Unit-2

Maintenance Management

2.1 Maintenance Management

The management and control of maintenance activities are equally important to performing maintenance. Maintenance management may be described as the function of providing policy guidance for maintenance activities, in addition to exercising technical and management control of maintenance programs. Generally, as the size of the maintenance activity and group increases, the need for better management and control become essential. In the past, the typical size of a maintenance group in a manufacturing establishment varied from 5 to 10% of the operating force. Today, the proportional size of the maintenance effort compared to the operating group has increased significantly, and this increase is expected to continue. The prime factor behind this trend is the tendency in industry to increase the mechanization and automation of many processes. Consequently, this means lesser need for operators but greater requirement for maintenance personnel. There are many areas of maintenance management and control.

2.1.1 Maintenance Department Functions And Organization

A maintenance department is expected to perform a wide range of functions including:

- Planning and repairing equipment/facilities to acceptable standards
- Performing preventive maintenance; more specifically, developing and implementing a regularly scheduled work program for the purpose of maintaining satisfactory equipment/facility operation as well as preventing major problems
- Preparing realistic budgets that detail maintenance personnel and material needs
- Managing inventory to ensure that parts/materials necessary to conduct maintenance tasks are readily available
- Keeping records on equipment, services, etc. Developing effective approaches to monitor the activities of maintenance staff

- Developing effective techniques for keeping operations personnel, upper-level management, and other concerned groups aware of maintenance activities
- Training maintenance staff and other concerned individuals to improve their skills and perform effectively
- Reviewing plans for new facilities, installation of new equipment, etc.
- Implementing methods to improve workplace safety and developing safety education-related programs for maintenance staff
- Developing contract specifications and inspecting work performed by contractors to ensure compliance with contractual requirements Many factors determine the place of maintenance in the plant organization including size, complexity, and product produced. The four guidelines useful in planning a maintenance organization are: establish reasonably clear division of authority with minimal overlap, optimize number of persons reporting to an individual, fit the organization to the personalities involved, and keep vertical lines of authority and responsibility as short as possible.

One of the first considerations in planning a maintenance organization is to decide whether it is advantageous to have a centralized or decentralized maintenance function. Generally, centralized maintenance serves well in small- and medium-sized enterprises housed in one structure, or service buildings located in an immediate geographic area. Some of the benefits and drawbacks of centralized maintenance are as follows:

Benefits

- More efficient compared to decentralized maintenance
- Fewer maintenance personnel required
- More effective line supervision
- Greater use of special equipment and specialized maintenance persons
- Permits procurement of more modern facilities
- Generally allows more effective on-the-job training Drawbacks
- Requires more time getting to and from the work area or job
- No one individual becomes totally familiar with complex hardware or equipment
- More difficult supervision because of remoteness of maintenance site from the centralized headquarters
- Higher transportation cost due to remote maintenance work In the case of decentralized maintenance, a maintenance group is assigned to a particular area or unit. Some important reasons for the decentralized maintenance are to reduce travel time to and from maintenance jobs, a spirit of cooperation between production and maintenance workers, usually closer supervision, and higher chances for maintenance personnel to become familiar with sophisticated equipment or

facilities. Past experience indicates that in large plants a combination of centralized and decentralized maintenance normally works best. The main reason is that the benefits of both the systems can be achieved with essentially a low number of drawbacks. Nonetheless, no one particular type of maintenance organization is useful for all types of enterprises.

2.1.2 Maintenance Management By Objectives &Principles

Improving a maintenance management program is a continuous process that requires progressive attitudes and active involvement. A nine-step approach for managing a maintenance program effectively is presented below:

• ***Identify existing deficiencies.***

This can be accomplished through interviews with maintenance personnel and by examining in-house performance indicators.

• ***Set maintenance goals.***

These goals take into consideration existing deficiencies and identify targets for improvement.

• ***Establish priorities.***

List maintenance projects in order of savings or merit.

• ***Establish performance measurement parameters.***

Develop a quantifiable measurement for each set goal, for example, number of jobs completed per week and percentage of cost on repair.

• ***Establish short- and long-range plans.***

The short-range plan focuses on high-priority goals, usually within a one-year period. The long-range plan is more strategic in nature and identifies important goals to be reached within three to five years.

• *Document both long- and short-range plans and forward copies to all concerned individuals.*

• *Implement plan.*

• *Report status.*

Preparing a brief report periodically, say semi-annually, and forward it to all involved individuals. The report contains for each objective identified in the short-range plan information on actual or potential slippage of the schedule and associated causes.

• *Examine progress annually.*

Review progress at the end of each year with respect to stated goals. Develop a new short-range plan for the following year by considering the goals identified in the long-range plan and adjustments made to the previous year's planned schedule, resources, costs, and so on. Over the years many maintenance management principles have been developed.

2.1.3 Elements Of Effective Maintenance Management

There are many elements of effective maintenance management whose effectiveness is the key to the overall success of the maintenance activity. Many of these elements are described below.

a) **MAINTENANCE POLICY**

A maintenance policy is one of the most important elements of effective maintenance management. It is essential for continuity of operations and a clear understanding of the maintenance management program, regardless of the size of a maintenance organization. Usually, maintenance organizations have manuals containing items such as policies, programs, objectives, responsibilities, and authorities for all levels of supervision, reporting requirements, useful methods and techniques, and performance measurement indices. Lacking such documentation, i.e., a policy manual, a policy document must be developed containing all essential policy information.

b) **MATERIAL CONTROL**

Past experience indicates that, on average, material costs account for approximately 30 to 40% of total direct maintenance costs. Efficient utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead to false starts, excess travel time, delays, unmet due dates, etc. Steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance of materials, and reviewing the completed job can help reduce material related problems. Deciding whether to keep spares in storage is one of the most important problems of material control.

c) **WORK ORDER SYSTEM**

A work order authorizes and directs an individual or a group to perform a given task. A well-defined work order system should cover all the maintenance jobs requested and accomplished, whether repetitive or one-time jobs. The work order system is useful for management in controlling costs and evaluating job performance. Although the type and size of the work order can vary from one maintenance organization to another, a work order should at least contain information such as requested and planned completion dates, work description and its reasons, planned start date, labor and material costs, item or items to be affected, work category (preventive maintenance, repair, installation, etc.), and appropriate approval signatures.

d) **EQUIPMENT RECORDS**

Equipment records play a critical role in effectiveness and efficiency of the maintenance organization. Usually, equipment records are grouped under four classifications: maintenance work performed, maintenance cost, inventory, and files. The maintenance work performed category contains chronological documentation of all repairs and preventive maintenance (PM) performed during the item's service life to date. The maintenance cost category contains historical profiles and accumulations of labor and material costs by item. Usually, information on inventory is provided by the stores or accounting department. The inventory category contains

Information such as property number, size and type, procurement cost, date manufactured or acquired manufacturer, and location of the equipment/item. The files category includes operating and service manuals, warranties, drawings, and so on. Equipment records are useful when procuring new items/equipment to determine operating performance trends, troubleshooting breakdowns, making replacement or modification decisions, investigating incidents, identifying areas of concern, performing reliability and maintainability studies, and conducting life cycle cost and design studies.

e) PREVENTIVE AND CORRECTIVE MAINTENANCE

The basic purpose of performing PM is to keep facility/equipment in satisfactory Condition through inspection and correction of early-stage deficiencies. Three principles factors shape the requirement and scope of the PM effort: process reliability, economics, and standards compliance. A major proportion of a maintenance organization's effort is spent on corrective Maintenance (CM). Thus, CM is an important factor in the effectiveness of maintenance Organization.

f) JOB PLANNING AND SCHEDULING

Job planning is an essential element of the effective maintenance management. A Number of tasks may have to be performed prior to commencement of a maintenance job; for example, procurement of parts, tools, and materials, coordination and delivery of parts, tools, and materials, identification of methods and sequencing, coordination with other departments, and securing safety permits.

Although the degree of planning required may vary with the craft involved and methods used, past experience indicates that on average one planner is required for every twenty craft persons. Strictly speaking, formal planning should cover 100% of the maintenance workload but emergency jobs and small, straightforward work assignments are performed in a less formal environment. Thus, in most maintenance organizations 80 to 85% planning coverage is attainable. Maintenance scheduling is as important as job planning. Schedule effectiveness is based on the reliability of the planning function. For large jobs, in particular those requiring multi-craft coordination, serious consideration must be given to using methods such as Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) to assure effective overall control.

g) BACKLOG CONTROL AND PRIORITY SYSTEM

The amount of backlog within a maintenance organization is one of the determining factors of maintenance management effectiveness. Identification of backlogs is important to balance manpower and workload requirements. Furthermore, decisions concerning overtime, hiring, subcontracting, shop assignments, etc., are largely based on backlog information. Management makes use of various indices to make backlog related decisions.

The determination of job priority in a maintenance organization is necessary since it is not possible to start every job the day it is requested. In assigning job priorities, it is important to consider factors such as importance of the item or system, the type of maintenance, required due dates, and the length of time the job awaiting scheduling will take.

h) PERFORMANCE MEASUREMENT

Successful maintenance organizations regularly measure their performance through

Various means. Performance analyses contribute to maintenance department efficiency and are essential to revealing the downtime of equipment, peculiarities in operational behavior of the concerned organization, developing plans for future maintenance, and so on. Various types of performance indices for use by the maintenance management are discussed later in this chapter.

2.3 Planned/Scheduled/Productive Maintenance

Planned maintenance is the activities carried out according to a predetermined schedule and hence known as scheduled maintenance or productive maintenance. It involves inspection of all machineries, overhaul, lubricate, repair and carry out all requisite maintenance before actual break down happens, thus avoiding a situation of emergency maintenance. Planned maintenance reduces the machine downtime, reduces the cost of maintenance increases productivity as compared to unplanned one and hence it is followed as per the maintenance policy of the company.

In this type of service, the emphasis is on machines:

(a) What does the manufacturer prescribe?

(b) Is the unit utilized for two or three shifts per day?

(c) Is it working under normal load?

(d) Are the conditions as good as those envisaged by the manufacturer?

(e) Do we allow for extra attention owing to corrosion-including conditions?

2.3.1 Characteristics of Planned Maintenance

- Instructions are more detailed than in routine maintenance.
- Calls for differently timed service for the same unit. Schedule is drawn with dates. Establishes the work-load for the crew.

- Entails considerable planning effort, faithful implementation and recording.
- Initial list of planned maintenance will be in detail.

2.3.2 Advantages of Planned Maintenance

Considers all the changes in conditions of use & increased wear of parts-

(i) Inspections, replacement of parts, adjustments is shown in overall plan.

(ii) Detailed instructions reduce the chance of missing any activity. Unforeseen work is reduced.

(iii) Provides as much attention on the equipment for the best judgment of the planner.

2.4 Breakdown Maintenance

Breakdown maintenance is also referred as repair maintenance. The basic concept behind the breakdown maintenance is to wait until the equipment fails, and then repair it on failure. The equipment is allowed to run till it become inoperative and no efforts are made in advance to prevent the failure of parts. This strategy is implemented basically when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost.

In most cases, there is no maintenance man available and no service is required except a little bit of cleaning and lubrication which is done by the worker himself. Also in this system neither any spare parts are kept nor are any maintenance manuals kept for reference.

Although, this strategy appears to be economical, but the work may suffer if the spare parts are not readily available and the machine is not restored to its operational condition immediately. Also, in this type of maintenance any effort is not made to know the cause of breakdown, which may lead to frequent failures in future.

When equipment breaks down or malfunctions, so that normal production activities cannot be continued, then production department calls on the maintenance department to rectify the defects. Maintenance department immediately attends to the equipment, checks it and does necessary repairs. After necessary repairs, the equipment/plant is handed over to production department. Such type of maintenance, which is unpredictable, is called breakdown maintenance.

2.4.1 Typical Causes Of Equipment Breakdown

(i) Lack of lubrication

(ii) Improper cooling system

(iii) Indifference towards minor faults.

(iv) In difference towards: Equipment vibrations, unusual sound coming out from the machine, excessive heating of equipment.

(v) Failure to replace worn out parts.

(vi) External factors/such as heavy voltage fluctuations.

2.4.2 Breakdown maintenance may be justified when:

(i) In small factories where shut down of plant does not involve high cost.

(ii) A machine breakdown does not create critical delays.

(iii) Back up equipment is readily available.

(iv) A breakdown does not cause further damage to the equipment.

(v) Breakdown maintenance is economical.

(vi) There is no planned interference with productive programmes.

2.4.3 Disadvantages Of Breakdown Maintenance

(i) Break down generally occurs at the inappropriate times. This leads to poor, hurried maintenance and excessive delays in production.

(ii) Reduction of output.

(iii) After the breakdown, maintenance staff and spares are arranged, which increase down time.

(iv) Faster plant detonation.

(v) Increased chances of accidents, hence less safety to both workers and machines.

(vi) More material spoilage.

(vii) Direct loss of profit.

(viii) Breakdown maintenance cannot be employed for those plant items, which are regulated by statutory provision, for example cranes, lift hoists and pressure vessels.

(ix) As there is no record of maintenance and there is no maintenance budget, therefore repair charges are to be paid form works payment. This may put crisis in works budget.

Hence we can see that breakdown maintenance is not a good system. Some-times it may lead to heavy damage to equipments. Therefore it cannot be adopted for plants or machines, whose down time costs are high.

2.4.4 Break Down of Corrective/Remedial Maintenance

Breakdown Maintenance is the method of operating the machines to run until they fail and then repair in order to restore them to an acceptable condition. Planned repair/rectifying the problem is carried out when it is more convenient and cost effective after its failure rather than to disrupt the production with RM. Also called as on-failure maintenance/corrective maintenance, can be defined as the maintenance which is required when an item has failed or worn out, to bring it back to working order. Corrective maintenance is carried out on all items where the consequences of failure or wearing out are not significant and the cost of corrective maintenance is not greater than preventative maintenance.

