Department	Mechanical		Program	M.tech		
Subject Name	Maintenance and Reliability		Subject Code	TMM- 102		
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Unit I: Maintenance

Evolution of maintenance, objective of maintenance, maintenance policies and philosophies, maintenance concept, maintenance management & tero technology, relationship with functional areas. importance of maintenance, elements of good maintenance, Economics of maintenance, training and safety aspects in maintenance. Classification of maintenance programs, corrective preventive and predictive maintenance, comparison of maintenance programs, preventive maintenance- concepts, functions, benefits, limitations

Links to the Resources:

1. http://site.iugaza.edu.ps/sabdelall/files/2010/02/Engineering_Maintenance_a_modern_approach.pdf

2. http://www.lifetime-reliability.com/free-articles/maintenance-management/Evolution_of_Maintenance_Practices.pdf

3. www.springer.com/cda/content/document/cda.../9781848000100-c1.**pdf**?SGWID...

Books to be Consulted:

1. Duffuaa, S. O. and Raouf, A., Planning and control of maintenance Systems: Modeling and Analysis; John Wiley Inc.,1999.

Lecture Notes:

Evolution of maintenance:

Over the last decennia industrial maintenance has evolved from a non-issue into a strategic concern. Perhaps there are few other management disciplines that underwent so many changes over the last half-century. During this period, the role of maintenance within the organization has drastically been transformed. At first maintenance was nothing more than a mere inevitable part of production, now it is an essential strategic element to accomplish business objectives. Without a doubt, the maintenance function is better perceived and valued in organizations. One could considered that maintenance management is no longer viewed as an underdog function; now it is considered as an internal or external partner for success. In view of the unwieldy competition many organizations seek to survive by producing more, with fewer resources, in shorter periods of time.To enable these serious needs, physical assets take a central role. However, installations have become highly automated and technologically very complex and, consequently, maintenance management had to become more complex having to cope with higher technical and business expectations. Now the maintenance manager is confronted with very complicated and diverse technical installations operating in an extremely demanding business context.

In an era of competitive marketplace and ever-changing economics, there are intense pressures on organizations in both the manufacturing and service sectors to respond to customers' demands and deliver high-quality products in a timely manner. These lead organizations to gear their strategies toward agility, quality, automation, and high performance. This has resulted in very high investments in equipment and people. To achieve the targeted rates of return on investment and survive in these dynamic economics, equipment has to be reliable and safe to operate without costly work stoppages and repairs. Many manufacturing companies have adopted just-in-time (JIT) lean programs and are operating with work-in-process so low that there is no inventory reserve to use in case equipment unavailability occurs. The above developments brought forward the role of maintenance as a key activity in manufacturing and service organizations.

Objective of maintenance:

Maintenance is defined as the combination of activities by which equipment or a system is kept or restored to a state in which it can perform its designated function. It is an important factor in product and service quality and can be used as a strategy for successful competition. Inconsistencies in production equipment operation result in excessive variability in the product and thus cause defective output. To be able to produce a high level of quality, production or service equipment must operate within specifications that are attainable by timely maintenance actions. A system is a collection of components that work together toward a common objective(s). Maintenance can be considered as a system with a set of processes and activities carried out in parallel with production or service systems. A diagrammatic relationship among organizational objectives, production/operation process, and maintenance is shown in Fig.1.1.Production/operation systems are usually concerned with converting inputs such as raw materials, manpower, and processes into products/services that satisfy customer needs. The primary outputs of the production/operation systems are finished products or services, and the secondary output is degraded or failed equipment. This secondary output generates demand for maintenance. The maintenance system takes this as an input and adds to it know-how, manpower, and spares, and produces equipment/facilities in good operating condition, that provide capacity for production or service.

The overall primary goal of a production or a service system is to maximize profit from the available market opportunities, and its secondary goal is concerned with economical and technical aspects of the conversion process. Maintenance systems assist in achieving these goals as well, by increasing profits and customer satisfaction. These are achieved by minimizing the plant downtime, improving the quality, increasing the productivity and by reliable timely delivery of orders to customers. Production and service systems have been optimized as an integrated system and have been studied quite extensively compared to maintenance systems. Possible reasons include the following:

(1) Traditionally, maintenance has been regarded as a necessary evil and at best a system driven by production

(2) Maintenance in an organization has complex relationships with other functions

(3) The output of maintenance is hard to measure and quantify. The role of maintenance systems has been long realized in manufacturing organizations; however, it has become clear that the functions of maintenance are also essential for service organizations such as hospitals, banks, educational institutions, and department stores. In organizations such as hospitals, for example, X-ray and brain scanning machines must be kept up all the time due to their criticality to human life. The concepts, models, and techniques in this book that are used for planning, designing, organizing, and controlling of maintenance systems are applicable to all organizations that perform a business function

