jobs looks more attractive. As such, few companies often resort to stealing them from original equipment manufacturers (OEMs) or other companies with similar equipment, because they also do not want to take trouble of training their workforce. But, if more companies would begin training maintenance, repair and service technicians, the problem would eventually solve itself.

Management Consultant Peter Druker defined the knowledge worker as a person who has formal education but may require manual dexterity skills to perform a job. This description fits the maintenance worker of today or tomorrow, who will see the knowledge content of the work continue to increase and who will thrive only if he or she uses their wits and keeps adding to their skill base.

Training or human resource development (HRD) was not given due importance earlier as maintenance was considered as secondary job. But lately it is being appreciated that training is very essential for maintenance personnel because

- Maintenance personnel have to encounter more uncertainties and unpredictable situations,
- Maintenance jobs are, generally, not repetitive,
- Maintenance is a multidisciplinary function,
- Maintenance repair technology is changing very fast and new developments are taking place regularly in that direction,
- Often maintenance personnel are confronted with situations where many necessary materials/ inputs are not available and ingenious or makeshift ways have to be used.
- Often the mistakes/ omissions by maintenance personnel is not visible immediately, but affects more seriously later.

Training increases the effectiveness of maintenance personnel in both, the human behaviour aspect and technical and skill aspect. It gives a clear picture of what is expected of them. Training also creates a feeling in maintenance personnel that their skills are important, needed and highly valued. For maintenance manpower effectiveness and manpower potential, following formula can be used

Manpower Effectiveness = Manpower Potential x Application Factor

The application factor is the product of moral, skill, motivation and other management factors and is always less than one. The job of training and human resource development is to increase this application factor to as near to one as possible, so that the effectiveness of maintenance manpower improves towards their potential and they are able to give more and better output. If our full manpower potential is not being used, we are wasting a part of our resources of skill and time and that may add up to considerable loss to our organization. The calculation of above formula is somewhat hypothetical, as it is difficult to quantify different factors, but it surely highlights the importance of training functions.

2.6.1. Human factor in maintenance

Human error in maintenance can impact the safety and performance in a number of ways. A maintenance person, who is well trained, motivated, under no undue pressure, given correct information and working with equipment which has been designed to be maintenance friendly, will most likely complete all specified maintenance jobs to a high standard. As with most types of work, the scope for human error in maintenance operations/ functions is vast. These can range from becoming distracted and forgetting important checks to knowing deviating from a proper work procedure in order to save time or to get the job done in unexpected circumstances. There are a number of factors which influence the behaviour of maintenance crew and the likelihood of human errors need to be considered, both in terms of safety of people and damage to equipments/ systems or subsequent breakdown.

The human errors may be in form of Slips and lapses, Mistakes and Violations etc. There are many human factor issues which can impact the safety and maintenance performance, e.g. safety commitments and perceived impracticality of any safety rules, communication, knowledge and skill, plant and equipment ergonomics, working condition, job designs, standards and monitoring of supervision, complacency and management style etc. Most of these issues can be identified, reviewed and improved by suitable training and awareness.

Like in few other areas, maintenance workmen must have following physical attributes

1. Natural or corrected near-distance visual acuity,
2. Colour vision sufficient to discern system and component colour coding,
3. Hearing sufficient to respond properly to audible alarms and use communication system,
4. Sufficient strength, power, range of motion and dexterity to allow access to facility etc.

2.6.2. Objectives

- *Knowledge Objective*: To learn about maintenance policies, systems/ strategies, condition monitoring and diagnosing, failure analysis and record keeping etc,
- *Attitudinal Objective*: Attitude is the approach towards job and job related person. Attitude influences behaviour, which affects the output and effectiveness of the maintenance person. As such training should also aim to modify the job attitude.
- *Job-behaviour objective*: Attention is focused opn the extent to which the knowledge, skilled and abilities acquired during the training can be generalized or transferred to maintenance problem solving efforts,
- *Skill Objective*: Skill generally refer to the ability and expertise of a person (generally physical) to perform his/ her job.
- *Advanced Technological Objective*: These objectives refer to short term trainings, aimed to acquaint the maintenance engineers/ supervisors about the modern developments taking place in the field of repair and maintenance.

The extent of these objectives vary from level to level. These objectives and aim should not remain on paper only. Management should also communicate to trainees that—

1. Results are expected from the maintenance training,
2. Support for implementation of the relevant course will be provided,
3. There will be a follow-up on the results or expertise achieved,
4. In case of multi-skill training, they would be scheduled for other trades in addition to their original trade; and so on.

2.6.3. Types of maintenance training programmes

As per one classification, maintenance trainings, it can be of three types— Classroom Training, On-job Training and a combination of the two. Most maintenance trainings are a combination programme, the portions of classroom and on-job trainings vary depending on the topic of the training and level of the workmen.

Again, the training programmes can be general or customized. Most maintenance training programmes are customized, i.e. specifically designed to meet some specific requirements. Few of such programmes are given herewith—

1. **Multi-Skilled Technician Programsmes:** These training programmes are designed for "cross-training" your craft and operations personnel. Many organizations are taking advantage of the ability of workers to perform multi-discipline tasks. This decreases the time to perform many jobs, resulting in significant cost savings. Refer Sec.12.7.
2. **Maintenance Management Courses:** Only recently the management of a maintenance organization has been given the attention it deserves. The reality is that maintenance organizations have changed from simple repair facilities to actual business units responsible for the pro-active care of equipment assets. Maintenance supervisors require

skills in people management, maintenance management, and project manageme effectively run a maintenance service business. Courses are designed to provide the skill required of a maintenance supervisor and improve their potential for hi responsibilities. Topics include team building, leadership, project management, pla and scheduling, autonomous maintenance, predictive maintenance, and 5-S etc.

3. **Customized Maintenance Training Programs:** Customized maintenance trai programme is a total maintenance and operation solution, tailored to the particular nee and circumstances of its users, and brings better optimization between various conne elements. Such trainings give one-stop opportunity for all maintenance and opera needs for that topic/ unit. Such trainings can be a regular course in plant's trai calendar or can be specially made for few special occasions. These trainings a generally, of shorter or medium duration. Huge numbers of such trainings are used in a plant/ industry. Few examples are given herewith
   - Vibration Monitoring, Tools, Techniques and Applications
   - Steam Turbines- Operation and Maintenance
   - Precision Bearing Maintenance
   - Maintenance Planning and Scheduling
   - Commercial Aircraft Carrier Maintenance
4. **Performance Test Trainings-** Such trainings are used for job performance evaluations i conjunction with knowledge evaluations as screening devices for
   - Hiring/ recruiting new employees, Also a hands-on evaluation of the skills require to perform the job (depending on the workforce diversity and culture) can be seen a less threatening than written evaluations/ tests,
   - As determinants of training that is needed (gap analysis),
   - For advancement and pay-for-skills,
   - For certification testing, etc.
5. **Accelerated Apprenticeship Training:** Many maintenance departments are staffed with an aging workforce. As these craftspeople retire, the maintenance departments lose a wealth of institutional knowledge. In many cases, substituting employees/ apprentices cannot be trained fast enough under the current programs to effectively replace retiring workers. In such cases, special trainings are arranged or existing trainings can be augmented to accelerate the training while increasing its effectiveness.
6. **Continuing Training (Refresher courses):** In this rapidly changing world, learning cannot stop at any stage. A semiskilled craftsperson learns to become a skilled craftsperson, and the skilled craftsperson has to constantly learn new technologies to stay at the top of his or her field /skill. As such refresher courses (continuing trainings) are arranged for existing craftsperson at some intervals to update their skill/ knowledge in their field.
7. **Induction and Orientation Training:** These trainings are arranged for new employees to acquaint them about equipments/ systems and facilities of the plan/ industry, organizational structure of the industry and the role of participants in the organization, general rules and regulations of the industry etc. Generally classroom trainings.
8. **Safety and Environmental protection Training:** This training is essential programme of most of the trainings. However, small independent trainings are also arranged to highlight the safety and environment protection measures and general statutory obligations etc. Few

such topics are— Lock and Tag procedure, Electrical safe work practices, Working in confined space, Personal protective equipments, How any job can be done safely etc.

9. **Maintenance Troubleshooting Training:** It teaches employees a fundamental sequence of steps to apply when attempting to locate and repair problems in electrical, mechanical equipment and other equipments. Refer to Chapter 16.

Huge numbers of "**Onsite Maintenance Courses**" or '**Composite** (both onsite and classroom) Courses" are available in industries or special training institutes to impart or enhance the skill and effectiveness of maintenance workmen. These are generally in three categories—mechanical, electrical and controls. Mechanical courses are like Pipes and Pipefitting, Pump Maintenance, Hydraulics and Pneumatics Fundamentals, Shaft Alignment, Valves and Valve Actuators, Rotating Mechanical Equipment, Air Conditioning Refrigerant Regulations etc. Electrical courses are Circuit Breaker Maintenance, Basic Protective Relaying, Generators and Voltage Regulators, Motors and Motor Controllers, Grounding and Shielding Electronic Systems, Power Distribution and Switchgear Maintenance, Power Transformer Maintenance and Testing etc. Controls courses are Digital Electronics Principles, Engine Control Fundamentals, Instrumentation and Controls Overview, Process Measurement Instrumentation and Variable-Speed Drives etc.

Again Industrial Safety trainings (e.g. working safely with chemicals, material handling safety etc), general courses (e.g. preventive maintenance techniques, use of measuring and monitoring gadgets etc) and composite courses like HVAC (heating, ventilation and air conditioning) etc are few important ones.

The duration of such trainings vary depending upon the content of course and type of person attending.

2.6.4. Training tools, modes and methods

As can be seen from any course of training, there are three distinct **learning styles**— "**Auditory**" (learn by hearing, "**Visual**" (learn by seeing) and "**Kinesthetic**" (learn by doing). A good training session combines all three of these learning styles so that everyone gains the maximum benefit from the session. A trainer gives the in-depth presentation of the material/ system/ programme so that you are hearing how to use or work with those. The trainer will also demonstrate how to work or use those so that you learn by seeing. Finally the trainer will allow you to hands-on exercises, so that you learn by doing. Experiences have shown that, in most cases, learning by doing is the most effective way to retain information because you programme both, your mind and your body, with the new knowledge.

Most maintenance trainings can be classified as "Formal" or "Less Formal". **Formal training** is given by universities, colleges and recognized government, semi-government or private institutions, as mentioned in Sec. 15.5, and institutions award degrees, diplomas and certificates, which is recognized by all.

Less-formal trainings are those which are acquired by the individuals from books, seminars, on-job trainings, trainings within their own organizations or through manufacturer's /supplier's representatives/ premises, interactions and visits at manufacturers/ suppliers place, exposures to different technical workshops and exhibitions and periodical meetings/ discussions with representatives of different industries/ plants and radio/ TV broadcasts etc. These trainings have limited recognitions.

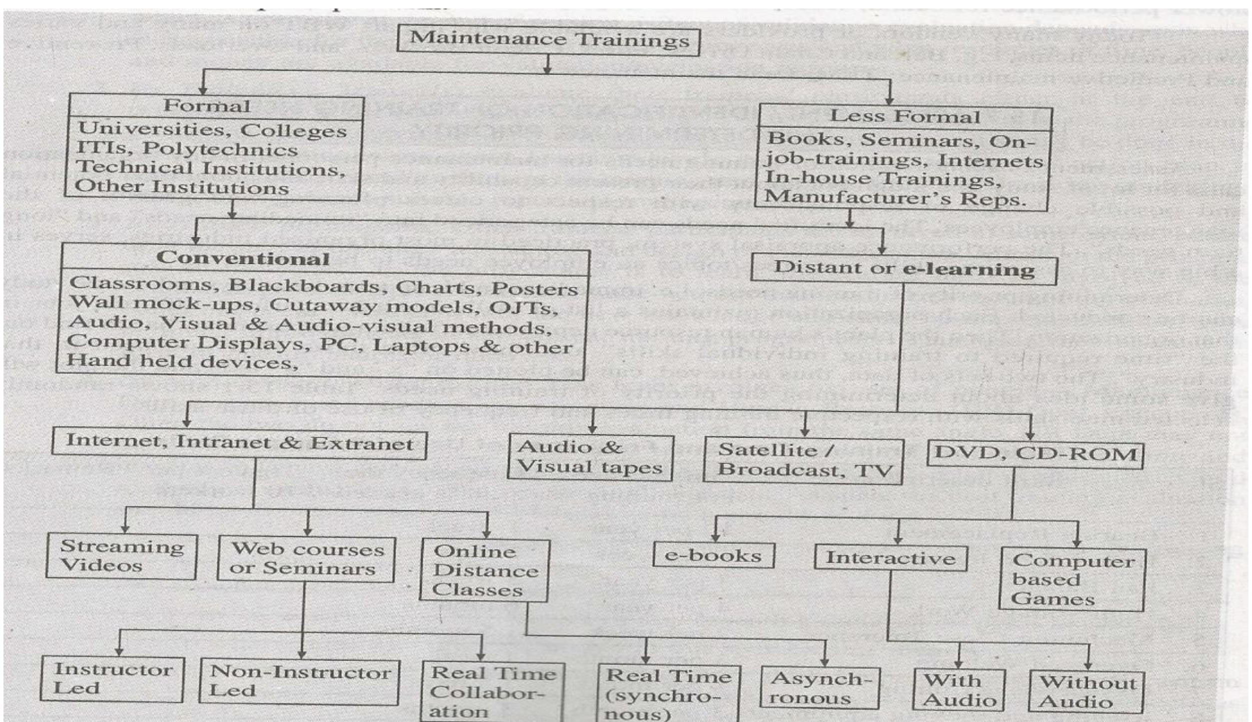
2.6.4.1. Computer based training

Presently CBT or Computer Based Learning (CBL) is used extensively, both for formal or class room training and for distant learning. It is a type of technology supported education/ learning, where the medium of instruction is through computer technology, particularly involving digital technologies. CBT is especially effective for training people to use computer applications because the CBT program, along with internet, can be integrated with the applications so that students can practice using the application as they learn and also give online tests.

