There is good presence of international construction companies. Multiplex, Skanska, Samsung, Bechtel, Turner are some of the international companies. Local companies including Arabtec, Khansaheb, ETA Ascon, Al Habtoor, Dutco, Al Shola, Al Shafar, ABM, Al Jaber are some of the leading names in the construction business in the United Arab Emirates.

In the absence of a formal building code, over the years, the municipality of the emirates accepted the practice of British standards. However, the UAE's emirates have developed their own building codes. In many cases the accepted systems are British standards or equivalent. The main objective of construction organizations in the UAE are mostly time driven. Companies with clear project management directives always aim at controlling the factors of Time (T), Quality (Q), and Money (M). Generally projects consist of three main components including scope, budget and schedule.

The companies face many problems including cost overruns, time extensions and conflicts with all parties concerned. The projects are generally unique with high risk, highly fragmented, highly competitive and with increasing challenges. The construction companies need to utilize the available resources effectively to meet the project requirements and deadlines without sacrificing the quality and safety.

CHAPTER 3: MAINTENANCE OF PLANT AND MACHINERY

3.1 Introduction

By the beginning of 20th century most of the industrial activities were performed manually. As the industrialization and mechanization started growing in the world, the needs of the machineries were felt very much. In the present world, every action is operated through machineries and controlled by computerized systems, internet websites and so on. It is unavoidable for any developing country to adhere to mechanization and move according to changing times. It is an accepted concept that maintenance is a key function in sustaining long-term profitability for organization (Al-Sultan and Duffuaa, 1995).

3.2 Importance of machineries in industries

In the past, skilled and unskilled labor was plenty and cheap, the essentialities of mechanization were not felt very much in those days. In the developing countries, the manual labor wages always used to be very cheap and availability was in plenty. But today, the situation is quite different. Manual labor has become very costly due to lots of industrial and development activities happening in all parts of the world like Asia, Europe, Middle East including countries like UAE, Qatar etc. Non-availability of labor for certain selected categories is always a hurdle for speedy job implementations particularly in construction industry. So it is imperative to introduce machineries to achieve timely completion with less manual errors. To ensure this, the contract awarding authorities nowadays specifically mention the machineries and machinery required to execute the specified project as a clause within the contract agreement itself. Therefore, the role of machineries and machinery is critical for the success of any industry.

3.3 Importance of Maintenance to Machineries

In industries, the activity of maintenance enhances the values of actual output versus desired outputs. Effective maintenance management contributes to the success of business and needs. As the machinery dependency rate has become vital in all trades of work, it is also important that all the machineries perform their function to the optimum level. In order to have a trouble free optimum performance of the machineries, the maintenance of the same is very much essential. One cannot assume to have a situation, wherein there is no need for maintenance function. Whatever may be the trade or field, maintenance is paramount, at least to have a trouble free working environment, for various systems, machinery and fields.

Maintenance is always a combination of all acts including technical and administrative actions, supervision, actions intended to retain an item, or restore it to a state in which it can perform the required function (IEV 191-07-07, 2005). Maintenance found its full recognition during the last decade that in a world class organization, it cannot be considered as an isolated function, but has become a full partner to the entire span of activities and function to facilitate the strategic goals of the organization (Etienne-Hamilton, 1994). The role of maintenance in modern manufacturing has become more important, with most of the organizations adopting maintenance as a profit-generating entity rather than cost and considers it as a linked unit along with other production activities. It would appear that the aim of the maintenance function is to contribute towards an organization's profit, bringing the need for maintenance operations to be in line with corporate business objectives (K.Y. Kutucuoglu, 2001). As a result of all of the above statements the traditional terms used to describe maintenance as "necessary evil" seem to become obsolete.

The maintenance trend has found its importance since invention of machineries. The older generations were using the basic lubrication as the, one and only maintenance strategy. The lubrication, with some kind of available oily form of materials, (mainly from trees, etc.) was done only when there was total stoppage of work due to increased friction, non-movement of the carts, bullock carts, etc., which were the main source of transportation for the earlier generations. They became the stepping-stones to today's modern transport systems.

