Evaluation of Maintenance Management Function at

Derba MIDROC Cement Production Factory

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CERTIFICATE OF ORIGINALITY

This is to certify that the project titled "**Evaluation of Maintenance Management Function at Derba MIDROC Cement Production Factory**" is an original work of the student and is being submitted in partial fulfillment for the award of Master's Degree in business Administration to Indira Gandhi National Open University. This report has not been submitted earlier either to this University or to any other University or Institution for the fulfillment of the requirement of a course of study.

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III, ABBREVIATIONS

CBM : Condition Based Maintenance

CMMS : Computerized Maintenance Management System

DMC : Derba MIDROC Cement

DOD : Department of Defense

EPC :Engineering Procurement and Construction

FMECA : Failure Mode and Effect Criticality Analysis

FMS : Flexible Manufacturing Systems

FTA : Fault Tree Analysis

GMCs : Generic Maintenance Concepts

HRD : Human Resource Development

HSE : Healthy Safety and Environment

JIPM : Japan Institute of Plant Maintenance

MESA : Maintenance Engineering Society of Australia

MF : Maintenance Function

MMF : Maintenance Management Function

MOVT : Motor Operated Valve Testing

Pm : Preventive Maintenance

PM :preventive Maintenance

PMT : Post Maintenance Testing

PSA : Probabilistic Safety Assessment

QRA : Quantitative Risk Analysis

RBI : Risk Based Inspection

RCM : Reliability Centered Maintenance

RCM : Reliability Centered Maintenance

SSCs : Structure System and Components

TEFS : Techno Economic Feasibility Study

TPM : Total Productive Maintenance

TPM : Total Productive Maintenance

TQM : Total Quality Management

IV, LIST OF TABLES AND FIGURES

V, ABSTRACT

Since the Industrial Revolution, maintenance of engineering equipment in the field has been a challenge. Although impressive progress has been made in maintaining equipment in the field in an effective manner, maintenance of equipment is still a challenge due to factors such as size, cost, complexity, and competition. Needless to say, today's maintenance practices are market driven, in particular for the manufacturing and process industry, service suppliers, and so on (Zweekhorst, A., 1996). An event may present an immediate environmental, performance, or safety implication. Thus, there is a definite need for effective asset management and maintenance practices that will positively influence critical success factors such as safety, product quality, speed of innovation, price, profitability, and reliable delivery.

Each year billions of dollars are spent on equipment maintenance around the world. Over the years, many new developments have taken place in this area.Incement production, the maintenance and operations departments are often the largest and each may comprise about 30% of total staffing(Dekker, R., 1996).

The overall objective of this research project is to study the role maintenance management canplay in DerbaMIDROC Cement factory in Ethiopia using primary data; unstructured questionnaire and observation. And Secondary data which were collected from company reports, web sites, journals and others. The collected data were analyzed using percentages and other statistical tools.

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1-INTRODUCTION

1.1 Background of Research

Production organizations are usually concerned with converting inputs such as raw materials, labor and processes into finished products of higher value at minimum cost satisfying the customer needs. Increased competition for timely delivery of high quality products has forced manufacturers to adopt automation. This has resulted in very high investments in plant and equipment. In order to achieve maximum return on investments, the production systems will have to minimize plant downtime, increase productivity, improve quality and deliver orders to customers in a timely fashion.

In recent times industrial plants have come up with large number of automated and sophisticated machinery with complex control systems. The results of failure can be disruptive, inconvenient, wasteful, and expensive in monetary values and in lives. Machine and product failures can have far-reaching effects on an organizations operation, reputation, and profitability. The increased emphasis on equipment availability, performance, quality, environment conditions and safety considerations has made maintenance function very important.

The Ethiopian cement industry while constituting a very small share of world industry output has been growing at a very slow pace relative to local demand and along with continually rising demand; this has created patterns on the cost of construction and doing business as well.

However, with the liberalization of the investment regime and especially after the launch of the Ethiopian renaissance, the Ethiopian cement industry has entered into a period of relative transformation. The industry structure is changing as new entrants join the market. Investment is growing significantly in the sector. Output has reached the 6.5 million metric ton mark by the end of the 2nd quarter of 2012, which is four fold the capacity registered in 2006-2008. Cement price is near historic high even after the recent decline. The Growth and transformation Plan envisages a 300 kgs. per capita consumption in Ethiopia by the end of the plan period. This requires quadrupling the local supply capacity to hit the 26.04 million metric tons per annum mark. This presents a great opportunity and challenge for the Derba MIDROC Cement (DMC) and new players in the market in terms of creating a better outlook especially dynamism, competition and efficiency. In order to respond to the acute shortage of cement and seeing the market potential and with a clear shift to invest in strategically important sectors such as cement that ensure faster and sustained economic development, the promoters and shareholders of DMC.

DMC decided to invest in a green field cement plant to be based in the Muger valley, which is surrounded by the Muger River and its tributaries. DMC was legally established on the 13th of February 2006 with a fully paid up capital of birr 500,000,000 (half a billion) with a contribution Birr 400 million and Birr 100 million by Sheik Mohammed H. Al-Amoudi and his wife Mrs.Sofia Salah Al-Amoudi respectively. According to the Memorandum of Association, the company will engage in production of cement, cement products, and in the production and processing of inputs for the cement industry. It will also engage in all other duties considered necessary to execute and enhance the business objectives of the company.

DMC is based on the Derba deposit close to Derba village and Chancho town, in Oromiya Regional State of Ethiopia at a distance of 8 kms, and 30 kms respectively. The location enjoys the twin advantage of proximity to raw material as well as market offered by Oromiya and Amhara Regional States of Ethiopia and the city of Addis Ababa. DMC's production capacity is 5, 600 tons per day clinker or 8000 tons per day cement. This brings the annual cement production capacity to 2.5 million ton.

Holtec Engineering and Management Consultant of India to carry out Techno – Economic Feasibility Study (TEFS), a pre investment study, which formed the detailed technical design and business concept of the project. Following the feasibility study, DMC entered an Engineering Procurement and Construction (EPC) agreement with China National Building Materials International Engineering Company for the supply and erection of the cement plant on turnkey bases.

Holtec Engineering and Management Consultant of India has also been commissioned to supervise erection and construction of the project.

1.2 Problem Statement and Research Questions

By applying proper maintenance management system, organizations can ensure that all company assets meet the design function of the asset, i.e. timely delivery of high quality products at the right price, achieve maximum return on investment, and maintain safety requirements. This could be achieved by applying general management principles of planning, scheduling, organizing and monitoring the maintenance function.

From the above perspective this research will help to gain understanding of the effects of maintenance management in Derba MIDROC Cement (DMC) production, since maintenance management is likely to have significant impact on the long-term prosperity of the firm.

To attain the desired results, the overall effort of the research in aggregate will be seeking answers for the following questions.

In many organizations maintenance management is considered as strategic weapon in a fight to provide high quality, low cost products to customers. Implementing well thought Maintenance management will bring a break through by lowering down time, maximizing availability, increasing productivity, minimizing wear and deterioration of plant and equipment, reducing waste and rework, reducing cost on parts and consumables, protects accidents and the environment, and hence reduces overall expenditure in maintenance and maximize life time profit to be made by the asset.

From the above perspective, is maintenance management a concern in strategy formulation in DMC?

Maintenance is a combination of science, art, and philosophy. Its execution relies on science; art of maintenance depends on individual attitude; and its philosophy should fit to the organization it serves.

In view of the above, this research tries to understand the maintenance philosophy of the management, since the top management's attitude to maintenance function affects the department.

The poor functioning of many factories is generally because of lack of efficient maintenance of production plant and equipment with no clearly stated objectives of the maintenancemanagement function. Maintenance objectives are basis of maintenance planning; the objectives should be compatible with the company objectives and must be linked with the production department's achievement of a planned output in a specified time. This planned output is normally a function of sales demand. It determines the long term production plans fitting the maintainability requirement of the plant.

In view of the above, this research asks, "does DMC have set clearly stated maintenance objective? "

Maintenance strategy is concerned with identifying the components of the plant and or equipment which might require maintenance, determining the most appropriate maintenance procedure and then listing the procedure in the form of schedule for a plant.

In view of the above, this research tries to find out answers to, whether DMC has maintenance strategy? If yes which strategy or strategies are implemented? Which factors were influential in the strategy formulation?

Planning and scheduling are the most important aspects of sound maintenance management. Planning is the process by which elements required to perform a task are

determined in advance of the job start time. Scheduling deals with specific time of planning planed jobs together with the order to perform the work, monitoring the work, controlling it, and reporting on job progress. Good planning is a prerequisite for sound scheduling. However, for successful planning, feedback from schedule is necessary.
Well planned, properly scheduled and effective communication can accomplish more work, more efficiently and at low-cost. Planned maintenance refers to maintenance work that is performed with advance planning, foresight, control and record. It is characterized by the following;

- The maintenance policy has been stated carefully
- The application of the policy is planned in advance
- The work is monitored to conform to the original plan
- Data are collected analyzed and used to provide direction for future maintenance policies Job specifications, work order, in section report. History records are the documents required in planned maintenance and the following benefits can be achieved by planning maintenance
    i. Reduction in emergency maintenance
    ii. Reduction in down time
    iii. Increase labor initialization on maintenance & production
    iv. Extends duration b/n overhauls
    v. Reduce spare requirement, assists stores control
    vi. Improves machine efficiency
    vii. Provides reliable cost and budgetary control
    viii. Provides information for considering machine replacement
    ix. Ensure safety of the staff and environment

In view of the above, this research tries to find out, how DMC maintenance management function plans, schedules, and controls its maintenance activity? Are maintenance policies available to aid planning and scheduling activities of the maintenance function? What benefits have been enjoyed by DMC by planning the maintenance activities?

Managing spare parts is the biggest challenge in material and maintenance management. The aim for managing spare parts is to avail the right spare parts, at the right place, at the right time, at the right quantity at the right price , and at the lowest total cost of the company.

In view of the above this research tries to explore How DMC

- Determines initial requirement of spare parts?
- Procures spare parts?
- Receives, stores & preserves spare parts
- Issues & replenish spare parts?
- Disposes Spare parts

The structure and organization of maintenance in any plant should be based on the detailed analysis of the maintenance needs of the plant. The objective is for maximizing production at the lowest cost and at highest quality and safety standards.

In view of the above, this research explores how DMC maintenance functions is organized to attain set objective.

Human Resource Development (HRD) can be seen as developing the work force in such a way as to match the organization needs and the needs of its workforce. Implicit in their approach is the recognition that the work force is its most valuable instrument of growth.

In view of the above, does DMC has considered that human resource is the most important instrument for growth? And what are the measures taken to develop the qualities of the work force to make it more useful to the organization?

Management of modern business enterprise is not just the culmination of producing products and services to sell to the customer and make profit. Due to the intrinsic network of various stake holders to the general public at large, a management has not only look for immigrate results like profitably but also take care of long term goals like satisfaction, public image ,good will & etc… . The assiduously built reputation of a company may be destroyed by a single incident of accident in its premises. Governments and the general public are demanding safe guarding the environment while undertaking production of any sort. In view of this requirement, safety and environmental issues have assured priority over many other requirementsfor a business enterprise.

The analysis of the causes of many accidents and environmental pollutions, have invariably identified" improper maintenance or lack of maintenance" as one of the major reasons.

Here, the researcher questions that,does DMC consider safety and environmental issues as an integral part of maintenance management function? What are the maintenance techniques used for improving safety & maintaining the environment?

1.3. Objectives of the Study

The main objective of this project is to research the maintenance management process of DMC and provide academic and pragmatic facts to researchers, readers, management practitioners, and DMC management in reference to the points stated below.

1) To examine where top managements of DMC positions the maintenance management function, as a tool towards achieving the overall objective of DMC. By giving guidance in formulation of objective strategies and policies & following the implementation of maintenance management objectives, strategies, and policies.
2) To investigate the planning, scheduling, and controlling activities of the maintenance management function besides the management of spare parts of DMC.
3) To assess the HRD, safety and environmental policies being undertaken by DMC
4) To make appropriate suggestion where necessary for the improvement of the maintenance management function of DMC.

1.4. Significance of the Study

The outcome of the study can influence

1. Influence the top management give due attention to the maintenance management function so that the maintenance management function can add to the accomplishment of DMC objective.
2. Add to the existing knowledge and inform top management while they set plan and implement objectives, strategies and policies of the maintenance management function
3. Indicate the scope of the maintenance management function, and hence, the function is complete in its structure to the current scenario.
4. Use the findings of the study as an input for organization's maintenance management functions to carry out its objective effectively and in other areas with similar characteristics to the case study.
5. Be of paramount importance in encouraging production operation managers to review literature and strengthen their decision making capability.
6. To provide basic information for further studies in future.

1.5. Scope and Limitation of the Study

1.5.1 Scope

Particular emphasis is given to examine the maintenance management function of DMC.

1.5.2 Limitations

Derba MIDROC Cement is located 80 Km's away the researchers' home town which requires a significant amount of finance and time. Lack of Industry experience, reference materials literature on the subject matter, and access to information which the respondents feel confidential are the major constraints.

1.6 Organization of the Report

The thesis consists of five chapters; chapter I the introduction part presents background to the problem. Chapter II reviews the maintenance management literature from the research perspective. Chapter III describes the research methodology applied. Chapter IV presents, discusses, and derives findings. Chapter V deals with conclusions and recommendations. Bibliographies follows chapter five.