Corrective maintenance may be programmed. On-failure maintenance can be effective if applied correctly. For example: non-critical low cost equipment, or where nor other strategy will work. Repair is restoring an asset by replacing a part which is broken or damage, or reconditioning that part to its original or acceptable working condition. The need for repairs can result from normal wear, vandalism, misuse or improper maintenance. Here the machine and the work on that machine stops operating. Repairs are done after the machine fails and hence this becomes a repair work. Ex: electric motor may not start drive shaft broken and hence the transmission fails, etc. The above type of repairing and setting the equipment to working condition can be called as corrective maintenance. Corrective maintenance activities include both emergency repairs (fire fighting) and preventive (or corrective) repairs. This system could be called as 'Operate to Failure (OTP)'-no predetermined action taken to prevent failure, i.e. taken after the failure happens. This method is expensive in terms of maintenance cost, increased downtime, lost output involve hazards, upset schedule resulting in panicky, Frayed tempers put unnecessary pressures and disturb delivery commitments.

2.4.5 Characteristics of Break-down Maintenance System

- No services except occasional lubrication unless failure occurs.
- No maintenance men on regular basis.
- Maintenance done by sub-contractors.
- No organized efforts to find out reasons.
- No stock of spares. No budget.
- No records.
- Initially it looks economical.
- Creates internal problems namely: who to do the repair? From where to get parts? How do we pay for them? Who will go & buy parts?

2.4.6 Objectives of BD/Corrective Maintenance

- To put back machinery back to work and minimize production interruptions.
- To control costs of maintenance crew to the minimum.
- To control cost of the operations of repairing.
- To control costs of repair & replacement parts to minimum.
- To control investment cost on purchase of standby or back up machines.
- To carry out appropriate repair intermittently at each malfunction to improve the life of the machine.

Advantages

- Low cost if correctly applied.
- Requires no advanced planning other than ensuring spares availability.

Disadvantages

- No warning of failure – safety risk.
- Uncontrolled plant outage – production losses.
- Requires large standby maintenance team.
- Secondary damage – longer repair time.
- Large spares stock requirement.
- Provision of standby plant.

2.5 Preventive Maintenance

Preventive maintenance (PM) is an important component of a maintenance activity. Within a maintenance organization it usually accounts for a major proportion of the total maintenance effort. PM may be described as the care and servicing by individuals involved with maintenance to keep equipment/facilities in satisfactory operational state by providing for systematic inspection, detection, and correction of incipient failures either prior to their occurrence or prior to their development into major failure. Some of the main objectives of PM are to: enhance capital equipment productive life, reduce critical equipment breakdowns, allow better planning and scheduling of needed maintenance work, minimize production losses due to equipment failures, and promote health and safety of maintenance personnel. From time to time PM programs in maintenance organizations end up in failure (i.e., they lose upper management support) because their cost is either unjustifiable or they take a significant time to show results. It is emphasized that all PM must be cost-effective. The most important principle to keep continuous management support is: "If it is not going to save money, then don't do it!" This chapter presents important aspects of PM.

2.5.1 Preventive Maintenance Elements, Plant Characteristics In Need Of A Pm Program, And A Principle For Selecting Items For Pm

There are seven elements of PM as shown in Fig.

Each element is discussed below.

1. *Inspection:* Periodically inspecting materials/items to determine their serviceability by comparing their physical, electrical, mechanical, etc., characteristics (as applicable) to expected standards
2. *Servicing:* Cleaning, lubricating, charging, preservation, etc., of items/ materials periodically to prevent the occurrence of incipient failures
3. *Calibration:* Periodically determining the value of characteristics of an item by comparison to a standard; it consists of the comparison of two instruments, one of which is certified standard with known accuracy, to detect and adjust any discrepancy in the accuracy of the material/parameter being compared to the established standard value

4 . *Testing:* Periodically testing or checking out to determine serviceability and detect electrical/mechanical-related degradation

5. *Alignment:* Making changes to an item's specified variable elements for the purpose of achieving optimum performance

6. *Adjustment:* Periodically adjusting specified variable elements of material for the purpose of achieving the optimum system performance

7. *Installation:* Periodic replacement of limited-life items or the items experiencing time cycle or wear degradation, to maintain the specified system tolerance Some characteristics of a plant in need of a good preventive maintenance program are as follows:

- Low equipment use due to failures
- Large volume of scrap and rejects due to unreliable equipment
- Rise in equipment repair costs due to negligence in areas such as regular lubrication, inspection, and replacement of worn items/components
- High idle operator times due to equipment failures
- Reduction in capital equipment expected productive life due to unsatisfactory maintenance program within an organization.

The answer "yes" or "no" to each question is given 5 or 0 points, respectively. A "maybe" answer is assigned a score from 1 to 4. A total score of less than 55 points indicates that the preventive maintenance program requires further improvements.

2.5.2 Elements of preventive maintenance.

- Servicing
- Alignment
- Testing
- Inspection
- Calibration Installation
- Adjustment

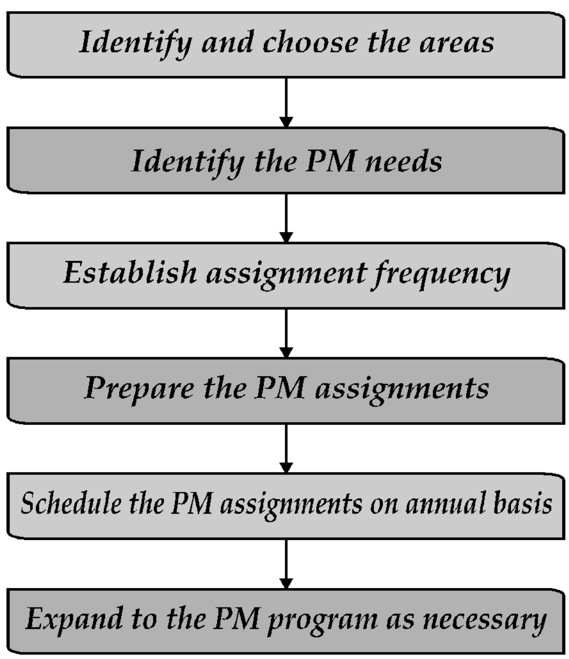
2.5.3 Important Steps For Establishing A Pm Program

To develop an effective PM program, the availability of a number of items is necessary. Some of those items include accurate historical records of equipment, manufacturer's recommendations, skilled personnel, past data from similar equipment, service manuals, unique identification of all equipment, appropriate test instruments and tools, management support and user cooperation, failure information by problem/cause/ action, consumables and replaceable components/parts, and clearly written instructions with a checklist to be signed off.

There are a number of steps involved in developing a PM program. presents six steps for establishing a highly effective PM program in a short period.

Each step is discussed below.

1. ***Identify and choose the areas.*** Identify and selection of one or two important areas to concentrate the initial PM effort. These areas should be crucial to the success of overall plant operations and may be experiencing a high degree of maintenance actions. The main objective of this step is to obtain immediate results in highly visible areas, as well as to win concerned management support.
2. ***Identify the PM needs.*** Define the PM requirements. Then, establish a schedule of two types of tasks: daily PM inspections and periodic PM assignments. The daily PM inspections could be conducted by either maintenance or production personnel. An example of a daily PM inspection is to check the waste water settle able solids concentration. Periodic PM assignments usually are performed by the maintenance workers. Examples of such assignments are replacing throwaway filters, replacing drive belts, and cleaning steam traps and permanent filters.
3. ***Establish assignment frequency.*** Establish the frequency of the assignments. This involves reviewing the equipment condition and records. Normally, the basis for establishing the frequency is the experience of those familiar with the equipment and the recommendations of vendors and engineering. It must be remembered that vendor recommendations are generally based on the typical usage of items under consideration.



4. ***Prepare the PM assignments.*** Daily and periodic assignments are identified and described in detail, then submitted for approval.
5. ***Schedule the PM assignments on annual basis.*** The defined PM assignments are scheduled on the basis of a twelve-month period.
6. ***Expand the PM program as necessary.*** After the implementation of all PM daily inspections and periodic assignments in the initially selected areas, the PM can be expanded to other areas. Experience gained from the pilot PM projects is instrumental to expanding the program.

2.6 Predictive Maintenance

Given today's competitive business environment and low margins, plants simply can't afford to wait for critical equipment to fail before making repairs. Nor can they rely on time-based preventive maintenance to minimize downtime. While less costly than breakdown maintenance, repairing or replacing components, just because the clock or counter says to do the work, is not cost-effective.

The gold standard for effective maintenance is a predictive approach that guides decisions about production assets. It monitors each asset's condition to determine its fitness for continued operation and initiates repairs only when the machine itself starts crying for help.

Predictive maintenance uses non-invasive techniques to monitor the pulse of a manufacturing plant. It checks, for example, the usability of greases and oils. It keeps track of vibration. It correlates abnormal temperatures with mechanical problems.

Predictive maintenance utilizes a combination of cost effective tools to obtain operating conditions of critical plant/equipment and based on these data, maintenance is performed prior to actual time that failure will occur. Thus, in predictive maintenance direct monitoring of critical equipment takes place, so that, actual time to failure are predicted, rather than waiting for maintenance, based upon "Mean Time to Failure."

Hence, we can define Predictive Maintenance as method of surveillance condition monitoring of critical equipment, to indicate the condition of equipment at any time t while performing its intended tasks and based upon that data, to carryout corrective maintenance prior to failure.

Predictive maintenance (PDM) techniques are helpful in determining the condition of any in-service equipment in order to predict when maintenance activities should be performing. This approach offers cost saving over routing or time-based preventive maintenance, because these tasks are performed only when they are warranted. The main aim of predicative maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures. The key is "the right information in the right time". By knowing which equipment needs maintenances, maintenance work can be better planned (spare parts, people etc.), and what would have been "Unplanned stops" are now transformed to shorter and fewer "Planned stops", thus increasing plant availability, other advantages include increased equipment lifetime, increased plant safety, fewer accident with negative impact on environment, and optimized spare part handling.

We all know about the three R's: reading, writing, and arithmetic (The phrase 'the three R's' is used because each word in the phrase has a strong R sounds at the beginning). Well, there are also three R's of maintenance routine, renewal, and repair. If we ignore the first two, the third is inevitable. Routine involves three things: inspection, adjustment, and lubrication (shown in figure 2.1). Inspection is the main part of predictive maintenance. Inspection is a means of predicting a need for future work. It may consist of visual inspections done with the help of condition-monitoring equipment to check all wearing parts and to avoid any breakdown. It must be kept in mind that dirty filters, leaky seals, excessive noise, vibration, or heat can only be seen or heard if the inspections are made. It wills not good to make up the inspection sheets or buy inspection equipment if the inspections are never carried out.

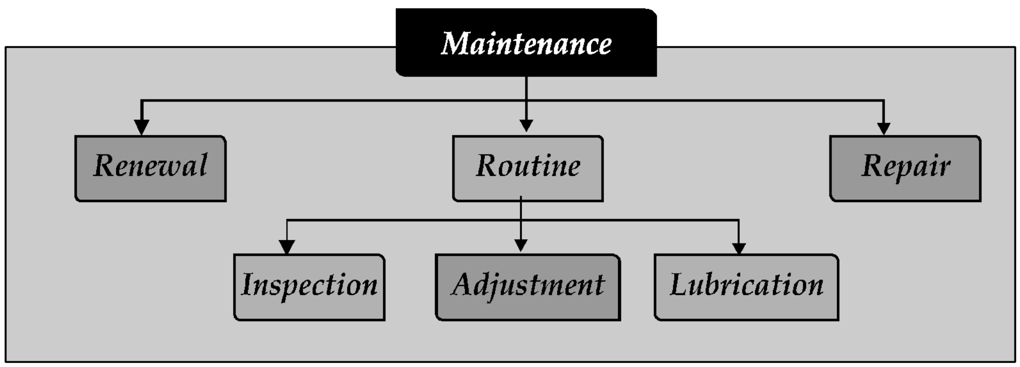


Figure -1

2.6.1 Equipment Wear Records

Predictive maintenance utilizes the methods shown in figure 1 to predict failures. An essential part of any predictive maintenance program is the equipment wear records. For inspection, a graph is plotted, in which the progress of wear in the equipment is shown with respect to time. Graph showing progressing wear is shown in figure 2 .

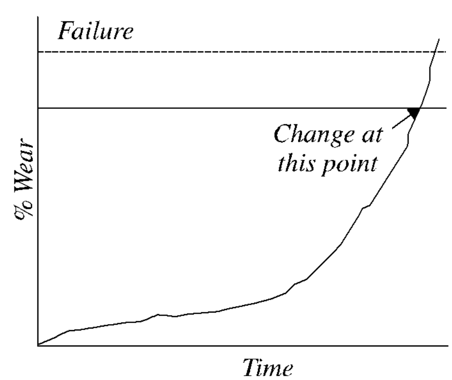


Figure -equipment wear records

When the component fails, it is noted on the chart and when it is replaced, a new chart is started. And this time the component is monitored and replaced as it approaches the life of the last (replaced) component, provided it is wearing at approximately the same rate. This prevents a breakdown and allows the maintenance staff with the flexibility to schedule the repair without interrupting production and this is the main advantage of predictive maintenance.

This process is not as easy or simple to carry out for equipment, however, with a little effort, the system can be made to complement any predictive maintenance program.

2.6.2 Predictive Maintenance is more than Maintenance

Traditionally, predictive maintenance is used solely as maintenance management tool. In most cases, this use is limited to preventing unscheduled downtime and/or catastrophic failures. Although this function is important, predictive maintenance can provide substantially more benefits by expanding the scope or mission of the program.