1.2 Strategic Holistic System Approach 3

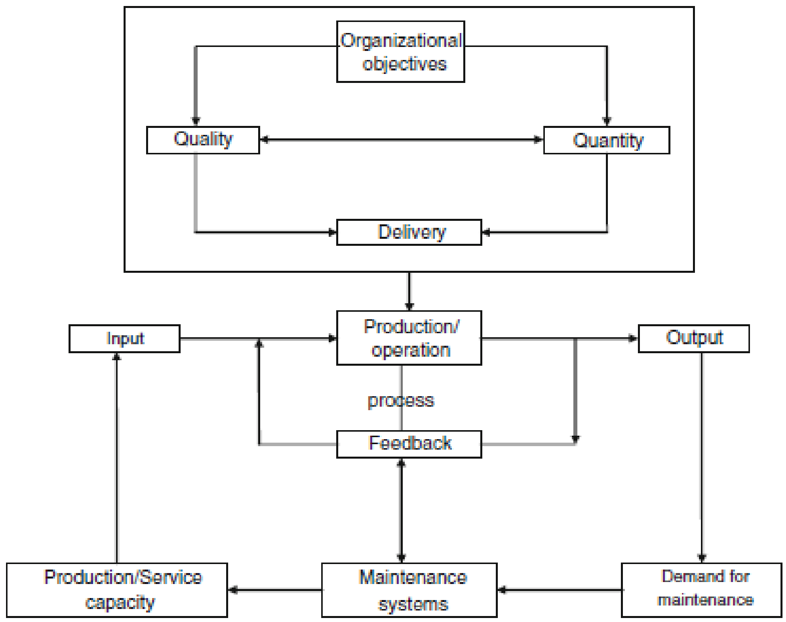

Fig. 1.1 Relationships between maintenance systems and organization objectives

A maintenance system can be viewed as an integrated input–output model. The inputs to such a model are labor, management, tools, spares, equipment, etc., and the output is equipment that is up, reliable, and well configured to achieve the planned operation of the plant. This enables us to optimize the resources for maximizing the output of a maintenance system. A typical maintenance system is shown in Fig.1.2. Activities needed to make this system efficient and effective include planning, designing, organizing, controlling, and improving that are shown in the figure.

1 Maintenance Systems

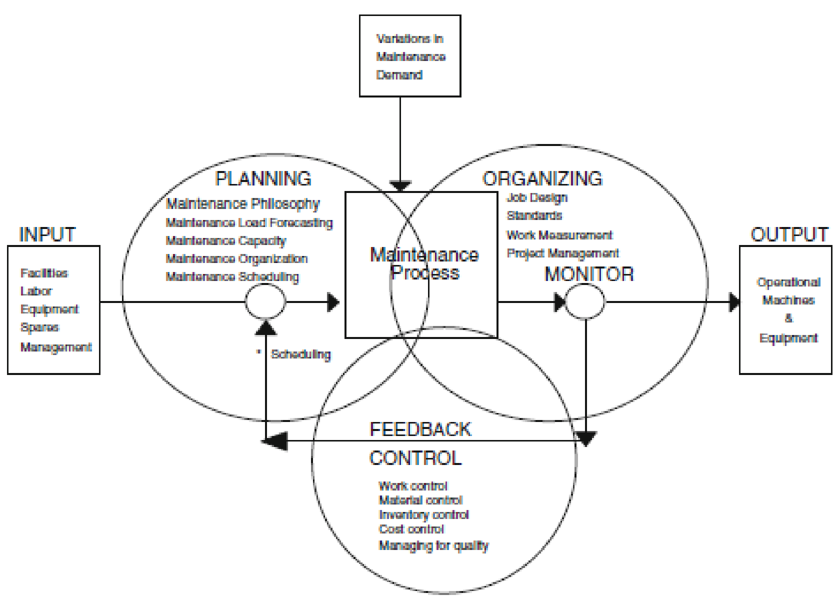

Fig. 1.2 Maintenance systems

Maintenance policies :

As new maintenance techniques happen to be available and the economic implications of maintenance action are comprehended, a direct impact on the maintenance policies is expected. Several types of maintenance policies can be considered to trigger, in one way or another, either precautionary or corrective maintenance interventions. As described in given table, those policies are mainly failure-based maintenance (FBM), time/used-based maintenance (TBM/UBM), condition-based maintenance (CBM), opportunity-based maintenance (OBM) design-out maintenance (DOM), and e-maintenance.

. Generic maintenance policies

Policy	Description
FBM	Maintenance (CM) is carried out only after a breakdown. In case of CFR behaviour and/or low breakdown costs this may be a good policy.
TBM / UBM	PM is carried out after a specified amount of time (*e.g.* 1 month, 1000 working hours, *etc.*). CM is applied when necessary. UBM assumes that the failure behaviour is predictable and of the IFR type. PM is assumed to be cheaper than CM.
CBM	PM is carried out each time the value of a given system parameter (condition) exceeds a predetermined value. PM is assumed to be cheaper than CM. CBM is gaining popularity due to the fact that the underlying techniques (*e.g.* vibration analysis, oil spectrometry,...) become more widely available and at better prices. The traditional plant inspection rounds with a checklist are in fact a primitive type of CBM.
OBM	For some components one often waits to maintain them until the "opportunity" arises when repairing some other more critical components. The decision whether or not OBM is suited for a given component depends on the expectation of its residual life, which in turn depends on utilization.
DOM	The focus of DOM is to improve the design in order to make maintenance easier (or even eliminate it). Ergonomic and technical (reliability) aspects are important here.
CFR = Constant failure rate, IFR=Increasing failure rate	

For the more common maintenance policies many models have been developed to support tuning and optimization of the policy setting. It is not our intention to explain the fundamental differences between these models, but rather to provide an overview of types of policies available and why these have been developed. Much has to do with the discussion in the previous section regarding the acuity of maintenance actions. Therefore, it is clear that policy setting and the understanding of its efficiency and effectiveness continues to be fine-tuned as any other management science. We advocate the reader, particularily interested in the underlying principles and type of models, to review McCall (1965), Geraerds (1972), Valdez-Flores and Feldman (1989), Cho and Parlar (1991), Pintelon and Gelders (1992), Dekker (1996), Dekker and Scarf (1998) and Wang (2002) for a full overview on the state-of-the-art literature.