Maintenance is upkeep of everything. Machineries/utilities/products should be maintained in good condition, so that they are always available for useful service and work. The definition of maintenance is also often stated as an activity carried out for any machinery to ensure its reliability to perform its required functions. Maintenance Management is the combination of systems and procedures which are tailor made to the organization's plant and machinery requirements and hence to ensure optimum efficiency levels with least cost. Maintenance management is also about the optimization of the maintenance strategies including breakdown, preventive, predictive, condition based and reliability centered maintenance systems to have an effective maintenance system (Mishra R.C, Pathak K, 2002).

To be in line world-class performance on maintenance and activities, more and more organizations are replacing their reactive, fire-fighting and breakdown strategies of maintenance with proactive strategies like preventive and predictive maintenance and total productive maintenance. While these newer maintenance strategies require increased commitments to training, resources and integration, they also promise improved performance (Laura S, 2003). If maintenance is not effective, it not only leads to the halting of work but also leads to industrial accidents invariably making loss of life and property. In petrochemical industries which operate for 24 hours and 365 days a year, even a small failure triggers off the shut-down of entire production. A tower crane breaking down in a construction site creates chaos and leads to a stage where hundreds of workmen will be idling due to stoppage of works which are parallel and dependent.

3.4 The Historical Role of Maintenance

Maintenance is an age-old function, which developed and progressed along with the development and improvement of operation of machinery. In the early ages, maintenance was probably, not a separate identity, but the job of maintenance was considered as part and parcel of operator's job. This was possible because of simplicity of machines and machinery in the earlier days. However, with the growth of industrialization, the complexity of the machines increased and the machines became less simple. This started creating problems for the operating personnel and the concept of maintenance as a separate discipline and separate identity started (Chunawalla S.A., 2003)

The evolutions of methods of maintenance are categorized in to three different generations. The first generation being 1930 to 1940, the second generation between 1950 to 1970, and third generation prevailed from 1980 onwards. The fourth generation is the present day maintenance which is in line with the World Class Maintenance requirements and the trend is increasing further and further with newer methodologies and applications finding their presence in the maintenance world.

The first generation has been during the earlier days of industrialization when mechanization was very much low and manual means of work was prevailing everywhere. Most of the machinery in the factories was basic and repairing and restoration process was done in a very short time due to presence of simple mechanisms. Thus downtime of machinery was never felt as a hurdle and there was no need for end users to put maintenance as a high priority issue.

The second generation in maintenance emerged as a result of growing complexity in plant and machinery design, and dependency of maintenance got increased due to mechanization of activities and the industry was beginning to depend on these complex machines. Repair and restoration was difficult and special skills and more time was needed to mend the machinery. As this dependency rate grew, downtime became more apparent as a problem and got a focused view from the management. People started to think that these failures should be prevented, which led to the concept of preventive maintenance. As maintenance cost started to rise sharply relative to other operating cost, there was a rising interest in the field of maintenance planning and control systems (Hisham B.J, 2003).

Beginning of 1980's the growth of mechanization and automation became still more inevitable and even small breakdowns in the plant and machinery was sensitive to the whole organization and could affect the operation of the whole plant and machinery. The necessity of maintenance systems were very much felt which were essential towards the growth. This has implied a meaning that reliability and availability have become the key issues since any failure or breakdown of machinery can cause serious consequences to the whole division. Third generation maintenance has undergone a shift of focus in maintenance to highlight those areas where the inherent design of the assets yields probabilities of failures that are unacceptable, and provide some guidance and motivation for improving those assets (Hisham B.J, 2003).

The fourth generation of maintenance entered with the rapid changes happening with newer development of machinery and processes and these processes got accelerated with the help of faster computers which started prevailing and penetrating to every other fields. The basic principles of the fourth generation of maintenance have been based on the previous three generations and with the following special features.

- Definite deliberation of risk, notably at higher levels of organizations, when dealing with machinery design and maintenance strategies.
- Coherence between functional demand, machinery design and maintenance will be greater than the currently existing integration methods.
- To adopt with the swift development in information technology to detect, predict, diagnose and prevent machinery failures.
- Increasing usage of computer modeling in maintenance strategy. The rapid development of computer technology in the artificial intelligence and expert systems, computer simulations and modeling may provide the real predictive tools for modeling the future.