As a maintenance management tools, predictive maintenance can and should be used as a maintenance optimization tool. The program‘s focus should be on eliminating unnecessary downtime, both scheduled and unscheduled; eliminating unnecessary preventive and corrective maintenance tasks; extending the useful life of critical systems; and reducing the total life-cycle cost of these systems.

Plant Optimization Total: Predictive maintenance technologies can provide even more benefit when used as a plant optimization tool. For example, these technologies can be used to establish the best production procedures and practices for all critical production systems within plants.

Reliability Improvement Tool: As a reliability improvement tool, predictive maintenance technologies cannot be beat. The ability to measure even slight deviations from normal operating parameters permits appropriate plant personnel (e.g., reliability engineers, maintenance planners) to plan and schedule minor adjustments that will prevent degradation of the machine or system, thereby eliminating the need for major rebuilds and associated downtime.

The difference: Other than the mission or intent of how predictive maintenance is used in your plant, the real difference between the limited benefits of a traditional predictive maintenance program and the maximum benefits that these technologies could provide the diagnostic logic used. In traditional predictive maintenance applications, analysis typically receives between 5 and 15 days of formal instruction.

This training is always limited to the particular technique (e.g., vibration, thermograph) and excludes all other knowledge that might help them understand the true operating condition of the machine, equipment, or system they are attempting to analyze.

2.6.3 Establishment of Standard

It is so complicated to establish the standard of any equipment. According to the figure we can sees how to establish a standard. It must be noted that if the equipment is replaced too frequently, it increase costs, and if it is not replaced frequently enough, then breakdowns occurs. To tackle this problem, this best method is to research equipment life, and note down the average time of replacement for that component and then try that time period. If it works, then use that time period, and if it doesn't then shorter it slightly until the replacement comes before the breakdowns. Just to ensure that the time-period calculated for replacement is approximately correct, it may be necessary to let a component run until breakdown from time to time.

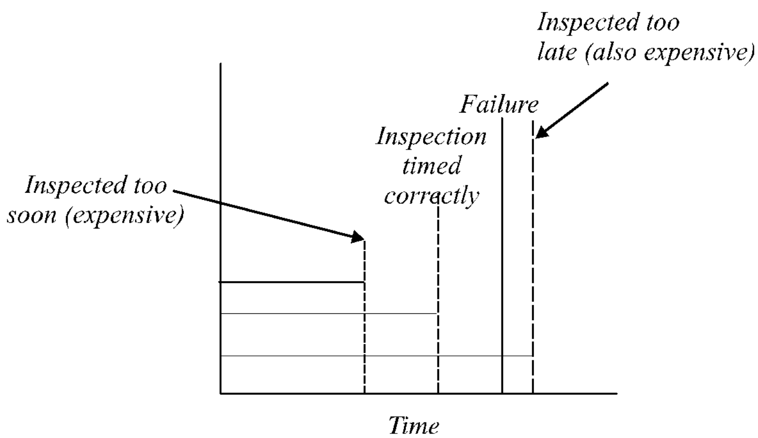


Figure - Establishment of standard

It is recommended to use predictive maintenance only for those components whose breakdown will lead to long period of downtime. This is a matter that a maintenance supervisor should discuss with a production supervisor. This will ensure maximum efficiency of the program.

2.6.4 Equipment Used in Predictive Maintenance

1. **Accelerometers:** Accelerometers and accessories are used for measuring responses in a vibration medium like motor and machinery, bearing associated cables and other instrumentation bearing accessories.
2. **Impact and impulse hammers:** These are used to carry out model testing of structures as well as for detecting defective structural items.
3. **Paperless recorders:** These are used for recording responses like oscilloscopes and FFT analyzers.
4. **Vibration analyzers:** These can be used to perform a series of tests, that will

provide the specific sources of vibration. Shock pulse meters and seismic meters are also used for this purpose.

5. **Ultrasonic tester:** They are used to measure thickness of plates. Ultrasonic leak detectors are also used to detect leaks.
6. **Data loggers:** These are small, portable, electronic devices equipped with small battery, microprocessor, internal memory for data storage, and sensors. It used for recording continuous data such as vibration responses and sound levels.
7. **Laser instruments:** Used for alignment verification and precision alignment.
8. **Stroboscopes:** Used for speed measurement and for balancing of rotating machinery.
9. **Infrared imaging cameras:** used for getting relative temperature contours in a system.
10. **Motor monitoring and testing:** Used for continuous monitoring of the motor conditions at load as well as at no load, and to take corrective action.
11. **Tachometers:** Used for speed measurement.
12. **Infrared thermometers:** Used for measuring temperature in a furnace or a heated object.
13. **Transmitters:** These are power amplifiers for electronic signal processing.
14. **Humidity meters:** Used to measure the humidity.
15. **Oil analysis spectrometers:** Used for evaluation of the extent of metallic particles in the fluid. Other techniques such as dilution measurement, water level indicators, and particle measuring devices indicate the contamination in different applications.
16. **Power measurement equipment:** It include equipments such as energy meter and power factor measuring instruments.
17. **Gas leakage detectors:** They are used for gas leakage detection in refineries and gas bottling plants.
18. **Acoustic emission analysis:** Used for detection of crack growth through electric crystals.
19. **Magnetic inductive cable tester:** Used for shallow subsurface cable defects.
20. **Eddy current transducers:** These directly observe the rotating shafts to measure the radial (and axial) vibration of the shaft. The level of the vibration can be compared with historical baseline values such as former start ups and shut downs, as load changes and to assess the severity.
21. **The shock pulse method (SPM):** It is the only successful monitoring technique specializing on rolling element bearings by determining accurate information on:

(a) The mechanical state of the bearing surfaces.

(b) The lubricating condition throughout the bearing life.

2.6.5predictive Maintenance Techniques

A variety of technologies can, and should be, used as part of a comprehensive predictive maintenance program. Because mechanical systems or machines account for most plant equipment, vibration monitoring is generally the key component of most predictive maintenance programs; however, vibration monitoring cannot provide all of the information required for a successful predictive maintenance program. This technique is limited to monitoring the mechanical condition and not other critical parameters required to maintain reliability and efficiency of machinery. It is a very limited tool for monitoring critical process and machinery efficiencies and other parameters that can severely limit productivity and product quality.

Therefore, a comprehensive predictive maintenance program must include other monitoring and diagnostic techniques. These techniques include vibration monitoring, thermograph, tribology, process parameters, visual inspection, ultrasonic's, and other nondestructive testing techniques. In this chapters a brief description of each of the techniques that should be included in a full-capabilities predictive maintenance program for typical plants. Subsequent chapters provide a more detailed description of these techniques and how they should be used as part of an effective maintenance management tools.

Vibration Monitoring

Because most plants consist of electromechanical systems, vibration monitoring is the primary predictive maintenance tool. Over the past 10 years, most of these programs have adopted the use of microprocessor-based, single-channel data collectors and windows-based software to acquire, manage, trend, and evaluate the vibration energy created by these electromechanical systems. Although this approach is a valuable predictive maintenance methodology, these systems' limitations may restrict potential benefits.

2.6.6 Thermograph

Thermograph is a predictive maintenance technique that can be used to monitor the condition of plant machinery, structures, and systems, not just electrical equipment. It uses instrumentation designed to monitor the emission of infrared energy (i.e., surface temperature) to determine operating condition. By detecting thermal anomalies (i.e., areas that are hotter or colder than they should be), an experienced technician can locate and define a multitude of incipient problems within the plant.

Infrared technology is predicated on the fact that all objects having a temperature above absolute zero emit energy or radiation. Infrared radiation is one form of this emitted energy. Infrared emissions, or below red, are the shortest wavelengths of all radiated energy and are invisible without special instrumentation. The intensity of infrared radiation from an object is a function of its surface temperature; however, temperature measurement using infrared methods is complicated because three sources of thermal energy can be detected from any object: energy emitted from the object itself, energy reflected from the object, and energy transmitted by the object. Only the emitted energy is important in a predictive maintenance program. Reflected and transmitted energies will distort raw infrared data. Therefore, the reflected and transmitted energies must be filtered out of acquired data before a meaningful analysis can be completed.

Variations in surface condition, paint or other protective coatings and many other variables can affect the actual emissivity factor for plant equipment. In addition to reflected and transmitted energy, the user of thermo graphic techniques must also consider the atmosphere between the object and the measurement instrument, water vapor and other gases absorb infrared radiation. Airborne dust, some lighting, and other variables in the surrounding atmosphere can distort measured infrared radiation. Because the atmospheric environment is constantly changing, using thermo graphic techniques requires extreme care each time infrared data are acquired.

Most infrared-monitoring systems or instruments provide filters that can be used to avoid the negative effects of atmospheric attenuation of infrared data; however, the plant user must recognize the specific factors that affect the accuracy of the infrared data and apply the correct filters or other signal conditioning required to negate that specific attenuating factor or factors.

Collecting optics, radiation detectors, and some form of indicator are the basic elements of an industrial infrared instrument. The optical system collects radiant energy and focuses it on a detector, which converts it into an electrical signal. The instrument‘s electronics amplifies the output signal and processes it into a form that can be displayed.

2.6.6.1 Types of Thermo graphic Systems

Three types of instruments are generally used as part of an effective predictive maintenance program: infrared thermometers, line scanners, and infrared imaging systems.

- **Infrared Thermometers:** Infrared thermometers or spot radiometers are designed to provide the actual surface temperature at a single, relatively small point on a machine or surface. Within a predictive maintenance program, the point-of-use infrared thermometer can be used in conjunction with many of the microprocessor-based vibration instruments to monitor the temperature at critical points on plant machinery or equipment. This technique is typically used to monitor bearing cap temperatures, motor winding temperatures, spot checks of process piping temperatures, and similar applications. It is limited in that the temperature represents a single point on the machine or structure; however, when used in conjunction with vibration data, point-of-use infrared data can be a valuable tool.

- **Line Scanners:** This type of infrared instrument provides a one dimensional scan or line of comparative radiation. Although this types of instrument provides a somewhat larger field of view (i.e., area of machine surface), it is limited in predictive maintenance applications.
- **Infrared Imaging:** Unlike other infrared techniques, thermal or infrared imaging provides the means to scan the infrared emissions of complete machines, process, or equipment in a very short time. Most of the imaging systems function much like a video camera. The user can view the thermal emission profile of a wide are by simply looking through the instrument‘s optics.

A variety of thermal imaging instruments are on the market, ranging from relatively inexpensive, black-and-white scanners to full-color, microprocessor-based systems.

Many of the less expensive units are designed strictly as scanners and cannot store and recall thermal images. This inability to store and recall previous thermal data will limit long-term predictive maintenance program.

Point-of-use infrared thermometers are commercially available and relatively inexpensive.

The typical cost for this type of infrared instrument is less than $1,000. Infrared imaging systems will have a price range between $8,000 for a black-and white scanner without storage capability to over $60,000 for a microprocessor-based, color imaging system.

Training is critical with any of the imaging systems. The variables that can destroy the accuracy and repeatability of thermal data must be compensated for each time infrared data are acquired. In addition, interpretation of infrared data requires extensive training and experience. Inclusion of thermograph into a predictive maintenance program will enable you to monitor the thermal efficiency of critical process systems that rely on heat transfer or retention, electrical equipment, and other parameters that will improve both the reliability and efficiency of plant systems. Infrared techniques can be used to detect problems in a variety of plant systems and equipment, including electrical switch gear, gearboxes, electrical substations, transmissions, circuit breaker panels, motors, building envelopes, bearings, steam lines, and process systems that rely on heat retention or transfer.

2.6.6.2 Infrared Thermograph Safety

Equipment included in an infrared thermograph inspection is usually energized; therefore, a lot of attention must be given to safety. The following are basic rules for safety while performing an infrared inspection:

- Plant safety rules must be followed at all times.
- A safety person must be used at all times. Because proper use of infrared imaging systems requires the technician to use a view finder, similar to a video camera, to view the machinery to be scanned, he or she is blind to the surrounding environment. Therefore, a safety person is required to ensure safe completion.

- Notify area personnel before entering the area for scanning.
- A qualified electrician from the fare should be assigned to open and close all electrical panels.
- Where safe and possible, all equipment to be scanned will be on-line and under normal load with a clear line of sight to the item.
- Equipment whose covers are interlocked without an interlock defect mechanism should be shut down when allowable. If safe, their control covers should be opened and equipment restarted.

2.6.7 Teratology

Teratology is the general term that refers to design and operating dynamics of the bearing-lubrication-rotor support structure of machinery. Two primary techniques are being used for predictive maintenance: lubricating oil analysis and wear particle analysis.

Lube Oil Analysis

Lubricating oil analysis, as the name implies, in an analysis technique that determines the condition of lubricating oils used in mechanical and electrical equipment. It is not a tool for determining the operating condition of machinery or detecting potential failure modes. Too many plants are attempting to accomplish the latter and are disappointed in the benefits that are derived. Simply stated, lube oil analysis should be limited to a proactive program to conserve and extend the useful life of lubricants.

Although some forms of lubricating oil analysis may provide an accurate quantitative breakdown of individual chemical elements – both oil additive and contaminants contained in the oil – the technology cannot be used to identify the specific failure mode or root-cause of incipient problems within the machines serviced by the lube oil system.

The primary applications for lubricating oil analysis are quality control, reduction of lubricating oil inventories, and determination of the most cost-effective interval for oil change. Lubricating, hydraulic, and dielectric oils can be periodically analyzed using these techniques to determine their condition. The results of this analysis can be used to determine if the oil meets the lubricating requirements of the machine or application. Based on the results of the analysis, lubricants can be changed or upgraded to meet the specific operating requirements.