2- LITERATURE REVIEW

2.1 Historical Overview

Here we briefly mention some main trends in the history of maintenance management, following the reviews given by Kelly, (Kelly,A.,1989; and Pintelon, L.M., andGelders, L.,F,1992).The first Scientific approaches to maintenance management date from the 1950's and 1960's. At that time preventive maintenance was advocated as a means to reduce failures and unplanned down time. In many companies large time-based preventive maintenance programs were set-up. First operations research models for maintenance appeared in the sixties, attempting to optimize these programs. In the 1970's condition monitoring came forward, focusing on techniques which predict failures using information using the actual state of equipment (e.g., luboil debris analysis, vibration monitoring). This proved to be more effective than the large time-based preventive maintenance programs. Detailed studies by manufacturers about the failures of their products resulted in better designs, with less failure as a result. In the 1980's the computer was brought to the maintenance function. Initially most attention was paid to facilitating administrative processes, later on by making management information readily available (e.g., the registration of the causes of overtime); yet their influence on decision making has been limited. An important approach worth mentioning is Reliability Centered Maintenance (RCM), (Anderson, R.T., andNeri, L., 1990). This was founded in the sixties and initially oriented towards airplane maintenance. It is only now, more than twenty years later that it has started to break through in many industries. It directs maintenance efforts at those parts and units where reliability is critical. Another approach which should be mentioned is total productive maintenance, originating from Japan, which centers about solving maintenance problems using a quality circles method(Nakajima, S., 1986).

2.2Challenges of Maintenance

Throughout the years the importance's of the maintenance function, and therefore also the maintenance management has grown .the wide spread automation and mechanization has reduced the number of production personnel and has increased the capital employed in production equipment and civil structures. as a result, the fraction of employees working in the maintenance area has grown, as well as fraction of maintenance spending on the total operational costs.(Dekker, R., 1996)

Intense competition on the supply side and heightened volatility in customer requirements on the demand side are the characteristics of the current business environment. Confronted with such reality, organizations are under great pressure to enhance their capability to create value to customers and improve the cost effectiveness of their operations on a continuous basis. Maintenance, being an important support function in businesses with significant investments in plants and machinery, plays an important role in meeting this tall order.

Acquiring the right mix of physical assets and making the best use of those already in place to meet business needs are the ways maintenance can contribute to improve competitiveness of capital intensive organizations. The performance demanded of maintenance has been made muchmore challenging by the following developments in the contemporary business environment:

2.2.1 Emerging Trends of Operation Strategies

The conventional wisdom embracing the concept of "economy of scale" is losing followers. An increasing number of organizations have switched to "lean manufacturing", "just-in-time production" and "six-sigma programs". These trends highlight a shift of emphasis from volume to quick response, elimination of waste, and defect prevention. With the elimination of buffers in such demanding environments, breakdowns, speed loss and erratic process yields will create immediate problem to the timely supply of products and services to customers.

Obviously, installing the right equipment and facilities, optimizing the maintenance of these assets, and effective deployment of manpower to perform the maintenance activities are crucial factors to support these emerging trends of operation strategies.

2.2.2Toughening Societal Expectations

There is widespread acceptance of the need to protect the environment and safeguard people's safety and health, especially in the developed countries. As a result, a wide range of regulations have been enacted in these countries to control industrial pollution and prevent accidents in the workplace. Scrap, defects, and inefficient use of materials and energy are sources of pollution. They are often the result of operating plant and facilities under less than optimal conditions. Machine breakdowns interrupt production. In cement production processes, dust pollution, co_2emissions, and quarry and plant water runoff are common cause of pollution. Apart from producing waste material, catastrophic failures of operating plant and machinery are also the major cause of industrial accidents and health hazards. Keeping facilities in optimal condition and preventing failures are an effective means to meet the ever more demanding societal challenge of pollution control and accident prevention. These are the core functions of maintenance.

2.2.3 Technological Changes

Technology has always been a major driver of change in diverse fields. It has also change data breathtaking rate in recent decades, with no signs of slowing down in the foreseeable future. Maintenance is no exception in being under the influence of rapid technological changes. Non-destructive testing, transducers, vibration measurement, thermography, ferrography, and spectroscopy make it possible to perform non-intrusive inspection. By applying these technologies, the condition of equipment can be monitored continuously or intermittently while it is in operation. This gave birth to condition-based maintenance, an alternative to the classical time driven approach to preventive maintenance (Tsang, H.C.,1995).

The deployment of new technologies is instrumental to enhancing system availability, improving cost effectiveness of operations, and delivering better or innovative services to customers. At the same time, the move also presents new challenges to maintenance. New knowledge has to be acquired to specify and design the new systems taking advantage of these emerging technologies. New capability has to be developed to commission, operate and maintain such new systems. During the phase-in period, interfacing old and new plant and equipment is another challenge to be handled by maintenance.

2.2.4 Changes in the People and Organizational Systems

The doctrine that focuses primarily on efficiency in industrial management worked well to produce exemplary performance in past eras when the business environment was highly stable. Companies were busy producing standard goods and services to satisfy the insatiable demand of their customers. And these companies were protected from the onslaught of outside competition through regulation or imposition of trade barriers in their home market. Product life cycle was long due to slow technological change and tolerance of accepting customers who would take whatever was available on the market. On the human dimension, people perceived work merely as a means to earning a living. All these have changed in today's turbulent environment. People at work - the individuals who make things happen in organizations - have undergone significant transformation (Tsang,H.C., 2000).

There is a growing body of knowledge about people at work, about organizations, and about management with new attitudes towards work. In an affluent society, people have a desire to improve the quality of life at work. Furthermore, the social and demographic changes that have taken place in the current era affect how we regard and define work. Some examples of these changes are:

- Pressures for equal treatment of women and minorities.
- Improvements in education.
- More faith in the ability of individuals to manage themselves.
- Challenges to authority and a growing psychology of entitlement.
- With rampant downsizings and restructurings, people have reduced loyalties to single organizations and increased loyalties to professions.

In face of the new reality, progressive organizations are exploring new directions in their Labor - management agreements. This leads to the appearance of a variety of innovative and highly successful organizational forms, such as horizontal structures, network organizations, self-managing work teams, virtual organizations, and strategic alliances. Some of these could be the appropriate options for meeting today's challenge of providing excellent maintenance services to organizations (Tsang, H.C., 2000).

2. 3Maintenance

Maintenance is typically regarded as a necessary evil, an expense account which is a popular target for cost reduction programs. The traditional perception of maintenance's role is to fix broken items. Taking such a narrow view, maintenance activities will be confined to the reactive tasks of repair actions or item replacement. Thus, this approach is known as reactive maintenance, breakdown maintenance, or corrective maintenance. A more recent view of maintenance is defined by Gerard's (Geraerds, W.M.J.,1985) as: "All activities aimed at keeping an item in, orrestoring it to, the physical state considered necessary for the fulfillment of its production function."

A similar definition of maintenance is given in British Standard;BS3811 (BSI, 1993). Obviously, the scope of this enlarged view also includes the proactive tasks such as routine servicing and periodic inspection, preventive replacement, and condition-monitoring. Depending on the deployment of responsibilities within the organization, these maintenance tasks may be shared by several departments. For instance, in an organization practicing Total Productive Maintenance (TPM) (Nakajima, S.,1988), the routine servicing and periodic inspection of equipment are handled by the operating personnel, whereas overhauls and major repairs are done by the maintenance department. If the strategic dimension of maintenance is also taken into account, it should cover those decisions taken to shape the future maintenance requirements of the organization. Equipment replacement decisions and design modifications to enhance equipment reliability and maintainability are examples of these activities.

The Maintenance Engineering Society of Australia (MESA) recognizes this broader perspective of maintenance and defines the function as: "The engineering decisions and associated actions necessary and sufficient for the optimization of specified capability." 'Capability' in this definition is the ability to perform a specific action within a range of performance levels. The characteristics of capability include function, capacity, rate, quality, responsiveness and degradation. The scope of maintenance management, therefore. Should cover every stage in the life cycle of technical systems (plant, machinery, equipment and facilities): specification, acquisition, planning, operation, performance evaluation, improvement, and disposal (Murray,M., et al. 1996) When perceived in this wider context, the maintenance function is also known as physical asset management.

2.4The Maintenance Function

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. (DOD Inst, 1968 and AMCP 706-132, 1975) 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. (Niebel, B.W., 1994) 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.

A maintenance department is expected to perform a wide range of functions including (Jordan, J.K., 1990; Higgins, L.R., 1998;and Dhillon, B.C., 1987) 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

2.5Maintenance Strategy

Thinking on maintenance should start on the design phase of systems. The type of equipment, the level of redundancy and accessibility will then strongly affect the maintainability. When purchasing systems, future maintenance costs should be take in to account as well.

Defining maintenance goals and formulating strategies is an important aspect of an integrated maintenance management within a company. (Pinetlon, L., Pinjala, K.S., and Vereecke, A., K.S.,2006)defined maintenance strategy as a series of unified and integrated pattern of decisions made in four structural and six infrastructure decision elements to achieve maintenance goals.

According to Pinjala and Pintelon (2006), the four decision elements (maintenance capacity, maintenance facilities, maintenance technology, and vertical integration) can be viewed as the maintenance resources. They are termed as structural, because decisions made in those areas are generally assumed to be fixed. For instance, a company outsourcing its entire maintenance activities cannot revert immediately to in-house maintenance. The majority of the maintenance budget is consumed by these structural elements.

The six infrastructure elements (maintenance organization; maintenance policy and concepts; maintenance planning and control systems; human resources; maintenance modifications and maintenance performance measurement and reward systems) can be viewed as maintenance management elements.

These structural and infrastructure elements are interrelated. For instance, effective utilization of maintenance resources depends upon the decisions taken in the infrastructure elements (Panesar,S.S., Kumar, R., and Markeset, T., 2008). Over a period of time decisions must be made in all of these maintenance strategy elements. The way these elements are managed or utilized can have a major impact on the maintenance function's ability to implement and support the company's manufacturing and business strategies. Companies mainly differ in their maintenance strategies by the combination of decisions taken in these elements. Several operating aspects and business requirements influence these decisions.

The effectiveness of maintenance can be known only if one is able to identify and evaluate a given maintenance strategy. An effective maintenance strategy is one that fits the needs of the industry. The process of formulating an effective maintenance strategy for a company can be a difficult task of quite daunting complexity. Furthermore, evaluating such a strategy can be much more complex. However there is a requirement of increased focus on developing an integrated maintenance approach for effective and efficient maintenance strategies that create value by improving the safety, reliability, availability, technical integrity, regularity, quality and functional performance of the production facilities.

2.5.1 Issues for Developing an Integrated Maintenance Management Framework

The formulation and establishment of an integrated frame work for maintenance strategy requires understanding the operational and maintenance objectives; the technical and functional system characteristics; the administrative and organizational issues; the system functions and performance targets; the internal and external resources; the geographical location; statuary requirements; as well as the support services. Therefore, one has to examine the types of resources (organization and level of competence (knowledge, skills, attributes, motivation)) available.

In Cement industry corporate goals of ensuring the highest possible Health Safety and Environment (HSE) level, highest possible production regularity, and highest possible cost effectiveness are the three main issues. A comprehensive integrated maintenance program should contribute to achieving these goals. Achieving the highest HSE level means that the production facilities are operated and maintained in such a manner that HSE risks are "eliminated" to zero level.

Optimizing production regularity means that production facilities are operated and maintained in such a manner that production up times are optimized and production down times minimized (Markeset, T.,2003),This means to optimize production regularity, to ensure optimum capacity utilization, to minimized unplanned shut downs, to minimize maintenance interventions and to minimize unplanned maintenance works. Achieving cost effectiveness means that the resources should be utilized in the best possible manner and equipment failures that could cause productions losses or could result in high repair/replacement costs should be prevented or reduced to an acceptable level(NORSOK Z008,. 2010). (NORSOK, Z016., 1998). HSE, production regularity and cost effectiveness therefore, can be considered as the three main concerns for development of efficient and effective maintenance strategy.

An important matter to realize is that these three important issues are interrelated. That means no change can be made without affecting the other two issues. For instance increasing production up times may affect HSE risk level and/or maintenance related cost. Furthermore, one needs to realize that to optimize maintenance performance, one need to optimize and integrate the technological, organizational and the human performance to quickly identify the underlying root cause for the failures (i.e. human error, organizational or technical error). Therefore these are also the key issues to be considered when one needs to develop efficient and effective maintenance strategies. Integrating personnel, technology and organization optimizes our decision capabilities, and hence improves maintenance performance.

2.5.2 Development Process of Effective and Efficient Maintenance Strategy

By integrating the diverse knowledge areas and different issues, an effective and efficient maintenance strategy can be developed. Figure 2.1 illustrates a process for maintenance strategy development (Panesar,S.S.,et al., 2008). The process starts with extensive collecting data, information and documentation from asset maintenance logs, history records, and experts about cement productions facilities and then followed by developing technical and functional hierarchy.

Criticality analysis (also known as Consequence classification) is then done with respect to overall company requirements (HSE, production regularity and economics consequences) (Panesar,S.S.,et al., 2008). The consequence classification is done to set up priority of maintenance activities while developing “just sufficient” and “just-in-time” maintenance program, to specify common spare part strategy for equipment of equal importance, to decide the extent and quality of technical documentation as well as to decide the priority of corrective maintenance activities .

Here the uncertainty with respect to prioritize the maintenance activity is improved by increasing our knowledge to understand the interaction among the technical, organizational and the people. This helps to quickly look the underlying causes for incidents (human error, organizational or technical) and improve our decision making to make “just-in-time” maintenance. This is done by integrating human-technology-organization.