3.5 Objectives of Maintenance

Maintenance, as a system, plays a key role in reducing cost, minimizing machinery downtime, improving quality, increasing productivity, providing reliable machinery and, as a result, achieving the organizational goals and objectives (Bashiri, 2011). The objectives of world-class maintenance systems (WMS) can be stated as follows:

- To always aim for zero failures and breakdowns
- To construct competitive capabilities for production by means of best practices in maintenance
- To achieve and maintain the highest standards of productivity
- To reduce overall machinery emergencies
- To facilitate the maintenance crew with ease of operations
- To reduce maintenance purchasing cost on procurement of spares and tools
- To provide a systematic approach for improving the efficiency of the production system by eliminating all losses
- To develop machinery, which are designed for maintainability and reliability to realize reduced life cycle cost
- To assure a good product quality through investigation, analysis and improvement of process, material and machinery conditions
- To aid in achieving zero accidents in a healthy and clean work environment and protect the natural environment
- To develop a flexible, multi-skilled organization with internal experts

- To optimize the maintenance cost and provide better services to operations through systemized maintenance techniques, teamwork, use of latest tools and technologies

3.6 Types of Maintenance

The industrial revolution has led to improvements in the manufacturing engineering sector where many systems and procedures to optimize the production activities were established which demanded effective capacity utilization of assets and machinery. Due to this demand of uninterrupted service requirements from the plant and machinery, the maintenance function also got evolved, which further resulted in development of different types of maintenance strategies. A review of literature reveals different maintenance methods and systems, which has been discussed briefly in this section along with its advantages and disadvantages.

3.6.1 Planned maintenance

Planned maintenance is the method of ensuring that maintenance requirements of machinery, plant, services and utilities are adequately covered. Ideally all maintenance activities should be of the preventive in nature and that planned maintenance will always meet this requirement.

Planned maintenance is defined as "maintenance organized and carried out with planning, control and maintain records to a predetermined plan". The main factors considered as bottom line were the extent and severity of utilization of machinery and operating conditions. In the planned maintenance, detailed instructions need to be followed strictly, which include instructions for inspections (check lists), repairs, and rectification replacement of components. The data is kept as record, which helps in effective planning and scheduling. The analysis of failure data clearly brings about the cause of failure, design issues, and operational problems.

The process of deterioration is often so slow that it passes unnoticed unless observed systematic maintenance at stated intervals. Most machinery failures start from minor causes which can be really eliminated if their presence was known earlier. Machinery which requires very little maintenance is more liable to major breakdown or overhaul, due to complete negligence, than machinery in which many minor faults demand continued monitor/vigilance. Systematic maintenance consistently executed will prevent conditions of unknown failures which develop all of a sudden and also control the related expenses.

Besides maintenance planning from an engineering standpoint, there are other major considerations for introducing planned maintenance which include a) need for effective utilization of manpower and resources, and b) possibility of reducing maintenance costs. As a maintenance function responsibility, it is worthwhile to carry out a review of activities to ensure that the maintenance programme is adequate, and that the labor and resources are effectively utilized which is the real meaning of planning and control in maintenance activity. It is known that the greatest single reason for failure of any planned maintenance programme is the error of not establishing any reliable control methods. A fully comprehensive planned maintenance programme will provide the following:

- Detailed examinations and listing of each section of the machinery to determine what has to be done and when it should be done
- Work classification by trade
- Individual and group man-hour requirements by trade
- Organization of material and labor for individual jobs, job priorities and overall shop loading
- Preparation of master overhaul, inspection and lubrication schedules for each item of the maintenance inventory
- The integration of the preventive maintenance programme with other maintenance work so that it becomes part of the overall planned programme
- The provision of maintenance records including breakdown reports and cost allocations, from which decisions on machinery replacement, service frequency, spares and manning requirements can be made.

Generally, the programme will be so designed that, having built up a work-load by trade against requirements, these requirements are translated into a shop loading which can be controlled. Some of the types of planned maintenance programme include the following:

3.6.1.1 Routine Maintenance

Routine maintenance can be considered as a cyclic operation recurring periodically. These are established by predefining the frequency of the tasks and also the time taken to complete the task. The backbone of any planned maintenance programme is the effective utilization of maintenance routines which are basically examining the system/component/machinery at fixed frequencies. The most commonly used routines are:

- Examination at a set frequency with subsequent defect reports and work orders
- Examination at a set frequency with immediate rectification of minor defects and a report on major work necessary to be done on work orders
- Systematic withdrawal of machinery for major overhaul
- Replacement of functional parts at prescribed intervals
- Scheduled lubrication and cleaning
- Spares scheduling and stock control

3.6.1.2 Periodical/Scheduled Maintenance

Generally machinery manufacturers assist organizations in developing a planned maintenance programme. The manufacturer enhances the life of the supplied machinery with established maintenance procedures which if strictly followed also paves the way for the claims of warranty. This is done by the organization owning and using the machinery.