Maintenance seminars and various maintenance trainings like lubrication, gas and air compressors, electrical safe working practices, AC motor controls, Hazardous area instrumentation and Shutdown, turnaround and outage etc, are being done through CBT.

2.6.4.2. Web based training

This is the modern version of e-learning. It is an innovative approach to distance learning in which computer-based training (CBT) is transformed by the technologies and methodologies of the World Wide Web, the Internet, and intranets. Web-based training presents *live* content, as fresh as the moment and modified at will, in a structure allowing self-directed, self-paced instruction in any topic. WBT is media-rich training fully capable of evaluation, adaptation, and remediation, all independent of computer platform.



The above classification fig. 2.8 shows the modes and tools of maintenance trainings.

WBT is an ideal vehicle for delivering training to individuals anywhere in the world at any time. Web browsers that support 3-D virtual reality, animation, interactions, chat and conferencing, and real-time audio and video will offer unparalleled training opportunities. With the tools at hand today, we can craft highly effective WBT to meet the training needs of a diverse population. Web-based performance support systems (WBPSS) further help today's busy workers perform their jobs by integrating WBT, information systems, and job aids into unified systems available ***on demand***. However, WBT designers are still struggling with issues of user interface design and programming for high levels of interaction.

WBT has many advantages over existing CBT, e.g. WBT has easy delivery of training to users, opportunities for group training (asynchronous and synchronous) as well as individual training, multi-platform capabilities (Windows, Mac, UNIX, PDA, phone, other wireless devices), easy updating of content, requires less technical support etc. However, it has few disadvantages or limitations, e.g. bandwidth/browser limitations may restrict instructional methodologies, leading to slower performance for sound, video, and intense graphics etc.

Today many vendors or providers are available who impart WBT on many and varies maintenance items, e.g. Belt and Chain Drives; Fuses, Circuit Breakers, and Overloads; Preventive and Predictive maintenance; TPM, Lean maintenance etc.

2.6.5. Evaluation of training

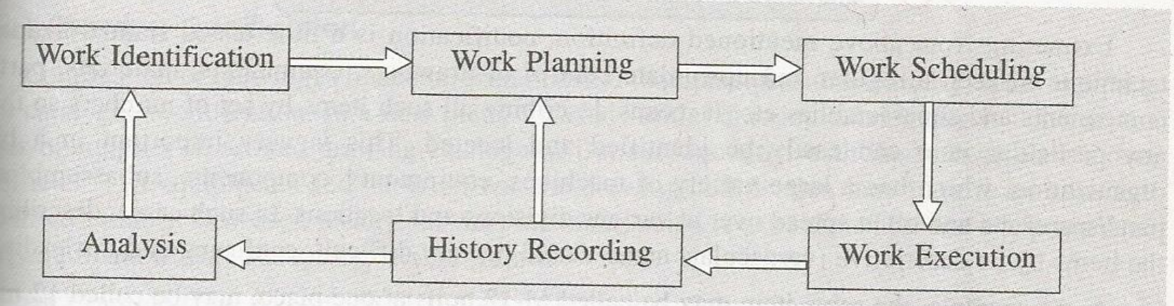
Evaluation, including feedback and follow-up, of trainings (including learning, OJT, other training courses and programmes) is very important as it determine how far the training has been implemented at trainee's plant/ work and how effective the training has been. Post training evaluation includes different feedback forms, action plans, follow-up reports, discussions, interviews, observation on jobs and, occasionally, tests. Evaluation has to be done from following four angles/ sources

1. *Validation*: In many formal training programmes, evaluation starts with validation session, which is normally at the end of session. Effect of validation evaluation depends upon who is responsible for the validation/ evaluation processes and what resources of time, people and money are available for validation/evaluation purposes.
2. *By Trainer(s)*: Trainer(s) evaluate their trainees/ participants either at the end of programme or at the end of individual sessions, to monitor the learning as the programme progresses and to determine how effective the training has been. This may be done in the form of questionnaires about learning levels achieved etc, asking for action plan to reinforce, practice and implement the learning and in other forms, like making models etc. The trainer submits suitable reports to management.
3. *By Trainee/ participants*: Often trainees/ participants are involved to some extent, before or at the start of training, in planning and design of the programme. Although the principal role of the trainee in the programme is to *learn, the learner must be involved in the* evaluation process. This is essential, since without their comments much of the evaluation could not occur. Neither would the new knowledge and skills be implemented nor there be much improvements in subsequent training programmes. This again may be done in form of questionnaires or otherwise.
4. *By Management/ Organization*: This level involves two set of people— Maintenance Dept or concerned production executives and Human Resource (HR) Dept. executives. Often the two do not see the training evaluation from the same angle. HR Dept may not have sufficient resources - people and money - to do post training evaluation and maintenance and concerned production head may not feel much concerned. Good methodical evaluation produces a good reliable data. As such, the post training evaluation should be the responsibility of both. They both should find out
   - To what extent were the identified training needs /objectives achieved by the training programme,
   - To what extent were the learners' objectives achieved?
   - *How successful were the* trainees in implementing their action plans or skills?
   - To what extent were they supported in this by their line managers?
   - To what extent the trainee's action plants or skills helped in achieving Return on Investment (<u>ROI</u>) for the organization, either in terms of identified objectives satisfaction or, wherever possible, a monetary assessment?

These evaluations will give immediate benefits in the form of decision on effective utilization of acquired skill and knowledge, finding the strength and weaknesses of the programme, trainees and trainers and assessing cost-benefit analysis and ROI on training expenditure. It will also guide for future training needs.

3.1. Codification ,Cataloguing and Systems Approach

The proper operation of an industry or production facility requires appropriate maintenance management process, in addition to many others. The **Holistic Approach** to maintenance clearly identifies key maintenance and reliability activities, explains their interactions and how they can be integrated into the whole management process. It enables optimization of the whole maintenance process rather than focusing on individual elements or jobs. A good maintenance management process can be considered as having six phases, as illustrated below—



For proper identification and communication of all these six phases, a 'System Approach' to maintenance is developed which include proper cataloguing, codification and computerization of all the actions /activities, assets and materials related to maintenance of all the departments and work areas and integrating them into one system. The system approach provides an enterprise database that enables to capture and analyze data about current and historical maintenance work. It also helps keep track of the cost of maintaining any piece of equipment, work orders and labor time, and key performance indicators (KPIs) and benchmarks throughout the maintenance operation. CMMS has been discussed in next chapter.

3.2. Definition

The system approach for maintenance starts with codification, classification and cataloguing. They are key value added and waste reduction functions of any activity or logistics in maintenance. Of these three key functions, the primary one is codification.

Codification– Though the term 'Codification' basically means the act or process of reducing to set laws and codes, it may mean slightly differently in different scenarios, such as the act or process of codifying (setting of written rules or principles or laws) for arranging in a systematic order (esp. in industrial or material scenario); act, process, or result of stating the rules and principles applicable in a given logical order to one or more broad areas of life in this form of a code (esp. for medical scenario); the process of collecting and restating the law of a jurisdiction in certain areas, usually by subject, forming a legal code (esp. in legal scenario); the process of standardizing and developing a norm for a language (linguistics scenario) etc. We would be taking the first meaning in this book.

Codification may be considered, in some extent, as classification or categorization, assigning codes (alpha-numeric, numeric or otherwise) for each categorized item or process or procedure for quicker identification in computerized or other documents. Codification manages information that is complex or could be ambiguous or misinterpreted, enabling its efficient, effective and timely use in business decisions. Information is streamlined through the consistent use of methodical and ordered principles and rules. Incorrect codification or no codification can significantly add to waste in terms of time, maintenance efforts, quality and money.

Cataloguing- It is a process of making a list or itemized display, as of titles, course offerings, or articles for exhibition or sale, usually including descriptive information or illustrations etc. Catalogues is a list or booklet or record of all the goods or processes or procedures. It is a complete enumeration of items arranged systematically with descriptive details. Catalogue is slightly different than Manual, which is, normally, a book which gives you practical instructions on how to do something or how to use or work with something, such as a machine.

3.3. Instruction manuals

Instruction manuals or user's guide are commonly used by everyone for a variety of household items, games and other such items. Similarly, in industries, instruction manual is essential technical documents/ literature, which has to be supplied along with or at the time of receipt of any equipment/ system, be it small or big. In industries, many copies of instructional manuals are supplied just before the receipt of equipments/ systems (or along with equipment for smaller items) so that the same can be used right from the time of receipt (including de-packing, storing, installation etc). When newly developed equipment/ system is to be supplied, it is common practice to provide 'Provisional Manual' along with or at the time of receipt and 'Final manuals' (with required modification/ additions done at site during commissioning) are supplied after commissioning. The instruction manual may not be only in the form of a book, but may include many drawings, blown-up views, work cards, wall diagrams, video cassettes, micro-films, Power point or any combinations of these, occasionally both, as printout and electronically. These manuals must provide a permanent record of clear technical information, needed to understand, operate, maintain, dismantle, re-erection, along with any special precautions to be taken etc. For smaller equipments, instruction manual and operating manual may be clubbed together, but for bigger equipments, those are separate, may be in many volumes.

The information needed from such manuals may be of following types—

(*i*) What is the equipment/system/plant and what is it for?

(*ii*) What does it consist of?

(*iii*) How to use it?

(*iv*) How does it work?

(*v*) How do we handle it? How to unpack, install and commission it?

(*vi*) How to maintain it?

(*vii*) What cares, precautions and safety measures are to be taken?

(*viii*) Details of improvements/ changes from specifications,

(*ix*) Who is the supplier, supplier's subcontractors and their credibility; Etc.

Based on the above mentioned requirements, the manuals are, generally, divided into following sections—

(*i*) **Technical data (Specification)**- This includes—

- Supply requirements, performance data (capacity, size, quantity and rate of output, delivery, volume, pressure, speed etc), dimensions, weight and other essential details about specification,
- Environmental factors, special safety and hazard warnings and precautions in connection with the use and handling of that equipment,
- List of data (reports, drawings, manuals/ leaflets of subcontractor's supply of bought- out items,

(*ii*) **Scope of Supply-** Items supplied by supplier/ manufacturer and items/ facilities needed from user/ purchaser.

(*iii*) **Operating Information**- This includes—

- Description of operating modes,
- Operating procedures (normal and emergency), with safety instructions. This also includes pre-operation and post-operation jobs/ cares,
- Operation's fault diagnosis and also necessary minor repairs, adjustments etc,
- Procedures for monitoring and reporting defects/faults/failures etc,

(*iv*) **Technical Descriptions**- This includes—

- Full technical details of equipments/ systems,
- Full technical descriptions of parts/components/sub-assemblies of equipments/ systems,
- Full technical description of supporting equipments/ instruments and facilities (power and drive sources, test gears/rigs, preparatory facilities, like roll changing rigs and installed condition monitoring equipments etc),

All the above mentioned details/ descriptions are supported with necessary drawings, blown-up views etc.

(*v*) **Handling Instructions**- This includes information about—

- Handling, transportation and unpacking, including removal of holding bolts/ fixtures,
- Erection, installation and connection details,
- Testing, commissioning and certifying (acceptance) procedures,
- Relocation, storage or disposal instructions, as applicable,

(*vi*) **Maintenance Instructions**- This includes—

- Various performance checklists and fault diagnosis instructions (daily, weekly, monthly and quarterly etc),
- Procedure about minor repair jobs, adjustments and calibration etc,
- Procedures about repairing and overhauling (dismantling, repairing and changing parts, reassembling) and testing etc. This also informs about need of any special tools/fixtures for dismantling/ assembling.

(*vii*) **Maintenance Schedules**- This includes-

- Periodical oiling and lubrication schedules,
- Preventive maintenance schedules and procedures,
- Calibration, overhaul and repair schedule,

(*viii*) **Spare Part Identification and Requirements**- For smaller equipments, spare parts are mentioned in the same manual, but for the bigger equipments, separate spares part catalogue/ lists are supplied. It generally includes–

- List of commissioning spares and essential spares for running for 2 ~ 3 years,
- Equipment identification drawings,
- Total spares part lists with manufacture's/ supplier's catalogue and drawing numbers; occasionally there are two lists—one for fast wear-out parts and another for rest of the spares,
- Illustrated list of specialized tools, rigs and fixtures etc.