The consequence classification is done based on analysis of functional failure consequences. Very high consequence requires a Reliability Centered Maintenance (RCM) approach or redesign to avoid failure. Safety systems are also redesigned if failures are classified as highly critical. Failures of sub-systems which have less serious failure consequences are classified in the low criticality category. For these systems one defines planned corrective or first line maintenance activities.

For systems in which failures have medium or high consequences one first screens and then after analyses using for example failure mode and effect criticality analysis (FMECA), or fuzzy logic, methodology to identify failure modes, failure effect, potential mitigating activities etc (Panesar, S.S.,et al, 2008).

2.5.2.1 Consequence Analysis for Prioritizing Maintenance

A Consequence classification of the whole system is made with respect to the maintenance of failure of any of the functions on the three main concerns (i.e. HSE, production regularity and economics).

This classification is to underscore what effect a functional failure can have on HSE, production and economics. This classification together with the other key information and parameters (HTO and RCFA) gives input to the following activities and processes:

- Selection of equipment where detailed RCM/RBI/FMECA analysis is recommended
- Establish preventive maintenance programme (time/age/condition based)
- Preparation and optimization of generic maintenance concepts (GMCs)
- Design evaluations
- Prioritization of work orders and
- Spare part evaluations

Figure2.2 below shows the overall work flow related to classification

- The functional classification is done to identify safety critical functional failures and link tags to this function All systems and/components related to an installation should be classified using the same classification scale
- The classification feeds in to a common risk model used for operational decision making as a result they need to be similar.
- The containment function consisting of pipes, vessels, valves are normally consequence classified via and risk based inspection (RBI) analysis. The containment has a dual function, i.e. safety system with a performance standard and

a production system with its production functions. Equipment with a containment function has two inputs in to the classification process as illustrated in the Figure 5

- Safety critical systems are defined via safety analysis (e.g. quantitative risk analysis (QRA)) in the design or amendment process. As such these systems are already identified and its function defined.

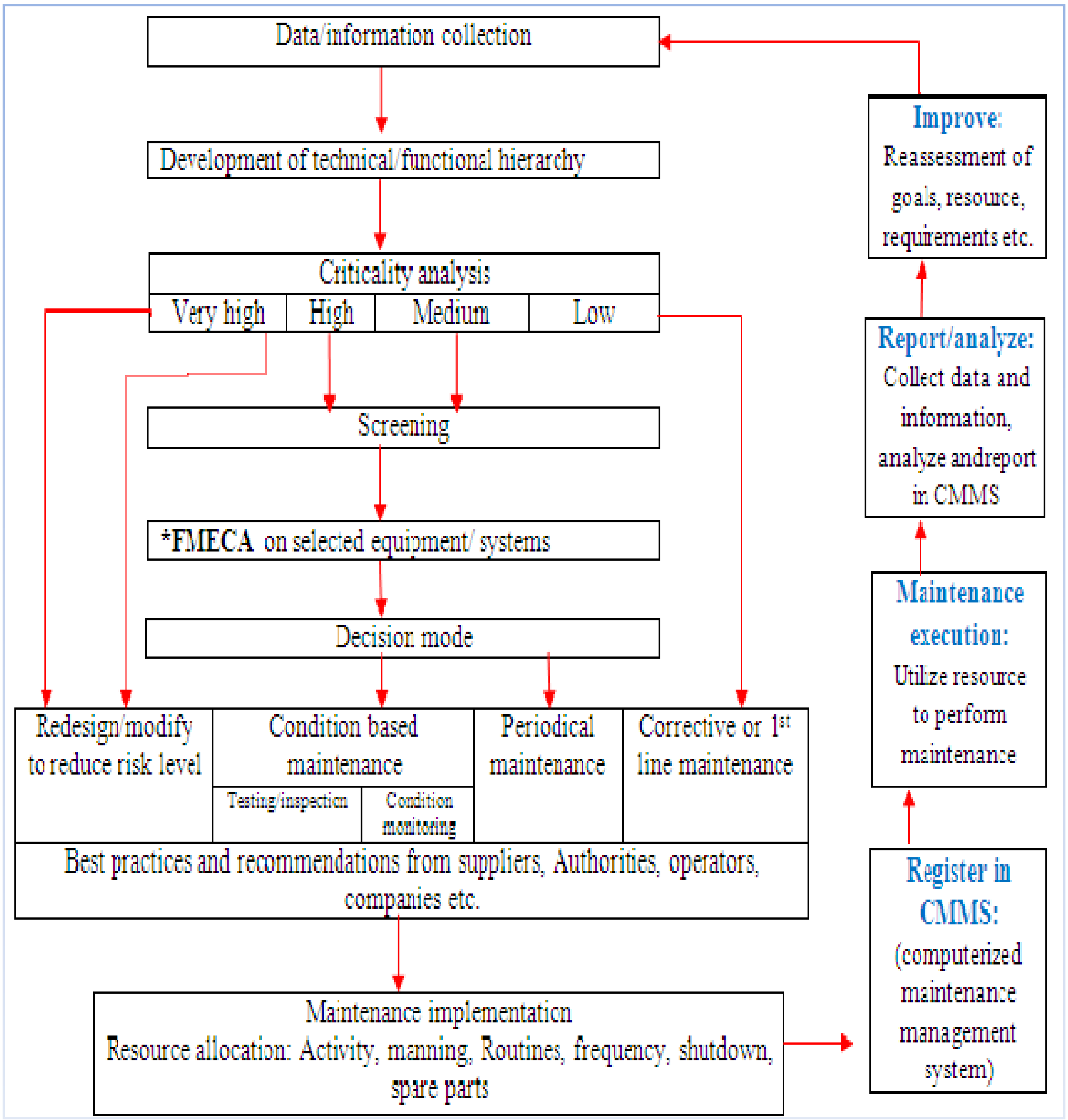

Figure 2.1: maintenance strategy development process (adapted from Kumar and Markeset, 2005)

- The outcome of the classification will be a set of attributes assigned to each component tag. The set of parameters should be aligned to the decision model. Examples of information to be assigned to each component tag are:
    - Safety function indicator
    - Leakage HSE consequence
    - HSE functional failure consequence

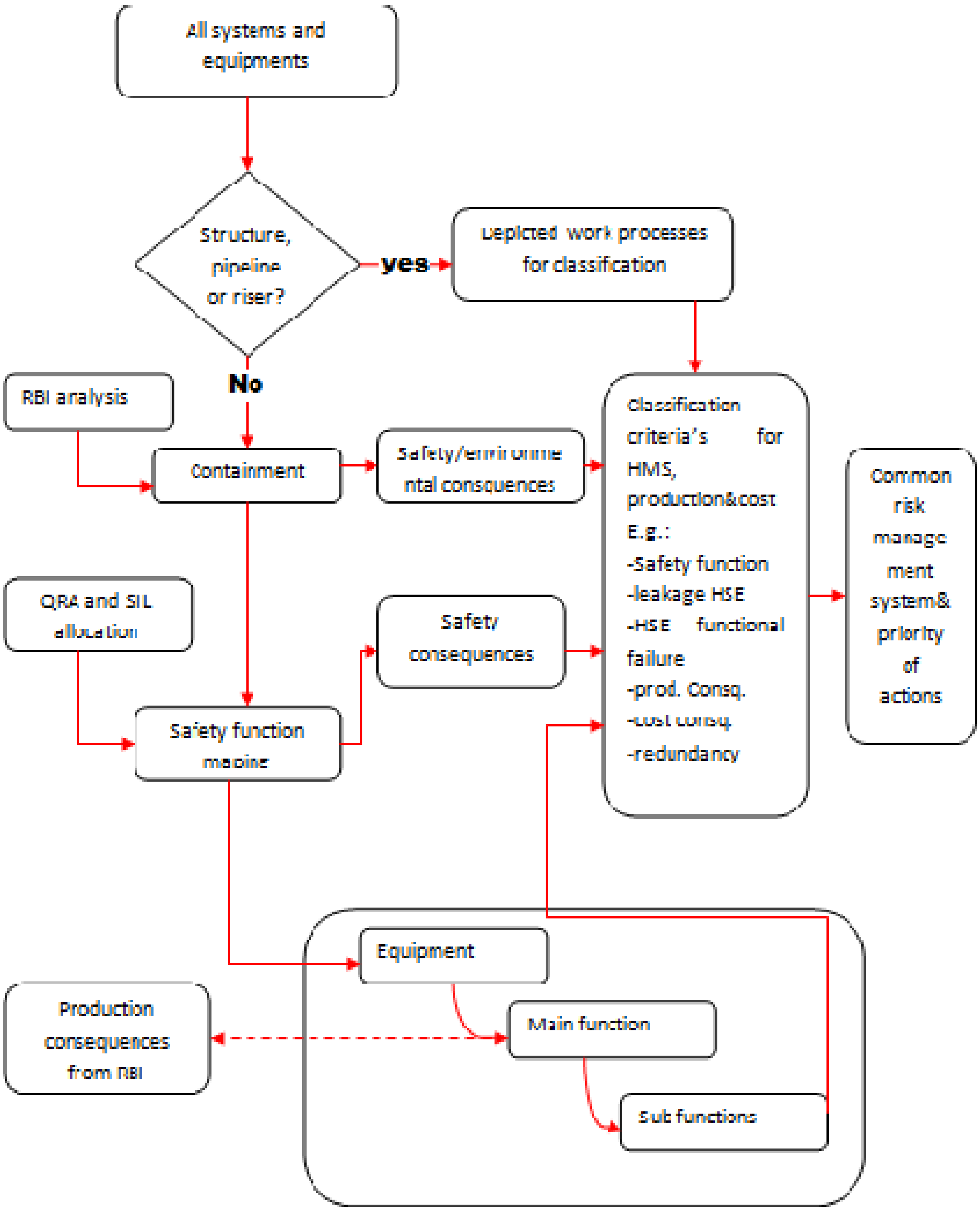

Figure 2.2: consequence classification process (source: NORSOK-Z008, rev. 3)

- Production consequence
- Cost consequence
- Redundancy

In developing effective and efficient maintenance strategy, it is important to clearly identify, define and document the systems/equipments with their boundaries by the use of the engineering numbering system. Selection criteria could be based on maintenance cost, main contributors to functional failure/unavailability and safety related incidents. For the consequence analysis which assesses the consequences of failures and the degree of functional redundancy, the consequence classes have to be properly defined prior to performance of the analysis.

2.5.3 Maintenance program

The classical way of establishing a maintenance program is using RCM analysis. However, this standard calls for using generic maintenance concepts in combination with more detailed RCM methods. It is important that the generic concepts are adjusted to local operational conditions.

The most common maintenance programs are briefly described in the following sections.

2.5.3.1

Corrective Maintenance

Although every effort is made to make engineering systems as reliable as possible through design, preventive maintenance, and so on, from time to time they do fail. Consequently, they are repaired to their operational state. Thus, repair or corrective maintenance is an important component of maintenance activity. Corrective maintenance may be defined as the remedial action carried out due to failure or deficiencies discovered during preventive maintenance, to repair an equipment/item to its operational state.(Department of Defense, AMCP 706-132., 1975; Omdhal, T.P., 1988; and Mckenna,T., and Oliverson, R., 1997) Usually, corrective maintenance is an unscheduled maintenance action, basically composed of unpredictable maintenance needs that cannot be preplanned or programmed on the basis of occurrence at a particular time. The action requires urgent attention that must be added, integrated with, or substituted for previously scheduled work items. This incorporates compliance with “prompt action” field changes, rectification of deficiencies found during equipment/item operation, and performance of repair actions due to incidents or accidents.

2.5.3.1.1Corrective Maintenance Types

Corrective maintenance may be classified into five major categories. (Departement of Defance, AMCP 706-132., 1975, and MICOM 750-8.,1972) These are: fail-repair, salvage, rebuild, overhaul, and servicing. These categories are described below.

1. Fail-repair: The failed item is restored to its operational state.

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

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

4. Overhaul: Restoring an item to its total serviceable state as per maintenance serviceability standards, using the "inspect and repair only as appropriate" approach.

5. Servicing: Servicing may be needed because of the corrective maintenance action, for example, engine repair can lead to crankcase refill, weldingon, etc. Another example could be that the replacement of an air bottle may require system recharging.

2.5.3.1.2 Corrective Maintenance Steps, Downtime Components, and Time Reduction Strategy System Level

Different authors have laid down different sequential steps for performing corrective maintenance. For example, Reference (Omdhal, T.P., 1988)presents nine steps (as applicable): localize, isolate, adjust, disassemble, repair, interchange, reassemble, align, and checkout. Reference (Mckenna,T., and Oliverson, R., 1997) presents seven steps (as applicable): localization, isolation, disassembly, interchange, reassemble, alignment, and checkout.

For our purpose, we assume that corrective maintenance is composed of five major sequential steps. These steps are: fault recognition, localization, diagnosis, repair, and checkout.

The major corrective maintenance downtime components are active repair time, administrative and logistic time, and delay time. (Department of Defense, AMCP 706-132., 1975; NAVORD OD 39223, 1969) The active repair time is made up of the following subcomponents:

- Preparation time
- Fault location time
- Spare item obtainment time
- Fault correction time
- Adjustment and calibration time
- Checkout time

Reduction in corrective maintenance time is useful to improve maintenance effectiveness.