The main control needed for any maintenance system is the planned and effectively carried out periodic and systematic inspection of all the mechanical machinery and components. The aims of inspections are as listed below:

- Proper preventive maintenance services are performed by the end user group or section
- Determine the action to be referred to the higher management in order to assist units, sections of groups in improving maintenance and overcoming major failures
- Instructing each user unit, section or group in correction of deficiencies in the maintenance procedures, and in the utilization of current and valid maintenance literature
- Ensuring the correct usage of machinery to its limits and compliance with the organization’s maintenance policies

- To determine the adequacy and effectiveness of the user units, operative trainings, their technical personnel maintenance competencies, practices and tools knowledge and update of other facilities
- Ascertain machinery serviceability and anticipate future maintenance and supply requirements
- Provide sufficient inventory of spares

3.6.1.3 Preventive maintenance

Mostafa S I, (2004) defined preventive maintenance (PM) as the practice that include all planned, scheduled and corrective actions prior to any machinery failure, in its scope. Preventive maintenance (PM) policies are always pre-planned at fixed time intervals in nature (Xiao-Gao L, 1995). PM is also defined as all actions performed on a clocked time or machine-run hours based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling the degradation aspect to an acceptable level. The maintenance concepts required for a technical plant and machinery system is the set of rules specifying what kind of maintenance is required (C W Gits, 1992). In other words it can be understood as utility based maintenance or also often referred to as "use-based maintenance" (Herbaty, 1990).

Preventive maintenance includes all types of planned maintenance works performed in order to prevent breakdowns, ensure optimum production by the machinery and extend its life. It is also about the care and servicing by personnel for the purpose of maintaining the machinery and facilities in a satisfactory operating condition by providing necessary systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects. Khalil et al (2009) identified the need for preventive maintenance for all the companies and envisaged the need to develop preventive maintenance strategy, especially to eliminate unplanned downtime of machinery.

A good preventive maintenance programme will achieve less downtime, few large scale and recurring repairs, low repair cost due to timely actions and predictions, reduced overtime wages to maintenance and repair staff, and better spare parts inventory control. By reducing the chances of downtime and it further helps to increase the production. Thus it has two principle objectives: technical, which ensures breakdown-free operation and ensures optimum life of the machinery, and financials which reduces costs by reducing downtime.

Preventive maintenance involves a detailed schedule of planned maintenance actions which are aimed at the prevention of breakdowns and failures. Preventive maintenance is also used to avoid the costly after effects of machinery breakdowns (Silver and Fiechter, 1995). The preventive maintenance policy always tries to determine a series of checks, replacements and/or component revisions with a frequency of inspection in relation to the failure rate. Generally preventive maintenance is effective in overcoming the problems associated with the wearing of components. When thorough checks are made through a good PM programme, it is not always necessary to substitute the components, and maintenance alone often sufficient. PM also includes work performed on selected machinery through offshoring/service contracts, inspections, cleaning activities, testing, lubrication efforts, and scheduled shutdown service. PM belief is that instead of reactive maintenance it is better to be proactive maintenance through early detection and early correction.

A very elaborate preventive maintenance programme may also result in unduly high cost, thereby offsetting the advantage of cost reduction in machinery production. Each project should fix its own standards of preventive maintenance requirement consistent with their objective of safety, environment and performance to get the optimum results. Planning for preventive maintenance begins with an assessment of scheduled maintenance of every machine from daily to yearly maintenance requirement. Based on this assessment the requirements, of men, material, tool, spare parts, maintenance manuals and charts supplied by manufacturers of machinery, adequate workshop facilities, and also mobile servicing units should be planned and worked out so that these things can be arranged in time. Workshop and stores facilities are also essential in the planning for preventive maintenance. PM planning should be systematic and thorough, and should be ensured through proper supervision.