3.4. Maintenance records and documentation

Maintenance records and documents are information/data pertaining ... installation and subsequent maintenance done, condition/ defects observed and rectified, various plans/schedules implemented and also various plans/ schedules for future etc. The terms 'documents' and 'records' have little different meanings.

Documents are written policies (indicating what to do); process descriptions (indicating how it happens or works); work instructions, procedures (indicating how to do), and some blank forms or blank portions. Normally processes lead to procedures. These are mainly used to communicate information. Good documents are clear, concise and user-friendly.

Records are worksheets, registers, log books, forms, charts and labels etc and are used to capture information, activities or results, when performing a procedure. Records are essential for monitoring, tracking, failure identification, revisiting information and references etc.

These records/documents may be in different forms and are stored in a system in such a way that they can be retrieved expeditiously. Some data are of permanent nature, (e.g. instruction manuals, drawings etc) and some are to be continuously updated (e.g. history cards etc).

Recording maintenance information involves money to an organization and it is wasted if recorded information is not analyzed to aid in decision making process to control on maintenance cost, improve availability, reliability and overall efficiency. As such, management has to take a decision on the various records and documents that are to be used and how the actual recording will be done on those.

Some of the necessary maintenance records and documents have already been mentioned in this and previous chapters. There may be some repetition but a few are mentioned here–

(i) History Records/ cards,

(ii) Instruction manual, operating manual, maintenance manual, job manual etc,

(iii) Various catalogues and codes, drawing lists and drawings, SMPs, SOPs and other permanent records,

(iv) Work specification, work order forms, Job cards, work permit forms and other such instruction forms,

(v) Inspection schedule, lubrication schedule, PM schedules etc,

(vi) Performance reports, job completion reports and other feedback reports,

(vii) Spares catalogue, spare cards, procurement requisitions and storage records etc,

(viii) Various condition monitoring and fault diagnosis (repetitive/otherwise) reports,

(ix) Failure analysis and failure pattern reports; Repetitive failure and MTBF analysis, etc

(x) Production Delay/downtime report and other defect/ reports,

(xi) Ratio of planned work vis-à-vis unplanned work; preventive work vis-à-vis corrective work;

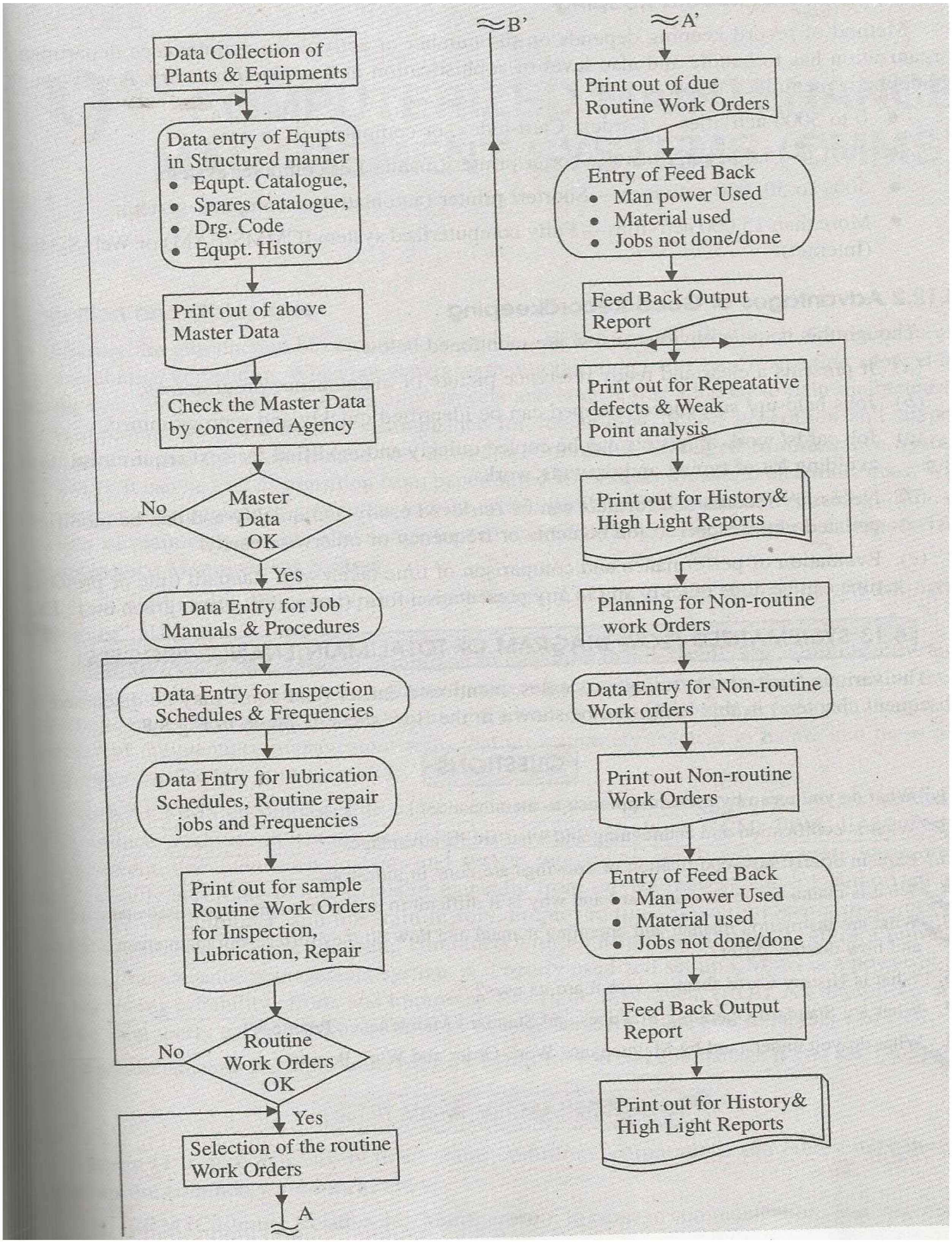
(xii) Maintenance requirement comparison between individual assets, between types of assets and between groups of assets, etc

(xiii) Indicators or reliability of equipments and subassemblies of different manufacturers,

(xiv) Performance details of individuals, both by names and by trades,

(xv) Indicators on possible standardization and variety reduction,

(xvi) Cost and Budget data; etc.



The figure 3.1 shows the systematic flow diagram of maintenance function.

3.5. Methods of Record keeping

Method of record keeping depends on the number of activities a maintenance departm[ent] organization has to handle and also level of sophistication in that plant/ industry. A very rough guideline is mentioned below—

- 0 to 5000 activities— Cardex, Card-index, or computers (if in use),
- 1001 to 15,000 activities— Shorter/printer (manual) or computer system,
- 5000 to 50, 000 activities— Shorter/ printer (automatic) or computer system,
- More than 15,000 activities— Fully computerized system (CMMS/EAM) or Web-System (Internet).

3.5.1 Advantages of Record keeping

Though this is quite obvious, a few are mentioned below

(*a*) It presents a clear and ready reference picture of maintenance programmes,

(*b*) Jobs held-up/ suspended/ stopped can be identified quickly and reprogrammed,

(c) Job cards/ work orders etc can be copied quickly and modified for next requirement, thus avoiding lot of typing and drawing works,

(*d*) Necessary records and formats can be retrieved easily and quickly and can be modified/ updated with respect to job contents or frequency or otherwise easily.

(*e*) Evaluation of performance and comparison of time taken with standard time or previous time can be done quickly and in any presentation form (text, table, chart, graph etc) ; Etc.

3.6. Failure Mode and Effect Analysis

The Failure Modes and Effects Analysis (FMEA), also known as Failure Modes, Effects, and Criticality Analysis (FMECA), is a systematic method by which potential failures of a product or process design are identified, analysed and documented. Once identified, the effects of these failures on performance and safety are recognised, and appropriate actions are taken to eliminate or minimise the effects of these failures. An FMEA is a crucial reliability tool that helps avoid costs incurred from product failure and liability.

Project activities in which the FMEA is useful:

☛ Throughout the entire design process but is especially important during the concept development phase to minimise cost of design changes

☛ Testing

☛ Each design revision or update

Other tools that are useful in conjunction with the FMEA:

☛ Brainstorming

☛ Fault Tree Analysis (FTA)

☛ Risk Management

3.6.1.Introduction

The FMEA process is an on-going, bottom-up approach typically utilised in three areas of product realization and use, namely design, manufacturing and service. A design FMEA examines potential product failures and the effects of these failures to the end user, while a manufacturing or process FMEA examines the variables that can affect the quality of a process. The aim of a service FMEA is to prevent the misuse or misrepresentation of the tools and materials used in servicing a product.

There is not a single, correct method for conducting an FMEA, however the automotive industry and the U.S. Department of Defense (Mil-Std-1629A) have standardised procedures/processes within their respective realms. Companies who have adopted the FMEA process will typically adapt and apply the process to meet their specific needs.

Typically, the main elements of the FMEA are:

• The ***failure mode*** that describes the way in which a design fails to perform as intended or according to specification;

• The ***effect*** or the impact on the customer resulting from the failure mode; and

• the ***cause***(s) or means by which an element of the design resulted in a failure mode.

It is important to note that the relationship between and within failure modes, effects and causes can be complex. For example, a single cause may have multiple effects or a combination of causes could result in a single effect. To add further complexity, causes can result from other causes, and effects can propagate other effects.

Who Should Complete the FMEA

As with most aspects of design, the best approach to completing an FMEA is with crossfunctional input. The participants should be drawn from all branches of the organisation including purchasing, marketing, human factors, safety, reliability, manufacturing and any other appropriate disciplines. To complete the FMEA most efficiently, the designer should conduct the FMEA concurrently with the design process then meet with the crossfunctional group to discuss and obtain consensus on the failure modes identified and the ratings assigned.

Relationship between Reliability and Safety

Designers often focus on the safety element of a product, erroneously assuming that this directly translates into a reliable product. If a high safety factor is used in product design, the result may be an overdesigned, unreliable product that may not necessarily be able to function as intended. Consider the aerospace industry that requires safe and reliable products that, by the nature of their function, cannot be overdesigned.

3.6.2.Application of the Design FMEA

As mentioned previously, there is not one single FMEA method. The following ten steps provide a basic approach that can be followed in order to conduct a basic FMEA. An example of a table lamp is used to help illustrate the process. Attachment 3.2 provides a sample format for completing an FMEA.

Step 1: Identify components and associated functions

The first step of an FMEA is to identify all of the components to be evaluated. This may include all of the parts that constitute the product or, if the focus is only part of a product, the parts that make up the applicable sub-assemblies. The function(s) of each part within in the product are briefly described.

Example:

Part Description	**Part Function**
Light bulb	Provides x ± y lux of illumination
Plug	2 wire electrical plug
Cord	Conducts power from outlet to lamp

Step 2: Identify failure modes

The potential failure mode(s) for each part are identified. Failure modes can include but are not limited to:

- complete failures
- intermittent failures
- partial failures
- failures over time
- incorrect operation
- premature operation
- failure to cease functioning at allotted time
- failure to function at allotted time

It is important to consider that a part may have more than one mode of failure.

Example:

Part Description	**Failure Mode**
Cord	Short circuit
	Open circuit
	Insulation failure

Step 3: Identify effects of the failure modes

For each failure mode identified, the consequences or effects on product, property and people are listed. These effects are best described as seen though the eyes of the customer.

Example:

Failure Mode	**Failure Effects**
Short	No light/ Electrical fire/ Blown fuse
Insulation fail	Shock/injury hazard

Step 4: Determine severity of the failure mode

The severity or criticality rating indicates how significant of an impact the effect is on the customer. Severity can range from insignificant to risk of fatality. Depending on the FMEA method employed, severity is usually given either a numeric rating or a coded rating. The advantage of a numeric rating is the ability to be able to calculate the Risk Priority Number (RPN) (see Step 9). Severity ratings can be customised as long as they are well defined, documented and applied consistently. Attachment 3.3 provides examples of severity ratings.

Example:

Failure Effects	**Severity**
No light	8-Very high
Shock/injury hazard	10-Hazardous-no warning

Step 5: Identify cause(s) of the failure mode
For each mode of failure, causes are identified. These causes can be design deficiencies that result in performance failures, or induce manufacturing errors.

Example:

Failure Mode	**Cause**
Insulation failure	Cord pinched

Step 6: Determine probability of occurrence
This step involves determining or estimating the probability that a given cause or failure mode will occur. The probability of occurrence can be determined from field data or history of previous products. If this information is not available, a subjective rating is made based on the experience and knowledge of the cross-functional experts. Two of the methods used for rating the probability of occurrence are a numeric ranking and a relative probability of failure. Attachment C provides an example of a numeric ranking. As with a numeric severity rating, a numeric probability of occurrence rating can be used in calculating the RPN. If a relative scale is used, each failure mode is judged against the other failure modes. High, moderate, low and unlikely are ratings that can be used. As with severity ratings, probability of occurrence ratings can be customised if they are well defined, documented and used consistently.

Example:

Cause	**Prob. Of Occurrence**
Cord pinched	2-Low (few failures)

Step 7: Identify controls
Identify the controls that are currently in place that either prevent or detect the cause of the failure mode. Preventative controls either eliminate the cause or reduce the rate of occurrence. Controls that detect the cause allow for corrective action while controls that detect failure allow for interception of the product before it reaches subsequent operations or the customer.