Some strategies for reducing the system-level corrective maintenance time are as follows:(Blanchard, B.C., Verma, D., and Peterson, E.L.,1995)

- **Efficiency in fault recognition, location, and isolation:** Past experience indicates that in electronic equipment, fault isolation and location consume the most time within a corrective maintenance activity. In the case of mechanical items, often the largest contributor is repair time. Factors such as well designed fault indicators, good maintenance procedures, well-trained maintenance personnel, and an unambiguous fault isolation capability are helpful in lowering corrective maintenance time.
- **Effective interchangeability**: Good physical and functional interchangeability is useful in removing and replacing parts/items, reducing maintenance downtime, and creating a positive impact on spares and inventory needs.
- **Redundancy**: This is concerned with designing in redundant parts that can be switched in at the moment of need so the equipment/system continues to operate while the faulty part is being repaired. In this case the overall maintenance workload may not be reduced, but the equipment/system downtime could be impacted significantly.
- **Effective accessibility**: Often a significant amount of time is spent accessing the failed part. Proper attention to accessibility during design can help reduce part accessibility time and, in turn, the corrective maintenance time.
- **Human factor considerations:** Attention paid to human factors during design in areas such as readability of instructions, size, shape, and weight of components, selection and placement of dials and indicators, size and placement of access, gates, and readability, and information processing aids can help reduce corrective maintenance time significantly.

2.5.4Preventive 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.(Department of Defense, AMCP 706-132., 1975) 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.(Omdhal, T.P., 1988)

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!"

2.5.4.1 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 (Department of Defense, AMCP 706-133., 1976) 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 forthe purpose of achieving optimum performance

6.Adjustment: Periodically adjusting specified variable elements of materialfor 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 programare as follows :(Niebel, B.W.,1994)

- 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

2.5.4.2 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. (Patton, J.D.,1983)

There are a number of steps involved in developing a PM program. Each step is discussed below. (Westerkamp, T.A., 1997)

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

2.5.5Condition Based Maintenance

Condition based maintenance has been described as a process that requires technologies and people skills that integrates all available equipment condition indicators (diagnostic and performance data, operator logged data, maintenance histories, and design knowledge) to make timely decisions about maintenance requirements of important equipment. Condition based maintenance assumes that equipment failure modes will follow one or more of the classical degradation styles and that there is sufficient local knowledge of the equipment's historical performance to perform an extrapolation of its remaining life. This in itself is a form of prognostics based partially on science, and partially on elicited experience of the plant staff. These measurement techniques, observations, tests, and operator intuitions are what forms the plant's condition based maintenance programme.

The goal of condition based maintenance is to optimize reliability and availability by determining the need for maintenance activities based on equipment condition. Using "predictive techniques", technologies, condition monitoring, and observations can be used to project forward in an effort to establish the most probable time of failure and this act to enhance the ability of the plant to plan and act in a proactive manner. PdM/CBM assumes that equipment has indicators that can be monitored and analyzed to determine the need for condition directed maintenance activities. Condition based maintenance allows the lowest cost and most effective maintenance programme by determining the correct activity at the correct time.

In comparison, preventive maintenance assumes that operating time is the key factor in determining the probable condition of equipment. If there is not a close relationship between operating time and the need for maintenance, these preventive maintenance activities are often not needed and maintenance resources are wasted. Sometimes the equipment is in worse condition after maintenance is performed and will fail sooner than if nothing were done.

Condition based maintenance is accomplished by integrating all available data to predict impending failure of equipment as well as to avoid costly maintenance. This process depends to a large extent on the ability to recognize undesirable operating conditions as measured by diagnostic monitoring systems. The process also allows equipment to continue operating in an undesirable condition while it is being monitored until maintenance can be scheduled. (International Atomic Energy Agency, 2002; and Kang, S., Chai, J.,2003)

2.5.5. Condition Monitoring Technologies` `

This section deals with the most typical of the technologies that can be applied to most of the power plants' equipment with prompt results and payback. It is important to identify which machine condition monitoring technologies will be the most useful and cost effective in achieving your goals and objectives. Each technique is limited to specific types of machinery and is useful in identifying specific types of problems. Each technique also provides different short and long term economic benefits.

Short term economic benefits include identifying and troubleshooting problems such as misalignment, unbalance, deteriorating bearings, worn gears or couplings, lack of lubrication, oil deterioration or contamination, loose electrical connections, electrical shorting, or poor insulation. These benefits are the most easily quantifiable since they involve specific machines and the cost of actual repairs. These short term cost savings can be substantial, and are often used as the `hard evidence' to justify the initial investment in hardware, software, personnel and training.

The most significant economic benefits, however, come from long term changes or improvements in maintenance or operating practices. It is these structural changes in maintenance and operating standards and procedures that provide an opportunity to eliminate some types of problems or failures completely, rather than simply provide advance warning of their occurrence.

It is also important to understand that there are practical limitations to each of the machine condition monitoring techniques; and that, in spite of the high degree of technology often involved, there is a very important human element necessary for success.

Visual observation, listening and touching are perhaps the most common condition based maintenance techniques used in industry today. In many cases human observation helps to identify a problem that was undetected by other predictive techniques or maintenance inspections. This can include loose, visibly worn or broken parts, oil leaks, chattering gears or hot bearing housings.

The value of observations is not limited to unmonitored equipment however, since sensory information may also be extremely valuable as a supplement to predictive data and analysis. It is recommended that both operations and maintenance personnel be trained observers, since that will provide the most complete and knowledgeable coverage of plant machinery.

A variety of technologies can and should be used as part of a comprehensive condition based maintenance programme. Since mechanical systems or machines account for the majority of plant equipment, vibration monitoring is generally the key component of most condition based maintenance programmes. However, vibration monitoring cannot provide all of the information that will be required for a successful condition based maintenance programme. This technique is limited to monitoring the mechanical condition and not other critical parameters required for maintaining reliability and efficiency of machinery. Therefore, a comprehensive condition based maintenance programme must include other monitoring and diagnostic techniques. These techniques include:

- Vibration monitoring.
- Acoustic analysis.
- Motor analysis technique.
- Motor operated valve testing.
- Thermography.
- Tribology.
- Process parameter monitoring.
- Visual inspections.
- Other nondestructive testing techniques.

Vibration Monitoring

Vibration analysis detects repetitive motion of a surface on rotating or oscillating machines. The repetitive motion may be caused by unbalance, misalignment, resonance, electrical effects, rolling element bearing faults, or many other problems. The various vibration frequencies in a rotating machine are directly related to the geometry and the operating speed of the machine. By knowing the relationship between the frequencies and the types of defects, vibration analysts can determine the cause and severity of faults or problem conditions. The history of the machine and the previous degradation pattern is important in determining the current and future operating condition of the machine.

Thermography

Thermal measurement technology measures absolute or relative temperatures of key equipment parts or areas being monitored. Abnormal temperatures indicate developing problems. Temperature and thermal behavior of plant components are the most critical factors in the maintenance of plant equipment. For this reason, temperature is frequently considered the key to successful plant maintenance and is the most measured quantity. There are two types of equipment used in this technology, contact and non-contact. Contact methods of temperature measurement using thermometers and thermocouples are still commonly used for many applications. However, non-contact measurement using infrared sensors has become an increasingly desirable alternative over conventional methods.

Tribology

A lubricant is a substance capable of reducing friction, heat, and wear when introduced as a film between solid surfaces. The secondary functions of a lubricant are to remove contaminants and protect the solid surfaces.

One of the basic technologies of condition based maintenance is lubricating oil analysis. The reason for this is that lube oil analysis is a very effective tool for providing early warning of potential equipment problems. The goals of oil monitoring and analysis are to ensure that the bearings are being properly lubricated. This occurs by monitoring the condition of both the lubricant and the internal surfaces that come in contact with the lubricant.

Acoustic Analysis

Acoustic emission is defined as the science that deals with the generation, transmission, reception and effects of sound. It is the detectable structural or air-borne sound that can manifest itself as a signal on mechanical objects, the pressure waves associated with leaking vapors or gasses, or the humming of electrical equipment. Acoustics technology includes frequencies as low as 2 Hz and as high as the mega-Hertz range. Through a process of filtering, frequency band passing, and sensor selection, the potential uses for acoustic testing to diagnose equipment condition and operability is virtually unlimited.

Acoustic work can be performed in either the non-contact or in the contact mode. In either case, it involves the analysis of wave shapes and signal patterns, and the intensity of the signals that can indicate severity. Because acoustic monitors can filter background noise, they are more sensitive to small leaks than the human ear, and can detect low-level abnormal noises earlier than conventional techniques. They can also be used to identify the exact location of an anomaly.

Evaluation of long term ultrasonic analysis trends can identify poor maintenance practices such as improper bearing installation or lubrication, poor steam trap maintenance, and improper hydraulic seal or gasket installation. Long term ultrasonic analysis can also identify machines that are being operated beyond their original design limitations, inadequately designed machines, or consistently poor quality replacement parts.

Motor Analysis Techniques

Monitoring electric motor condition inevitably involves determining the extent of electrical insulation deterioration and failure. Traditional insulation tests have concentrated on the ground wall, with a common test being insulation resistance. Less attention is paid to turn to turn or phase-to-phase insulation, yet there is evidence that deterioration of this thin film is also a major cause of motor failures.

Motor Operated Valve Testing

The purpose of MOV performance testing is to confirm that the setup and operation of an MOV is within acceptable limits. The acceptance criteria for MCC based performance testing may be derived from the baseline test data.

Once the acceptance criteria have been established, static performance test results are used to periodically evaluate actual MOV performance against the established acceptance criteria. Periodic static performance testing is not intended to re-affirm the acceptance criteria, but simply the existence of acceptable margin.

Each of the MCC-based technologies start with measurement of supply current, supply voltage and switch actuation times at the MCC. These signals are combined electronically or in software to create meaningful measurement parameters.

Other Techniques

Numerous other non-destructive techniques can be used to identify incipient problems in plant equipment or systems. Therefore, these techniques are used as the means of confirming failure modes identified by the condition based maintenance techniques identified in this chapter. Other techniques that can support condition based maintenance include acoustic emissions, eddy-current, magnetic particle, residual stress and most of the traditional non-destructive methods.

2.5.5.2Results reporting

The purpose of a condition based maintenance programme is to communicate information about the condition of the machinery under surveillance. The condition based maintenance report should include only information that helps the reader to clearly understand the results of the condition monitoring efforts. The report should include:

- An equipment status report including operating availability and component availability
- A priority work list including work pending, work in progress and work completed
- Status definitions for satisfactory, marginal and critical
- A summary of the operating status of each component to include fully operational,
- marginal, critical, and inoperable
- Individual equipment status reports for equipment that is marginal or worse

The report serves two primary functions:

1. It provides a valuable source of information for plant maintenance, operations, and engineering.
2. It continually shows the impact of condition based maintenance on the plant to upper management. This line of communication justifies the programme and allows for continued management support.

The reporting period is determined by the needs of the plant but should be prepared at least annually. It is important to note that the report should not contain any raw data collected from a diagnostic system. It should be concise and clear.

The following elements should be included in a condition based maintenance periodic report:

- **Management summary -** Provide a synopsis that highlight the activities performed during the reporting period. When possible, use photographs of actual plant conditions that illustrate successes.

- **Equipment performance -** Provide a list of equipment that condition based maintenance indicates is in an abnormal condition and has been placed on an alert or watch list. A windows format and supporting documentation could be used to identify equipment condition. Also indicate in this section those pieces of equipment that have been removed from the alert or watch list.
- **Information sharing** – Provide a section to be used by condition based maintenance personnel to explain various aspects of the programme or to share examples where assistance has been provided to other station departments.
- **Cost-benefit** – Provide cost savings that are attributed to condition based maintenance activities. Consider costs that were avoided because equipment replacement, maintenance labour hours, and purchase of replacement power were not needed.
- **Continuous improvement and operating experience** – Provide discussions on new technologies and training received by condition based maintenance personnel. This section could also be used to document any internal or external examples of operating experience factored into the condition based maintenance programme.
- **Other components of reporting results are developing a watch list and programme metrics**.

2.5.6Reliability Centered Maintenance (RCM)

Reliability centered maintenance (RCM) is a systematic process used to determine what has to be accomplished to ensure that any physical facility is able to continuously meet its designed functions in its current operating context.(McKenna, T., and Oliverson,R., 1977) RCM leads to a maintenance program that focuses preventive maintenance (PM) on specific failure modes likely to occur. Any organization can benefit from RCM if its breakdowns account for more than 20 to 25% of the total maintenance workload. (Picknell, J., and Steel, K.A., 1997)

With the arrival of the Boeing 747, a wide-body aircraft, U.S. airlines realized that their maintenance activity would require considerable change due to a large increase in scheduled maintenance costs. In 1968, airline operators jointly organized a study group to develop methodology for resolving the problem. The group was called Maintenance Steering Group No. 1 (MSG1).(Air Transport Association, Washington, 1968) The resulting documents,MSG1, (Air Transport Association, Washington, 1968) MSG2, (Air Transport Association, Washington, 1970)and MSG3,(Air Transport Association, Washington, 1980) appeared in 1968, 1970, and 1980, respectively. (Anderson, R.T., and Neri,L., 1990)

The term “reliability centered maintenance” appeared for the first time as the title of a report on the processes used by the civil aviation industry to prepare maintenance programs for aircraft.(Moubray, J., 1997; and August, J., 1999) The report, prepared by United Airlines, was commissioned by the U.S. Department of Defense in 1974.(Nowlan, F.S., and Heap, F.S.,1978)

2.5.6.1RCM Goals and Principles

Some of the important goals of RCM are as follows: (Air Transport Association, Washington, 1968)

- To develop design-associated priorities that can facilitate PM.
- To gather information useful for improving the design of items with proven unsatisfactory, inherent reliability.
- To develop PM-related tasks that can reinstate reliability and safety to their inherent levels in the event of equipment or system deterioration.
- To achieve the above goals when the total cost is minimal.