An important aspect of machinery selection is the ease and simplicity of its maintenance while in use. The built-in maintenance features of the machine should be looked first for while buying a piece of machinery. The design features which are compatible with overall economy in running, maintenance and repairs are conducive to low cost operation. A machine fitted with life-time lubricated bearings would reduce maintenance effort to a great extent as compared to another machine with conventional bearings requiring lubrication every 8 or 16 hours. Under powered and overloaded machinery will always increase the maintenance requirement. Long-term benefits of executing proper preventive maintenance include: I) improved system reliability; II) decreased cost of replacement; III) decreased system downtime and ineffective inventory management.

3.6.1.4 Predictive maintenance

A sound description of predictive maintenance is the application of technologies and early detection processes to monitor and detect changes in condition to allow more precise intervention. Predictive maintenance can be defined as follows: "measurements that detect the onset of a degradation mechanism, thereby allowing casual stressors to be eliminated or controlled prior to any significant deterioration in the component physical state".

Under predictive maintenance, diagnostic machinery and tools are used to measure the physical condition of machinery and its components and generally it may include vibration analysis, shock pulse methods, ultrasonic, thermo graphic analysis, oil analysis, electrical surge comparisons, coolant analysis, wear particle analysis, and performance trending (Eade, 1997). All machines will generally give early warning signs or symptoms, predicting their impending failure. When one of these indicators reaches a specified level through these monitoring devices, work is undertaken to restore the machinery to proper condition. This means that machinery is taken out of service only when there is direct evidence exists that the deterioration has taken place. Predictive maintenance works on the similar principle as preventive maintenance although it employs a different criterion for determining the need for specific maintenance activities.

3.6.1.5 Condition-based maintenance

Condition-based maintenance (CBM) includes scheduled maintenance as well as the corrective maintenance. CBM is not a technology or a technique, but it depends on other technologies to provide this objective evidence.

According to Bevilacqua et al, (2000), a pre-requisite for the application of condition-based maintenance is the availability of a set of measurements and data acquisition systems to monitor the machine performance in real time. The continuous survey of working conditions and the environment can easily and clearly indicate an abnormal situation (e.g. the exceeding of a controlled parameter threshold level), allowing the machinery process administrator to consistently perform the necessary controls and if necessary stop the machine before a major failure can occur. Also to use this strategy, the referred condition must be monitored and measurable with respect to the standard conditions. The monitoring could be made manually or by sensors. Temperature, pressure and vibration are examples of monitoring parameters. Bevilacqua et al, (2000) have also explained the differences between the condition-based maintenance and predictive maintenance. Unlike the condition-based maintenance policy, predictive maintenance verily depends on acquiring controlled parameters data which are analyzed to find a possible temporal trend. This makes it possible to predict when the controlled quantity value will be reaching or exceeding the threshold values. The "predictive" component part of the predictive maintenance stems out from its goal of predicting the future trend of the machinery's condition while condition based maintenance includes scheduled and corrective maintenance also. The maintenance staff will then be able to plan, depending on the operating conditions, when the component substitution or revision is really unavoidable.

3.6.1.6 Design-out maintenance

Design-out maintenance (DOM) is a system that strives to eliminate the cause of failure or minimize the need for maintenance to the lowest possible level. It is appropriate for items with higher maintenance cost, which arises generally due to poor maintenance, poor manufacturer design or operating conditions well beyond the design specifications. It is applied to the product or machinery at the design stage itself, so that machinery, plant and machinery are so designed accordingly with an allowance to manage the needs or requirements which will arise during their life span. The identification of items to be designed out depends on the cost of redesign and the cost of recurring maintenance (Maity, 2001).