Example:

Cause	**Current controls**
Cord pinched	Review CSA standards Warranty data from preceding products

Step 8: Determine effectiveness of current controls
The control effectiveness rating estimates how well the cause or failure mode can be prevented or detected. If more than one control is used for a given cause or failure mode, an effectiveness rating is given to the group of controls. Control effectiveness ratings can be customised provided the guidelines as previously outlined for severity and occurrence are followed. Attachment 3.5 provides example ratings.
Example:

Current controls	**Control effectiveness**
Review CSA standards Warranty data from preceding products	5-Moderate

Step 9: Calculate Risk Priority Number (RPN)

The RPN is an optional step that can be used to help prioritise failure modes for action. It is calculated for each failure mode by multiplying the numerical ratings of the severity, probability of occurrence and the probability of detection (effectiveness of detection controls) (RPN=S x O x D). In general, the failure modes that have the greatest RPN receive priority for corrective action. The RPN should not firmly dictate priority as some failure modes may warrant immediate action although their RPN may not rank among the highest.

Step 10: Determine actions to reduce risk of failure mode

Taking action to reduce risk of failure is the most crucial aspect of an FMEA. The FMEA should be reviewed to determine where corrective action should be taken, as well as what action should be taken and when. Some failure modes will be identified for immediate action while others will be scheduled with targeted completion dates. Conversely, some failure modes may not receive any attention or be scheduled to be reassessed at a later date.

-Actions to resolve failures may take the form of design improvements, changes in component selection, the inclusion of redundancy in the design, or incorporation design for safety aspects. Regardless of the recommended action, all should be documented, assigned and followed to completion.

The following attachments are given to guide the filling of FMEA form as follows :

<u>Attachment 3.2</u>

FMEA Form

Failure Modes & Effect Analysis

Product: ____________________ Completed by: ____________________

Date Completed: ____________________ Revision No.: ____________________

Item/Part No.	Part Description	Part Function	Failure Mode	Failure Effects	Severity	Causes	Prob. of Occurrence	Current Controls	Control Effectiveness	RPN	Recommended Actions
Step 1			Step 2	Step 3	S4	Step 5	S6	Step 7	S8	S9	Step 10

Attachment 3.3

Severity Ratings

Example 1

Critical	Safety hazard. Causes or can cause injury or death.
Major	Requires immediate attention. System is non-operational.
Minor	Requires attention in the near future or as soon as possible. System performance is degraded but operation can continue.
Insignificant	No immediate effect on system performance.

Example 2

1	None	Effect will be undetected by customer or regarded as insignificant.
2	Very minor	A few customers may notice effect and may be annoyed.
3	Minor	Average customer will notice effect.
4	Very low	Effect recognised by most customers.
5	Low	Product is operable, however performance of comfort or convenience items is reduced.
6	Moderate	Products operable, however comfort or convenience items are inoperable.
7	High	Product is operable at reduced level of performance. High degree of customer dissatisfaction.
8	Very high	Loss of primary function renders product inoperable. Intolerable effects apparent to customer. May violate non-safety related governmental regulations. Repairs lengthy and costly.
9	Hazardous – with warning	Unsafe operation with warning before failure or non-conformance with government regulations. Risk of injury or fatality.
10	Hazardous – without warning	Unsafe operation without warning before failure or non-conformance with government regulations. Risk of injury or fatality.

Attachment 3.4

Probability of Occurrence Ratings[1]

1	Unlikely	≤ 1 in 1.5 million (≤ .0001%)
2	Low (few failures)	1 in 150, 000 (≤ .001%)
3		1 in 15, 000 (≤ .01%)
4	Moderate (occasional failures)	1 in 2,000 (0.05%)
5		1 in 400 (0.25%)
6		1 in 80 (1.25%)
7	High (repeated failure)	1 in 20 (5%)
8		1 in 8 (12.5%)
9	Very high (relatively consistent failure)	1 in 3 (33%)
10		≥1 in 2 (50%)

Note: if a failure rate falls between two values, use the lower rate of occurrence. For example, if failure is 1 in 5, use a rating of 8.

Attachment 3.5

Control Effectiveness Ratings

1	Excellent; control mechanisms are foolproof.
2	Very high; some question about effectiveness of control.
3	High; unlikely cause or failure will go undetected.
4	Moderately high
5	Moderate; control effective under certain conditions.
6	Low
7	Very low
8	Poor; control is insufficient and causes or failures extremely unlikely to be prevented or detected.
9	Very poor
10	Ineffective; causes or failures almost certainly not prevented or detected.

3.6.3. Benefits of conducting FMEA

- Increase customer satisfaction by improving safety and reliability and mitigating the adverse effect of problems before they reach the customer.
- Improve development efficiency in terms of time and cost by solving reliability and manufacturing problems during design stages. The more we move in the development stage, the more rectifying problems becomes more expensive.
- Document, prioritize, and communicate potential risks by making issues explicit to FMEA team members, management, and customers.
- Help reduce the chances of catastrophic failure that can result in injuries and/or adverse effect on the environment.
- Optimize maintenance efforts by suggesting applicable and effective preventive maintenance tasks for potential failure modes.

3.6.4. FMEA Applications

Although FMEA started in the aerospace and automobile industry, it found application in various areas, such as the healthcare industry. With patient safety a priority in healthcare, the technique has seen application in healthcare. Medical devices and medical services such as drug delivery have added FMEA as a means to understand the risks not considered by individual design and process personnel. FMEA allows a team of persons to review the design at key points in product development or medical service and make comments and changes to the design of the product or process well in advance of actually experiencing the failure. The Food and Drug Administration (FDA) has recognized FMEA as a design verification method for Drugs and Medical Devices. Hospitals also use FMEA to prevent the possibility of process errors and mistakes leading to incorrect surgery or medication administration errors. FMEA is now an integral part of many hospitals' continuous improvement program.

3.7. Spare parts Management

Spare parts Management plays an important role in achieving the desired plant availability at an optimum cost. Presently, the industries are going for capital intensive, mass production oriented and sophisticated technology. The downtime for such plant and machinery is prohibitively expensive. It has been observed in many industries that the non-availability of spare parts, as and when required for repairs, contributes to as much as 50% of the total down time. Also, the cost of spare parts is more than 50% of the total maintenance cost in the industry. It is a paradox to note that the maintenance department is complaining of the non-availability of the spare parts to meet their requirement and finance department is facing the problem of increasing locked up capital in spare parts inventory. This amply signifies the vital importance of spare parts management in any organisation.

The unique problems faced by the organisation in controlling/managing the spare parts are as follows. Firstly, there is an element of uncertainty as to when a part is required and also the quantity of its requirement. This is due to the fact that the failure of a component, either due to wearing out or due to other reasons, cannot be predicted accurately.
Secondly, spare parts are not that easily available in the market as they are not fast moving items. The original equipment manufacturer has to supply the spares in most of the cases. New models are introduced to incorporate the design improvements and old models are phased out. Hence the spares for old models are not readily available. Particularly, this is more so in case of imported equipment as the design changes are taking place faster in the developed countries.
Thirdly, the number and variety of spare parts are too large making the close control more and more tedious. For instance, the number of items of spares in a medium scale engineering industry may be around 15,000 and that in a large scale chemical industry may be around 100,000. Fourthly, there is a tendency from the stage of purchase of the equipment to the stage of the use of the spare parts, to requisition spare parts more number than that are actually required and accumulation of spares takes place.
Finally, the rate of consumption of spare parts for some are very high and for some are very low. These problems are to be faced by systematic spare parts management.

The objective of spare parts management is to ensure the availability of spares for maintenance and repairs of the plant and machinery as and when required at an optimum cost. Also, the spares should be of right quality. There are many actions required to ensure the spare parts management effective.

There is a need for systematic actions while managing spare parts as given below:

a. Identification of spare parts
b. Forecasting of spare parts requirement
c. Inventory analyses
d. Formulation of selective control policies for various categories
e. Development of inventory control systems
f. Stocking policies for capital & insurance spares
g. Stocking policies for rotable spares or sub- assemblies
h. Replacement policies for spare parts
i. Spare parts inspection

j. Indigenisation of spares
k. Reconditioning of spare parts
l. Establishment of spare parts bank
m. Computer applications for spare parts management.

Every organisation should proceed systematically and establish an effective spare parts management system. Codification helps the organisation minimizing duplication of spare parts stocking thereby reducing inventory, aids the accounting process and facilitates the computerisation of spare parts control systems. The inventory analyses carried out on the basis of different characteristics of the spare parts, such as annual consumption value, criticality, lead time, unit cost and the frequency of use, help the company in establishing suitable policies for selective control. This also helps in focusing our efforts on real problem areas.

A good inventory control system will help systemizing the ordering procedure and also achieving an optimum level of inventory. In addition, selectively efforts should be made to evolve optimum replacement policies for selected spare parts, for which cost of down time and cost of replacement are very high. So, we have to identify such spare parts and carry out the exercise for evolving optimum replacement policies.

For the spare parts which are very expensive and those which are to be imported, it is essential that the useful life for such spares is extended by appropriate applications of reconditioning and repair techniques. Also, efforts should be made to indigenise the spare parts in view of the hard-to-get foreign exchange involvement. Also, for similar industries establishing of spare parts bank goes a long way in reducing the total inventory holding of the expensive spare parts and also reduces the stock holding cost. For different industries, it will be helpful to establish spare parts banks and a suitable information system for the exchange of spares. Lately, the application of computers for the processing of spare parts information and operating an effective spare parts control system will be very helpful for the organisation and will ensure timely actions for an efficient and effective spare parts management.

3.7.1. **IDENTIFICATION OF SPARE PARTS**

When a spare part is required to put back in operation an equipment which is under breakdown, it becomes necessary to identify the part for getting the same issued from the store or for purchasing the same from the vendor. While identifying it becomes essential to give the complete description including the size and type of the spare to draw from the stores and it becomes essential for all concerned ie., the maintenance personnel and stores personnel are aware of such description. If it is the vendor, he may not be satisfied with the description and he may also require the manufacturer's part number.

It is a cumbersome and time consuming task during every transaction to identify a spare part by its description and manufacturer's part number accompanied by the parent equipment's name, make and model designation. Therefore, it is essential to give a numerical name or code to each spare part. This process of giving code to each spare part is called codification. Since, the range of spares used in any organisation is too large and there are quite a few spares meant for specific equipment, it is always preferred to use codes which are significant ie., from the code number one will be able to find out

- the equipment type, make & model
- the type/class of the spare-part
- the size (in some cases)

If the spare part code is to incorporate the equipment type etc., then the codification of equipment becomes a prerequisite for spare part codification.
The number of digits required for spare part code depends on the actual requirement ie., the range of equipment in use and the types and number of spare parts in the organisation. It is very common to come across 9 to 16 digit codes for spare parts. For instance, a 10-digit code may signify,
1st digit - imported or indigenous
2nd, 3rd & 4th digits - machine type, make & model
5th, 6th & 7th digits - spare-part class
8th, 9th & 10th digits - size or serial number.
By classifying and codifying all the spare parts, it becomes easy to minimize the duplication of spare parts thereby effecting reduction in the inventory. Codification also helps easy accounting and computerisation in addition to easier communication between concerned parties.
In addition to codifying the spare part, it will be of immense benefit to codify the location of spare parts. Stock location number helps the stores personnel to locate the part and issue the same as and when the same is requisitioned. Also the stock verification and upkeep programme becomes less and less cumbersome.
After codifying the spare parts and assigning stock location numbers, all the users should be made aware of and should be supplied with the relevant codes and stock location numbers in the form of a spare parts catalogue.
The spare parts catalogue should contain the following information:

- Spare parts codification plan
- Spare part code
- Spare part description
- Drawing number
- Manufacturer's code & part number
- Stock location number.

The spare parts catalogue may be produced in sufficient copies so as to make available for all the users such as the maintenance personnel, stores personnel and purchase personnel. This is a very important aspect often neglected in the organisation.
The next step in identification of spare parts is to put an identification tag or mark with the code to enable the stores personnel identify during the time of issue. If sufficient care is not taken to incorporate the code, a lot of time is spent in locating the part and that time is actually added to the down-time which is really very expensive in case of vital spare parts. There are a variety of stickers which are scratch-proof, water-proof and temperature-proof available in the market. Efforts should be made by the organisations to make use of such identification tags and it will go a long way in reducing the downtime.

3.7.2. **INVENTORY ANALYSIS AND SELECTIVE CONTROL**

For the successful spare parts management, it is essential to analyze the spare parts inventory based on various characteristics such as the frequency of issues, the annual consumption value, the criticality, the lead time and the unit price. This is essential as it would not be possible to exercise the same type of control for all items and it may not really be effective. Inventory analysis aids selection of policies for selective control.
Commonly used inventory analyses are:
(1) FSN Analysis
(2) ABC Analysis

(3) VED Analysis
(4) SDE Analysis
(5) HML Analysis

FSN Analysis:

Classification based on Frequency of Issues/Use:-

F, S & N stand for Fast moving, Slow moving and Non-moving items. This form of classification identifies the items frequently issued, less frequently issued for use and the items which are not issued for longer period, say, 2 years. For instance, the items can be classified as follows:

Fast Moving (F) = Items that are frequently issued say more than once a month.
Slow Moving (S) = Items that are issued less than once a month.
Non-Moving (N) = Items that are not issued\used for more than 2 years.