In addition, detailed analysis of the chemical and physical properties of different oils used in the plant can, in some cases, allow consolidation or reduction of the number and types of lubricants required to maintain plant equipment elimination of unnecessary can reduce inventory levels and therefore maintenance costs.

As a predictive maintenance tool, lubricating oil analysis can be used to schedule oil change intervals based on the actual condition of the oil. In midsize to large plant, a reduction in the number of oil changes can amount to a considerable annual reduction in maintenance costs. Relatively inexpensive sampling and testing can show when the oil in a machine has reached a point that warrants change.

2.6.8 Wear Particle Analysis

Wear particle analysis is related to oil analysis only in that the particles to be studied are collected by drawing a sample of lubricating oil .whereas lubricating oil analysis determines the actual condition of the oil sample, wear particle analysis provides direct information about the wearing condition of the machine-train. Particles in the lubricant of a machine can provide significant information about the machine‘s condition. This information is derived from the study of particle shape, composition, size, and quantity.

- **Analysis of Particulate Matter:** Two methods are used to prepare samples of wear particles. The first method, called spectroscopy or spectrographic analysis, uses graduated filters to separate solids into sizes. Normal spectrographic analysis is limited to particulate contamination with a size of 10 microns or less. Larger contaminants are ignored. This fact can limit the benefits that can be derived from the technique. The second method, called cerographic analysis, separates wear particles using a magnet. Obviously, the limitation to this approach is that only magnetic particles are removed for analysis. Nonmagnetic materials, such as copper, aluminum, and so on that make up many of the wear materials in typical machinery are therefore excluded from the sample. Wear particle analysis is an excellent failure analysis tool and can be used to understand the root-cause of catastrophic failures. The unique wear patterns observed on failed parts, as well as those contained in the oil reservoir, provide a positive means of isolating the failure mode.
- **Type of Wear:** Five basic types of wear can be identified according to the classification of particles: rubbing wear, cutting wear, rolling fatigue wear, combined rolling and sliding wear, and severe sliding wear. Only rubbing wear and early rolling fatigue mechanisms generate particles that are predominantly less than 15 microns in size.

(i) **Rubbing Wear:** Rubbing wear is the result of normal sliding wear in a machine. During a normal break-in of a wear surface, a unique layer is formed at the surface. As long as this layer is stable, the surface wears normally. If the layer is removed faster than it is generated, the wear rate increases and the maximum particle size increases. Excessive quantities of contaminant in a lubrication system can increase rubbing wear by more than an order of magnitude without completely removing the shear mixed layer. Although catastrophic failure is unlikely, these machines can wear out rapidly. Impending trouble is indicated by a dramatic increase in wear particles.

(ii) **Cutting Wear Particles:** Cutting wear particles are generated when one surface penetrates another. These particles are produced when a misaligned or fractured hard surface produces an edge that cuts into a softer surface, or when abrasive contaminant becomes embedded in a soft surface and cuts an opposing surface. Cutting wear particles are abnormal and are always worthy of attention. If they are only a few microns long and a fraction of a micron wide, the cause is probably contamination. Increasing quantities of longer particles signals a potentially imminent component failure.

(iii) **Rolling Fatigue:** Rolling fatigue is associated primarily with rolling contact bearings and may produce three distinct particle types: fatigue spall particles, spherical particles, and laminar particles. Fatigue spall particles are the actual material removed when a pit or spall opens up on a bearing surface. An increase in the quantity or size of these particles is the first indication of an abnormality. Rolling fatigue does not always generate spherical particles, and they may be generated by other sources. Their presence is important in that they are detectable before any actual spalling occurs. Laminar particles are very thin and are formed by the passage of a wear particle through a rolling contact. They often have holes in them. Laminar particles may be generated throughout the life of a bearing, but at the onset of fatigue spalling the quantity increases.

(iv) **Combined Rolling and Sliding Wear:** Combined rolling and sliding wear results from the moving contact of surfaces in gear systems. These larger particles result from tensile stresses on the gear surface, causing the fatigue cracks to spread deeper into the gear tooth before pitting. Gear fatigue cracks do not generate spheres. Scuffing of gears is caused by too high a load or speed. The excessive heat generated by this condition breaks down the lubricating film and causes adhesion of the mating gear teeth. As the wear surfaces become rougher, the wear rate increases. Once started, scuffing usually affects each gear tooth.

(v) **Severe Sliding Wear:** Excessive loads or heat causes severe sliding wear in a gear system. Under these conditions, large particles break away from the wear surfaces, causing an increase in the wear rate. If the stresses applied to the surface are increased further, a second transition point is reached. The surface breaks down, and catastrophic contamination with a size of 10 microns or less. Larger contaminants are ignored. This fact can limit the benefits derived from the technique.

2.6.8 Limitations of Tribology

- Capital Cost
- Recurring Cost
- Accurate Samples

Visual Inspections

Visual inspection was the first method used for predictive maintenance. Almost from the beginning of the Industrial Revolution, maintenance technicians performed daily "walkdowns" of critical production and manufacturing systems in an attempt to identify potential failures or maintenance-related problems that could impact reliability, product quality, and production costs. A visual inspection is still a viable predictive maintenance tool and should be included in all total-plant maintenance management programs.

Ultrasonic's

Ultrasonic's, like vibration analysis, is a subset of noise analysis. The only difference in the two techniques is the frequency band they monitor. In the case of vibration analysis, the monitored range is between 1 Hertz (Hz) and 30,000 Hz; ultrasonic's monitors noise frequencies above 30, 000 Hz. These higher frequencies are useful for select applications, such as detecting leaks that generally create high-frequency noise caused by the expansion or compression of air, gases, or liquids as they flow through the orifice, or a leak in either pressure or vacuum vessels. They higher frequencies are also useful in measuring the ambient noise levels in various areas of the plant.

As it is being applied as part of a predictive maintenance program, many companies are attempting to replace what is perceived as an expensive tool (i.e., vibration analysis) with ultrasonic's. For example, many plants are using ultrasonic meters to monitor the health of rolling-element bearings in the belief that this technology will provide accurate results. Unfortunately, this perception is invalid. Because this technology is limited to a broadband (i.e., 30 kHz to 1 MHz), ultrasonic's does not provide the ability to diagnosis incipient bearing or machine problems. It certainly cannot define the root cause of abnormal noise levels generated by either bearings or other machine-train components.

As part of a comprehensive predictive maintenance program, ultrasonic's should be limited to the detection of abnormally high ambient noise levels and leaks. Attempting to replace vibration monitoring with ultrasonic's simply will not work.

2.7 Computer aided maintenance

Restoration and rehabilitation of historical structures took place centuries before the collapse of Civic Tower of Pavia in 1989 and installing a large digital monitoring system in Santa Maria del Fiore Cathedral in Florence in 1987. But since that time a combined use of experimental methods and numerical techniques has been understood as a tool of identification of estimates of structural properties and material parameters. Especially good examples of such a methodology can be found in Italy. Similar needs emerge in Poland, where mechanics of historical constructions with monitoring of deformations, modeling and assessment has been since the last decade recognized as a new challenge. Presented examples of the researches cover various fields of maintenance of historical structures. We shall discuss main structural risks and follow the examples to show how they build a common framework of computer aided maintenance of structures (CAMS), although it has not been fulfilled in a single project yet.

2.7.1 Main structural risks

For the purpose of our discussion we may classify various reasons of structural failure as “structure related”, “element related” and “material related”. Material and element related reasons are sources of damage accumulation within material of the structure. These are mainly material creep (intrinsic property), ageing because of chemical and weathering corrosion, fatigue due to thermal and water table cycles or micro seismic and traffic loads and also man induced material incompatibilities while grouting and after flat jack tests. Element related reasons result from structural interventions like adding frames of steel reinforced concrete, new or replaced tie rods, restoration or reinforcement of vaults, subsoil cementing or underpinning of pillars and walls. These interventions change boundary conditions of the particular and usually of neighboring elements as well. Failure reasons related to a structure are also of boundary condition type rather than material one. These are load changes due to seismic events (seismic zone migration towards north-west) and very strong winds (much stronger then in medieval ages) or changes of a structure support due to landslides, subsoil creep, biodegradation of soil and ground water table changes. Looking across Europe it can be stated, that some failure reasons dominate in one region (e.g. seismicity) while being rare or absent in the others. From this point of view in Poland dominate structural related reasons like soil creep induced by ground water table changes and biodegradation of organic compounds of the soil, landslides, structural interventions and par seismic loads related to rock bursts or heavy traffic. Next section presents examples of the researches inspired by such reasons.

Examples of computer aided researches on historical structures in Poland

Examples were chosen to cover a broad spectrum of research from non”destructive

Survey to structural interventions and from theoretical study to practical implementation. To illustrate a framework of CAMS let us discuss a process of rehabilitation of a historical structure shown in Figure A crucial point is an assessment of the structure to which one can come in several ways. Following are examples of path “1” (computer”aided survey and geometrical modeling), “3” and “4” (computer”aided structural modeling and restoration), “2” and “5” (computer”aided monitoring and assessment), “2”, “6” and “4” (computer”aided monitoring and structural modeling) and a combination of “2”, “3”, “6”, “7” and “4” (computer”aided damage monitoring system).

Computer”aided survey and geometrical modeling

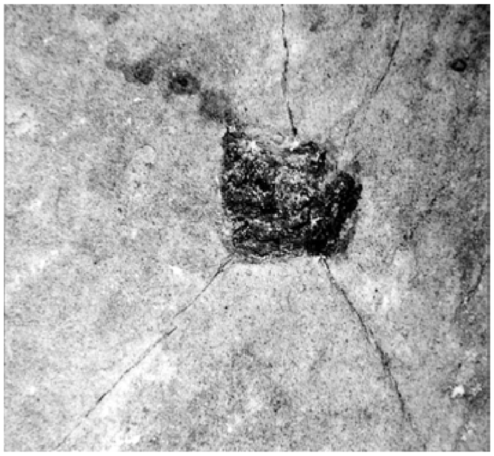
Assessment based on engineering experience of an expert is represented by path “1”. But even in this simple case computer aided experimental investigation during inspection stage can be done and proof to be very helpful. This computerized methods are mainly sonic and radar tests which detect material in homogeneities and crack distribution within structural elements. This is feasible thanks to numerical modeling of wave propagation phenomena within a heterogeneous body.

An interesting example of such a research by the original method of semi tomography (ultrasonic layer inspection) was presented in .

The research was done in Krzy¿owa near Wroc³aw where there is situated XIX century Historical Complex, previously property of Helmut von Moltke

In columns of the stable serious damages due to the deep corrosion of embedded steel rods were observed (Fig.2, 3). The aim of the research was to find crack distribution and orientation to assess the safety of the structure being restored and raised by one storey. *Fig. 2 Cracked column [5]. Fig. 3 Corroded steel rod [5].* Measurements of the ultrasonic wave propagation time in various horizontal cross-sections of the columns were interpreted according to the model developed by the authors. The key idea is shown schematically in Figure 4 were assumption was made that the signal coming from transmitter to receiver in the case of crack existence follows curvilinear pass which can be satisfactorily approximated by an arc of the circle passing through the crack tip and transmitter/receiver localization points. Then performing the measurements in several horizontal cross-sections and elaborate the data on a computer there was produced CAD model of each surveyed pillar (Fig. 5). *Fig. 4 The idea of determining the crack tip position when its beginning is visible on the surface. If the straight line connecting transmitter and receiver crosses the crack then the wave follows the nearest possible circular path* This geometrical modeling helped to assess that the cracks run from the one to another holes in

fig 2



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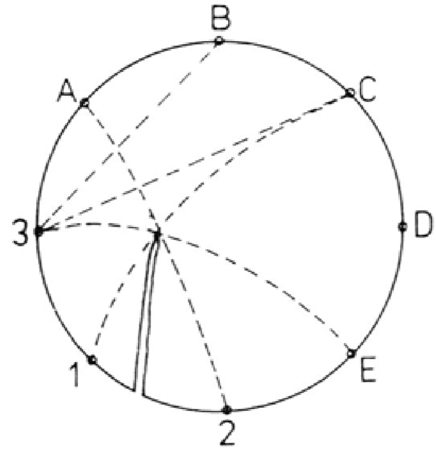

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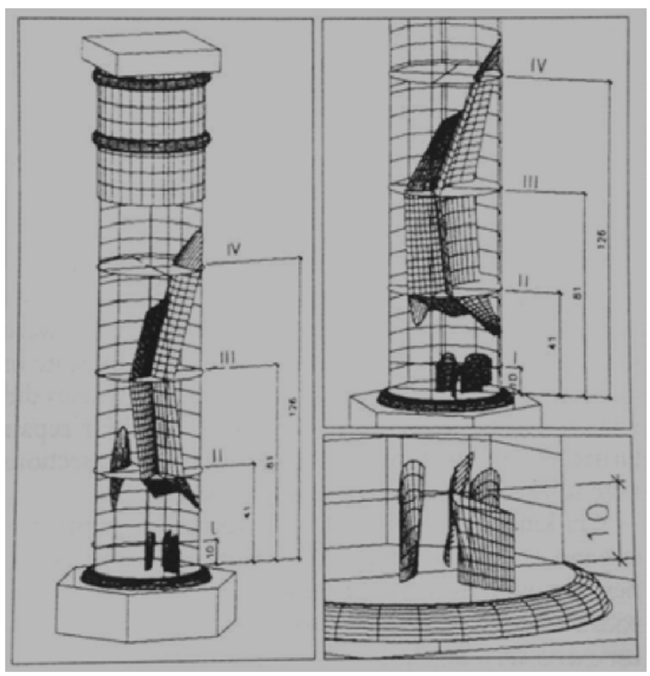
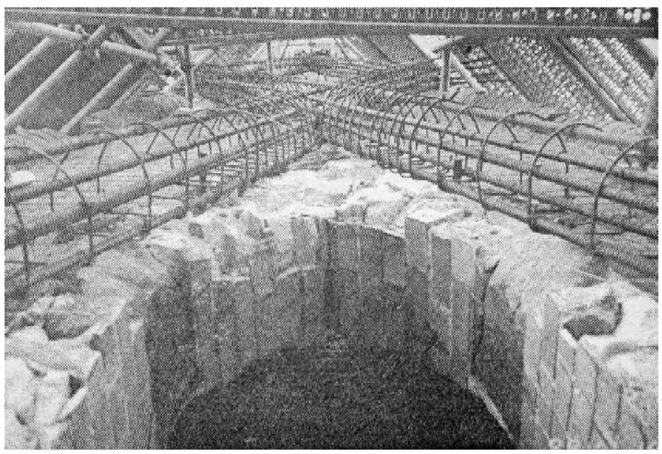


fig 5

2.7.2 Computer"aided structural modeling and restoration

The church of Our Lady in Chojna near Szczecin was built in XIII"XIV century and so was its tower which collapsed in 1843. New, almost 100 m high, neogothic tower has already been repaired several times. It was decided in 1992 after the survey including laboratory testing of material samples to build an outer skeleton of reinforced concrete to consolidate original cracked structure of the upper part of the tower to preserve it in its actual state. The strengthening structure is a 3D frame with 20 cm thick plate base. Static behavior of the structure was modeled by elastic FEM elements with 156 triangular plate elements for the base plate and taking into account directions of principal stresses. A local view of the construction of the strengthening and the shape of the reinforced concrete frame are shown in Figure 6.