The whole evolution of maintenance was based not solely on technical but rather on techno-economic considerations. FBM is still applied providing the cost of PM is equal to or higher than the cost of CM. Also, FBM is typically handy in case of random failure behaviour, with constant failure rate, as TBM or UBM are not able to reduce the failure probability. In some cases, if there exists a measurable condition, which can signal the probability of a failure, CBM can be also feasible. Finally, a FBM policy is also applied for installations where frequent PM is impracticable and expensive, such as can be the maintenance of glass ovens. Either TBM or UBM is applied if the CM cost is higher than PM cost, or if it is necessary because of criticality due to the existence of bottleneck installation or safety hazards issues. Also in case of increasing failure behaviour, like for example wear-out phenomena, TBM and UBM policies are appropriate. Typically, CBM was mainly applied in those situations where the investment in condition monitoring equipment was justified because of high risks, like aviation or nuclear power regeneration. Currently, CBM is beginning to be generally accepted to maintain all type installations. Increasingly this is becoming a common practice in process industries. In some cases, however, technical feasibility is still a hurdle to overcome. Another reason that catches the attention of practitioners in CBM is the potential savings in spare parts replacements thanks to the accurate and timely forecasts on demand. In turn, this may enable better spare parts management through coordinated logistics support. Finding and applying a suitable CBM technique is not always easy. For example, the analysis of the output of some measurement equipment, such as advanced vibration monitoring equipment, requires a lot of experience and is often work for experts. But there are also simpler techniques such as infrared measuring and oil analysis suitable in other contexts. At the other extreme, predictive techniques can be rather simple, as is the case of checklists. Although fairly low-level activity, these checklists, together with human senses (visual inspections, detection of "strange" noises in rotating equipment, etc.) can detect a lot of potential problems and initiate PM actions before the situation deteriorates to a breakdown.

At present FBM, TBM, UBM and CBM accept and seize the physical assets which they intend to maintain as a given fact. In contrast, there are more proactive maintenance actions and policies which, instead of considering the systems as "a given", look at the possible changes or safety measures needed to avoid maintenance in the first place. This proactive policy is referred to as DOM. This policy implies that maintenance is proactively involved at earlier stages of the product life cycle to solve potential related problems. Ideally, DOM policies intend to completely avoid maintenance throughout the operating life of installations, though, this may not be realistic. This leads one to consider a diverse set of maintenance requirements at the 32 L. Pintelon and A. Parodi-Herz early stages of equipment design. As a consequence, equipment modifications are geared either at increasing reliability by raising the mean-time-between-failures (MTBF) or at increasing the maintainability by decreasing the mean-time-to-repair (MTTR). Per se DOM aims to improve the equipment availability and safety. Some equipment modifications may merely request ergonomic considerations to reduce MTTR, others may need totally new designs. Often DOM projects are combined with efforts to increase occupational safety or increase production capacity, such as set up reduction programs. A rather passive, but considerably important maintenance policy that needs to be mentioned is OBM. Typically OBM is applied for non-critical components with a relatively long lifetime. For these components no separate maintenance programs are scheduled; maintenance happens if an opportunity arises due to a maintenance intervention for another component of that machine. More recently in the mid-1990s, with the emergence of the Internet as an enabling technology and the growth of e-business as the standard on business communication, e-maintenance also appeared in the radar of maintenance policies. E-maintenance rather than a policy can also be considered as a means or enabler to some, if not all, the previous policies. However, it is more than just an acronym; it is a step forward to full-integrated maintenance techniques without the boundaries of place. It is in fact a maintenance policy on its own that can support other policies. In particular, academics and practitioners watch with anticipation the great impact it may have on CBM. Conditions measured on site can be remotely monitored, opening entirely new dimensions and opportunities for maintenance services. Therefore, e-maintenance has captured much attention of maintenance researchers given its great impact on business practice. An example of this evolution is tele maintenance, which allows the diagnosis of installation and to perform limited type of repairs from a remote location using ICT and sophisticated control and knowledge tools.

Maintenance concept:

The idea of an "optimized" maintenance program suggests that an adequate mix of maintenance actions and policies needs to be selected and fine-tuned in order to improve uptime, extend the total life cycle of physical asset and assure safe working conditions, while bearing in mind limiting maintenance budgets and environmental legislation. This does not seem to be straightforward, and may require a holistic view. Therefore, a "maintenance concept" for each installation is necessary to plan, control and improve the various maintenance actions and policies applied. A maintenance concept may in the long term even become a philosophy, tenet or attitude to perform maintenance. In some cases advance maintenance concepts are almost considered strategies on their own. What is certain is that maintenance concepts determine the business philosophy concerning maintenance, and that they are needed to manage the complexity of maintenance per se.

In practice, it is clear that more and more companies are spending time and effort determining the right maintenance concept. As a matter of fact, maintenance concepts need to be formulated considering the physical characteristics and the context within which installations operate. Not surprisingly, as system complexity is increasing and maintenance requirements are becoming more complex, maintenance concepts will require different levels of complexity. Literature provides us with various concepts that have been developed through a combination of theoretical insights and practical experiences. Choosing and implementing the best concept in a given context is hard. To the question "what concept is best for us?", no short and straightforward answer exists. The right answer to the question is determined by the context, with its complex interaction of technology, business, organization, and so forth. Designing and implementing a good concept will take time and effort. Many companies establish teams with members from different areas (engineering, production, maintenance, ...) to accomplish this difficult task. On the market, many consultants offer their services to assist in this process. This outside help may be very useful to get started and to obtain a better insight into own situation. However, it is useful to note that many consultants have "their" concept (e.g. RCM) they are used to implementing, which may bias their judgment on what concept is "right". Nevertheless, some outside guidance can be useful, but in order to have a good concept that fits all the companies needs, this should be built by in-house people, using all the knowledge available.

Relationship with functional areas:

Planning activities generally include the following

1. Strategic systems alliances
2. Maintenance strategies
3. Maintenance load forecasting
4. Maintenance capacity
5. Maintenance organization
6. Maintenance scheduling.