This classification helps spare parts management in establishing most suitable stores layout by locating all the fast moving items near the dispensing window to reduce the handling efforts. Also, attention of the management is focused on the Non-Moving items to enable decision as to whether they are required in the future or they can be salvaged. Experience shows that many industries which are more than 15 years old have more than 50% of the stock as non-moving spares.

Even if a few of them are disposed off and the locked up capital is made available, it will make available additional working capital to the organisation. Action for disposal should be taken based on the value of each item of spare.

SDE Analysis:-

Classification based on the lead time:

This classification is carried out based on the lead time required to procure the spare part. The classification is as follows:

Scarce (S) : Items which are imported and those items which require more than 6 months' lead time.

Difficult (D) : Items which require more than a fortnight but less than 6 months' lead time.

Easily available (E) : Items which are easily available ie., less than a fortnights' lead time.

This classification helps in reducing the lead time required at least in case of vital items. Ultimately, this will reduce stock-out costs in case of stock-outs. A comprehensive analysis may ultimately bring down lead time for more & more number of items. This will also result in streamlining the purchase and receiving systems and procedures.

VED Analysis:-

Classification Based On Criticality:

Several factors contribute to the criticality of a spare part. If a spare is for a machine on which many other processes depend, it could be of very vital importance. Also if a spare is, say, an imported component for which procurement lead time could be very high its non- availability may mean a heavy loss. Similarly spares required for fighter aircraft at the time of war could be of great value in terms of fighting capability. In general, criticality of a spare part can be determined from the production downtime loss, due to spare being not available when required.

Based on criticality, spare parts are conventionally classified into three classes, viz. vital, essential and desirable.

VITAL (V) : A spare part will be termed vital, if on account of its non-availability there will be very high loss due to production downtime and/or a very high cost will be involved if the part is procured on emergency basis. In a process industry, most spare parts for the bottleneck machine or process will be of vital nature. For example, bearings for a kiln in a cement plant will be considered vital.

ESSENTIAL (E) : A spare part will be considered essential if, due to its non-availability, moderate loss is incurred. For example, bearings for motors of auxiliary pumps will be classified as essential.

DESIRABLE (D) : A spare part will be desirable if the production loss is not very significant due to its non-availability. Most of the parts will fall under this category. For example, gaskets for piping connection.

The VED analysis helps in focusing the attention of the management on vital items and ensuring their availability by frequent review and reporting. Thus, the downtime losses could be minimized to a considerable extent.

ABC Analysis:-

Classification Based on Consumption:

Another method of classifying spares is on the basis of **annual consumption value.** As it is true for any inventory situation, Pareto's principle can be applied to classify maintenance spares based on consumption value.

Pareto principle: The significant items in a given group normally constitute a small portion of the total items in a group and the majority of the items in the total will, in aggregate, be of minor significance.

This way of classification is known as ABC classification.

CLASS A: 10% of total spares contributing towards 70% of total consumption value.

CLASS B: 20% of total spares which account for about 20% of total consumption value.

CLASS C: 70% of total spares which account for only 10% of total consumption value.

In a specific spares control system, it is quite possible that in a single year, many spares would not have been consumed at all. In such cases, it is better to perform ABC analysis on longer consumption period data, say 3 years. Then only spares will not be left out in this classification.

Policy for 'A' items

* Maximum control
* Value Analysis
* More than one supplier
* Control by top executives.

Policy for 'B' items

* Minimum control
* Bulk Orders
* More items from same supplier.

HML Analysis:-

Classification based on unit price:

This classification is as follows:

High Cost (H) : Item whose unit value is very high, say, Rs.1000/- and above.

Medium Cost (M) : Item whose unit value is of medium value, say, above Rs.100/- but less than Rs.1000/-.

Low Cost (L) : Item whose unit value is low, say, less than Rs.100/-.

This type of analysis helps in exercising control at the shop floor level ie, at the use point. Proper authorisation should be there for replacing a high value spare. Efforts may be necessary to find out the means for prolonging the life of high value parts through reconditioning and repair. Also, it may be worthwhile to apply the techniques of value analysis to find out a less expensive substitute.

Some other Classifications based on other characteristics:

A) Capital Spares:

These are vital spares for critical equipment. The stock-out cost for such spares is very high and the unit cost also is very high. The number of items consumed during the life time of the equipment may be 1 or 2 or 3. Hence, the decision has to be made as to the number of items to be stored.

B) Insurance Spares:

An insurance items is a spare part that will be used to replace a failed identical part in an operating equipment whose penalty cost for downtime is very high. Hence, by definition, it is an insurance against such failures for which the down time costs are very high. They do not become obsolete until the parent equipment is retired from service no matter if they do not move for many years.

C) Overhaul spares:

Spare parts which must be replaced every time the equipment is dissembled and re-assembled.

D) Wear and Tear Spares:

Spare parts which have regular wear and tear in the course of operation of the equipment and need to be replaced after definite number of hours of equipment operation.

E) Consumable spares:

These are regularly used items such as fasteners, seals, bearings, etc. These are to be stored by the materials department.

4.1. An Introduction to Total Productive Maintenance (TPM)

In today's industrial scenario huge losses/wastage occur in the manufacturing shop floor. This waste is due to operators, maintenance personal, process, tooling problems and non-availability of components in time etc. Other forms of waste includes idle machines, idle manpower, break down machine, rejected parts etc are all examples of waste. The quality related waste are of significant importance as they matter the company in terms of time, material and the hard earned reputation of the company. There are also other invisible wastes like operating the machines below the rated speed, start up loss, break down of the machines and bottle necks in process. Zero oriented concepts such as zero tolerance for waste, defects, break down and zero accidents are becoming a pre-requisite in the manufacturing and assembly industry. In this situation, a revolutionary concept of TPM has been adopted in many industries across the world to address the above said problems. This deals in length about this TPM.

4.2.What is Total Productive Maintenance (TPM)?

It can be considered as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance program, which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM program is to markedly increase production while, at the same time, increasing employee morale and job satisfaction.

TPM brings maintenance into focus as a necessary and vitally important part of the business. It is no longer regarded as a non-profit activity. Down time for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process. The goal is to hold emergency and unscheduled maintenance to a minimum.

4.3. TPM - History:

TPM is an innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from USA. Nippondenso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippondenso, maintenance became a problem, as more maintenance personnel were required. So the management decided that the operators would carry out the routine maintenance of equipment. (This is Autonomous maintenance, one of the features of TPM). Maintenance group took up only essential maintenance works.

Thus Nippondenso, which already followed preventive maintenance, also added Autonomous maintenance done by production operators. The maintenance crew went in the equipment modification for improving reliability. The modifications were made or incorporated in new equipment. This lead to maintenance prevention. Thus *preventive maintenance* along with *Maintenance prevention* and *Maintainability Improvement* gave birth to ***Productive maintenance***. The aim of productive maintenance was to maximize plant and equipment effectiveness.

By then Nippon Denso had made quality circles, involving the employees participation. Thus all employees took part in implementing Productive maintenance. Based on these developments Nippondenso was awarded the distinguished plant prize for developing and implementing TPM, by the *Japanese Institute of Plant Engineers* (JIPE). Thus Nippondenso of the Toyota group became the first company to obtain the TPM certification.

4.4.Why TPM?

TPM was introduced to achieve the following objectives. The important ones are listed below.

- Avoid wastage in a quickly changing economic environment.
- Producing goods without reducing product quality.
- Reduce cost.
- Produce a low batch quantity at the earliest possible time.
- Goods send to the customers must be non-defective.

4.5.Similarities and differences between TQM and TPM:

The TPM program closely resembles the popular Total Quality Management (TQM) program. Many of the tools such as employee empowerment, benchmarking, documentation, etc. used in TQM are used to implement and optimize TPM. Following are the similarities between the two.

1. Total commitment to the program by upper level management is required in both programmes.
2. Employees must be empowered to initiate corrective action, and
3. A long-range outlook must be accepted as TPM may take a year or more to implement and is an on-going process. Changes in employee mind-set toward their job responsibilities must take place as well.

The *differences* between TQM and TPM are summarized below.

Category	**TQM**	**TPM**
Object	Quality (Output and effects)	Equipment (Input and cause)
Mains of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes.

4.6.TPM Targets:

1. Obtain Minimum 90% OEE (Overall Equipment Effectiveness)
2. Run the machines even during lunch. (Lunch is for operators and not for machines!)
3. Operate in a manner, so that there are no customer complaints.
4. Reduce the manufacturing cost by 30%.
5. Achieve 100% success in delivering the goods as required by the customer.
6. Maintain an accident free environment.
7. Increase the suggestions from the workers/employees by 3 times. Develop Multi-skilled and flexible workers.

Motives of TPM	1. Adoption of life cycle approach for improving the overall performance of production equipment. 2. Improving productivity by highly motivated workers, which is achieved by job enlargement. 3. The use of voluntary small group activities for identifying the cause of failure, possible plant and equipment modifications.
Uniqueness of TPM	The major difference between TPM and other concepts is that the operators are also made to involve in the maintenance process. The concept of *"I (Production operators) Operate, You (Maintenance department) fix"* is not followed.
TPM Objectives	1. Achieve Zero Defects, Zero Breakdown and Zero accidents in all functional areas of the organization. 2. Involve people in all levels of organization. 3. Form different teams to reduce defects and self-Maintenance.
Direct benefits of TPM	1. Increase in productivity and OEE (Overall Equipment Efficiency) 2. Reduction in customer complaints. 3. Reduction in the manufacturing cost by 30%. 4. Satisfying the customers needs by 100 % (Delivering the right quantity at the right time, in the required quality.) 5. Reduced accidents.
Indirect benefits of TPM	1. Higher confidence level among the employees. 2. A clean, neat and attractive work place. 3. Favourable change in the attitude of the operators. 4. Achieve goals by working as team. 5. Horizontal deployment of a new concept in all areas of the organization. 6. Sharing knowledge and experience. 7. The workers get a feeling of owning the machine.

4.7.Stages in TPM implementation:

Step A - PREPARATORY STAGE:

STEP 1 - Announcement by Management to all about TPM introduction in the organization:

Proper understanding, commitment and active involvement of the top management in needed for this step. Senior management should have awareness programmes, after which announcement is made. Decision the implement TPM is published in the in house magazine, displayed on the notice boards and a letter informing the same is send to suppliers and customers.

STEP 2 - Initial education and propaganda for TPM:

Training is to be done based on the need. Some need intensive training and some just awareness training based on the knowledge of employees in maintenance.

STEP 3 - Setting up TPM and departmental committees:

TPM includes improvement, autonomous maintenance, quality maintenance etc., as part of it. When committees are set up it should take care of all those needs.

STEP 4 - Establishing the TPM working system and target:

Each area/work station is benchmarked and target is fixed up for achievement.

STEP 5 - A master plan for institutionalizing:

Next step is implementation leading to institutionalizing wherein TPM becomes an organizational culture. Achieving PM award is the proof of reaching a satisfactory level.

STEP B - INTRODUCTION STAGE

A small get-together, which includes our suppliers and customer's participation, is conducted. Suppliers as they should know that we want quality supply from them. People from related companies and affiliated companies who can be our customers, sisters concerns etc. are also invited. Some may learn from us and some can help us and customers will get the message from us that we care for quality output, cost and keeping to delivery schedules.

STAGE C - IMPLEMENTATION

In this stage eight activities are carried which are called eight pillars in the development of TPM activity. Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administration and are for control of safety, sanitation as working environment.

STAGE D - INSTITUTIONALISING STAGE

By now the TPM implementation activities would have reached maturity stage. Now is the time to apply for award.

4.8.TPM Organization Structure:

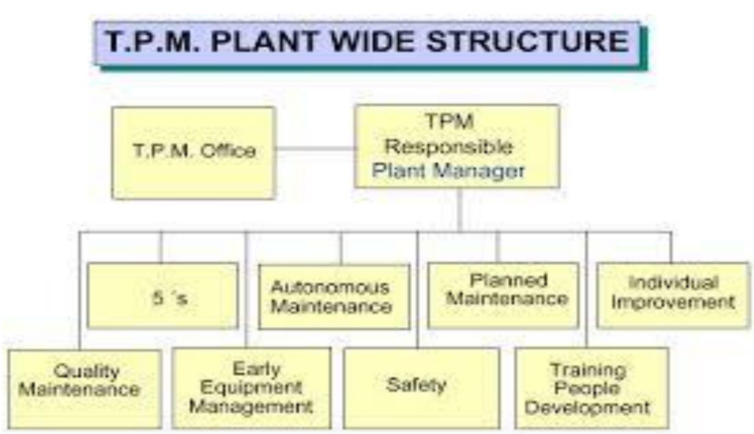


Fig-4.1

4.9. OEE (Overall Equipment Efficiency):

The basic measure associated with Total Productive Maintenance (TPM) is the OEE. This OEE highlights the actual "Hidden capacity" in an organization. OEE is *not* an exclusive measure of how well the maintenance department works. The design and installation of equipment as well as how it is operated and maintained affect the OEE. It measures both efficiency (doing things right) and effectiveness (doing the right things) with the equipment. It incorporates three basic indicators of equipment performance and reliability. Thus OEE is a function of the three factors mentioned below.