Many principles of RCM are discussed below:(Nowlan, F.S., and Heap, F.S.,1978)

- **RCM is system/equipment focused**.
- **RCM is concerned more with maintaining system function** as opposed to maintaining individual component function.
- **Safety and economics drive RCM.**Safety is of paramount importance, thus it must be ensured at any cost and then cost effectiveness becomes the criterion.
- **RCM is function-oriented**. RCM plays an instrumental role in preserving system/equipment function, not just operability for its own sake.
- **Design limitations are acknowledged by RCM**. The goal of RCM is to maintain the inherent reliability of the equipment/system design and at the same time recognize that changes in inherent reliability can only be made through design rather than maintenance. Maintenance at the best of times can only achieve and maintain a level of designed reliability.
- **RCM is reliability-centered**. RCM is not overly concerned with simple failure rate, but it places importance on the relationship between operating age and failures experienced. RCM treats failure statistics in an actuarial fashion.
- **An unsatisfactory condition is defined as a failure by RCM**. A failure could be either a loss of acceptable quality or a loss of function.

- **RCM is a living system.** RCM collects information from the results achieved and feeds it back to improve design and future maintenance.

2.5.6.2RCM Components

The four major components of RCM are: reactive maintenance, preventive maintenance, predictive testing and inspection, and proactive maintenance.

2.5.7 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is maintenance activities that are productive and a continuous improvement strategy which involves everyone in the organization from operators to senior management in equipment improvement targeting 'zero-accidents', 'zero-defect' and 'zero-failures' in equipment lifecycle level through the activities of overlapping small groups in hierarchical system. It encompasses all departments including: Maintenance, Operations, Facilities, Design Engineering, Project Engineering, Inventory and Stores, Purchasing, Accounting and Finance.

TPM is now having a major impact on bottom line results by revitalizing and enhancing the quality management approach to substantially improve capacity while significantly reducing not only maintenance costs but overall operational costs. Its successful implementation has also resulted in the creation of much safer and more environmentally sound workplaces.

2.5.7.1 Goals of Total Productive Maintenance

The goal of TPM focuses on improving corporate culture through improvement of human resources and plant equipment. The Japan Institutes of Plant Maintenance (JIPM) has put forward the five goals of TPM which are the minimum requirements for the TPM development (Japan Institute of Plant Maintenance, 1971).

1. Improving equipment effectiveness.
2. Improving maintenance efficiency and effectiveness.
3. Early equipment management and maintenance prevention.
4. Training to improve the skills of all people involved.
5. Involving operators in routine maintenance.

2.5.7.2 The Relationship Between TPM and TQM

Venkatesh J. delineates the relationship between TPM and TQM (Venkatesh, J.,1996). According to him TQM and TPM has many similarities and differences that both aiming at maximizing the efficiency of the man/machine system through eliminating wastes, involving employees and preventing problems to deliver quality service and product to delight the customer. Like TQM, which is companywide total quality control, TPM is equipment maintenance performed on a companywide basis. In order to achieve the TQM target of "building quality into the product during the manufacturing process", it is necessary to perform full TPM activities and improve human resources so that "the quality can be built into the products thorough the equipment. Many of the tools such as employee empowerment, benchmarking, documentation, etc. used in TQM are used to implement and optimize TPM.

Following are the similarities between the two.

1. In both cases leadership commitment is required for the implementation.
2. Employees must be empowered to initiate corrective action, and
3. Changes in employee mindset toward their job responsibilities must take place as well.

Even though TQM and TPM have some features in common, there are also issues that differentiate them. The main differences is that TPM concentrate on the machine, process and slow trends, while TQM deals with Quality tools and management of fast changes.

2.5.7.3 The Benefits of TPM

Johansson and Nord depicted the following benefits derived from the implementation of TPM (Johansson, B., and Nord, c., 1999):

- Productivity is improved through fewer losses in the company.
- Quality is also improved as a result, that the failures and malfunctions are reduced and the order and method are focused.
- The cost are lower, because the losses, and other not value generating work are reduced.
- The delivery time can be kept better, because the production without disturbances is easier to plan.
- Environment and security are better, because leakages are tightened.
- Motivation is higher, because the responsibility and rights are delegated and the investment in the personnel is done, in the form of education.

Furthermore, better understanding of the performance of their equipment can be achieved by operator through better training which leads to have better equipment performance. Robinson and Ginder demonstrate that improving OEE increases the effective capacity, which allows decreased lead time and reduced cost per unit as the same capacity produces more throughput in turn profitability increased.

2.5.7.4 The Relation between RCM and TPM

The Reliability Centered Maintenance process was evolved within the civil aviation industry to fulfill precise need to maintain 'basic equipment conditions" where looseness, contamination or lubrication problems are not allowed. As a result, high standard of training, high skill level of operator's and maintenance man are compulsory where most manufacturing, road transport and mining industries fail to have such capacity. This undermines the application of RCM in most of the industries.

For this reason, the application of TPM as a companywide improvement strategy is highly advisable to ensure:

- 'Basic equipment conditions' are established; and
- 'Equipment competent' operators are developed

The other key difference between RCM and TPM is that RCM is promoted as a maintenance improvement strategy whereas TPM recognizes that the maintenance function alone cannot improve reliability. Factors such as operator 'lack of care' and poor operational practices, poor 'basic equipment conditions', and adverse equipment loading due to changes in processing requirements (introduction of different products, raw materials, process variables etc) all impact on equipment reliability. Unless all employees become actively involved in recognizing the need to eliminate or reduce all "losses" and to focus on 'defect avoidance' or 'early defect identification and elimination' failures will never be cost effectively eliminated in a manufacturing or mining environment (Robinson, C.J. and Ginder, A.P.,1995).

2.5.8 Computerized Maintenance Management Systems (CMMS

A computerized maintenance management system (CMMS) is a type of management software that performs functions in support of management and tracking of O&M activities. Computerized Maintenance Management Systems provide a way for companies to track equipment and inventory assets, detail when and how work orders are to be performed in maintaining those assets, and accumulate all of the associated costs for labor, materials and tools.

2.6Maintenance Planning, Scheduling and Control

Planning and control consists of:

- Anticipating future work
- Visualization of the nature and details of the work

- Determination of the best method to perform the work
- Arranging for the required materials
- Securing alterations in production programme or scheduling of maintenance work to conform to production plans
- Allocation of work to individuals
- Instructing the individuals about the schedules and methods
- Follow-up and monitoring the progress or work; and
- Evaluation of the work and performance.

2.6.1Anticipation of Maintenance Work

The most important function of maintenance is anticipation of future work. This can be done by information provided by the following sources:-

- Instructions and guidance given by manufacturers of the machine.
- Technical knowledge of the maintenance and production personnel.
- Knowledge of the degree of utilization of the machine.
- Record of the behavior of the machine and work done on it.
- Complaints and requests from production personnel on the basis of difficulties experienced by them while operating the machines.
- Examination of the state of the various parts of the machine during their life span.

2.6.2 Visualization of the Nature and Details of Work:

Planning for materials, man-powers methods and time required for a job depends on the nature and details of the job. Visualization of the details of the work to be undertaken in the future can be done on the following basis.

Maintenance System

1) PM Main Lists
2) Routine Lists
3) PM Cards
4) Maintenance Instructions

Main List contains the following information:-

1. Unit Number
2. Machine/Part of machine
3. Time Interval
4. Special /Routine
5. Category Of Workmen/Type of work

6. Maintenance Instructions
7. Activity Description
8. Routine List/PM Card No

Preparation of PM Main List

All PM activities to be carried out by a particular trade at a particular frequency for a sub assembly of a unit should be grouped as one activity .The relevant details are to be given in the maintenance instruction. Number of frequencies should be minimum to facilitate planning & control.

Routine Lists

Routine Lists are prepared from Main Lists. Routine Lists will consist PM activities of Routine Nature of not requiring special planning or stoppage affecting the production schedule for a group of equipment in a division or section. All such activities will be carried out during a specified week by a designated category of worker. Each Routine List will be numbered and scheduled over the year.

PM Cards

PM Card consists of all PM activities which require special planning or stoppage involving production loss and whose frequencies are same. Activities in each PM Card will be scheduled in a particular week of the year with due consideration to the production plan.

Maintenance Instructions

Maintenance Instructions give the detailed description of the maintenance activity. This is to enable the worker carry out the activity as per the specified method.

2.6.3 Determination of the method to perform the work:

The discipline of Method Study aids the maintenance engineers in deciding the most effective methods of performing work. The techniques of PERT helps in sequencing and scheduling of different activities carried on a plant or machines.

2.6.4 Scheduling of Work to Specific Time Periods:

Scheduling of maintenance requires concurrence of production personnel to release the machine during the specified time. Maintenance personnel cannot expect to carry out their own plan and then to assume that it will be acceptable to production people. Scheduling of maintenance work can be done on the basis of the importance of this work in relation to production requirements and the duration of machine downtime and its consequent effects on production and sales programme.

Scheduling of maintenance work require dovetailing of maintenance and production schedules. For this purpose, it is necessary to involve production personnel in decisions regarding the job to be carried out, priority of each job and the time when it should be undertaken. Maintenance department should for this reason prepare a tentative schedule of maintenance work for at least two weeks and circulate it to production dept. and then get their agreement.

The maintenance department should for its own work, think in terms of a long term schedule and a short term schedule. Each of these schedules would include the following activities on the basis of the information provided by the source indicated.

Type of schedule activities		source of information
Long term:	1. Lubrication	1.Manufacturers recommendation
	2. Inspection recommendation	2. Technical Experience
	3. Overhauling	3. Analysis of history of machine
	4. Cleaning of machine	4. Analysis of life span
	5. Replacement	
Short term	1. Repairs	1. Inspection reports
	2. Replacement	2. Compliant and requests of operating personnel

Here, the term 'long term' means a plan for a period of a year or more. Short term plan can be for a period between 15 days to two months. It can sometimes even be a plan for the next week.

2.6.4.1 Work Orders

The individuals who are required to execute the work need to be instructed about the work to be done by them, the method they should adopt, the time when they should commence work and the time at which they are expected to complete the job. One good way of passing on necessary information is the use of work orders.

Work Orders are absolutely necessary to control the execution of the plan and for later evaluation for the following reasons.

- The work order contains a number which assists in identifying the job on schedule boards or for future references; the work order number should preferably also indicate cost centre where the work is carried out. The work order contains information that is necessary for correct allocation of maintenance costs:

- Work Order provides information about scheduling time (and the consequent labour costs) and material as well as actual time taken and material actually consumed as a necessary means of assessing performance.

For reasons stated above, every maintenance work should be undertaken against a work order. Routine work which is carried out every day (e.g. cleaning and oiling) can be done against a standing work order. For other jobs a Work Order should be issued every time such job arises. This is the only way to correctly account for and apportion every minute of time spent by maintenance.

2.6.5 Planning & Scheduling of Maintenance Work:

Basic requirements of organizing planning and scheduling of maintenance work are:

To the extent possible a separate and a capable person should handle the planning and scheduling work and he would report to the In-charge of the Maintenance Department. He should be responsible for coordinating the

a) Schedule of maintenance personnel

b) Spare parts stock control, and

c) Shutdown or breakdown time control

This person will assist Maintenance In-charge in evolving the maintenance methods, develop and improve them, development of new maintenance tools and materials. He will also assist the In-charge in establishing 'time' for various work which will be the basis for working out the maintenance schedules.

Maintenance In-charge will have the full responsibility for the work of the maintenance department. He should report only to the top manager of the establishment. The planning and scheduling person has the basic responsibility for determining the job priorities, ensuring that required tools and materials are available and written schedules of jobs are prepared and distributed.

The person holding the charge of maintenance planning should be the same level as that of the in-charge of production departments to be effective. His understanding of various maintenance methods, crafts and shop services is important.

2.6.5.1 Sources of Scheduling Data:

1. Repair note is the primary source of information for scheduling purpose.

2. Maintenance Methods and time estimates, evolved earlier for various maintenance work, will give information regarding the various trades and the work-load involved.

3. Load schedule and the progress report of the various maintenance crews will give information with respect to their availability.
4. Special Material for maintenance and Spare Parts records in the stores will be the source of information as to their availability.
5. Plant Production schedule is the source of information as to the time when the equipment could be available for maintenance work and necessary servicing.

2.6.5.2 Types of Schedules:

The size of the maintenance organization and the complexity of the plant's maintenance functions will determine the types and frequency of schedules. In general, however, there are three principal classes of schedules which should be used regardless of the plant size. They are:

1. The preventive maintenance master overhaul and inspection schedule.
2. The weekly work schedule
3. The daily man assignment schedule.
4. The area maintenance schedule.

1.PreventiveMaintenance Master Schedule:

In most plants, there are many items of equipment which must be taken out of service at regular intervals for inspection and overhaul. The frequency of such occurrences varies with the equipment. Experience, guided by statistics, permits establishing the frequency, so that the lowest overall maintenance cost results. After the frequencies have been determined, long-range master schedules are prepared. These must be coordinated with plant production schedules (optimum point is when the maintenance cost equals cost of lost production shutdown period).
The maintenance overseer prepares detailed methods write-up which include step-by-step descriptions of each inspection and/or overhaul. The work to be done by each trade and shops is set forth in detail so that their activities can be measured and scheduled accurately. The master schedules are integrated into the daily and weekly schedules so that the regular preventive-maintenance work becomes a part of the overall plan-maintenance programme. This ensures continuity and regularity of the preventive phases of maintenance work.