A description of each of these activities is given in the next subsections

Strategic Systems Alliance:

Maintenance departments should have their own strategic plans that are aligned with their organizations' strategic objectives and managed with maximum efficiency and effectiveness taking into consideration the holistic system approach. Strategies for maintenance operations should be selected among alternatives to achieve organizations' objectives. Recent works of Tsang , Murthy et al. , and Al-Turki have discussed issues related to maintenance strategic planning and identified several important issues that are essential in deciding maintenance strategic plan. These issues include maintenance outsourcing, organization, methodology, and support. At the strategic level, management decides the organization's strategic goals, and from these goals, the maintenance unit goals are derived to support the organization's strategic goals and mission. Then, the right organization, maintenance methodology, and support are selected to achieve these goals. Maintenance methodology is the strategy to be used at the equipment maintenance level, and the support includes maintenance key processes, manning, information system, training, and performance management and reward system.

Maintenance Strategies:

The maintenance methodology is derived from the maintenance system objectives that are aligned with the organization's mission and strategic goals. To implement the methodology, the following strategies can play an effective role if applied in the right mix and fashion. The strategies are as follows:

1. Breakdown/corrective maintenance
2. Preventive maintenance

2:1 Time- or use-based preventive maintenance

2:2 Condition-based preventive maintenance

3. Opportunity maintenance
4. Fault finding
5. Design modification
6. Overhaul
7. Replacement
8. Reliability-centered maintenance
9. Total productive maintenance

Breakdown/Corrective Maintenance

This type of maintenance is only performed when the equipment is incapable of further operation. There is no element of planning for this type of maintenance. This is the case when the extra cost of other types of maintenance cannot be justified. This type of strategy is sometimes referred to as run to failure strategy. It is applicable mostly to electronic components.

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Time- or Use-Based Preventive Maintenance:

Preventive maintenance (PM) is any planned maintenance performed to counteract potential failures. It could be implemented based on the use or equipment condition. The time- or use-based PM is performed on an hours run or calendar basis. It needs a high level of planning. The specific routines to be carried out are known as well as their frequencies. In determining the frequency, usually knowledge about failure distribution or equipment reliability is needed.

Condition-Based Preventive Maintenance:

Condition-based maintenance is carried out on the basis of the known condition of the equipment. The condition of the equipment is determined by monitoring key equipment parameters whose values are affected by the condition of the equipment. This strategy is also known as predictive maintenance.

Opportunity Maintenance:

This type of maintenance, as the name implies, is carried out when the opportunity arises. Such opportunities may arise during shutdown periods of a particular system and can be utilized for carrying out known maintenance tasks.

Fault Finding:

Fault finding is an act or inspection performed to assess the level of failure set on. An example of fault finding is checking the spare tire of a car prior to taking a long trip.

Design Modification:

Design modification is carried out to bring equipment to a current acceptable condition. It involves improvement and sometimes manufacturing and capacity expansion. It usually requires coordination with engineering and other departments in the organization to do this type of work.

Overhaul:

Overhaul is a comprehensive examination and restoration of equipment or a major of equipment to an acceptable condition. This is usually a major task.

Replacement:

This strategy is to replace the equipment instead of performing maintenance. It could be a planned replacement or replacement upon failure. Each of the maintenance strategies described above has a role to play in the plant operation. It is the optimal mix of these maintenance strategies that results in the most effective maintenance philosophy. The size of the plant and its planned level of operation coupled with the applicable maintenance strategy can assist in estimating the maintenance load or the desired output of the maintenance system.

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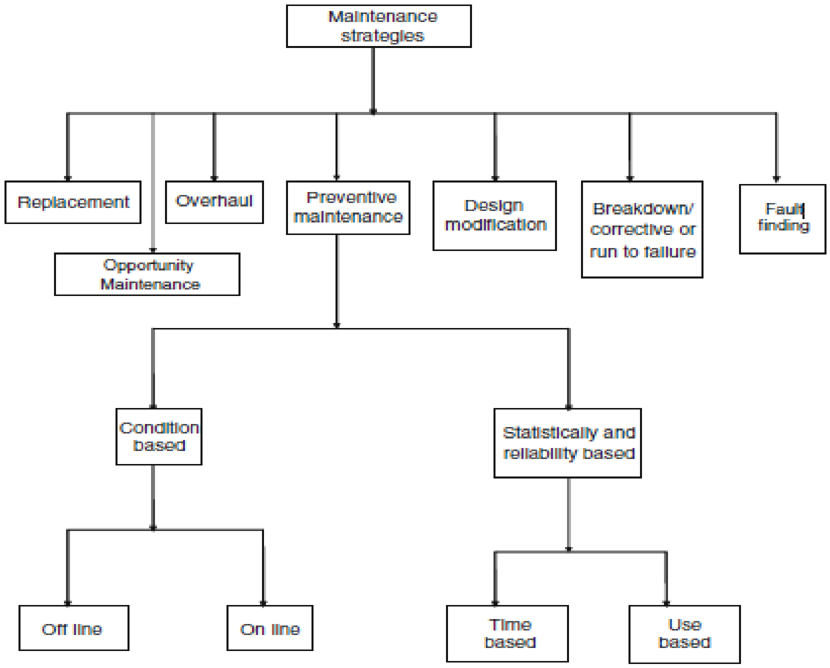


Maintenance strategies

Maintenance Load Forecasting:

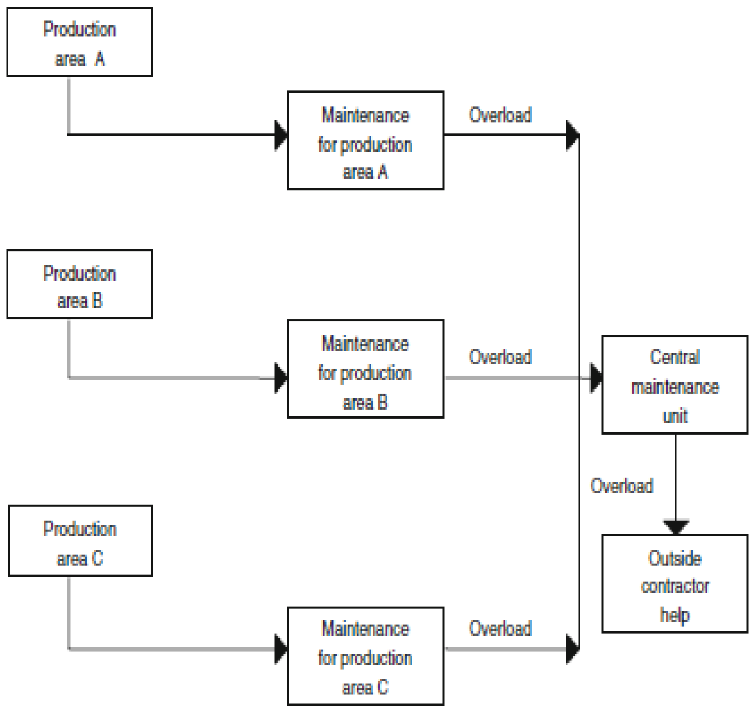
Maintenance load forecasting is the process by which the maintenance load is predicted. The maintenance load in a given plant varies randomly and, among other factors, can be a function of the age of the equipment, the rate of its use, maintenance quality, climatic factors, and skills of maintenance craftsmen. Maintenance load forecasting is essential for achieving a desired level of effectiveness and resource utilization, and without it, many maintenance functions cannot be performed well.

Maintenance Capacity Planning:

Maintenance capacity planning determines the resources needed to meet the demand for maintenance work. Those resources include manpower, material, spare parts, equipment, and tools. Critical aspects of maintenance capacity are the numbers and skills of the craftsmen, required maintenance tools, etc. Since the maintenance load is a random variable, the exact number of various types of craftsmen cannot be determined. Therefore, without reasonably accurate forecasts for the future maintenance work demand, it would not be possible to do proper long-range capacity planning. In order to have better utilization of manpower, organizations tend to reduce the number of available craftsmen than their expected need. This is likely to result in the backlog of uncompleted maintenance work. This can be completed by letting the existing craftsmen work overtime or by seeking outside contractor assistance. This backlog can also be cleared when the maintenance load is less than the capacity. This is actually the main reason for keeping a backlog. Making long-run estimations is one of the areas in maintenance capacity planning that is both critical and not well developed.

Maintenance Organization:

Many factors influence maintenance organization. The factors include plant size, maintenance load, type of organization, and craftsmen skills. Based on these factors and other, maintenance may be organized on departmental, area, or central basis. Each type of organization has its pros and cons. In large organizations, decentralization of maintenance can produce quicker response time and can allow the craftsmen to become more experienced on the problems of a particular section of the plant. However, the creation of a number of small units tends to reduce the flexibility of the maintenance system as a whole. The range of skills available becomes reduced, and manpower utilization is usually less than that in a centralized maintenance unit. In some cases, a compromise solution is possible which is called a cascade system. This system enables production area maintenance units to be linked to the central maintenance unit..



Cascade system

Maintenance Scheduling:

Maintenance scheduling is the process of assigning resources and manpower to jobs to be accomplished at certain times. It is necessary to ensure that the needed craftsmen, the parts, and the materials required are available before a maintenance task can be scheduled. Critical equipment in a plant, are those whose failure will shut down the production process or endanger human life and safety. Maintenance work pertaining to such equipment is treated on a priority basis and is attended to before any other job is undertaken. Occurrences of such jobs cannot be predicted with certainty, and as such, the schedules for planned maintenance in these instances have to be revised. The effectiveness of a maintenance system is influenced by the maintenance schedule developed and its ability to accommodate changes. A high level of maintenance schedule effectiveness is indicative of a high level of maintenance effectiveness.

Organizing and Designing Activities:

Organizing and designing a maintenance system includes the following:

1. Job design

2. Standards

3. Project management.

Maintenance systems are known to be driven by the work load that is issued by the production or operation department as work request. The work requests are planned, executed, and controlled by a work order system. The work orders describe the work, its location, the crafts needed, and the priority of the job.

Job Design

Job design, as related to maintenance work, comprises the work content of each job and determines the method that is to be used, the special tools needed, and the skilled persons required. If the design is standardized, it becomes a standard job.

Time Standards

Once the maintenance task goes through the job design stage, it is necessary to estimate the time needed for completing the job Niebel . Realistic time standards go a long way in monitoring and increasing effectiveness of craftsmen, thus minimizing the plant downtime. It is not essential to have standards for all the maintenance jobs. It is noticed that twenty percent of the maintenance jobs take approximately eighty percent of the time available for maintenance workforce. Efforts should be made to have time standards developed for such time-consuming jobs. It should be obvious that job time standards are needed for maintenance load forecasting, capacity planning, and developing maintenance schedules.

Project Management

Planned major overhauls and preventive maintenance service are periodically carried out in most of the large plants. During this period, the entire plant or part of the plant is shut down. It is advantageous to plan and chart the work in order to minimize the downtime and make the best use of resources. Project management involves developing networks of activities and then using techniques such as the critical path method (CPM) or program evaluation and review technique (PERT). Once the network has been developed which includes work breakdown, job sequence, and time estimates for each activity, computer software such Primavera may be used for scheduling the activities and determining the best utilization of resources for more on maintenance planning and scheduling see . A control phase of such a project includes measuring progress regularly, comparing it with the schedule, and analyzing the variance as a percentage of the total work. Corrective actions can be taken to eliminate the shortcomings.

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Control Activities

Control is an essential part of scientific management. Control as applied to a maintenance system includes the following activities:

1. Work control
2. Inventory control
3. Cost control
4. Quality control.

Work Control

The maintenance system is driven by demand for maintenance work. The maintenance work load is greatly influenced by the maintenance strategies. The management and control of the maintenance work is essential for achieving set plans. The work order system is the tool used for controlling the maintenance work. A well-designed work order with a sound reporting system is the heart of the maintenance system.