1. Availability or uptime (downtime: planned and unplanned, tool change, tool service, job change etc.)
2. Performance efficiency (actual vs. design capacity)
3. Rate of quality output (Defects and rework)

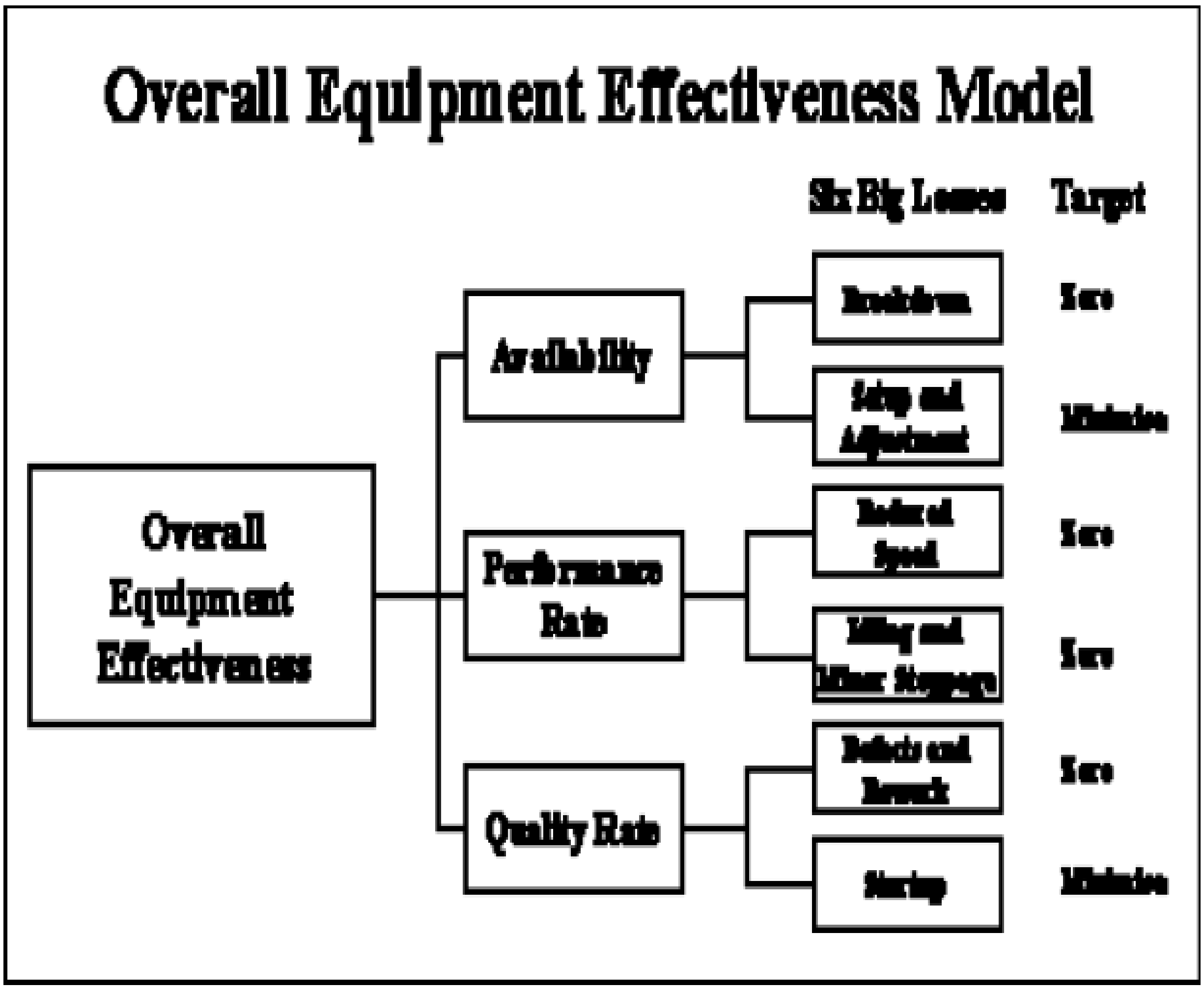


Fig.- 4.2

Thus ***OEE = A x PE x Q***

A - Availability of the machine**.** Availability is proportion of time machine is actually available out of time it should be available.

Availability = (Planned production time – unscheduled downtime)/ Planned production time

Production time = Planned production time – Downtime

Gross available hours for production include 365 days per year, 24 hours per day, 7 days per week. However this is an ideal condition. Planned downtime includes vacation, holidays, and not enough loads. Availability losses include equipment failures and changeovers indicating situations when the line is not running although it is expected to run.

PE - Performance Efficiency**.** The second category of OEE is performance. The formula can be expressed in this way:

Performance (Speed) = (Cycle time x Number of products processed)/ Production time

Net production time is the time during which the products are actually produced. Speed losses, small stops, idling, and empty positions in the line indicate that the line is running, but it is not providing the quantity it should.

Q - Refers to quality rate. Which is percentage of good parts out of total produced. Sometimes called "yield". Quality losses refer to the situation when the line is producing, but there are quality losses due to in-progress production and warm up rejects. We can express a formula for quality like this:

Quality (Yield) = (Number of products processed – Number of products rejected) (Number of products processed)

A simple example on how OEE is calculated is shown below.

- Running 70 percent of the time (in a 24-hour day)
- Operating at 72 percent of design capacity (flow, cycles, units per hour)
- Producing quality output 99 percent of the time

When the three factors are considered together (70% availability x 72% efficiency x 99% quality), the result is an overall equipment effectiveness rating of 49.9 percent.

4.10. Pillars of TPM:

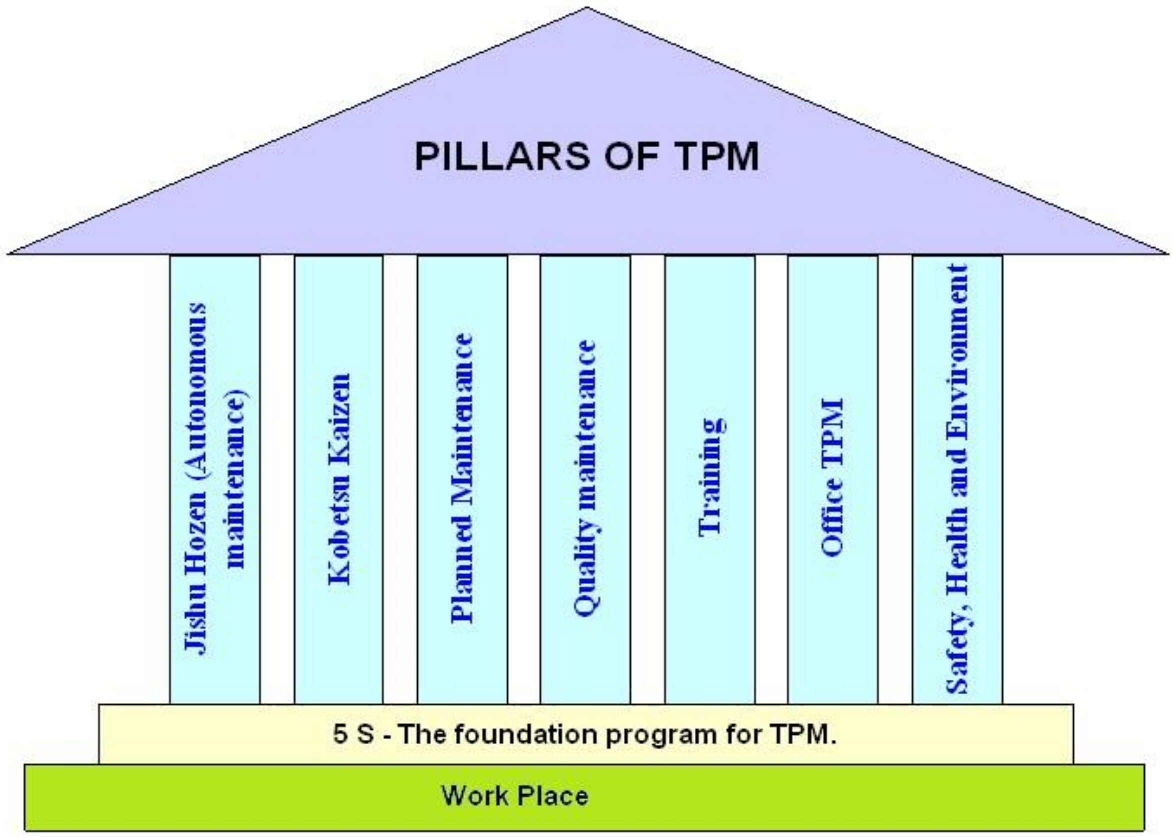


Fig-4.3

4.10.1. PILLAR 1 - 5S:

TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work place involving the employees with a commitment to sincerely implement and practice house keeping. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. 5s is a foundation program before the implementation of TPM, hence in the above figure, 5s has been positioned in the base. **If this 5S is not taken up seriously, then it leads to 5D. They are Delays, Defects, Dissatisfied customers, declining profits and Demoralized employees.** Following are the pillars of 5S.

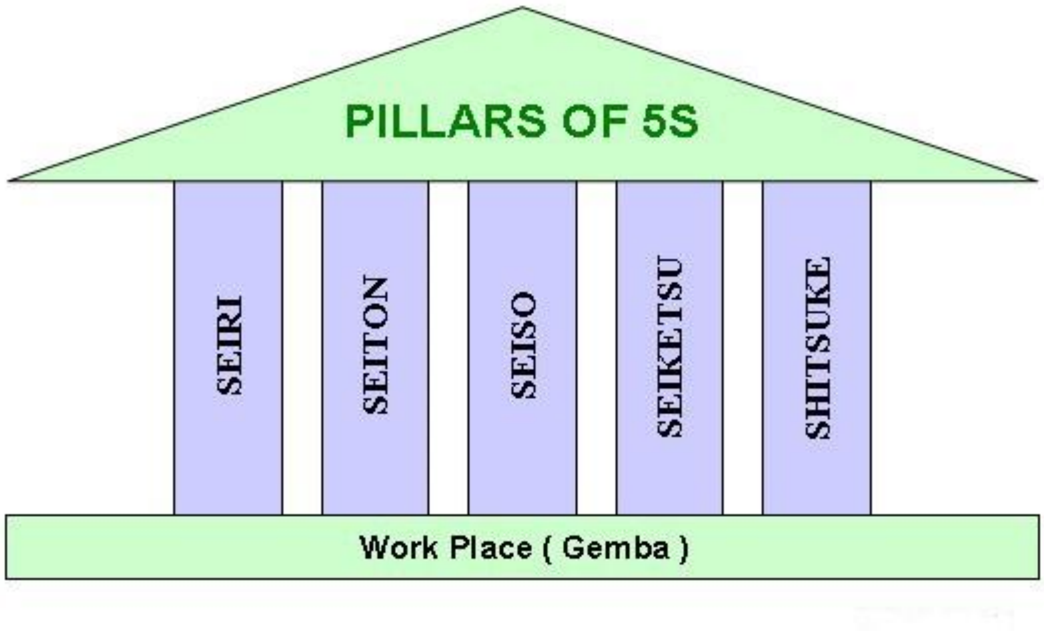


Fig- 4.4

Japanese Term	English Translation	Equivalent 'S' term
Seiri	Organisation	Sort
Seiton	Tidiness	Systematise
Seiso	Cleaning	Sweep
Seiketsu	Standardisation	Standardise
Shitsuke	Discipline	Self - Discipline

SEIRI - Sort out:

This means sorting and organizing the items as critical, important, frequently used items, useless, or items that are not need as of now. Unwanted items can be salvaged. Critical items should be kept for use nearby and items that are not be used in near future, should be stored in some place. *For this step, the worth of the item should be decided based on utility and not cost*. As a result of this step, the search time is reduced.

Priority	Frequency of Use	How to use
Low	**Less than once per year, Once per year<**	**Throw away, Store away from the workplace**
Average	**At least 2/6 months, Once per month, Once per week**	**Store together but offline**
High	**Once Per Day**	**Locate at the workplace**

SEITON - Organise:

The concept here is that "*Each items has a place, and only one place*". The items should be placed back after usage at the same place. To identify items easily, name plates and coloured tags has to be used. Vertical racks can be used for this purpose, and heavy items occupy the bottom position in the racks.

SEISO - Shine the workplace:

This involves cleaning the work place free of burrs, grease, oil, waste, scrap etc. No loosely hanging wires or oil leakage from machines.

SEIKETSU - Standardization:

Employees has to discuss together and decide on standards for keeping the work place / Machines / pathways neat and clean. This standards are implemented for whole organization and are tested / Inspected randomly.

SHITSUKE - Self discipline:

Considering 5S as a way of life and bring about self-discipline among the employees of the organization. This includes wearing badges, following work procedures, punctuality, dedication to the organization etc.

This 5S implementation has to be carried out in phased manner.

4.10.2. PILLAR 2 - JISHU HOZEN (Autonomous maintenance):

This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating. By use of this pillar, the aim is to maintain the machine in new condition. The activities involved are very simple nature. This includes cleaning, lubricating, visual inspection, tightening of loosened bolts etc.