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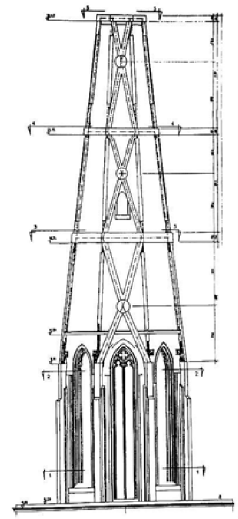


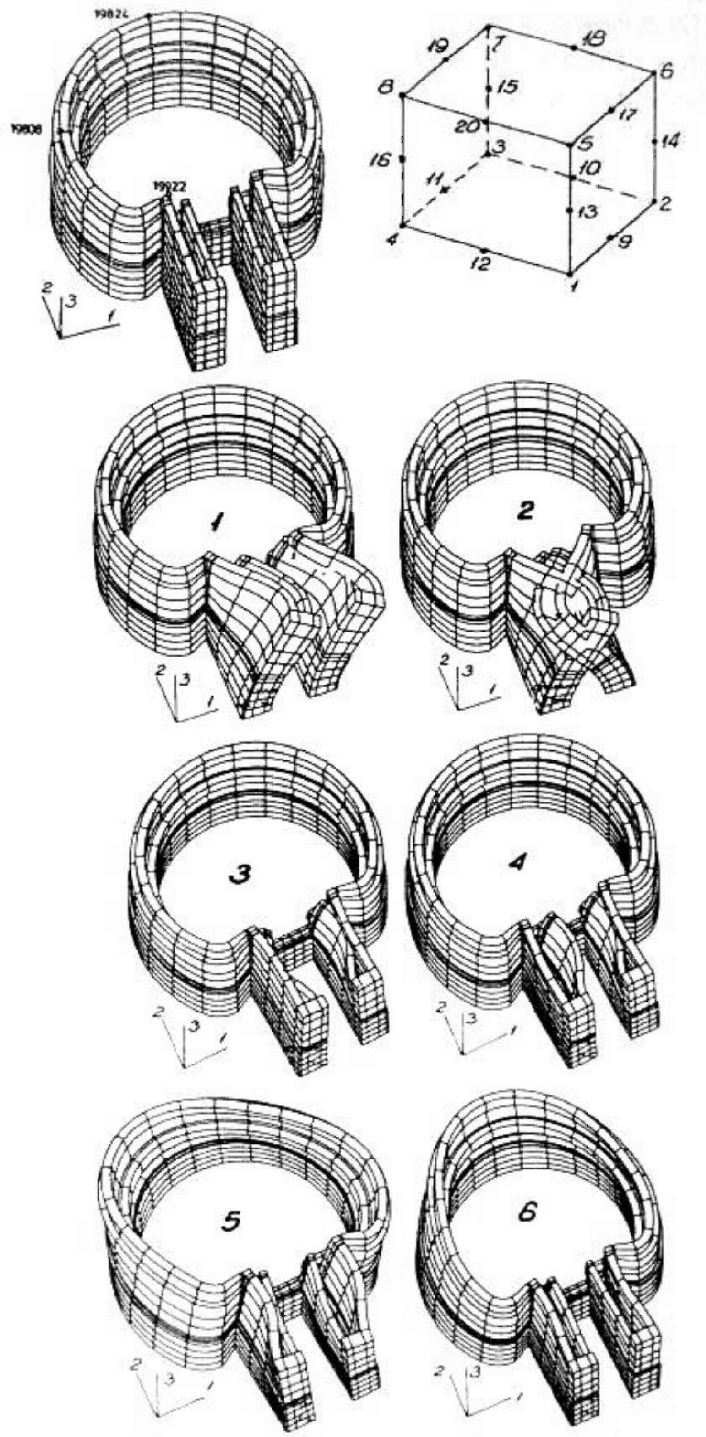
fig 6b

2.7.3 Computer"aided monitoring and assessment

Computer"aided maintenance of the structure with monitoring of deformations during the structural intervention is an example of Malbork Castle. Malbork castle is the biggest teutonic castle in Europe and was the capital of the teutonic knights state in Poland after Grand Master moved here his residence from Venice in 1306. The castle is situated on a sandy hill while its western wall is founded on oak piles at the footing of a slope in the vicinity of Nogat River.

2.7.4 Computer"aided monitoring and structural modeling

A study of the influence of par seismic loads on historical structures and numerical modeling of dynamic structural response is in many cases a useful diagnostic tool. An example of such a research is the dynamic structural modeling of Barbican in Cracow. This well preserved XV century historical monument, formerly the main entrance to the capital of Poland, today is at the risk of vibrations from traffic, especially of a tram communication origin. To assess its structural safety in short and long terms it was decided to perform dynamic load spectra measurements. Modeling was done by FEM with elastic 3D 20-nodal elements (with over 20 000 of elements). There was studied a dynamic response to external loads (as measured in 1982) and modal frequencies of the model . These modal frequencies of orders 1 to 6 are shown in Figure 8 where the last two frequencies belong to the main part of the structure. Fig 8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2.7.5 Computer"aided damage monitoring system

The concept of DAmage MONitoring (DAMON) system follows the ideas expressed in and is an attempt to combine together structural modeling and monitoring into a feedback system (path "6" and "7" in Fig. 1) to assess structure health and predict possible cracks development thus allowing to maintain the structure in an adequate way in advance. All components of the system were developed at a laboratory level. As the idea was inspired by a restoration of XIV century St. John's church in Gdañsk monitoring system including sensors and their configuration as well as 3D FEM model with over 200 000 elements are designed to be applied to this case. The key point was to find numerically effective method which can be used to model existing and emerging discontinuities (cracks), subsoil plasticity and stiffness degradation of the structure due to material softening.

2.8 SCHEDULED MAINTENANCE

Scheduled maintenance is just similar to time based maintenance. It is a stitch in time procedure aimed at avoiding breakdown. Scheduled maintenance practice incorporates in it, inspections, lubrication, repair and overhaul of certain equipments which if neglected can cause breakdown. Scheduled maintenance practice is generally followed for over hauling of machines.

In scheduled maintenance, maintenance schedules are designed based on time based maintenance or operation based maintenance as recommended by the manufacturer.

Scheduled maintenance indicates:

1. What work is to be done?
2. How often is it to be done?
3. By whom is it to be done?
4. Time required completing the work.
5. Separate schedules for different machines.
6. Expertise, skills and experience required to complete the work.
7. Scheduled maintenance is to be carried out in a phased manner by maintenance staff or jointly by maintenance and production staff in a single phase.

2.8.1 Maintenance Scheduling

1. Maintenance scheduling is the sequential arrangement of works to be carried out in maintenance.
2. The decision on a sequence is based upon priority and the availability of materials and spares.
3. Scheduling is effective only if there is a mutual co-operation and understanding between the maintenance and production staff.

4. Most critical equipment have to receive prompt attention.
5. The other priorities are based on preventive, predictive or any other type of maintenance system prevailing in the organization.

2.8.2 Principle Of Scheduled Maintenance

Scheduled maintenance is based on the principle that each and every part of an equipment or plant must be inspected and repaired well in time as per manufacturers recommendation to make the operation free of breakdowns and accidents. It fits well on a proverb 'Stitch in time saves nine'. Hence scheduled maintenance increases reliability of machine and confidence of operating staff. Thus indirectly it helps in increasing the profitability of an organization.

Scheduling principles envisages the vision, the principles or paradigms in order to evolve effective scheduling will come through effective planning process. The principle used for planning and scheduling are for achieving the forecasted skill levels, the schedules and job priorities for every forecasted work available, allowing the crew supervisor to handle day's work, and then measure schedule compliances.

Routine maintenance needs the use of principles, as they create a framework for successful scheduling of planned work. Each principle sets guidelines on how the maintenance should handle different scheduling process.

2.8.3 Six maintenance Scheduling Principles

Six principles that greatly contribute to the overall success of scheduling are:

1. Planners plan the hobs for lowest required skill levels.
2. The entire plant must respect the importance of schedules and job priorities.
3. Crew supervisors forecast available work hours one week ahead by the highest skills available.
4. Schedule assigns planned work for every forecasted work hour available.
5. Crew supervisor matches personnel skills and tasks.
6. Schedule compliance of wrench time, provides the measure of scheduling effectiveness.

2.9 SPARE PARTS MANAGEMENT

SPARE PART

Spare part is a part of a machine ready to replace an identical part of the machine if it becomes faulty during operation .the import trade control defines spare parts as those parts of machines, which because of wear and tear use or breakage, Need replacement .therefore we can define spare part as a part identical to the part of a machines, which need replacement due to wear and tear during the operating life of the equipment.

Spare parts may look small and appear cheaper than the machine or raw material, but they play a vital role in maintaining ensuring and reinforcing the reliability of any equipment.

Spare parts include materials such as;

(i) Pipes, tubes, springs, bearings, seals, gaskets, electrical cables, hoses etc.

(ii) Sub-assemblies as essential parts of the machines like engines, motors, compressors and generators etc.

(iii) Complete units which are to be fitted with a machine, i.e. circulating pumps, controls, gears etc.

Items such as plates, sheets, rods strips etc, which have to be fabricated for manufacturing units are not treated as spare parts but simply are called materials.

2.9.1 Special A-z Features Of Spares

The features peculiar to spare parts which distinguish them from other materials are;-

(a) Their requirement is very small.

(b) There is excessive stock in all positions of the distribution channel.

(c) Their requirement is uncertain. Their requirement shall be only at the time of breakdown of a machine or on regular maintenance of a machine.

(d) They are uneconomical to manufacture, as their demand is uncertain and small.

(e) They have a high tendency for obsolescence.

(f) They have a large variety.

(g) They are difficult to standardize.

(h) There are problems in identification.

(i) Decision making is delegated to lower levels.

(j) A small range of item is able to make a large percentage of requirements.

(k) Stock out cost is greater than the spare part price.

(l) Price includes large margin of profits.

(m) It is difficult to forecast future requirements.

(n) Lead time is long.

(o) It is difficult to get failure data.

(p) Issue from stores may not reflect realistic consumption, due to repairing old spare parts.

(q) There is a lack of information system.

(r) Spares are critical from operational point of view.

(s) Spares are increasingly used with age of machines.

(t) Number of suppliers small.

(u) There are difficulties in import substitution or development of new sources or development of drawing s.

(v) It is not possible to control them by the usual inventory control techniques, as several departments are involved in controlling.

(w) Use of supplier's part numbers is common, instead of internal codification.

(x) Adherence to part number results in duplication in storage, as the same part cannot be supplied by more than one supplier with his part number.

(y) Inspection is not always easy, as testing facilities are not readily available.

(z) Only incomplete specifications are available by supplier's part number.

2.9.2 Categorisation Of Spares

Organizations classify spares in a variety of ways, like regular, fast moving, slow moving, emergency, consumable, moving, none moving, electrical, mechanical, proprietary, and permissible and project spares. But the spare parts must be classified, as maintenance, over hauling, commissioning and insurance spares by introducing scientific controls.

MAINTENANCE SPARES

These are the fast moving spars like bearings, gaskets, springs, belts and hardware items. Normally these are available in plenty and these spare parts can be stocked after building a data base on the consumption pattern.

OVERHAULING SPARES

These are the spares, which are specially needed during regular overhauls, in order to give a new lease of life to the equipment. Hence these spares should not be stocked. These may be ordered just in time before overhauling, depending upon the lead time.

COMMISSIONING SPARES

These spares are needed to start a project or when the equipment is to be commissioned. These spares are declared surplus after the machine starts its operation.

ASSEMBLY SPARES

Motors, engines, pumps, generator etc are some of the assembles, which are used in an industry in most of the operations. These assemblies are repairable and after repairs, such assemblies are stored. These spares can be categorized, as motor spares, pump spares, engine spares etc. these assemblies which are kept standby are called rotable spares or floats.

For example, if an engine of a bus fails, then the same is removed and a repaired engine is fitted in the bus. Then this repaired standby engine is called a float. This float is 4 to 5% of the actual number of assembles in operation.