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Inventory Control:

It has been previously stated that for scheduling a maintenance work, it is essential to assure that required spares and material are available. It is physically impossible and economically impractical for each spare to arrive exactly when and where it is needed. For these reasons, inventories are maintained. Inventory control is the technique of maintaining spares and materials at desired levels. It is essential that an optimal level of spares be maintained, which minimizes the cost of holding the item in stock and costs incurred if the spares are not available. It also provides the information needed to ascertain the availability of the required spares for a maintenance work. If the spares are not available, then the action has to be taken to procure the spares and inform the scheduling department when the needed spares become available. Spare parts provisioning and inventory control techniques are discussed below

Cost Control:

The maintenance cost has many components, which are direct maintenance lost production, equipment degradation, backups, and over maintenance costs. Maintenance cost control is a function of the maintenance philosophy, operation pattern, type of system, and procedures and standards adopted by the organization. It is a major component in the equipment life cycle. The control of maintenance cost optimizes all the costs in maintenance, while achieving set organizational objectives such as availability, "quality rate," and other efficiency and effectiveness measures. Cost reduction and control can be used as an edge for competition in providing products and services.

Quality Control:

In the production process, quality of the output may be considered as fitness for use and "quality is doing it right the first time." Quality control is exercised by measuring the attributes of the product or service and comparing the same with the product or service specifications, respectively. Maintenance can also be viewed as a process, and the quality of its output can be controlled. In the case of maintenance work, "doing it right the first time" is very essential. Quality may be assessed as the percentage of accepted maintenance jobs according to the standard adopted by the organization. High quality is usually assured by checking the critical maintenance jobs or by maintenance supervision

Managing for Quality and Training:

Managing for quality is a managerial responsibility. Usually, maintenance managers/engineers are not fully aware of the importance of improving maintenance production quality. The key for managing for quality lies first in the awareness of the need to improve and second in selecting appropriate improvement techniques. Craftsmen performing substandard maintenance work must be identified. This can be achieved by keeping track of repeat jobs by a given craftsman. Further analysis can be carried out to locate the cause(s) of such substandard work. The likely reasons are non-availability of special tools, craftsman not possessing the needed skill level or poor supervision, etc. Eradicating such causes and monitoring the maintenance work completed can result in improved maintenance production quality. A forecast of new technologies/processes to be acquired by the company should be made, and craftsmen should be trained ahead of the arrival of the equipment in question.

Classification of maintenance programs:

Maintenance work can be divided into two broad categories: planned and unplanned work. Planned work implies that, all resources necessary to accomplish the tasks have been preplanned and are available and, the work is to be performed according to a set schedule. Unplanned work may have a set of standard instructions available, may have the necessary skills and parts nearby, or may be slotted into a maintenance schedule on an adhoc basis, but does not meet both the preplanned and prescheduled criteria. Planned maintenance refers to maintenance work that is performed with advance planning, foresight, control, and records. Preventive maintenance (PM) is a series of preplanned tasks performed to counteract known causes of potential failures of those functions. It is carried out to ensure equipment availability and reliability. Equipment availability can be defined as the probability of equipment being able to operate whenever needed. The equipment reliability is the probability that the equipment will be functioning at time t þ Dt, given that it was functioning at time t. Preventive maintenance is considered as "planned" work, the distribution by craft hours in a well run industrial maintenance facility is expected to be as described in figure 1(a)

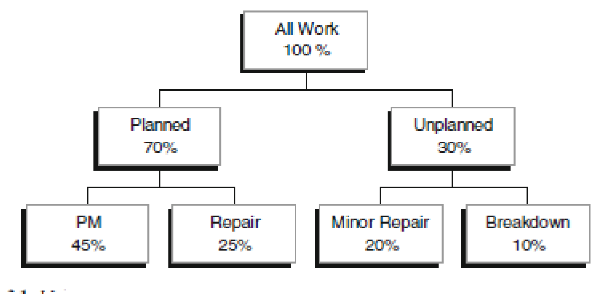

fig 1(a)

Preventive maintenance can be conditioned based or based on the historical data of equipment failure. Figure 1(b)shows a makeup of preventive maintenance. It consists of two categories; these are statistical and reliability based or condition

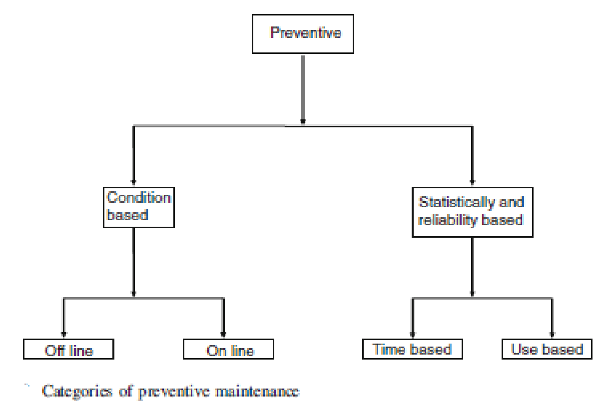

fig 1(b)

The first category is based on data obtained from the equipment historical record. The second category is based on the equipment performance and condition.

<u>Preventive Maintenance</u>:

PM is defined as a series of preplanned tasks performed to counteract known causes of potential failures of the intended functions of an asset. It can be planned and scheduled based on time, use, or equipment condition. It is the preferred approach relative to breakdown maintenance, for four primary reasons:

• The frequency of premature failures can be reduced through proper lubrication, adjustments, cleaning, and inspections triggered by performance measurement.

• If the failure cannot be prevented, periodic inspection and measurement can help to reduce the severity of the failure and its possible domino effect on other components of the equipment and thereby mitigate the negative consequences to safety, the environment, or production throughput.