Policy:

1. Uninterrupted operation of equipments.
2. Flexible operators to operate and maintain other equipments.
3. Eliminating the defects at source through active employee participation.

Steps in JISHU HOZEN:

1. Preparation of employees.
2. Initial cleanup of machines.
3. Take counter measures
4. Fix tentative JH standards
5. General inspection
6. Autonomous inspection
7. Standardization and

Each of the above-mentioned steps is discussed in detail below.

1. Train the Employees: Educate the employees about TPM, Its advantages, JH advantages and Steps in JH. Educate the employees about the equipment they use, the frequency of oiling, day-to-day maintenance activities required and the abnormalities that could occur in the machine and way to find out the abnormalities.

2. Initial cleanup of machines:

- Arrange all items needed for cleaning.
- On the arranged date, employees clean the equipment with the help of maintenance department.
- Dust, stains, oils and grease has to be removed. When cleaning oil leakage, loose wires, unfastened nuts and bolts and worn out parts must be taken care.
- After clean up, problems are categorized and suitably tagged. White tags are place where operators can solve problems. Pink tag is placed where the aid of maintenance department is needed.
- Contents of tag are transferred to a register.
- Make note of area, which were inaccessible.
- Open parts of the machine are closed, and the machine is run.

3. Counter Measures:

o Inaccessible regions had to be reached easily. E.g. If there are many screw to open a flywheel door, hinge door can be used. Instead of opening a door for inspecting the machine, acrylic sheets can be used.

o To prevent work out of machine parts necessary action must be taken.

o Machine parts should be modified to prevent accumulation of dirt and dust.

4. Tentative Standard:

- JH schedule has to be made and followed strictly.
- Schedule should be made regarding cleaning, inspection and lubrication and it also should include details like when, what and how.

5. General Inspection:

- The employees are trained in disciplines like Pneumatics, electrical, hydraulics, lubricant and coolant, drives, bolts, nuts and Safety.
- This is necessary to improve the technical skills of employees and to use inspection manuals correctly.
- After acquiring this new knowledge the employees should share this with others.
- By acquiring this new technical knowledge, the operators are now well aware of machine parts.

6. Autonomous Inspection:

- New methods of cleaning and lubricating are used.
- Each employee prepares his own autonomous chart / schedule in consultation with supervisor.
- Parts, which have never given any problem, or part, which don’t need any inspection, are removed from list permanently based on experience.

- Including good quality machine parts. This avoids defects due to poor JH.
- Inspection that is made in preventive maintenance is included in JH.
- The frequency of cleanup and inspection is reduced based on experience.

7. Standardization:

- Upto the previous step only the machinery / equipment was the concentration. However in this step the surroundings of machinery are organized. Necessary items should be organized, such that there is no searching and searching time is reduced.
- Work environment is modified such that there is no difficulty in getting any item.
- Everybody should follow the work instructions strictly.
- Necessary spares for equipments is planned and procured.

4.10.3. PILLAR 3 - KAIZEN:

"Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are move effective in an organizational environment than a few improvements of large value. This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well.

Kaizen Policy:

1. Practice concepts of zero losses in every sphere of activity.
2. Relentless pursuit to achieve cost reduction targets in all resources
3. Relentless pursuit to improve over all plant equipment effectiveness.
4. Extensive use of PM analysis as a tool for eliminating losses.
5. Focus of easy handling of operators.

Kaizen Target:

Achieve and sustain zero loses with respect to minor stops, measurement and adjustments, defects and unavoidable downtimes. It also aims to achieve 30% manufacturing cost reduction.

Tools used in Kaizen:

1. Why - Why analysis.
2. Poka yoke. (Poka-Yoke is Japanese term, which in English means ‘Mistake Proofing’ or 'error prevention').
3. Summary of losses.
4. Kaizen register.
5. Kaizen summary sheet.

The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPM activities, Kaizen pursues efficient equipment, operator and material and energy utilization that is extremes of productivity and aims at achieving substantial effects.

4.10.4. PILLAR 4 - PLANNED MAINTENANCE:

It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. This breaks maintenance down into four "families" or groups, which was defined earlier.

1. Preventive Maintenance
2. Breakdown Maintenance
3. Corrective Maintenance
4. Maintenance Prevention

With Planned Maintenance we evolve our efforts from a reactive to a proactive method and use trained maintenance staff to help train the operators to better maintain their equipment.

Policy:

1. Achieve and sustain availability of machines
2. Optimum maintenance cost.
3. Reduces spares inventory.
4. Improve reliability and maintainability of machines.

Target:

1. Zero equipment failure and break down.
2. Improve reliability and maintainability by 50 %
3. Reduce maintenance cost by 20 %
4. Ensure availability of spares all the time.

Six steps in Planned maintenance:

1. Equipment evaluation and recoding present status.
2. Restore deterioration and improve weakness.
3. Building up information management system.
4. Prepare time based information system, select equipment, parts and members and map out plan.
5. Prepare predictive maintenance system by introducing equipment diagnostic techniques and
6. Evaluation of planned maintenance.

4.10.5. PILLAR 5 - QUALITY MAINTENANCE:

It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, and then move to potential quality concerns. Transition is from reactive to proactive (Quality Control to Quality Assurance).

QM activities is to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The condition is checked and measure in time series to very that measure values are within standard values to prevent defects. The transition of measured values is watched to predict possibilities of defects occurring and to take counter measures beforehand.

Policy:

1. Defect free conditions and control of equipments.
2. QM activities to support quality assurance.
3. Focus of prevention of defects at source.
4. Focus on poka-yoke. (Fool proof system)
5. In-line detection and segregation of defects.
6. Effective implementation of operator quality assurance.

Target :

1. Achieve and sustain customer complaints at zero
2. Reduce in-process defects by 50 %
3. Reduce cost of quality by 50 %.

Data requirements:

Quality defects are classified as *customer end defects* and *in house* defects. For customer-end data, we have to get data on

1. Customer end line rejection
2. Field complaints.

In-house, data include data related to products and data related to process

Data related to product:

1. Product wise defects
2. Severity of the defect and its contribution - major/minor
3. Location of the defect with reference to the layout
4. Magnitude and frequency of its occurrence at each stage of measurement
5. Occurrence trend in beginning and the end of each production/process/changes. (Like pattern change, ladle/furnace lining etc.)

6. Occurrence trend with respect to restoration of breakdown/modifications/periodical replacement of quality components.

Data related to processes:

1. The operating condition for individual sub-process related to men, method, material and machine.
2. The standard settings/conditions of the sub-process
3. The actual record of the settings/conditions during the defect occurrence.

4.10.6. PILLAR 6 – EDUCATION & TRAINING:

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill. It is not sufficient know only "Know-How" by they should also learn "Know-why". By experience they gain, "Know-How" to overcome a problem what to be done. This they do without knowing the root cause of the problem and why they are doing so. Hence it becomes necessary to train them on knowing "Know-why". The employees should be trained to achieve the four phases of skill. The goal is to create a factory full of experts. The different phase of skills is

Phase 1: Do not know.

Phase 2: Know the theory but cannot do.

Phase 3: Can do but cannot teach

Phase 4: Can do and also teach.

Policy:

1. Focus on improvement of knowledge, skills and techniques.
2. Creating a training environment for self-learning based on felt needs.
3. Training curriculum / tools /assessment etc conductive to employee revitalization
4. Training to remove employee fatigue and make, work enjoyable.

Target:

1. Achieve and sustain downtime due to want men at zero on critical machines.
2. Achieve and sustain zero losses due to lack of knowledge / skills / techniques
3. Aim for 100 % participation in suggestion scheme.

Steps in Educating and training activities:

1. Setting policies and priorities and checking present status of education and training.
2. Establish of training system for operation and maintenance skill up gradation.
3. Training the employees for upgrading the operation and maintenance skills.
4. Preparation of training calendar.
5. Kick-off of the system for training.
6. Evaluation of activities and study of future approach.

4.10.7. PILLAR 7 - OFFICE TPM:

Office TPM should be started after activating four other pillars of TPM (JH, Kaizen, QM, PM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation. Office TPM addresses twelve major losses. They are :-

1. Processing loss
2. Cost loss including in areas such as procurement, accounts, marketing, sales leading to high inventories
3. Communication loss
4. Idle loss
5. Set-up loss
6. Accuracy loss
7. Office equipment breakdown
8. Communication channel breakdown, telephone and fax lines
9. Time spent on retrieval of information
10. Non availability of correct on line stock status
11. Customer complaints due to logistics
12. Expenses on emergency dispatches/purchases.

How to start office TPM?

A senior person from one of the support functions e.g. Head of Finance, MIS, Purchase etc should be heading the sub-committee. Members representing all support functions and people from Production & Quality should be included in sub committee. TPM co-ordinate plans and guides the sub committee.

1. Providing awareness about office TPM to all support departments
2. Helping them to identify P, Q, C, D, S, M in each function in relation to plant performance
3. Identify the scope for improvement in each function
4. Collect relevant data
5. Help them to solve problems in their circles
6. Make up an activity board where progress is monitored on both sides - results and actions along with Kaizens.
7. Fan out to cover all employees and circles in all functions.

Kaizen topics for Office TPM:

- Inventory reduction
- Lead time reduction of critical processes
- Motion & space losses
- Retrieval time reduction.
- Equalizing the work load

- Improving the office efficiency by eliminating the time loss on retrieval of information, by achieving zero breakdown of office equipment like telephone and fax lines.

Office TPM and its Benefits:

1. Involvement of all people in support functions for focusing on better plant performance
2. Better utilized work area
3. Reduce repetitive work
4. Reduced administrative costs
5. Reduced inventory carrying cost
6. Reduction in number of files
7. Productivity of people in support functions
8. Reduction in breakdown of office equipment
9. Reduction of customer complaints due to logistics
10. Reduction in expenses due to emergency dispatches/purchases
11. Reduced manpower
12. Clean and pleasant work environment.

Extension of office TPM to suppliers and distributors:

This is essential, but only after we have done as much as possible internally. With suppliers it will lead to on-time delivery, improved 'in-coming' quality and cost reduction. With distributors it will lead to accurate demand generation, improved secondary distribution and reduction in damages during storage and handling. In any case we will have to teach them based on our experience and practice and highlight gaps in the system, which affect both sides. In case of some of the larger companies, they have started to support clusters of suppliers.

4.10.8. PILLAR 8 - SAFETY, HEALTH AND ENVIRONMENT:

Target:

1. Zero accident,
2. Zero health damage
3. Zero fires.

In this area focus is on to create a safe workplace and a surrounding area that is not damaged by our process or procedures. This pillar will play an active role in each of the other pillars on a regular basis.

A committee is constituted for this pillar, which comprises representative of officers as well as workers. Senior vice President (Technical), heads the committee. Utmost importance to Safety is given in the plant. Manager (Safety) is looking after functions related to safety. To create awareness among employees various competitions like safety slogans, Quiz, Drama, Posters, etc. related to safety can be organized at regular intervals.

4.11. Difficulties faced in TPM implementation:

One of the difficulties in implementing TPM as a methodology is that it takes a considerable number of years. The time taken depends on the size of the organization. There is no quick way for implementing TPM. This is contradictory to the traditional management improvement strategies. Following are the other difficulties faced in TPM implementation.

• Typically people show strong resistance to change.

• Many people treat it just another “Program of the month ” without paying any focus and also doubt about the effectiveness.

• Not sufficient resources (people, money, time, etc.) and assistance provided

• Insufficient understanding of the methodology and philosophy by middle management

• TPM is not a “quick fix ” approach, it involve cultural change to the ways we do things

• Departmental barrier existing within Business Unit

• Many people considered TPM activities as additional work/threat.

4.12. Productivity circle

The Productivity Improvement Circles or PIC concept is relatively new concept

In the Philippines, it is an adaptation of the highly acclaimed Japanese Quality Control Circles or QCC concept. Introduced in 1980, renamed and modified later by the Academy’s Productivity & Development Center (PDC), this concept has always been promoted as one the basic tools towards enhancing productivity.

A Productivity Improvement Circle (PIC) is a small group of workers from the same workshop to participate in self/ mutual development and problem-solving activities that would help increase company productivity.

Maintenance is undertaken to preserve the proper functioning of a physical system so that it will continue to do what it was designated to do. Its function and performance characteristics not only take account of output, unit cost and effectiveness of using energy, but also such factors as end product quality, process control, comfort enhancement and protection of the employed personnel, compliance with environment protection regulations, structural integrity and even physical appearance of the productive system. Maintenance is often wrongly regarded as a cost centre, since the costs are visible, while the benefits are difficult to estimate.

4.12.1. **DEFINITION**

Quality Circle is a small group of 6 to 12 employee doing similar work who voluntarily meet together on a regular basis to identify improvements in their respective work areas.

4.12.2. **PHIILOSOPHY**

Quality Circle is a people – building philosophy, which provides self-motivation and improves work environment. It represents a philosophy of managing people specially those at the grass root level.

4.12.3. **CONCEPT**

The concept of Quality Circle is primarily based upon recognition of value of the worker as a human being, as someone who willingly put efforts to improve the job, his wisdom, intelligence, experience, attitude and feelings.