Example: In a road transport, a bus is operative when engine, gear box, steering assembly, differential assembly are fitted in it and these are in operation. 4 to 5% of these assemblies are kept as stand by as floats, ready to meet the demand of failure of the various assemblies.

INSURANCE SPARES

These are vital parts of a machine, which have life nearly equal to that of a machine itself and are held as a standby against any breakdowns. These standby units have a high reliability of performance and can be capitalized.

2.9.3 Cost Considerations

There are large number of factors which affect the spare parts costs in any organization:-

1. **Location of a plant:** it is a key influencing parameter in spare parts policies. If the using section of a factory is located in remote backward area or far away from industrial centers, airports, national highways, railways stations and seaports, then it becomes necessary for any industry to carry more stocks, to account for transportation and other approach bottlenecks. Therefore investment on spares increases.
2. **Government Regulations:** Any change in Government regulations on imports, foreign currency, custom rules and other taxation policies adversely affects the cost of spares.
3. **Nature of an industry:** The sophistication of an industry, degree of automation, use of high technology in the industry is also some of the influencing factors on the cost of spares.
4. **Highly mechanized automation industry:** Such type of plant's design is very complex. These plants are also very sensitive to breakdown, failure of components, as well as operation. Only trained staff should be allowed to handle and operate such plants. On account of high technology the spares cost is also very high.
5. **Availability of Power:** In some of the areas, the power availability is very poor, hence utilization of the plant is very low, which adversely affects the cost.
6. **Use of imported machines:** In case of an industry, where imported machines are installed and their spares are not kept in stock, then, in case of a breakdown or maintenance, the spares are to be arranged on emergency basis, which also costs more.
7. **Availability of drawings:** This is a helping factor. If the drawings of machines and their major parts are available, then the parts which are not available in market, then such parts can be manufactured based on the available drawings.
8. **Working Capital:** In spare parts, about 20% of the capital is blocked. Therefore if working capital is a constraint, then necessary spare parts cannot be stocked. In such cases spares are only arranged when needed. This leads to emergency purchases resulting into more cost.

CHOICE OF EQUIPMENT

In section of a machine/equipment for an industry, the user must take following actions:

(i) User must discuss with the manufacturer regarding maintenance schedules.

(ii) User must ensure adequate support for the supply of spares within a reasonable time.

(iii) User must take all technical details, detailed drawings, spares catalog, failure data, details of critical parts and reliability information.

(iv) Before purchasing new machines, compatibility with existing machines must be considered. Standardization of machines help in reduction of spares parts inventory.

(v) User must ensure that only necessary and important spares are being purchased with the machine. User should avoid the dumping of unwanted spares by the manufacturer.

(vi) A detailed analysis of techno-economic studies of equipments as well as cost criticitically availability of spares should be done. User must ensure reliability, quality and maintainability of machines before taking a decision for the purchase of a new machine.

ORDERING COSTS

Process of purchase of spare parts from the initial stage to the final stage of procurement, involves cost. The various processes in volved in procurement of spares, after the receipt of requirement from maintenance department or production department or any other department are:

(i) Scrutiny of indents for the correct specifications and correct quantity.

(ii) Calculation of the financial implication and financial approval from the competent authority. Many a times, financial approval is taken by the indenter itself and the same is sent to purchase section along with the indent.

(iii) Decision is to be taken by the purchase department for the mode of purchase. Purchase is to be done from local market by hand quotations, by limited tenders or by open tenders depending upon the quantity and the total cost of the items to be purchased.

(iv) In the case of the purchase from the local market, the purchase committee obtains hand quotations from the local dealers, decides at the spot and purchase is done. It is necessary to obtain at least three quotations.

(v) If the purchase is to be done by limited tenders, then short listing of vendors is done depending upon the performance of the vendors. Then the tenders or quotations from above vendors are invited.

(vi) If the purchase is to be done by open tenders then, advertisement is to be given in the leading newspapers. In case of global purchase, advertisement is to be given globally as well as on the internet. Now a days, in the era of technology, all purchase advertisements are being given on the internet.

(vii) Techno-economical analysis of the offers received from vendors is done by the purchase committee. The purchase committee decides the vendor and the quantity to be purchased from the vendor. Sometimes if the prices of the offer are higher, then the negotiations are done with the vendors. As per directions of Chief Vigilance Commissioner of India, negotiations are to be done with the vendor, who has quoted lowest.

(viii) Issue of purchase orders. Sometime, if the quantity is large, then the purchase department divides the purchase orders between two or three vendors, on the condition, that the other vendors also agree to supply the spares at the price of the first vendor.

(ix) Receipt of spare parts, their quality inspection by quality control department.

(x) Entry in stock, storage and codification of the spares.

All the above processes involve costs, which includes the following elements:

(i) Salary of staff.

(ii) Office space.

(iii) Cost involved in stationery, advertisements, tenders.

(iv) Fallow up costs, inspection cost.

(v) Cost on storage.

STOCK OUT COSTS

Stock out cost or under stocking cost arises due to non stocking of the spare parts. This is usually measured in terms of opportunity lost due to loss of production by the idling cost of a plant/production line. If the stock out results in an additional expenditure, then the extra charges incurred will have to be added to this cost. There are other intangible elements like loss of customer goodwill, loss of image, reduction in future sales, loss of morale of workers, efforts in restarting the equipment etc. but many organizations consider only the profit lost due to loss of production for want of spare parts as stock out cost.

2.9.4 a-z Techniques Of Cost Reduction

There are large number of cost reduction techniques which can be applied for spare parts.

These include:-

(a) Lead time analysis.

(b) Consumption control.

(c) Budgetary control.
(d) Codification.
(e) Standardization.
(f) Simplification.
(g) Variety reduction.
(h) Value engineering.
(i) Timely disposal of obsolete items.
(j) Spares bank.
(k) Minimum and maximum levels.
(l) Inventory control
(m) Selective control.
(n) Cost critically availability analysis
(o) Negotiations.
(p) Reconditioning.
(q) Preventive maintenance policies.
(r) Maintenance documentation.
(s) Vender development.
(t) Vender rating.
(u) Use of learning curve of pricing.
(v) Price forecasting.
(w) Computer applications.
(x) Development of drawings.
(y) Reliability, availability, maintainability and condition monitoring.
(z) Transportation and optimum service level.

We shall now discuss some of the important cost reduction techniques.

2.9.5 Lead Time Analysis

Lead time can be defined as the period that elapses between the recognition of the need of a spare part and its fulfillment.

(i) If the spares are to be procured form own sources like, shop floor, sub store, factory main store or own workshop, then lead time will be much-much small. In this case the internal processing time is eliminated. More over the external lead time will also be shortened, because no outside suppliers are involved.

(ii) If the spares are to be procured form suppliers, local dealers, manufacturers or foreign sources, then the lead time can be divided into two components.

INTERNAL LEAD TIME

It is the time that elapses between converting intent to a purchase order. It consists of following elements:

(i) Scruiteny of indents.

(ii) Quantity decision.

(iii) Financial approval.

(iv) Budget allocation.

(v) Invitation of tenders.

(vi) Purchase committee meetings and finalization of vendors and purchases.

(vii) Placement of purchase orders.

TENDERS

Tenders are of following types:

(i) Hand quotations: This is only implemented in case of an emergent need of spares. In this case the quotations are collected from local firms by purchase committee. At least three quotations are collected. Purchase committee takes spot decision, and the spares are purchased, inspected and payment released.

(ii) Limited Tenders: This practice adopted, when vendors are shortlisted by the organization. Tenders are sent to the shortlisted vendors and offers are invited from then.

(iii) Open Tenders: Open offers are invited from leading manufacturers, suppliers by giving a press notification in leading newspapers and also on internet.

(iv) Global Tenders: In this case offers are invited form manufacturers or supplier form global market.

TECHNO-ECONOMIC ANALYSIS OF OFFERS

Tenders are of one bid system and two bid system. Techno-economic analysis is done only of tenders which are of two bid system. In two bid system of tenders, (BEC) Bid Evaluation Criteria is incorporated. Initially the bid is evaluated on technical grounds as per BEC only. Only those firms or suppliers are approved, who fulfill the Bid Evaluation Criteria (BEC). The financial bid is opened only of these firms.

EXTERNAL LEAD TIME

It is the time that elapses between the time of placement of purchase order to the time of receipt of goods in stores after inspection by quality control department. It consists of following elements:

(a) After the placement of purchase order, the firms are asked to submit the security deposit in the form of demand draft of a nationalized bank or a banker's cheque or a bank guarantee within a stipulated time.

(b) Manufacturing time taken by the firms.

(c) Transportation time.

(d) Inspection time taken by the quality control department.

(e) Time taken to take into stock accounts and codification by the stores department.

REDUCTION STRATEGY IN LEAD TIME

(i) Reduction in internal lead time: Internal lead time is very high in procedure oriented Government Departments. It can be reduced by reviewing the system procedure, delegation of authority and restricting the purchases by limited tenders, instead of open tenders.

(ii) Purchase department may invite tenders for fast moving A class items in such a way, so that a time bound supply contract is signed between the purchaser and the finalized supplier for a period of one, two or three years. In such a case the tenders are invited for a consumption of one, two or three years.

After finalization of tenders, vendors are shortlisted and a written contract agreement is signed with staggered supplies. As such internal lead time is reduced for the contract period.

(iii) A safety stock is maintained to meet out the fluctuations during external lead time.

(iv) Transportation time can be reduced by proper selection of transporter.

(v) Inspection lead lime can be reduced by follow up action and providing suitable facilities to inspection departments.

2.9.6 Codification

An industry may have spare parts ranging into 50,000 items or more. Hence identification of spare parts in the stores is a major problem. Misleading nomenclature, faulty numbering, use of temporary codes, adherence to supplier part number etc. are some of the reasons, which make identification difficult. It may also happen that a particular spare part may have different names in different stores of the same organization, thereby increasing the inventory cost.

Classic example is an electric firm in UK, whose a 3/8 inch diameter, 6" long screw driver was known by three names i.e. plunger drive pin, dowel pin, locating plug in different stores. Such things can be avoided by codification. By codification items are referred uniquely by a code.

Codes can be number, alphabets or both. The number of places varies form seven to fourteen depending upon the type of information. The total number of places is split into group and sub-group. Each sub group signifying a classification based on some characteristics. Normally the major group consists of important categories such as tools, hard wares, mechanical spares, electrical spares and so on. The other digits can be used to depict (a) Metal like steel, copper etc. (b) Dimensional characteristics (c) Suppliers name (d) Location (e) Equipment category etc.

The process of codification takes a very long time to ensure uniqueness, flexibility, understandability and utility.

2.9.7 Value Engineering Or Value Analysis

Value analysis is an important approach in cost reduction technique. It is defined as an organized creative approach to identify and eliminate unnecessary costs without affecting the functional utility, performance guarantee, safety and quality.

It is a basic in spares planning and it reduces the cost and enables a user to substitute imported spares with indigenous spares. In a value analysis, a series of questions are asked, like, why, how, where, when and what else. The various phases in value analysis are:-

(i) Identification of the function.

(ii) Evaluation of the function by comparison.

(iii) Development of alternative strategies.

(iv) Choice of the best strategy.

(v) Implementation of the strategy.

For this purpose, value analysis forms a group, comparison executives from design, marketing, finance, purchases, stores and maintenance. They undergo brainstorming exercises for improving their intelligence and analytical ability. In value analysis the following type of spare parts are considered:-

(i) Spare parts having maximum consumption.

(ii) Highly critical and production holding spares.

(iii) Parts requiring high reliability or right specification.

(iv) The products with least contribution per unit.

(v) Non-critical spares accounting for high consumption value.

In all above, drawings are obtained, specifications examined thoroughly by putting rupee value on the tolerances.

VARIETY REDUCTION BY STANDARDISATION

Standardization is one of the effective tools to optimize the number and improve the quality of service to users. A standard is a model or general agreement of a rule established by a authority, consensus or custom created and used by various levels and interest. With standardization, the number of spares are reduced. This brings the idea of interchangeability and as such reduces inventory level.

A large number of techniques like frequency distribution, preferred number series, and market research. Profit analysis and quality control are used to standardize the item. ISI now known as (BSI) has developed over 15000 standards.

SPARE BANK

The main aim of spares bank is to reduce the working capital, more particularly avoiding the lock up of funds in slow moving spare parts. The concept of spare band is a very good theme in the following cases.

1. Same type of the industries having same type of machines can think of a common spare parts bank for the slow moving, insurance and costly parts.
2. This concept can be more practical if standardization of parts is done and there is interchangeability of parts.
3. These organizations can also have a spare parts bank created by the manufacturer itself, provided that guarantee is given by the manufacturers to supply the spares in need.

Main difficulty in creation of spare bank is to decide about spare parts, bank manager, the quantity of the spares to be stocked and the source from which to be purchased. This difficulty can be solved if industry association or professional agencies take up this task. The fund quantity can be decided on the size of an industry or requirement of spare parts by an industry.

SPARE PARTS SELECTIVE CONTROLS

NECESSITY OF SELECTIVE CONTROL

1. The major complaint of the maintenance is that the spare parts required for maintenances are not available when these are needed.
2. Main aim of an industry is that spares should be available at the time of maintenance i.e. at the down time of plant/machines/. Moreover there should not be overstocking, so that funds are unnecessarily locked up. Some time overstocking leads to dead stocks.
3. In a modern maintenance system, it is essential to maintain an adequate stock of spare parts and supply them by following a proper procedure to work site, when parts are needed by maintenance department.

In the present era, when machines are using high technology, shut down cost is very high. Moreover overstocking of spares involves additional blockage of money. Hence it is very necessary that stocking of spare parts must be controlled in such a manner, which avoids both, shutdown of machines and additional blockage of funds.