• Where we can monitor the gradual degradation of a function or parameter, such as product quality or machine vibration, a warning of impending failure may be detected.

• Finally, because an unplanned interruption is often extremely damaging to production schedules and output, and the actual cost of an emergency breakdown is higher than a planned one, and the quality of repair can suffer under the pressure of an emergency, preventive maintenance is preferred to unplanned maintenance.

The most critical question in preventive maintenance is what task or series of tasks should be performed to prevent failure. Clearly, if we understand the actual failure mechanism of the equipment, we can then decide what tasks are logical to prevent failure and which ones are irrelevant. If the PM program requires changing the headlights on an automobile each month, will that have an impact on the failure rate? Most likely not, because the failure mechanism is not related to time, but to other variables, such as the distance, the car is driven behind a large truck on a gravel road.If the dominant failure mechanism is time based or wear, i.e., if the probability of a failure gradually increases with time, age, or usage, then the maintenance tasks may be time based. If however, the probability of a failure is constant regardless of time, age, or usage, and there is a gradual degradation from the onset of failure, then the maintenance tasks may be condition based. Time-based tasks are warranted if the periodic restoration or component replacement restores the equipment to perform its intended function. This task could range in complexity from a comprehensive overhaul of the entire unit to a simple job such as a filter replacement. Condition-based tasks, warranted when the failure prevention approach is unknown, focus on measuring a parameter which indicates a deterioration or degradation in the functional performance of the equipment. The measurements and inspections themselves may be regularly scheduled, but the restorative or preventive tasks are not. These measures can be related directly to the machine operations, such as vibration, running temperature, amperage drawn, the lubricating oil contaminants, or noise level, or can be a surrogate measure of machine

operation, such as the product quality, its dimensions, wear patterns, or composition. The actual failure distributions, or conditional probability of failure curves, have been developed most extensively for equipment systems and components in the airline industry. These studies suggest that the predominant patterns show a constant probability of failure with age, with the exception of “infant mortality” or failure in the earliest period after commissioning. Therefore, when equipment is new—or recently overhauled—it exhibits a probability of failure higher than at a later period. This is attributed to possible design, manufacture, overhaul or installation errors, or inappropriate initial operating and maintenance procedures. Once these are corrected, failure is virtually unrelated to age. If we look at rolling bearings as an example, only a small percentage of bearings actually fail in service, but usually outlive their host equipment. Most bearing failures occur because of poor or improper lubrication, solid or liquid contaminants entering the bearing, or because of improper handling or mounting. When bearings are properly handled, mounted, aligned, lubricated, sealed, and kept from extreme temperatures, their predominant failure mode is fatigue—old age. Therefore, non-intrusive condition-based preventive maintenance is the logical choice for monitoring bearings—oil analysis, vibration, temperature, or noise. Time-based maintenance, e.g., overhauls, is technically feasible if the item has an average identifiable life. Most items survive to that age and the action restores the item's condition to its desired function. CBM is technically feasible if it is possible to detect degraded conditions or performance, there is a practical inspection interval, and the time interval (from the inspection to the functional failure) is long enough to allow corrective actions or repairs. Because complex equipment and components will have several plausible failure causes, it is necessary to develop a series of preventive maintenance actions—some condition-based and some time-based for the same equipment—and to consolidate these into a PM program

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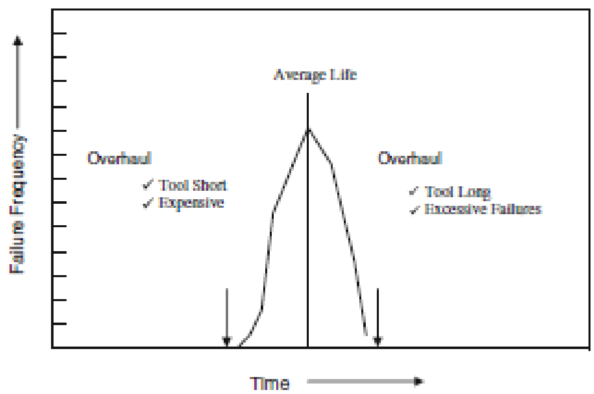

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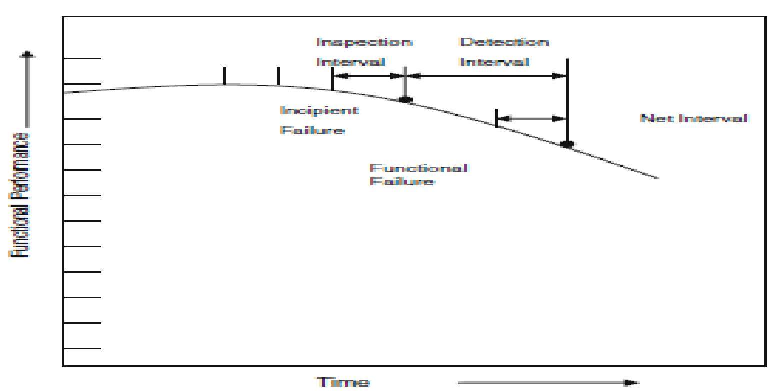
Time-based overhaul

The program will have tasks grouped by periodicity, i.e.



Condition-based maintenance

daily, weekly, annually, operating hours, and cycles, and grouped by trade, mechanic, electrician, operator, and technician Preventive maintenance is the prime requirement to reduce the frequency and severity of equipment breakdowns. Three broad measures are used to monitor the comprehensiveness of the PM program:

- PM coverage—the percentage of critical equipment for which PM has been developed
- PM compliance—the percentage of PM routines that have been completed according to their schedule
- Work generated from PM routines—the number of maintenance actions that have been requested originating from the PM routines.