2. The Weekly Work Schedule:

The weekly schedule provides information to each trade and the machine shop concerning the work to be done on each job for each day in the following week. It should be prepared and released on 4th day or at least latest by 5th day noon, to cover work to be done for the next week.

The weekly schedule must be prepared in co-operation with the shop supervisors and integrated with the plant production schedule. This schedule contains the number of men hours required daily for each trade for each job. Information derived from statistical analysis of plant maintenance department records is used to estimate the amount of time to be allowed for each trade for handling emergency work that are not possible to be scheduled in advance.

The man-hour data provides the basis for scheduling the maintenance force. Also by reviewing the unscheduled back log at the time the schedule is made, the need for hiring additional craftsmen, shop personnel, or laborers is evaluated. When the back log shows tendency to increase, steps should be taken to enlarge the work force. Another advantage to be derived from the weekly schedule is related to the statistical analysis of emergency work. If such an analysis shows that 10 per cent or more of any trade's time is required to handle unscheduled work, further analysis should be made to determine caused of this emergency work. In most cases, a more effective preventive maintenance program based on these facts will permit the amount of unscheduled work to be reduced substantially.

3. The Daily Man Assignment Schedule:

Towards the close of each day, each foreman prepares a daily man-assignment schedule for each person under his supervision. These schedules are based on the weekly schedule, but are modified as necessary to compensate for change forced by fluctuating amounts of unscheduled work and unexpected delays in the scheduled work.

The scheduling group should be advised by the foreman of all variations from the weekly schedule, as well as of all completed work. Whether or not the daily schedule is written will depend on the size and complexity of the organization. Generally, there is no need for a formal schedule. The scheduling usually consists of the foremen's handling the trades-men, one or more work orders, or job plan with the sequence in which they are to be done. Upon completion of the work, the foremen notifies the scheduling group. Each day's progress is reflected in the next day's schedule. By 4th day noon, sufficient data are available to prepare the weekly schedule for next week on a realistic basis.

4. Area Maintenance Schedules:

Many of the functions performed by the area maintenance personnel can be scheduled on detailed weekly schedules. Such items as Lubrication, instrument inspection, machine inspection and adjustment, and the like are of this nature. Usually these activities can be scheduled with considerable accuracy. Periodic audits of these schedules are made by the scheduling group to determine the validity of their time estimates.

2.6.6 Maintenance control

Maintenance Control can be of three types as follows:-

1. Work Control
2. Equipment Control
3. Cost Control

1. Work Control: is done through periodic reporting of the progress of various maintenance activities.

2. Equipment Control: is the process of carrying out Failure Analysis and Downtime Analysis and of taking corrective measures such as Design-out Maintenance and Design-for Maintenance.

3. Cost control: is exercised by the identification of high-cost areas through periodic reporting of PM Costs & CM Costs department/section/equipment-wise and initiating necessary action to reduce the same.

2.6.7 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.

2.7Maintenance Organization

Organizing is the process of arranging resources (people, materials, technology etc.) together to achieve the organization's strategies and goals. The way in which the various parts of an organization are formally arranged is referred to as the organization structure. It is a system involving the interaction of inputs and outputs. It is characterized by task assignments, workflow, reporting relationships, and communication channels that link together the work of diverse individuals and groups. Any structure must allocate tasks through a division of labor and facilitate the coordination of the performance results. Nevertheless, we have to admit that there is no one best structure that meets the needs of all circumstances. Organization structures should be viewed as dynamic entities that continuously evolve to respond to changes in technology, processes and environment, (Daft, L.r., 1989).

Frederick W. Taylor introduced the concept of scientific management (time study and division of labor), while Frank and Lilian Gilbreth founded the concept of modern motion study techniques. The contributions of Taylor and the Gilbreths are considered as the basis for modern organization management. Until the middle of the twentieth century maintenance has been carried out in an unplanned reactive way and for a long time it has lagged behind other areas of industrial management in the application of formal techniques and/or information technology. With realization of the impact of poor maintenance on enterprises' profitability, many managers are revising the organization of maintenance and have developed new approaches that foster effective maintenance organization.

Maintenance cost can be a significant factor in an organization's profitability. In manufacturing, maintenance cost could consume 2–10% of the company's revenue and may reach up to 24% in the transport industry (Chelson, V.J., Payne, C. and Reavill, R.P., 2005). contemporary management considers maintenance as an integral function in achieving productive operations and high-quality products, while maintaining satisfactory equipment and machines reliability as demanded by the era of automation, flexible manufacturing systems (FMS), "lean manufacturing", and "just-in-time" operations.

However, there is no universally accepted methodology for designing maintenance systems, *i.e.,* no fully structured approach leading to an optimal maintenance system (*i.e.,* organizational structure with a defined hierarchy of authority and span of control; defined maintenance procedures and policies, *etc.*). Identical product organizations, but different in technology advancement and production size, may apply different maintenance systems and the different systems may run successfully. So, maintenance systems are designed using experience and judgment supported by a number of formal decision tools and techniques. Nevertheless, two vital considerations should be considered: strategy that decides on which level within the plant to perform maintenance, and hence outlining a structure that will support the maintenance; planning that handles day to- day decisions on what maintenance tasks to perform and providing the resources to undertake these tasks.

The maintenance organizing function can be viewed as one of the basic and integral parts of the maintenance management function (MMF). The MMF consists of planning, organizing, implementing and controlling maintenance activities. The management organizes, provides resources (personnel, capital, assets, material and hardware, etc.) and leads to performing tasks and accomplishing targets. Figure 2.3 shows the role organizing plays in the management process. Once the plans are created, the management's task is to ensure that they are carried out in an effective and efficient manner. Having a clear mission, strategy, and objectives facilitated by a corporate culture, organizing starts the process of implementation by clarifying job and working relations (chain of command, span of control, delegation of authority, etc.).

In designing the maintenance organization there are important determinants that must be considered. The determinants include the capacity of maintenance, centralization *vs* decentralization and in-house maintenance *vs* outsourcing. A number of criteria can be used to design the maintenance organization. The criteria include clear roles and responsibilities, effective span of control, facilitation of good supervision and effective reporting, and minimization of costs.

Maintenance managers must have the capabilities to create a division of labor for maintenance tasks to be performed and then coordinate results to achieve a common purpose. Solving performance problems and capitalizing on opportunities could be attained through selection of the right persons, with the appropriate capabilities, supported by continuous training and good incentive schemes, in order to achieve organization success in terms of performance effectiveness and efficiency.

2.7.1Maintenance Organization Objectives and Responsibility

A maintenance organization and its position in the plant/whole organization is heavily impacted by the following elements or factors:

• Type of business, e.g., whether it is high tech, labor intensive, production or service;

• Objectives: may include profit maximization, increasing market share and other social objectives;

• Size and structure of the organization;

• Culture of the organization; and

• Range of responsibility assigned to maintenance.

Organizations seek one or several of the following objectives: profit maximization, specific quality level of service or products, minimizing costs, safe and clean environment, or human resource development. It is clear that all of these objectives are heavily impacted by maintenance and therefore the objectives of maintenance must be aligned with the objectives of the organization.

The principal responsibility of maintenance is to provide a service to enable an organization to achieve its objectives. The specific responsibilities vary from one organization to another; however they generally include the following according to Duffuaa*et al.* (1998):

1. Keeping assets and equipment in good condition, well configured and safe to perform their intended functions;
2. Perform all maintenance activities including preventive, predictive; corrective, overhauls, design modification and emergency maintenance in an efficient and effective manner;
3. Conserve and control the use of spare parts and material;
4. Commission new plants and plant expansions; and
5. Operate utilities and conserve energy.

The above responsibilities and objectives impact the organization structure for maintenance.

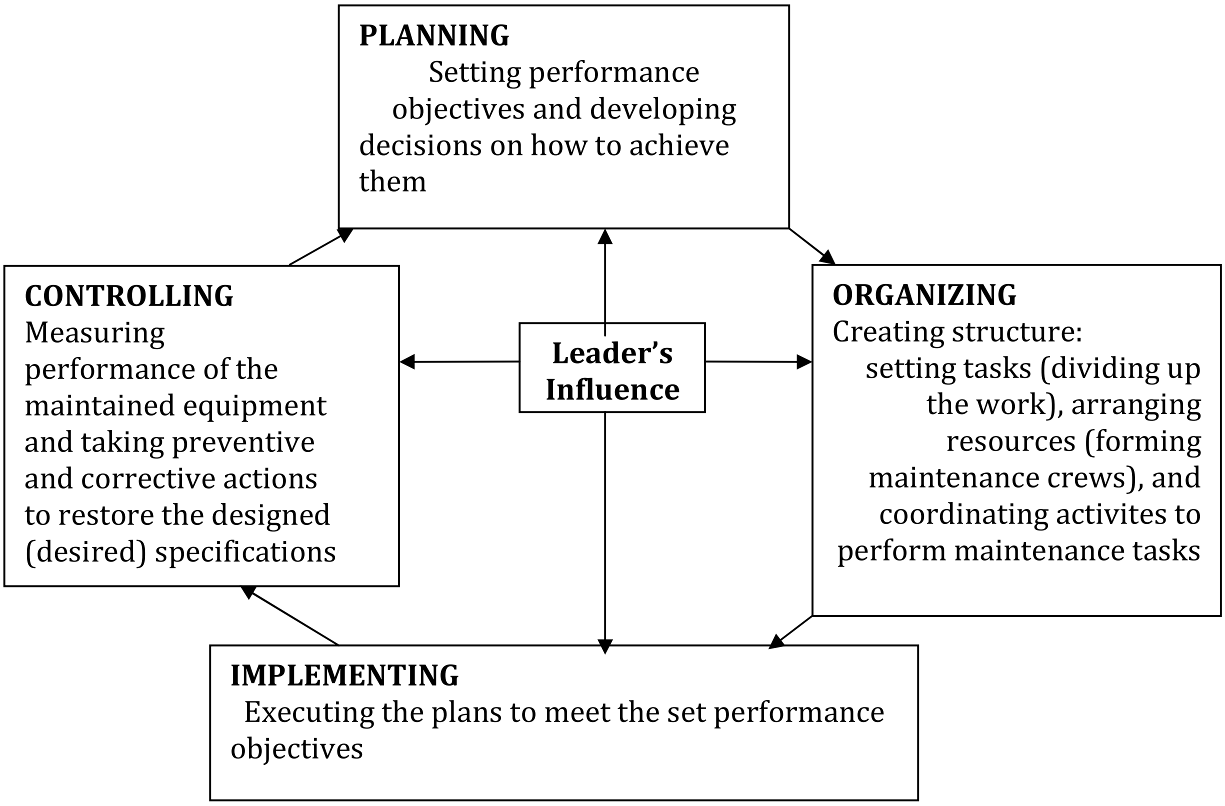

Figure 2.3 Maintenance organizing as a function of the management process

2.7.2 Determinants of a Maintenance Organization

The maintenance organization's structure is determined after planning the maintenance capacity. The maintenance capacity is heavily influenced by the level of centralization or decentralization adopted. In this section the main issues that must be addressed when forming the maintenance organization's structure are presented. The issues are: capacity planning, centralization *vs* decentralization and in-house *vs* outsourcing.

2.7.2.1 Maintenance Capacity Planning

Maintenance capacity planning determines the required resources for maintenance including the required crafts, administration, equipment, tools and space to execute the maintenance load efficiently and meet the objectives of the maintenance department. Critical aspects of maintenance capacity are the numbers and skills of craftsmen required to execute the maintenance load. It is difficult to determine the exact number of various types of craftsmen, since the maintenance load is uncertain. Therefore accurate forecasts for the future maintenance work demand are essential for determining the maintenance capacity. In order to have better utilization of manpower, organizations tend to reduce the number of available craftsmen below their expected need. This is likely to result in a backlog of uncompleted maintenance work. This backlog can also be cleared when the maintenance load is less than the capacity. Making long run estimations is one of the areas in maintenance capacity planning that is both critical and not well developed in practice.

2.7.2.2 Centralization *vs.* Decentralization

The decision to organize maintenance in a centralized, decentralized or a hybrid form depends to a greater extent on the organization is philosophy, maintenance load, size of the plant and skills of craftsmen. The advantages of centralization are:

- Provides more flexibility and improves utilization of resources such highly skilled crafts and special equipment and therefore results in more efficiency;
- Allows more efficient line supervision;
- Allows more effective on the job training; and
- Permits the purchasing of modern equipment.

However it has the following disadvantages:

- Less utilization of crafts since more time is required for getting to and from jobs;
- Supervision of crafts becomes more difficult and as such less maintenance control is achieved;
- Less specialization on complex hardware is achieved since different persons work on the same hardware; and
- More costs of transportation are incurred due to remoteness of some of the maintenance work.

In a decentralized maintenance organization, departments are assigned to specific areas or units. This tends to reduce the flexibility of the maintenance system as a whole. The range of skills available becomes reduced and manpower utilization is usually less efficient than in a centralized maintenance. In some cases a compromise solution that combines centralization and decentralization is better. This type of hybrid is called a cascade system. The cascade system organizes maintenance in areas and whatever exceeds the capacity of each area is challenged to a centralized unit. In this fashion the advantages of both systems may be reaped. For more on the advantages and disadvantages of centralization and decentralization.(Duffuaa,S.O., *et al.* 1998; and Niebel, B.,1994).