SELECTIVE CONTROLS

Selective control refers to the variation in methods of control from item to item on some selective basis. The criteria used for this purpose are:-

(i) Based on the cost of product item.

(ii) Lead time.

(iii) Usage time/usage rate.

(iv) Procurement difficulties.

(v) Criticality of spare parts.

The selective control is more effective. In this, the spare parts are categorized in significant groups depending upon the selective criteria, such as value, usage and frequency of consumption. Such grouping helps the organization for scientific control on stock of spare parts. The various approaches adopted by industries are:-

2.9.8 Various Approaches Of Selective Control

Table : Various approaches for selective control

S. No.	Classification	Criteria
1.	A.B.C. Analysis	Annual usage value of items
2.	H.M.L. Analysis (High, Low, Medium)	Unit price of the material (it does not depend upon consumption)
3.	V.E.D. Analysis (Vital, Essential, Desirable)	Criticality of the item (material criticality)
4.	S.D.E. Analysis (Scarce, Difficult, Easy)	Procurement difficulties
5.	F.S.N. Analysis (Fast, Slow, Non-moving)	Issue form stores
6.	V.E.I.N. Analysis (Essential, Important, Normal)	Usage value
7.	S.O.S. (Seasonal, Off Seasonal)	Seasonality of items
8.	X.Y.Z. Analysis	Inventory value of item used

ABC ANALYSIS

The inventory of an industrial organization generally consists of thousands of items with varying prices, usage rate and lead time. It is neither desirable nor possible to play equal attention to all the items. For example, a TV. set has above 5 percent of its parts, contributing to 80 percent of total cost of a TV. set. This is true for majority of items like car, refrigerator etc.

Such a study was done by a 19th country Italian economist Vil ferado Pareto on a variety of machines/equipments and consumption of spare parts. He came out with a principle known as Pareto principle (20/80), that major proportion of the total inventory comprises of as little as 20% of the total items. He concluded that 20% of the items cost comprises of about 80% of the total cost of an inventory. He split the spares in three categories A, B & C.

This concept applied to inventory control is also called ABC analysis. This ABC analysis is a basic analytical tool which enables management to concentrate its efforts, where results will be greater. This concept is being used by industries to solve majority of production, quality and inventory problems.

Statistics reveal that just a few items account for bulk of annual consumptions of the materials. These a few items are called A class items, which hold key to the business. The other items known as B & C, which are number but their contribution is less significant. ABC analysis thus tends to segregate the items into three categories A, B, C on the basis of their annual usage. The categorization is made to pay right attention and control demanded by items.

(i) **A-Class Items:-** These items hardly constitute 15 to 20% of the total items and account for 75 to 80% of the total money spent on inventories. These items require rigid and tight control and need to be stocked in small quantities. These items are to be procured very frequency.

(ii) **B-Class Items:-** These items are generally 10-15% of the total items and constitute 10-15% of the total cost of the inventory. These are intermediate items and can be called as slow moving items.

(iii) **C-Class Items:-** these items are about 70-75% in number and constitute 5-10% of the total cost of an inventory. These are very slow moving items.

(iv) **Advantages of ABC Analysis:- ABC**

(a) This ABC analysis approach helps the manager to exercise selective control and focus his attention only on a few items.

(b) By exercising strict control on A class items, the materials manager is able to show the results within a short period of time.

(c) ABC analysis results in reduced clerical costs, saves time and efforts and results in better planning and control.

(d) ABC analysis directly focuses on the merit of items and, thus, becomes an effective management control tool.

(v) **Limitation of ABC Analysis:-** ABC analysis is a fundamental tool for exercising selective control over numerous inventory items. But it does not permit precise consideration of all relevant problems of inventory management.

ABC analysis is not one time exercise and items are to be reviewed and recatagorised periodically. Features and Policy guidelines for ABC analysis is given in the following table:-

Table : Features and Policy Guidelines for ABC Analysis

S. No.	A Class (High Value)	B Class (Moderate Value)	C class (Low Value)
1.	Tight control on stock level	Moderate control	Less control
2.	Low safety stock	Medium safety stock	Large safety stock
3.	Order frequently	Less frequently	Bulk ordering
4.	Individual posting in stores	Individual posting	Collective posting
5.	Continuous check on schedules and revision when called or	Broad check on schedule revisions	Hardly any check required
6.	Weekly control statement	Monthly control reports	Quarterly control reports
7.	Procured from multiple sources	Two or more reliable sources	Two reliable sources for each item
8.	Minimize waste, obsolete and surplus	Quarterly control over waste	Annual review regarding waste
9.	Continuous effort to reduce lead time	Modern efforts	Minimum efforts

(vi) Procedure for making ABC analysis

(i) Calculate the total inventory for each item held in inventory by multiplying the number of units used in a year by its unit price.

(ii) Tabulate these in descending order of their values, placing first the item having the highest total value and so on.

(iii) Prepare a table showing item no., unit cost, annual units consumed and annual rupee value of units used.

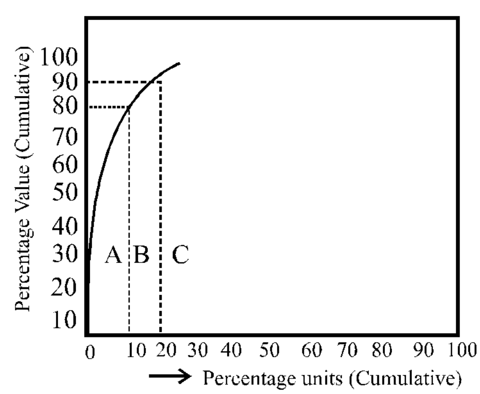


Fig. : ABC Analysis

(iv) Compute the running total items, item by item and also for rupee value of consumption.

(v) Compute the cumulative percentage for the item count and cumulative annual usage value.

(vi) Classify the items as per the norms for ABC items.

(vii) The cumulative percentages are represented graphically as under:

2.9.9 Fsn Analysis

FSN means, fast moving, slow moving and non moving. Classification is based on usage of items. This approach is very similar to ABC analysis. Here also the whole spares are divided into three categories.

(i) **Fast moving spares:** These are the spares which have very high consumption value and are required very oftenly in maintenance. Engine oil, diesel filters, brake liners etc. are some examples of fast moving spares of Road Transport Industry.

After inviting the tenders, the agencies for supply of fast moving spares are fixed for 1 to 3 years as the case may be. The orders are placed on yearly or half yearly basis on the consumption pattern. But the deliveries are staggered on fortnightly or monthly basis depending upon the external lead time, so that minimum fund is locked up in inventory.

(ii) **Slow Moving Spares:** These are the spares which are required off and on basis. The examples are propeller shafts, axles, steering wheel etc. These account for 15-20% of the total number of spares as well as 15-20% of the total cost of spares.

In this case also the organization after inviting the open tenders, fixes the supply agencies. Orders are given on half yearly or yearly basis with staggered deliveries of one month or two months as the case may be, depending upon consumption pattern.

(iii) **Non-Moving items:** These are the spares, which are required on the basis of, 'As and when required.' These spares requirement comes after a long internal of time. But these spares are about 70-75% in number but their cost is 5-10% of the total cost of inventory. These are non-emergency spares and as such their stock is reviewed after 6 months or whenever need arises.

The above classification is based on consumption pattern and therefore helps in controlling obsolescence of various items by determining the distribution and handling pattern.

2.9.10 Ved Analysis

This analysis consists of dividing the inventory into three groups, according to their criticality, usually called Vital, Essential and desirable spares.

(i) **V-items** are those items, which are considered vital for smooth running of the system and without these items, the whole system becomes in-operative. Therefore adequate stock of these items is required all the time. The organization has to suffer a great loss in case of stock out of these items.

(ii) **E-items** These are items which are considered essential to the efficient running of the system. Although stock out of these items may not result in the complete breakdown of the plant, but stock out if these shall certainly affect the output or in other words efficiency of the plant/system.

(iii) **D-items** These are desirable items. Stock out of such items neither stops the plant, nor do these have very adverse effect on the efficiency of the plant/system. But availability of these spare parts shall certainly increase the efficiency of the system.

The above VED analysis is useful in controlling inventory of spare parts. It can also be used in case of raw materials, whose availability is rare.

ABC analysis and VED analysis can be combined to control the spares based on desire of the customer's service level as shown below:

Table 2.3

ABC Classification	VED Analysis		
	V	E	D
A	Constant control regular follow up low stock, ordering more frequently	Average stock no risk stock outs	No stock
B	Moderate stocks no risk of stock outs	Average stock some risk can be taken	Very low stock some risk can be taken
C	High stock Restricted orders, no risk	Average stock same risk can be taken	Low stock some risk can be taken

VEIN ANALYSIS

V = Vital

E = Essential

I = Important

N = Normal

Analysis is based on usage value.

(i) **Vital:** In a chain operation, if a machine is the starting point and is feeding to a large number of machines, then it is more vital than the down stream equipment. A vital part of the first machine is most critical because it will affect adversely the other feeding machines, in case of its break down.

(ii) **Essential:** Essential spares are those spares, in which stock out would result in moderate losses.

(iii) **Important:** An important item is one, whose stock out will not have much effect on the working of the plant. But the fitment of the item is a requirement from factory law and other compulsions etc. Like fitment of plug in naked wire.

(iv) **Normal:** These are those items, which do not affect on the working of the plant, just like seat covers in a car. But these spare parts can provide some comforts and additional benefits.

2.9.11 Sde Analysis

It is based on the nature of procurement or (availability) of items. Here S represents scarce items, D difficult items and E easy to obtain items. Such classification helps in determining suitable purchase strategies and to control lead time. Scarce items maybe imported items as well.

ANALYSIS

This analysis is based on the value of the stocks on hands (i.e. capital employed to procure inventory). Items whose inventory values are high are called X category and whose values are low are called Z items. Generally XYZ analysis is used in association with ABC analysis.

CONCEPT

Music 3D concept tries to integrate three types of analysis by ABC/VED/SDE and each dimension is taken at two levels. Here spare parts are classified into categories.

(i) High sales value (HSV):- If it is beyond Rs 50,000/- per annum and this may go up to 80% of annual sales. Sales value accounts for 20% of the number of items.

(ii) Low sales value or low consumption value of about 20% of the items. This accounts for the remaining 80% of the items.

Here lead time is also classified as long lead time (LLT) with lead time of more than 12 months and short lead time (SLT) with less than 12 months.

Now combining the three methods, we get cost critically availability as shown below

Table 2.4: Cost Critically Availability

	High Sales Value Rs		**High Sales Value Rs**	
	LLT	SLT	LLT	SLT
Critical	1	2	3	4
Non-Critical	5	6	7	8
	No = 20% small Sales value 80%		No = 80% Sales value 20%	

Therefore the spares have been divided into 8 categories. Category 1,2,5 & 6 belong to spares which count 20% of the total number but their sales value is 80%. Similarly category 3,4,7 & 8 count for 80% of the spares, but their sales value is only 20%.

The above classification helps the spare parts executive, to selectively control in a better manner, the planning, forecasting and inventory of spares. This approach is superior to all other approaches and gives multi advantage to the organization.

ILLUSTRATION ON ABC ANALYSIS

Examples: Ten items are kept in the inventory. The details regarding the number of items used per annum and prices per unit are given below:

Table : Classify the items into A,B and C class.

Item No.	Annual Usage	Price
101	200	40.00
102	100	360.00
103	2000	0.20
104	400	20.00
105	6000	0.40
106	1200	0.80
107	120	100.00
108	2000	0.70
109	1000	1.00
110	80	400.00

Solution: Compute the annual usage value

Table

Item No.	Annual Usage value	Rank
101	200×40 8000	4
102	$100 \times 360 = 36000$	1
103	$2000 \times 0.2 = 400$	9
104	$400 \times 20 = 8000$	5
105	$6000 \times 0.04 = 240$	10
106	$1200 \times 0.8 = 960$	8
107	$120 \times 100 = 12000$	3
108	$2000 \times 0.7 = 1400$	6
109	$1000 \times 1 = 1000$	7
110	$80 \times 40 = 32000$	2

As such 1st rank and 2nd rank items can be taken as A-class items.

3rd, 4th, 5th items can be taken as B-class items.

6th, 7th, 8th, 9th items are C-class items.

2.10 Inventory

Any kind of resource having economic value and is maintained to fulfill the present and future need of any organization is known as inventory. For example spare parts of machinery, raw material and goods (semi-finished or finished).

Inventory Control of Spare

For scheduling and maintenance of the work, it is essential to ensure that required spares and materials are available. It is physically impossible and economically impractical for each spare to arrive exactly when it is needed 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 to maintain an optimal level of spares that minimizes the cost of holding the item in stock and the cost incurred. If the spares are not available then action has to be taken to supply the spare and inform the scheduling department when the needed spares become available.

Main objectives of inventory controls:

(a) To avoid losses due to pilferage, spoilage and obsolescence.

(b) To maximize the service level to the firms and customers.

(c) To relate stock and quantities as per demand.

(d) To avoid stock outs.

(e) To minimize investment in inventory.

2.10.1 Factors Affecting Inventory

(a) Inventory Cost: It consists of:

- **(i) Purchase cost:** It is price per unit multiplied by demand per unit time.

  (Price per unit × Demand per unit time)

- **(ii) Capital cost:** Amount invested in an item is capital cost.

- **(iii) Ordering cost:** Cost required for the procurement is called ordering cost. It is the amount of money spent to get an item into inventory.

  It consists of two types:

  - Fixed cost.
  - Variable cost.

- **(iv) Inventory carrying or holding cost:** The cost required for holding or carrying the given level of inventory and it varies with quantity of holding and time period of holding in stock.

- **(v) Shortage cost:** When there is demand and stock is not available then we incur a shortage stock or stock out cost.