According to Oyebisi (2000), “Design-out maintenance is proactive in nature and it is also the effective maintenance strategy in terms of scientific value and overall cost implications”. In contrast to other maintenance strategies, which all aim to minimize the effect of failure alone, design-out maintenance aims to eliminate the cause of maintenance itself. Failures are prohibited and maintenance is simplified during the design phase itself to machinery and its parts. This strategy was used in the design of the Boeing 777, where maintenance was simplified and the staff had enough space to perform replacements and repair in all parts of the airplane. In this type of maintenance it is also essential for the designer to have mechanisms that link the machine reliability and maintenance parameters with the user's operational requirements (Lad, B.K., et al. 2010)

3.6.1.7 Total productive maintenance

Total productive maintenance is based on the teamwork and provides a method for the achievement of better levels of overall machinery effectiveness through people and not through technology or systems alone (Willmott, 1994). A typical TPM development program for any organization should emphasize upon the need for top management's initiative in launching and implementing TPM, formulation of TPM policies, goals and concepts and its effective communication within the organisation and as well frame a system of training and employee involvement (Fredendall et al, 1997). It can be considered as a combination of both reactive and proactive maintenance. TPM was developed in a capital intensive manufacturing environment, and has been practiced both in terms of machinery reliability and organizational reliability (Fredendall et al, 1997).

3.6.1.7.1 Objectives of TPM

- To maximize the Overall Machinery Effectiveness OEE through total employee participation and involvement
- To improve the machinery reliability and maintainability at all levels which will improve quality and productivity
- To ensure maximum economy in machinery and management for the entire life of the machinery
- To cultivate the machinery-related expertise among operators and skills among operators
- To create an enthusiastic work environment

TPM is "a way of working together to improve the machinery effectiveness". It is a methodology and philosophy of strategic machinery management focused on the goal of building product quality by maximizing machinery effectiveness. It also embraces the continuous improvement principles and ensures total participation by all employees and by all departments (Society of Manufacturing Engineers, 1995). TPM is a production-driven improvement methodology that is designed to optimize machinery reliability and ensure efficient management of plant assets. It is a method for bringing about change. It is a set of structured activities that can lead to improved management of plant assets when properly performed by individuals and teams (Robinson, 1995). Pomorski (2004) defined TPM as a structured machinery-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating machinery and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.

The differences in the Japanese and Western approach in defining TPM are subtle, with commonality highlighted more than significant variation. The Japanese approach emphasizes the role of teamwork, small group activities and the participation of all employees in the TPM process to accomplish machinery improvement objectives. The Western approach focuses on the machinery while understanding that operator involvement and participation in the TPM effort is required. While very similar, the Japanese approach seems to be more people and process focused while the Western definition approaches first from machinery improvement objectives, "which moves the emphasis away from both maintenance and teamwork and towards machinery management and utilization with operator participation." (Bamber et al., 1999)

3.6.2 Reactive maintenance

The reactive maintenance is all about the temporary repairs made in order to return the machinery to its serviceable and operation levels for the moment, with permanent repairs put off until a later time (Gallimore, 1988). Literally it can be interpreted as, "performing maintenance activities in reaction to the breakdown or failure of machinery".

When any failure occurs to the service providing machines, to make it operational and to perform its uninterrupted service again, speed is the essential factor while executing repair or when the reactive maintenance is being carried out. There may be situations when these kinds of reactive maintenance may be performed during production working hours also and probably continuing into an evening or night shift, leading to high labor costs with possibly, little supervision, more waiting time for the spare parts and non-availability of working space like engine rooms/controlled areas. There is generally a faulty assumption by many concerned, that the cost of the breakdown is the only cost incurred in getting the machinery back into service. But the actual cost of breakdown or in other words the true cost is considerably higher. Various elements of the costs including direct cost of the repair, the on-costs of wages paid to idle operatives, the cost of temporary replacements, opportunity costs levied by the lenders, the cost of production spoiled and the cost of production lost. It will also follow that the magnitude of the breakdown repairs is greater than if the rectification had been carried out under controlled conditions, so preventing premature failure. Furthermore, if spare parts are not immediately available in the event of an unexpected breakdown, one may face the extra costs of sub-contracting production during the period of shutdown if necessary while the spare parts are being manufactured and fitted.