Elements of Planned Maintenance

Planned maintenance refers to maintenance work that is performed with advance planning, foresight, control, and records. It includes the whole range of maintenance, and it applies to replacement, preventive, and breakdown strategies. It is characterized by the following:

- The maintenance policy has been stated carefully.
- The application of the policy is planned in advance.
- The work is controlled to confirm the original plan.
- Data are collected, analyzed, and used to provide direction for future maintenance policies.

In this section, the steps for developing a planned maintenance program are presented.

Plan Administration

The first step toward developing a comprehensive planned maintenance program is to put together a task group that initiates and develops the plan. A single person should be appointed to head the task group, and management commitment is essential for the plan. After announcing the plan and forming the necessary organization for it, the task group should embark on putting together the program.

Facility Inventory

The facility inventory is a list of all facilities including all equipment in a site. It is made for the purpose of identification. An inventory file of all equipment should be developed showing equipment identification, description of facility, location, type, and priority (importance).

Identification of Equipment

It is essential to develop a system by which each equipment is identified uniquely. A coding system that helps in this identification process should be established. The code should indicate location, machine type, and machine number. This coding system should differ from plant to plant, and its design should reflect the nature of the facility.

The Facility Register

The facility register is a file (electronic or hard copy) including technical detail about items that are included in the maintenance plan. These data are the first to be fed to the maintenance information system. The equipment (item) record should include an identification number, location, type of equipment, manufacturer, date of manufacturing, serial number, specification, size, capacity, speed, weight, power service requirement, connection details, foundation detail, overall dimension, clearance, reference drawing number, reference number for service manuals, and interchangeability with other units.

Maintenance Schedule

A maintenance schedule must be developed for each equipment in the program. The schedule is a comprehensive list of maintenance tasks to be carried on the equipment. The schedule includes the name and identification number of the equipment, location, reference number of the schedule, detailed list of tasks to be carried out (inspections, preventive maintenance, replacements), the frequency of each task, the crafts needed to carry out the task, time for each task, special tools needed, material needed, and details of any contract maintenance arrangements.

Job Specification

The job specification is a document describing the procedure for each task. It is intended to provide the details of each task in the maintenance schedule. The job specification should indicate the identification number of the item (equipment), the location of the item, the maintenance schedule reference, the job specification reference number, the frequency of the job, crafts required for the job, the details of the task, components to be replaced, special tools and equipment needed, reference drawings, and manuals and safety procedures to be followed.

The Maintenance Program

The maintenance program is a list allocating maintenance tasks to specific time periods. When developing the maintenance program, a great deal of coordination must be done in order to balance the workload and meet production requirements. This is the stage at which the planned maintenance is scheduled for execution.

Program Control

The maintenance program developed must be executed as planned. Close monitoring is needed in order to observe any deviation from the schedule. If deviations are observed, a control action is needed.

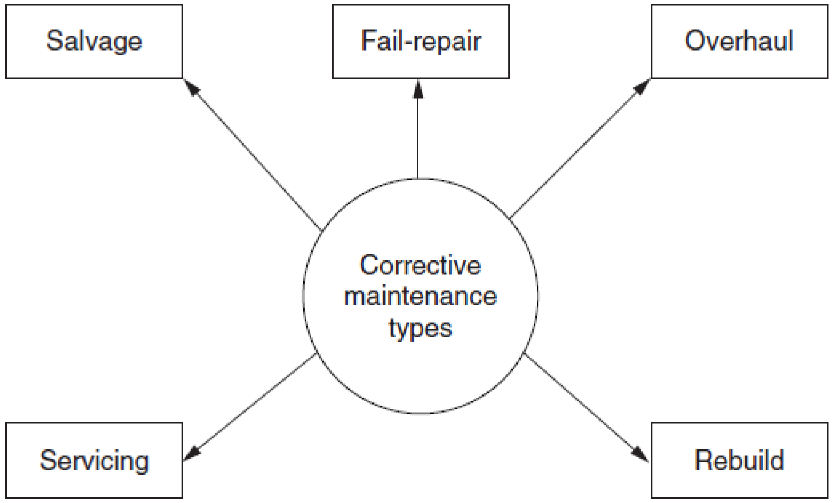
Corrective maintenance:

Although every effort is made to make engineering systems as reliable as possible through design, preventive maintenance, and so on, from time to time they do fail. Consequently, they are repaired to their operational state. Thus, repair or corrective maintenance is an important component of maintenance activity. Corrective maintenance may be defined as the remedial action carried out due to failure or deficiencies discovered during preventive maintenance, to repair an equipment/item to its operational state. Usually, corrective maintenance is an unscheduled maintenance action, basically composed of unpredictable maintenance needs that cannot be preplanned or programmed on the basis of occurrence at a particular time. The action requires urgent attention that must be added, integrated with, or substituted for previously scheduled work items. This incorporates compliance with “prompt action” field changes, rectification of deficiencies found during equipment/item operation, and performance of repair actions due to incidents or accidents.

A substantial part of overall maintenance effort is devoted to corrective maintenance, and over the years many individuals have contributed to the area of corrective maintenance. This chapter presents some important aspects of corrective maintenance.

CORRECTIVE MAINTENANCE TYPES

Corrective maintenance may be classified into five major categories as shown in below figure



These are: fail-repair, salvage, rebuild, overhaul, and servicing. These categories are described below.

1.*Fail-repair:*

The failed item is restored to its operational state.

2.*Salvage:*

This element of corrective maintenance is concerned with disposal of non repairable material and use of salvaged material from non repairable equipment/item in the repair, overhaul, or rebuild programs.

3.*Rebuild:*

This is concerned with restoring an item to a standard as close as possible to original state in performance, life expectancy, and appearance. This is achieved through complete disassembly, examination of all components, repair and replacement of worn/unserviceable parts as per original specifications and manufacturing tolerances, and reassembly and testing to original production guidelines.