2.7.3 Design of the Maintenance Organization

A maintenance organization is subjected to frequent changes due to uncertainty and desire for excellence in maintenance. Maintenance and plant managers are always swinging from supporters of centralized maintenance to decentralized ones, and back again. The result of this frequent change is the creation of responsibility channels and direction of the new organization's accomplishments *vs* the accomplishments of the former structure. So, the craftsmen have to adjust to the new roles. To establish a maintenance organization an objective method that caters for factors that influence the effectiveness of the organization is needed. Competencies and continuous improvement should be the driving considerations behind an organization's design and re-design.

2.7.3.1 Current Criteria for Organizational Change

Many organizations were re-designed to fix a perceived problem. This approach in many cases may raise more issues than solve the specific problem (Bradley, 2002). Among the reasons to change a specific maintenance organization's design are:

- Dissatisfaction with maintenance performance by the organization or plant management;
- A desire for increased accountability;
- A desire to minimize manufacturing costs, so maintenance resources are moved to report to a production supervisor, thereby eliminating the (perceived) need for the maintenance supervisor;
- Many plant managers are frustrated that maintenance seems slow paced, that is, every job requires excessive time to get done. Maintenance people fail to understand the business of manufacturing, and don't seem to be part of the team. This failure results in decentralization or distribution of maintenance resources between production units; and
- Maintenance costs seem to rise remarkably, so more and more contractors are brought in for larger jobs that used to get done in-house.

2.7.3.2 Criteria to Assess Organizational Effectiveness

Rather than designing the organization to solve a specific problem, it is more important to establish a set of criteria to identify an effective organization. The following could be considered as the most important criteria:

- Roles and responsibilities are clearly defined and assigned;
- The organization puts maintenance in the right place in the organization;
- Flow of information is both from top-down and bottom-up;
- Span of control is effective and supported with well trained personal;
- Maintenance work is effectively controlled;
- Continuous improvement is built in the structure;
- Maintenance costs are minimized; and
- Motivation and organization culture.

2.7.4 Basic Types of Organizational Models

To provide consistently the capabilities listed above we have to consider three types of organizational designs.

- **Centralized maintenance**. All crafts and related maintenance functions report to a central maintenance manager. The strengths of this structure are: allows economies of scale; enables in-depth skill development; and enables departments (*i.e.,* a maintenance department) to accomplish their functional goals (not the overall organizational goals). This structure is best suited for small to medium size organizations. The weaknesses of this structure are: it has slow response time to environmental changes; may cause delays in decision making and hence longer response time; leads to poor horizontal coordination among departments and involves a restricted view of organizational goals.
- **Decentralized maintenance**. All crafts and maintenance craft support staff report to operations or area maintenance. The strengths of this structure are that it allows the organization to achieve adaptability and coordination in production units and efficiency in a centralized overhaul group and it facilitates effective coordination both within and between maintenance and other departments. The weaknesses of this structure are that it has potential for excessive administrative overheads and may lead to conflict between departments.
- **Matrix structure,** a form of a hybrid structure. Crafts are allocated in some proportion to production units or area maintenance and to a central maintenance function that supports the whole plant or organization. The strengths of this matrix

structure are: it allows the organization to achieve coordination necessary to meet dual demands from the environment and flexible sharing of human resources. The weaknesses of this structure are: it causes maintenance employees to experience dual authority which can be frustrating and confusing; it is time consuming and requires frequent meetings and conflict resolution sessions. To remedy the weaknesses of this structure a management with good interpersonal skills and extensive training is required.

2.7.5 Material and Spare Parts Management

The responsibility of this unit is to ensure the availability of material and spare parts in the right quality and quantity at the right time at the minimum cost. In large or medium size organizations this unit may be independent of the maintenance organization; however in many circumstances it is part of maintenance. It is a service that supports the maintenance programs. Its effectiveness depends to a large extent on the standards maintained within the stores system. The duties of a material and spare parts unit include:

- Develop in coordination with maintenance effective stocking polices to minimize ordering, holding and shortages costs;
- Coordinate effectively with suppliers to maximize organization benefits;
- Keep good inward, receiving, and safe keeping of all supplies;
- Issue materials and supplies;
- Maintain and update records; and
- Keep the stores orderly and clean.

2.7.6 Establishment of Authority and Reporting

Overall administrative control usually rests with the maintenance department, with its head reporting to top management. This responsibility may be delegated within the maintenance establishment. The relationships and responsibility of each maintenance division/section must be clearly specified together with the reporting channels. Each job title must have a job description prescribing the qualifications and the experience needed for the job, in addition to the reporting channels for the job.

2.7.7 Quality of Leadership and Supervision

The organization, procedures, and practices instituted to regulate the maintenance activities and demands in an industrial undertaking are not in themselves a guarantee of satisfactory results. The senior executive and his staff must influence the whole functional activity. Maintenance performance can never rise above the quality of its leadership and supervision. From good leadership stems the teamwork which is the essence of success in any enterprise. Talent and ability must be recognized and fostered; good work must be noticed and commended; and carelessness must be exposed and addressed.

2.7.8 Incentives

The varied nature of the maintenance tasks, and differing needs and conditions arising, together with the influence of production activity, are not tuned to the adoption of incentive systems of payment. There are, however, some directions in which incentives applications can be usefully considered. One obvious case is that of repetitive work. The forward planning of maintenance work can sometimes lead to an incentive payment arrangement, based on the completion of known tasks in a given period, but care must be taken to ensure that the required standards of work are not compromised. In some case, maintenance incentives can be included in output bonus schemes, by arranging that continuity of production, and attainment of targets, provides rewards to both production and maintenance personnel.

2.7.9 Education and Training

Nowadays it is also recognized that the employers should not only select and place personnel, but should promote schemes and provide facilities for their further education and training, so as to increase individual proficiency, and provide recruits for the supervisory and senior grades. For senior staff, refresher courses comprise lectures on specific aspects of their work; they also encourage the interchange of ideas and discussion.

The further education of technical grades, craft workers, and apprentices is usually achieved through joint schemes, sponsored by employers in conjunction with the local education authority. Employees should be encouraged to take advantage of these schemes, to improve proficiency and promotion prospects.

A normal trade background is often inadequate to cope with the continuing developments in technology. The increasing complexity and importance of maintenance engineering warrants a marked increase in training of machine operators and maintenance craftsmen through formal school courses, reinforced by informed instruction by experienced supervisors.

The organization must have a well defined training program for each employee.

The following provides guidelines for developing and assessing the effectiveness of the training program:

- Evaluate current personnel performance;

- Assess training need analysis;
- Design the training program;
- Implement the program; and
- Evaluate the program effectiveness.

The evaluation is done either through a certification program or by assessing the ability to achieve desired performance by persons who have taken a particular training program.

The implementation of the above five steps provides the organization with a framework to motivate personnel and improve performance.

2.7.10 Management and Labor Relations

The success of an undertaking depends significantly on the care taken to form a community of well-informed, keen, and lively people working harmoniously together. Participation creates satisfaction and the necessary team spirit. In modern industry, quality of work life (QWL) programs have been applied with considerable success, in the form of management conferences, work councils, quality circles, and joint conferences identified with the activities. The joint activities help the organization more fully achieve its purposes.

2.8Inventory Control in Maintenance

Usually, the major complaint of those involved in maintenance is the unavailability of materials and spares at the moment of need. Today, as modern engineering equipment grows more complex, the cost of inventorying spares has increased alarmingly.

In many maintenance organizations, materials account for one-third to one-half of the operating budget, and more in some capital-intensive industrial sectors.(Westerkamp, T.A.,1997) Needless to say, maintenance functions rely heavily on the availability of items such as spares for production equipment and machinery. Specific examples include lubricants, valves, pipe fittings, paints, angle iron, channel iron, controls, and nuts and bolts. A well-managed inventory system of such items helps reduce maintenance cost, worker and equipment downtime, and improves productivity. Inventory control plays an important role in maintenance.

The history of inventory control begins in the early 1900s, and it was used only for clerical help for first-line management.(Greene, J.H.,1987) Today, inventory control has risen to higher organizational levels with responsibilities in areas such as planning and control.

2.8.1Inventory Purposes, Types, and Basic Maintenance Inventory-Related Decisions

Inventory can help organizations in many ways. Figure 2.4presents six important purposes. (Render, B. and Heizer, J.,1997; Vonderembse, M.A. and White, G.P.,1996) There are many types of inventory. The commonly identified types include raw materials inventory, finished goods inventory, supplies inventory, work-in-process (WIP) inventory, transportation inventory, and replacement parts inventory. (Vonderembse, M.A. and White, G.P.,1996)In the case of raw materials inventory, items are purchased from suppliers for use in production processes. Finished goods inventory is concerned with finished product items not yet delivered to customers. The supplies inventory is concerned with parts/materials used to support the production process. Usually these items are not an element of the product.

The WIP inventory is concerned with partly-finished items (i.e., components, parts, subassemblies, etc.) that have been started in the production process but must be processed further. The transportation inventory is concerned with items being shipped from suppliers or to customers through the distribution channel. The replacement parts inventory is concerned with maintaining items for the replacement of other items in the company or its customer equipment/systems as they wear out.

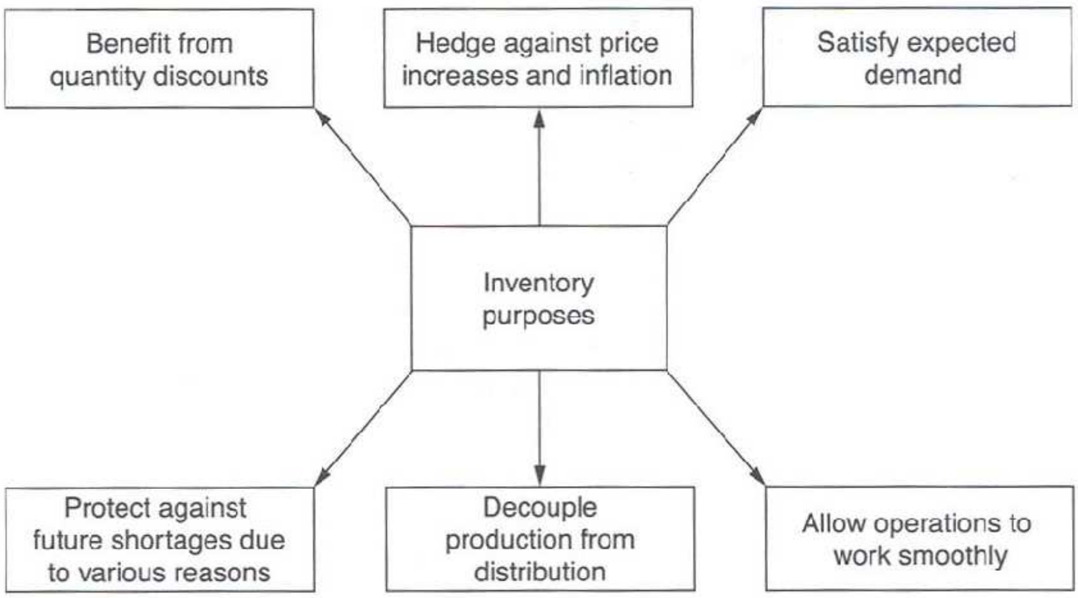

figure 2.4Important purposes of inventory.

Maintenance management personnel make decisions on basic areas such as those listed below with respect to inventory. (Westerkamp, T.A.,1997)

- **Items/materials to be stored**: Decisions require consideration of factors such as ability of the vendor to supply at the moment of need, cost, and the degree of deterioration in storage.
- **Amount of items/materials to be stored:** Decisions are made by considering factors such as degree of usage and delivery lead time.
- **Item/material suppliers:** Decisions on suppliers of items/materials are made by considering factors such as price, delivery, quality, and service.
- **Lowest supply levels:** Decisions on lowest levels of supplies, in particular the major store items, are made by considering factors such as purchasing's historical records and projected needs.
- **Highest supply levels:** As time-to-time supply usage rate drops, the decisionson the highest supply levels are made by keeping in mind factors such as past ordering experience and peak vacation period.
- **Time to buy and pay**: Decisions on these two items are often interlocked. Such decisions are made by considering factors such as vendor announcements about special discounts, past purchasing records, and store withdrawals and equipment repair histories.
- **Place to keep items/materials:** As location control is crucial to a productive maintenance department, decisions concerning storage of items/materials are made by keeping in mind that they can be effectively retrieved. Past experience indicates that a single physical location for each item is the best.
- **Appropriate price to pay**: Pricing is of continuous concern, and decisions concerning it are primarily governed by perceived, not actual, supply and demand.

2.8.2 ABC Classification Approach for Maintenance Inventory Control

In any maintenance inventory control system, parts/materials required for routine maintenance should be readily available. In the case of non routine maintenance, items must be controlled in such a way that the capital inventory investment is most effective. (Niebel, B.W., 1994)

In controlling inventory, one must seek information on areas such as those listed below. (Arnold, J.R.T.,1996)

- Importance of the inventory item
- The way it should be controlled
- Quantity to be ordered at one time
- Specific point in time to place an order

The ABC classification approach provides information for routine and nonroutine maintenance. Consequently, it allows different levels of control based on the item's relative importance. The ABC approach is based on the reasoning that a small percentage of items usually dictate the results achieved under any condition. This reasoning is often referred to as Pareto principle, named after Vilfredo Pareto (1848–1923), an Italian sociologist and economist.(Hayes, G.E. and Romig, H.C.,1977)

The ABC approach classifies in-house inventory into three categories (i.e., A, B, and C) based on annual dollar volume. The following approximate relationship between the percentage of inventory items and the percentage of annual dollar usage is observed: (Arnold, J.R.T.,1996; Dickie, H.F., 1951)

- A: Of the items, 20% are responsible for 80% of the dollar usage.
- B: Of the items, 30% are responsible for 15% of the dollar usage.
- C: Of the items, 50% are responsible for 5% of the dollar usage.