When these additional costs are added to the emergency repair cost in terms of material and labor, the cost of the breakdown can be substantial. It can, therefore, be stated that normally, unless an item of machinery is so situated that it will not interrupt the machinery production, breakdown maintenance is inherently, inefficient on all accounts, creating an indeterminate workload on the maintenance staff and there is no justification for its continuance in construction. Even in the case of many of the uncritical units it may be cheaper to bring them under a planned schedule of replacement, or to have a determined process of failure management with whole of the repair process executed in a systematic way than to allow them to run to ultimate failure. The following types of maintenance are also included under reactive maintenance:

3.6.2.1 Breakdown/Corrective Maintenance

When any sudden breakdown occurs in any machine or plant service, the repair maintenance staffs endeavours to locate the same as, mechanical, electrical or some other trade fault and correct the same immediately. The repair maintenance function presupposes previous breakdowns. This function involves the disassembling of the machinery, to locate the fault if it has occurred through any broken part, then to find out that part and to replace it, to reassemble the machinery and then check the machinery to ensure that it has restored its functional capacity. The repair maintenance function may be of a major nature or it may be a minor one. It may extend, to a few minutes, a few hours in a day or even a few days depending upon the size and complexity of the machinery, the nature of the fault and the availability of repair staff and machinery. In other words, it is corrective maintenance. It restores an item to acceptable condition again.

Breakdown maintenance is also called as run-to-failure maintenance for organization who does not have any maintenance functions/crew in place and generally maintenance is always overlooked. It may be described as a fire-fighting approach to maintenance and the machinery is allowed to run until failure. Then the failed machinery is repaired or replaced (Swanson L, 2001, Paz and Leigh, 1994). In the organizations with more breakdown maintenance the strategies for the maintenance activities are not planned. (Mostafa S I, 2004).

Major repairs and overhauling are the requirements managed by a machine owner after an machinery attain major failure, or after the normal expected service life of a machine has been fully achieved. Major remedial repair work is generally needed to restore a component/system which has failed prematurely due to improper corrective maintenance, improper preventive maintenance, lack of inspection and adjustment, or machine abuse. Remedial repairs are often reactive in nature and are needed immediately.

Proper machinery maintenance and inspection and regular system analysis can hold remedial repair to a minimum. The hydraulic cylinder wiper seal is a good example. Seal wear is unavoidable. Therefore, as one part of preventive maintenance, the wear progress should be monitored and replacements made where necessary. If this is not done, the hydraulic pump, control valve, and cylinder will soon need repair because contaminants will have entered the hydraulic system of the component. In this case, repair of the pumps, valve, and cylinder constitutes remedial repair and the relative increase in the cost also.

Essentially, remedial repair has two objectives: First is rapid return of the machinery to operational condition; second is to determine the reason for failure and make correction to avoid repetition of failure. A typical example is a worn hydraulic pump due to dirt. Replacing the pump without finding and correcting the dirt will result in an early repeat failure. Troubleshooting information available from the machinery manufacturer will help determine the initial cause and contain instructions for correcting the problem.

Generally, major repairs which are part of the breakdown/corrective maintenance correct the premature failures resulting from error or oversight in the preventive maintenance programme. This underlines the importance of a well-planned and well executed maintenance. Machinery overhaul restores the machine to an acceptable level of productivity and availability, and assures it additional normal and predictable wear life. Overhauling consists of that repair work necessary to restore a machine component to productivity after its normal wear life. In overhauling, individual components and parts are inspected, measured, and tested. Decisions are made to reuse repair and reuse, or to replace the parts. The goal is restoration that will assure additional trouble-free performance.

By system analysis and an effective preventive maintenance programme, the need for component overhauls is determined prior to a breakdown. Overhaul work can then be scheduled at an appropriate time. During overhaul, a careful inspection of all parts may reveal the impending service needs on other components and systems. Each overhauled component must be tested in operation before it is installed in the machine. In a complete machine overhaul, not every part will have to be replaced. Each system of the machine should be tested, its condition diagnosed, and remaining service life estimated. When a complete machine overhaul is in process, all wearing parts that will not last for an acceptable time period should be replaced. Thus parts with some remaining life will be replaced.

3.7 Opportunity based maintenance

The opportunistic maintenance find its application which is demanded and determined by the nearness or concurrence of control or substitution times for different components on the same machine or plant. During this type of maintenance execution, the situation may lead to the whole plant being shut down at set times of intervals to perform all relevant maintenance interventions and activities at the same time (Bevilacqua et al, 2000). In other words if the machine has been taken up for maintenance, the engineers may use that opportunity to inspect the condition of other related components and assemblies, based on which they will repair or replace the parts if necessary. When a heavy vehicle is being repaired for its brake liners, the crew also checks the condition of the housing and the brake cylinders. This is called the opportunity based maintenance.