4.12.4. **OBJECTIVE**

The objectives of Quality Circles are multi-faced – Change in attitude; self-development; development of team spirit, improvement in organizational culture.

4.12.5. **ORGANISATIONAL *STRUCTURE***

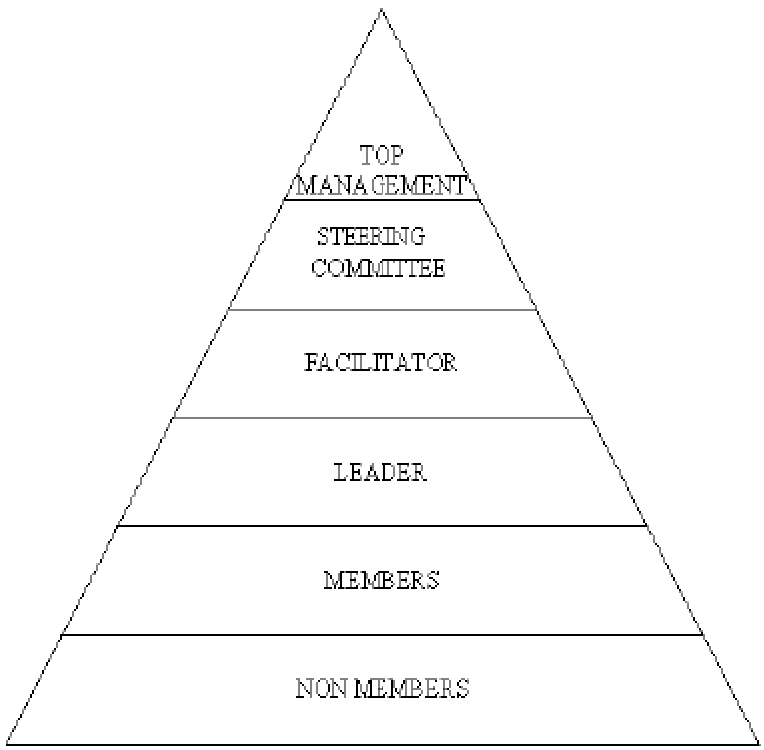


Fig-4.5

4.12.6. **LAUNCHING QUALITY CIRCLES**

The launching of Quality Circles involves the following steps:

- Expose middle level executives to the concept.
- Explain the concept to the employees and invite them to volunteer as members of Quality Circles.
- Nominate senior officers as facilitators.
- Form a steering committee.
- Arrange trainings
- A meeting should be fixed preferably one hour a week for the Quality Circle to meet.
- Formally inaugurate the circle.
- Arrange necessary facilities for the Quality Circle meeting and its operation.

4.12.7. **TRAINING**

Appropriate training for different sections of employees needs to be imparted.

4.12.8. **PROCESS OF OPERATION**

Figure 2 exhibits the operation of quality circles:

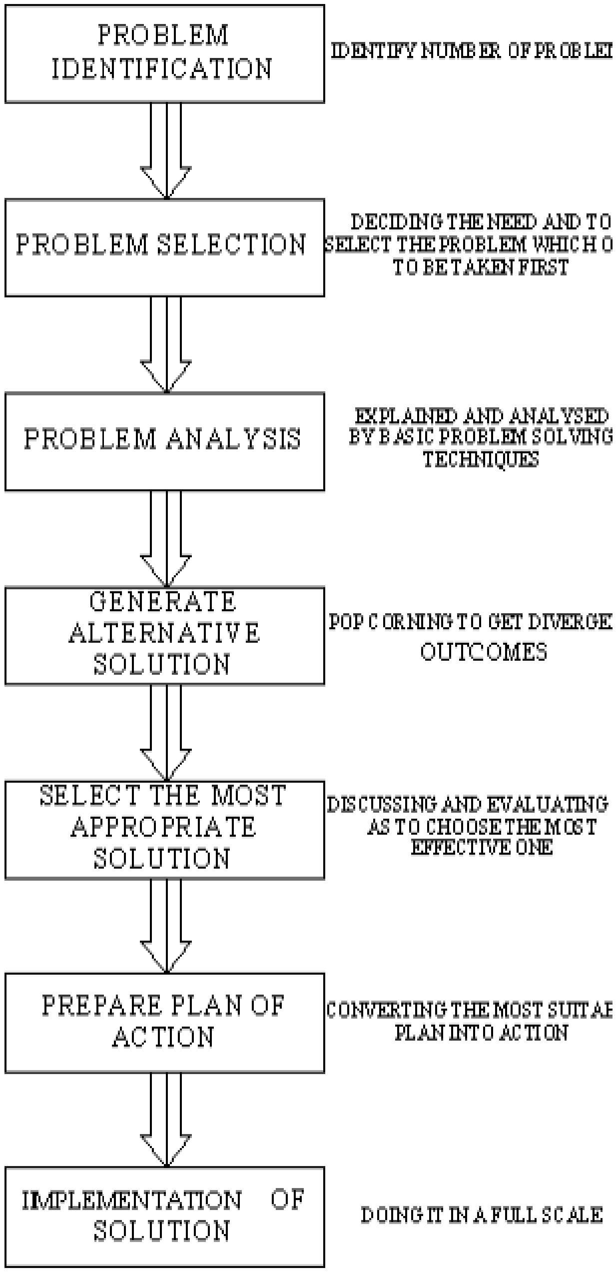


Fig.- 4.6

4.12.9. **CHARACTERS OF QC**

• Circle membership: It is more or less homogeneous group of people usually from the same work areas. However, whenever required experts may be invited for guidance or advice.

• Circle size: Usually a group of 6 to 12 members seems quite effective; however, it depends upon the people employed in a particular section.

. Voluntary participation: The main objective of QC is attendance and participation in meetings voluntarily without any compulsion.

• QC meetings***:*** An hour's duration is usually quite adequate for a meeting. Whatever may be the frequency, regular meetings should be ensured.

• Autonomy: An important ingredient of a QC is the sense of autonomy experienced by its members.

4.12.10. **PHASES IN QC DEVELOPMENT**

Once a QC is formed, it has to pass through the following distinct phases of development:

• Problem to be identified analyzed and solved.
• Solutions to be implemented in due time.
• Monitoring to be carried out.
• Higher management to encourage QCs to innovate Problem solving methods.

4.12.11. **BASIC PROBLEM SOLVING TECHNIQUES**

The following techniques are most commonly used to analyze and solve work related problems.

• Brain storming.
• Pareto Diagrams.
• Ishikawa diagram (Fishbone diagram).
• Cause & Effect Analysis.
• Data Collection.
• Data Analysis.

The tools used for data analysis are:

• Tables.
• Bar Charts.
• Histograms.
• Circle graphs.
• Line graphs.
• Scatter grams.
• Control Charts.

4.12.12. **CAUSES FOR FAILURE OF QC**

Some of the common causes for failure are:

• Low morale of employees due to autocratic management and lack of trust.
• Lack of training.
• Incompetent leadership.
• Lack of management support.

Quality circle concept succeeded in Japan, South Korea and a few other Asian countries, but it was a different kind of experience in Europe and USA. In Europe and USA, it became very popular from middle of 70s to middle of 80s, and subsequently, started its journey of declining from there onwards. The reasons can be attributed to:

• In Japan, it was mainly considered as a development process of grass-root employees, and organizational improvement was given secondary importance, where as in Europe and USA, the focus was given to organizational improvement and no proper attention was paid to improvement of people.
• Work associated to QC is totally carried out as an internal process in Japan, whereas in Europe and USA, it was left to the external consulting agency. In India too, these reasons are equally valid and applicable.

4.13. MAINTENANCE PERFORMANCE EVALUATION

1. INTRODUCTION:

1.1 Maintenance performance evaluation is an essential step to effect improvement in the maintenance planning, organizing and control.

1.2 The evaluation can be made on the following factors:-

1. Plant Availability
2. Cost of Maintenance
3. Effectiveness of Maintenance Planning
4. Frequency of break downs/MTTF
5. MTTR/Mean Time to Repair
6. MWT/Mean Waiting Time

2. ANALYSIS OF PLANT AVAILABILITY:

This is essentiality to know the overall effectiveness of the maintenance. In most of capital intensive industries, the plant availability is the most important factor as low availability means heavy down-time losses. Hence the achievement of maintenance objectives are to be reflected by the plant availability achieved.

Plant Availability can be plant-wise or major equipment wise to draw the attention of higher levels of management for maintenance decision making.

$$\text{Plant Availability} = \frac{\text{Total Available Hours - Total Down-time}}{\text{Total Available Hours}}$$

Where,

Total Available Hours = Working days x Hours per day x No. of machines.

3. ANALYSIS OF COST OF MAINTENANCE:

This analysis is helpful to assess the cost effectiveness of the maintenance system. This also helps in maintenance budgeting and cost control. Cost of maintenance as a ratio of the value of plant and equipment measured year to basis will bring out the facts whether cost control measures are required to be undertaken immediately or not. Such an analysis equipment wise will indicate whether the equipment can be replaced by a new/another equipment.

4. ANALYSIS OF EFFECTIVENESS OF PLANNING:

The effectiveness of planning is assessed by the following rations:

$$\frac{\text{Labour Hours on Scheduled Maintenance}}{\text{Total Labour Hours on Maintenance}}$$

or

$$\frac{\text{Total Down Time due to scheduled Maintenance}}{\text{Total Down Time due to Maintenance}}$$

Higher the above ratio more effective is maintenance planning. But at the same time plant availability also should have been improved.

5. FREQUENCY OF BREAK-DOWNS/MTTF:

Frequency of breakdowns of mean time of failure reflects on the plant condition. Increase in the frequency of break will help the management identify the causes of the failures and take remedial measures to reduce the frequency of such failure. This is termed as design-out maintenance. This analysis, year to year basis, will indicate the effectiveness of design out maintenance action.

6. ANALYSIS OF MEAN TIME TO REPAIR (MTTR):

Mean Time To Repair or MTTR reflects on the improvements in design & modification of plant by which the time required an equipment is reduced. This also will indicate efficiency or the skill of the people who carry out the repair jobs. MTTR is computed as follows:

$$\frac{\text{Total Repair Time in Hours}}{\text{No. of break-downs}}$$

7. ANALYSIS OF MEAN WAITING TIME (MWT):

Mean Waiting Time is part of the down time indicating the mean down-time lost in waiting for materials or labour for attending to a break down. Mean waiting Time is the ratio of Total Machine Hours lost due to waiting for materials or labour to the total number of breakdowns.

Increased MWT will help the management in identifying the areas for improvement such as organizing of trade force or improving the stores systems & procedures or improving the spare part control systems.

8. PRIEL'S INDICES OF MAINTENANCE EFFECTIVENESS:

So far, we have discussed only the important factors for maintenance performance evaluation. However, a comprehensive list of indices for Maintenance Effectiveness suggested by Priel given in the Annexure-1 for reference.

9. CONCLUSION:

Though there are many factors suggested as a tool for maintenance performance evaluation, it is very essential to choose only such factors which are quite relevant, easy to generate necessary data and easy to interpret the results and monitor the maintenance, planning, organizing and control activities.

<u>ANNEXURE-1.PRIEL'S INDICES OF MAINTENANCE EFFECTIVENESS</u>

GROUP-1 - MAINTENANCE EFFORT (INPUT)

Manpower:

$$\text{Manpower efficiency} = \frac{\text{Total man-hours allowed on job}}{\text{Total man-hours worked on same jobs}}$$

$$\text{Incentive coverage} = \frac{\text{Total man-hours on bonus}}{\text{Total direct man-hours available for jobs}}$$

$$\text{Craft/ Worker Utilization} = \frac{\text{Total direct craft hours applied}}{\text{Total hours clocked all crafts}}$$

$$\text{Overdue tasks} = \frac{\text{No. of jobs one week overdue}}{\text{No. of jobs completed in same period}}$$

Economy:

$$\text{Work-order turnover} = \frac{\text{No. of jobs completed in period}}{\text{No. of jobs on hand at present}}$$

$$\text{Cost of main hours} = \frac{\text{Total cost of (direct + indirect) Maintenance}}{\text{Total direct maintenance hours applied}}$$

$$\text{Breakdown repairs cost} = \frac{\text{Total cost of repairs}}{\text{Total cost of direct maintenance}}$$

Service Operation:

Degree of scheduling = Total direct hours on scheduled service / Total direct hours available

Breakdown repair hours = No. of hours spent on breakdown repairs / Total direct production hours same period

Maintenance Intensity:

Maintenance hours applied = Total direct maintenance hours applied / Total direct production hours same period

Maintenance ratio for investment = Total direct maintenance hours applied / Total plant investment to date

Maintenance cost component = Total maintenance cost for applied / Total Production cost for same period

Service Cost :

Scheduled service cost = Total cost of scheduled service / Total production cost for same period

Breakdown severity = Total cost of breakdown repair / Total No. of breakdowns

<u>GROUP-2 - MAINTENANCE EFFECTS (OUTPUTS)</u>

Plant Condition:

Breakdown frequency = No. of maintenance breakdown / Total No. of breakdown

Visual and descriptive = Estimate of plant condition from / Production supervisory personnel

Machine utilization = Total running time in hours / Total shift hours

Plant Performance:

Length of running period = Total production output in hours / No. of repairs in the same period