(b) Funds paucity: Unavailability if fund is a factor which affects inventory. Due to this, store is not able to place the order sometimes. It leads to threat of stock out.

(c) Order cycle: It is the time between two consistent orders. It can be determined by one of the way:

- **(i) Continuous review:** When the inventory is reviewed continuously, the highest and lowest level of item is fixed as per the consumption pattern and total lead time of an item.

(ii) **Follow up action:** Continuous follow up with vendor is done, after placement of order. So the supply of item is within the specified external lead time.

(d) **Storage facility:** There are some items which are affected by humidity, temperature, chemical decomposition by sunlight etc. For storing such an inventory special facilities are provided.

2.10.2 Safety Stock

Safety stock is also called buffer stock or reserve stock and this term is used to describe a level of extra stock due to uncertainties in supply and demand. Adequate safety stock levels permit business operation to proceed according to their plans. Safety stock is held when there is uncertainty in the demand level or in the lead time for the product. It serves as an insurance against stock outs.

Safety stocks are mainly used in a "make Stock" manufacturing strategy. This strategy is employed when the lead time of manufacturing is too long to satisfy the customer demand at right costs quality waiting time.

The main goal of safety stock is to absorb the variability of the customer demand. Indeed the production planning is based on a forecast, which is different from the real demand. By absorbing these variations, safety stock improves the customer service level.

Determination of safety stock

If the level of safety stock maintained is high, it locks up capital and there is also possibility of risk of obsolescence. If the level of stock is low, there is a risk of stock out, resulting into stoppage of production. Generally the internal lead time is fixed or there is a very little variation in internal lead time. But there may be much variation in external lead time on account of external factors. When the variation in external lead time is predominant, safety stock can be computed as.

Safety stock = (Maximum lead time – Normal lead time) × Consumption rate

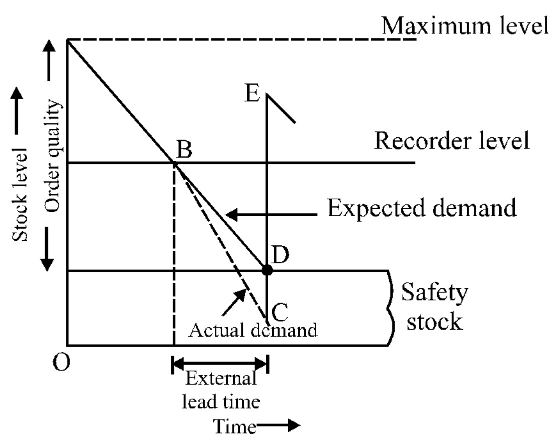


Figure 2.2

The above figure indicates:

(a) Safety stock.

(b) Order quantity.

(c) Reorder level.

(d) Fluctuation in demand

If the fluctuation in consumption rate is predominant, then the safety stock can be calculated by using the following formula.

Safety stock $= K \times \sqrt{D}$

Where K is a factor chosen on the basis of the assurance level required for protecting the item for stock-out and D is the average consumption during lead time.

For various assurance levels, the values of K are as given below:

Assurance level (%)	50	75	80	85	90	98	99	99.9
Value of K	0	0.7	0.8	1.0	1.3	2.1	2.3	3.3

The following K-values are suggested for each item on the basis of ABC and VED classification.

K values

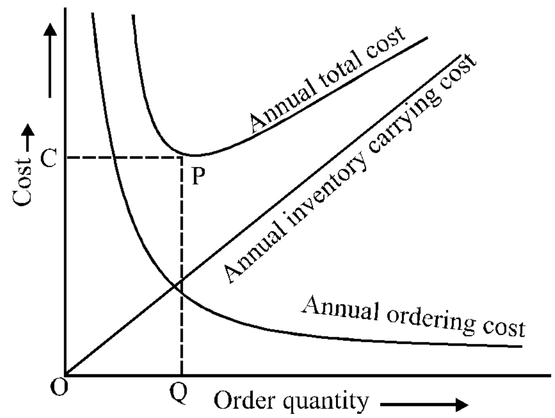
	V	**E**	**D**
A	2	1	0.5
B	2.5	2	1
C	3	2.5	2

In a practical situation, the consumption over a period fluctuates. Having fixed up the ordering quantity based on EOQ system, the order has to be placed while the stock level is equal to the sum of average lead time consumption and safety stock.

2.10.3 Concept of Economic Order Quantity

Economic order quantity (EOQ) is the number of units that a company should add to inventory with each order to minimize the total costs of inventory such as holding costs, order costs and shortage costs. The EOQ is used as part of a continuous review inventory system in which level of inventory is monitored at all times and a fixed quantity is ordered each time the inventory level reaches the specific reorder point.

The EOQ provides a model for calculating the appropriate reorder point and the optimal reorder quantity to insure the instantaneous replenishment of inventory with no shortages.



OQ × Economical order quantity

Figure 5.3

The EOQ model assumes that demand is constant and that inventory is depleted at a fixed rate until it reaches zero. The EOQ model finds the quantity that minimizes the sum of three costs.

Inventory Control Approaches

Inventory control is an approach used to determine:

(a) What to order (quantity to be ordered).

(b) When to order (time of ordering).

So, there are two types of replenishment methods:

(a) Fixed order quantity system (Q-system).

(b) Periodic review approach (P-system).

(a) Fix Order Quantity (Q-system)

In the fixed order quantity system, the order quantity is fixed and the ordering time varies according to the fluctuation in demand. This is also Q-system.

The fixed order quantity is event triggered. An order is initiated by it when a specific reorder level is occurred, so in the fixed order quantity the event of reaching the specific level in concerned. There are no time limits for the event. Solely depending on the demand for the particular item the event of reaching the reorder level may take place at any time.

It is considered as perpetual system where the withdrawal from the inventory or just an addition to inventory would be regularly updated and recorded. These updated records would help in knowing whether the reorder point is accomplished. In order to reach the fixed order quantity regular monitoring of the inventory that is remaining is needed.

Parameters to operate the system:

(i) Reorder quantity: It may be established mathematically that

$$Q = \sqrt{\frac{2D \times S}{i}}$$

Where, Q = Economic order quantity

i = Inventory carrying cost per period

S = Set up cost/ordering cost (in Rs/order)

D = Demand rate/demand per period.

(ii) Reorder level: The sum of safety stock and lead time consumption called reorder level (ROL)

$$ROL = m + L \times C$$

m = Minimum or safety stock

L = Lead time (days/weeks/months)

C = Consumption rate (per day/per week/per month)

(iii) Maximum stock level: Sum of the safety stock and order quantity is equal to the maximum stock level.

$$M = m + Q$$

Where, M = Max stock

m = Safety stock

Q = Order quantity

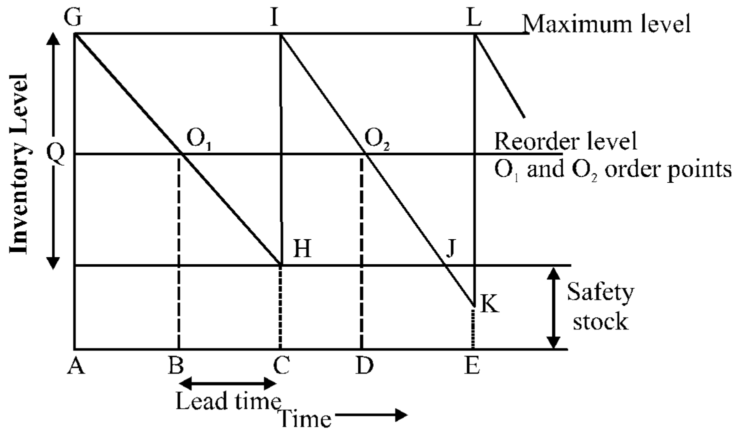
(iv) Average inventory

$$Average\ stock = \frac{Minimum\ stock + Maximum\ stock}{2}$$

$$= \left(\frac{m + M}{2}\right) = \left(\frac{m + m + Q}{2}\right)$$

$$= \frac{2m + Q}{2} = m + \frac{Q}{2}$$

Now if we consider an over-simplified procurement and consumption cycle for an item having a steady consumption all through the year and which is available instantaneously on placing an order (without fail), the procurement and consumption cycle can be shown as given in figure .



Figure

Q = Reorder quantity

O_1 & $O\text{-}_2$ = Ordering points

m + Q = Maximum stock

at time 'A' the stock is zero and hence an order will be placed and (the delivery being instantaneous) the stock will be brought up to a level 'O_1'. The item will be steadily issued up to a time 'B' and another order will be placed at 'B' to bring up to stock to H and so on. The average inventory in this model will be Q/2. Also the delivery of each order is instantaneous.

2.10.4 Periodic Review System (P-System)

In the EOQ system, we have to place the order as and when the stock level reaches the reorder level. That means that a continuous watch on the stock level is required and there will be orders released almost daily as there are large number of items. The possibility of combining more number of items in the same order for a supplier is very much reduced. Periodic review system aims at eliminating such disadvantages. In this system, the stock level of all or a group of items are reviewed periodically. The review period and the replenishment level are fixed and order is placed while the stock level is less than the replenishment level. Ordering quantity is equal to replenishment level minus stock level.

(a) Replenishment level = Safety stock + Consumption rate × (review period + Lead time)

$$= m + C(R + L)$$

Where, m = Minimum or safety stock

C = Consumption rate

R = Review period

L = Lead time

(b) Reorder quantity

(i) When lead times is less than review period

Q = Maximum stock – stock actually held at the time of review

(ii) When lead time is more than review period

Q = Maximum stock – (stock in hand + stock on order)

(iii) Determination of optimum review period interval t

$$Q = \sqrt{\frac{2DS}{i}}$$

Optimal time between order is

$$t = \frac{Q}{D}$$

$$t = \frac{Q}{D} = \frac{1}{D}\sqrt{\frac{2DS}{i}}$$

$$= \sqrt{\frac{2S}{Di}}$$

Where, D = demand rate or demand per year.

When stock level is reviewed periodically, the safety stock also should take into consideration the fluctuation in consumption during the review period.

Various other parameters for periodic review systems are as follows:

(a) Review period.

(b) Replenishment or maximum level.

(c) Safety stock or Reorder Quantity

Review period is based on the ordering quantity as recommended for EOQ system, i.e., the duration for which the quantity can last. In the earlier example an ordering quantity of 24 Nos. bearings was recommended and the same can last for 10 weeks. Hence, the review period recommended will be 10 weeks. As the review period thus arrived may vary from item to item, review period should be suitably chosen for a group of items which is near optimal.

The safety stock may be computed as follows:

Safety stock = K × Consumption during lead time and review period

(if fluctuation in consumption rate is predominant)

As the number of items could be many and their annual consumption value may range widely, it may be necessary in many occasions to have different groups with different review periods. For instance, for P_1, for P_2 items review period may be R_2 and for P_3 items the review period may be R_3. This may result in near optimum results.

A graphic representation of Periodic Review System is given in Figure.

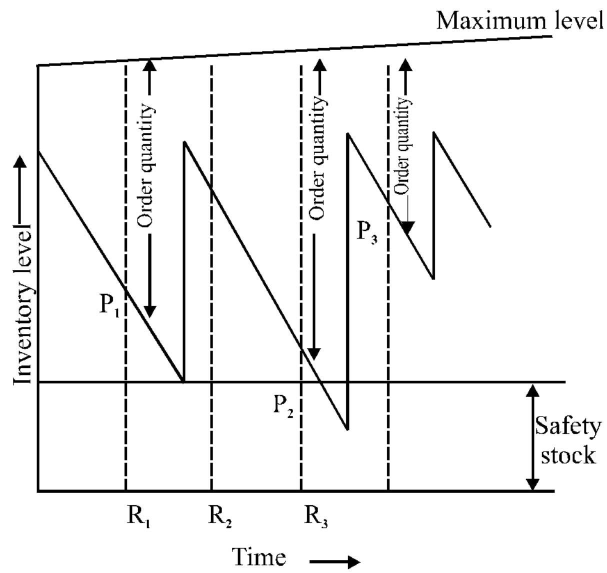


Figure - Periodic review systems

R_1, R_2, R_3 = review period.

P_1, P_2, P_3 = reorder levels.

2.10.5 Differences between Q-System and P-System

Table

Factors	Q-System	P-System
Order quantity	Constant	Variable
When to place order	When inventory becomes equal to reorder level	When review period comes
Record keeping	Each time a withdrawal/ addition is mode	Carried out only at review period
Size of inventory	Less than P-System	
Effort/time to maintain	More than P-System due to continuous monitoring	
Types of items covered under the system	High priced, critical and important items	Items not considered in Q-System

Solved Example

Example 2. A manufacturer has to supply his customers 3600 units of his products per year. Shortages are not permitted. Inventory carrying cost amounts Rs. 1.2 per unit per annum. The set up cost per order is Rs. 80/-find:

(a) Economic order quantity.

(b) Optimum number of orders per annum.

(c) Average annual inventory cost (minimum).

(d) Optimum period of supply per optimum order.

Solution:

Annual demand = 3600 units

Inventory carrying cost, I = Rs 1.2 unit/annum.

Ordering cost = Rs 80/order.

(a) EOQ (Economic order quantity)

$$= \sqrt{\frac{2DS}{i}} = \sqrt{\frac{2 \times 3600 \times 80}{1.2}}$$

$$= 692.82 = 693\ units$$

(b) Optimum orders per annum

$$N = \frac{D}{Q} = \frac{36{,}00}{693} = 5.19 \approx 5$$

(c) Minimum annual inventory cost

$$T = \sqrt{2D \times S \times i} = \sqrt{2 \times 3600 \times 80 \times 1.2}$$

(d) Optimum period of supply per optimum order

$$= \frac{1}{N} = \frac{1}{5} = 0.2\ years$$

❑❑❑❑

Working Notes