3.8 World-class maintenance systems

R Kodali et al, (2009) studied the failure causes of TPM implementation in organizations to the lack of involvement of the management in maintenance functions and proposed various solutions in the form of “best practices”, which can lead to the development of world-class maintenance systems (WMS) within organizations. Wireman (1991) defined world-class maintenance as maintenance without waste, where waste is related to the gaps between the actual ways of execution versus planned way of execution. With poorly managed maintenance operations, the gap tends to increase consistently, since the focus always remains with reacting to problems rather than settling the issues every now and then with short notices. Many organizations have realized the need of effective maintenance of production facilities and operating systems.

It is emphasized by many researchers that it is vital for the maintenance management teams to be integrated with the corporate goals and strategies and to ensure effective machinery availability, to bring out quality products from right machines, on-time deliveries, and competitive pricing with reduced downtime of plant and machinery. Today's modern organizations demand key cost and service advantages which are very much supported by their maintenance management teams. Ingalls (2002) defined world-class maintenance organizations as the one which consistently demonstrate industry best practices in all the aspects and produce bottom-line results to the expectations. The later part of that statement i.e. to produce bottom-line results is what separates the best from the rest which is the conventional versus world class maintenance systems. He also stressed that the ability to be successful in this area lies within the best practices and consistent systems that make up the best maintenance function. Regardless of who executes the maintenance operation, whether it is a specialized skilled or multi-skilled or a highly trained operator/mechanic, maintenance practices are always the keystone for world-class maintenance and must be implemented and practiced with the right strategy.

3.9 Newer Techniques in Maintenance

The conventional techniques even though practiced world-wide have limitations on their full implementations. There is always a compliment of one strategy with the other in the field of maintenance. The reliability of the machinery can be improved in a better way with the implementation of newer technologies which are prevailing nowadays. In the field of reliability engineering, increasing acquisition costs always results in higher levels of reliability as it aims at augmenting newer fleet and machinery but works up to a certain point only and beyond that, it is no longer beneficial and at this point, a more reliable technology in terms of maintenance improvements, modern methods etc. is required for further improvement of reliability (Dhudsia, 1992). In line with this, there has been explosive growth in new maintenance concepts and techniques. Hundreds have been developed over the past years, and more are emerging.

The new developments include:

- Decision support tools, including hazard studies, failure modes and effects analyses and expert systems
- Designing machinery with a much greater emphasis on reliability and maintainability
- A major shift in organizational thinking towards participation, team working and flexibility
- The maintenance itself is considered as the essential function of any organization

A major challenge, faced by maintenance personal nowadays is not only to learn what these techniques are, but to decide which are worthwhile and which are not in their own organizations. If we make the right choices, it is possible to improve asset performance and at the same time contain and even reduce the cost of maintenance. If we make the wrong choices, new problem are created while existing problems only get worse.
In a nutshell, the key challenges facing modern maintenance managers can be summarized as follows:

- To select the most appropriate techniques to deal with each type of failure process in order to fulfill all the expectations of the owners of the assets, the users of the assets and of society as a whole
- In the most cost effective and enduring fashion with the active support and cooperation of all the people involved

3.10 Maintenance Records

The operation of an effective maintenance records system provides the following information:

- The percentage of planned work achieved in the period
- The ratio of planned to unplanned work
- Downtime for the period
- Ratio of preventive work to corrective work
- Maintenance requirement comparisons between individual machinery, between types of machinery, or between groups of machinery
- Indicators for reliability of the products of particular manufacturers

- Trends in spare parts consumption
- Machinery failure patterns
- Performance detail for personnel, by individual or by trade group
- Materials used, for guidance on re-stocking policies
- Indicators on possible standardization policies
- Petroleum, Oil, Lubricants (POL) consumption
- Cumulative hours machinery in service

Records are kept in many different ways, ranging from card files to computer data stores. The labor required for updating records or work done can only be justified if use is made of the information. If a computer is used, lengthy printout sheets can be time consuming also. However, the computer is a useful tool for providing summary information on a regular basis so that trends can be observed. Whatever system of record is used, detailed investigations have to be reserved for individual machinery for which the cost is justified.

Successive crew on the machinery can refer to the working history and to their predecessor's comments. This can be useful in passing on the defect history or wear trends. These systems do not provide detailed financial records, which would be provided on separate cards or as a function of the construction machinery accounts department.