The following three steps are associated with the ABC classification approach:

1. Determine the item characteristics that can influence inventory management
2. Results. Often, this is the annual dollar usage.
3. Group items based on the criteria established above.
4. Practice control relative to the group importance.

Factors such as annual dollar usage, material scarcity, and unit cost affect the importance of an item. (Arnold, J.R.T.,1996)

Control policies for a, b, and c classification items

After the classification of inventory items, control policies can be established. Some of these policies associated with each classification are as follows:

• **Classification A items**: These are high-priority items. Practice tight control including: frequent review of demand forecasts, complete accurate records, periodic and frequent review by management, close follow up, and expediting to minimize lead time.

• **Classification B items:** These are medium-priority items. Practice regular controls including: good records, regular processing, and normal attention.

• **Classification C items:** These are low-priority items. Practice simple controls, but ensure they are sufficient to meet demand.

Keep plenty of low-cost items, and use the money and control effort saved to minimize inventory of high-cost items.(Arnold, J.R.T.,1996)

2.8.3 Inventory Control Models

Various mathematical inventory control models have been developed, many of which can be applied to maintenance inventory control. These models are based on the assumption that demand for an individual item can be either independent of or dependent on the demand for other items. This section presents three models for managing independent demand items.

2.8.3.1 Economic Order Quantity Model

The economic order quantity model may be traced back to 1915 and is one of the most widely known inventory control methods. (Harris, F.W., 1915) Some assumptions associated with the model are as follows:

- Constant and known demand
- Instantaneous receipt of inventory
- Constant and known time between order placement and receipt of the order
- Infeasible quantity discounts
- Stock outs can be avoided by placing orders at the right time
- Two variable costs: holding cost and ordering or setup cost

2.8.3.2 Production Order Quantity Model

In the economic order quantity model, it was assumed that the complete inventory order was received by the maintenance department at one time. However, there are instances when the department may receive its order over a period of time. To handle this case a different model is needed. The main assumption is that the manufacturer units cannot instantaneously produce all the units ordered. Consequently, this finite replenishment rate can impact the calculation of EOQ significantly.

Under the finite replenishment rate scenario, the inventory does not jump to the order quantity level at the occurrence of replenishment because some items are being removed from the inventory at the time of replenishment. Consequently, the maximum inventory will never reach the level of the quantity ordered.

2.8.3.2 Quantity Discount Model

Another assumption associated with the economic order quantity model is that the unit procurement price remains constant irrespective of the number of units purchased. In real life, this may or may not be true as many companies offer quantity discounts. Thus, the order quantity can influence the purchase price of a unit. As the discount quantity increases, the unit cost goes down but the holding cost goes up because of large orders.

In this case, the important trade-off is between the increased holding cost and the reduced unit cost.

2.8.3.4 Safety Stock

The main purpose of having the safety stock is to mitigate the risk of running out of items at the moment of need. One technique for providing safety stock is known as the "two-bin system." In this case, a fixed replenishment order is placed as soon as the stock level hits the preset reorder point. More specifically, the items are stored in two bins, the replenishment order is placed as soon as the first bin becomes empty, the items from the second bin are used until receiving the ordered items. The value of the preset reorder point depends upon factors such as the rate of demand and its associated variability, the stock out cost, and the lead time and its associated variability.(Kelly, A. and Harris, M.J.,1979) Reference (Arnold, J.R.T.,1996)states the following five factors on which the safety stock required depends:

1. Reorder frequency
2. Desired level of service
3. Ability to forecast/control lead times
4. Demand variability during the lead time
5. Length of the lead time interval

As the uncertainty in demand raises the possibility of a stock out, the demand for items can be specified by means of a probability distribution. Past experience indicates that often demand during the lead time follows the normal probability distribution. Thus, the safety stock necessary to get a desired level of service is given by(Vonderembse, M.A. and White, G.P.,1996)

$$\mathrm{ST} = \mathrm{z}\delta$$

Where:-ST =safety stock necessary to get a desired service level,

σ =demand standard deviation during lead time,

z = number of standard deviations from the mean value required to get desired level of service.

Consequently, the order point is expressed by

OPD = $\mu + \mathrm{z}\delta$

Where:-ODP = order point,

μ =mean demand during lead time.

The value of z is estimated according to the desired level of service.

2.9Maintenance Costing

The maintenance phase is an important element of the equipment life cycle during which equipment must be maintained satisfactorily for effective performance. The cost of maintaining equipment often varies from 2 to 20 times the acquisition cost. The cost of maintenance is defined as costs that include lost opportunities in uptime, rate, yield, and quality due to non operating or unsatisfactorily operating equipment in addition to costs involved with equipment-related degradation of the safety of people, property, and the environment.(Mckenna,T. and Oliverson, R.,1997)However, often maintenance cost is simply described as the labor and materials expense needed to maintain equipment/items in satisfactory operational state.(Dhillon, B.S.,1989).(Neibl, B.W.,1994; and Cavalier, M.p. and Knapp, G.M.,1996) have classified fundamental costs associated with maintenance more specifically into four areas: direct costs, lost production costs, degradation costs, and standby costs.

Direct costs are associated with keeping the equipment operable and include costs of periodic inspection and preventive maintenance, repair cost, overhaul cost, and servicing cost. Lost production costs are associated with loss of production due to primary equipment breakdown and unavailability of standby equipment. Degradation costs are associated with deterioration in the equipment life due to unsatisfactory/ inferior maintenance. Standby costs are associated with operating and maintaining standby equipment. Standby equipment is used when primary facilities are either under maintenance or inoperable.

2.9.1 Reasons for Maintenance Costing and Factors Influencing Maintenance Costs

Some of the many reasons for maintenance costing are as follows:

- Determine maintenance cost drivers
- Prepare budget
- Provide input in the design of new equipment/item/system
- Provide input in equipment life cycle cost studies
- Control costs
- Make decisions concerning equipment replacement
- Compare maintenance cost effectiveness to industry averages
- Develop optimum preventive maintenance policies
- Compare competing approaches to maintenance
- Provide feedback to upper level management
- Improve productivity

Many factors influence maintenance costs, including asset condition (i.e., age,type, and condition), operator expertise and experience, company policy, type of service, skills of maintenance personnel, operational environment, equipment specification, and regulatory controls.(Levitt, J.,1997)

2.9.2 Maintenance Budget Types, Preparation Approaches, and Steps

A maintenance budget serves as an important tool to control financial resources necessary for running the maintenance department. Budget administration uses various types of accounting procedures and computer-based systems to manage, control, and measure departmental effectiveness.(Hartmann, E., et al, 1981) One of these two types of budgets is often used in maintenance operations:(Westerkamp, T.A.,1997)

- Operating budget
- Project (or appropriation) budget

The operating budget is concerned with itemizing each category of operating expense forecasted for every department in the organization. A purpose of this type of budget is to control normal operating labor, material, and overhead costs forecasted for the coming fiscal year. The budget includes items such as preventive maintenance, semi-annual plant shutdown repairs and overhauls, minor modifications, and routine repair.

The project budget is concerned with special projects or programs such as computerized maintenance management systems, major capital equipment purchases, and major construction projects. Funds for projects such as these are not included in the operating budget. The project budget is divided into particular types and amounts of materials, labor, and overhead expenses needed to complete a defined project.

2.9.2.1 Budget Preparation Approaches

Two effective approaches that can be used to prepare budgets are discussed here:

historical approach and zero-based approach.(Westerkamp, T.A.,1997)

With a historical approach, the budget is based on historical perspective. Most budgets fall into this category. Professionals involved in the preparation of this type of budget rely on the experience of earlier years to determine cost estimates for the coming year. This approach is efficient, rational, and requires a relatively small amount of paperwork. The main drawback is that past errors tend to be perpetuated and ineffective operations are funded proportionately to effective ones.

The zero-based approach is concerned with developing the budget from the ground up without any historical basis. Each budget item is justified by current requirements or priority versus the availability of funds. Budget items and subitems are grouped by priority into work packages and, in turn, the work packages are classified into three categories: expenditures required by law, expenditures not required by law, and new or first-time budget items. Some of the advantages of the zero-based budget approach are as follows:

- More thoughtful and thorough process
- Better use of the funds available
- More clear understanding of organizational objectives and goals at all management levels

The zero-based budget approach has drawbacks in that it requires more time because it is a more detailed process, and it requires more documentation in comparison to the historical approach.

2.9.2.2 Budget Preparation Steps

Professionals working in the area have developed a process for preparing a maintenance budget. This process is as follows:(Westerkamp, T.A.,1997)

- Collect information on trends over the past few years.
- Seek input from the accounting department concerning cost trends and improvements.
- Seek input from the operations group concerning its plans for the coming year.
- Obtain information on sales by product and department.
- Determine maintenance labor-hours by skill and department, particularly for equipment with high repair costs.
- Estimate the amount of material required by department, in particular high-cost and high-volume items.
- Estimate overhead expenses.
- Distribute expenses or costs by weeks and total them for each month.
- Establish separate cumulative cost charts for every important variable, e.g., material, labor, and overhead.
- Update individual and total costs periodically and plot them on appropriate charts.
- The last two steps are basically concerned with the budget use.

2.10Quality and Safety in Maintenance

Quality may be defined as conformance to requirements or degree to which a product, function, or process satisfies the needs of customers and users.(Omdahl, T.P., ed.,1988) Maintenance quality assurance is the actions by which it is determined that parts, equipment, or material maintained, modified, rebuilt, overhauled, or reclaimed conform to the specified requirements.(Mckenna, T. and Oliverson, R.,1997) Maintenance quality is important because it provides a degree of confidence that maintained or repaired parts/equipment/systems will operate reliably and safely.(Beckmerhagen, I.A., Berg, H.P. and Harnack, K.,1996)

In the United States, there is a fatal work-related injury every 103 minutes and a disabling injury every 8 seconds. In 1998 the total cost of work injuries was in the order of $125.1 billion. (National Safety Council, Chicago, 1999) Furthermore, unintentional injuries are the fifth leading cause of death, with an estimated cost of $480.5 billion per year.(National Safety Council Chicago, 1999) Accidents occurring during maintenance work or concerning maintenance are frequent. For example, in 1994, 13.61% of all accidents in the U.S. mining industry occurred during maintenance work and, since 1990, the occurrence of such accidents has increased each year. It is essential that maintenance engineering should strive to eliminate or control potential safety hazards to ensure satisfactory protection to people and material from such things as electrical shock, high noise levels, fire and radiation sources, toxic gas sources, protruding structural members, and moving mechanical assemblies. (Department of The Army Washington, 1975)

2.10.1Post-Maintenance Testing

Post-maintenance testing (PMT) helps increase the quality of maintenance performed. Basically, PMT has three objectives: (Department of Energy, 1990-1993 ed.)

1. Ensure that the original deficiency has been rectified appropriately.
2. Ensure that no new deficiencies have been introduced.
3. Ensure that the item under consideration is ready to perform its specified mission.

PMT should be carried out after all types of corrective maintenance activities as well as after some preventive maintenance actions as considered appropriate. Testing should be commensurate with the specific type of maintenance accomplished and the importance of structure/system/part to facility reliability and safety. In some situations, this may only require verification and checkout, but in others formal documented PMT may be necessary.

2.10.1.1 PMT Key Elements

PMT involves several key elements including:(Department of Energy, 1990-1993 ed)

- Clearly defined responsibilities of each group involved
- Availability of guidance to planners to identify appropriate tests
- Scope of equipment tested incorporates all facility equipment/systems

- Performance of tests under the relevant system operational parameters
- Specification of appropriate tests incorporates inputs received from operating, maintenance, and technical support groups
- Testing performed with the consent of operator/owner, using authorized instructions/procedures, and conducted and reviewed by competent persons
- A form is used to document, authorize, and review PMT results

2.10.1.2 Operator-Documented PMT Responsibilities

The responsibilities of operator or owner of items/equipment requiring documented PMT include(Department of Energy, 1990-1993 ed)

- Defining the need for a level of PMT as well as for document approval
- Minimizing the redundancy of PMT and the PMT excessiveness
- Providing assistance to maintenance activity as required by performing applicable testing
- Clearly defining operational parameters and associated criteria
- Emphasizing the importance of ensuring configuration management
- Ensuring the proper authorization, performance, examination, and documentation of PMT before returning the equipment/item to operation
- Ensuring the performance of all associated delay tests before or in conjunction with returning the equipment/item to operation
- Restoring structures, systems, and components to exact set points for active or standby modes subsequent to testing

2.10.1.3Common PMT Activities

Some representative PMT activities are as follows:(Department of Energy, 1990-1993 ed)

- Leak rate testing
- Current, voltage, or integrity checks
- Component calibration or alignment
- Nondestructive tests as specified by code
- Visual or dimensional inspections
- Part operational exercise including pressure, temperature, flow, and vibration
- Response time

2.10.2Cement Manufacturing and its Environmental Implications

Many of the aspects of the cement making process are potentially environmentally damaging, although these risks can be minimized. The areas of potential concern are listed below.

2.10.2.1 Dust Emissions

The manufacture of cement generates large quantities of dust. These must be prevented (both on environmental and economic grounds) from escaping to the atmosphere. The two areas where dust has the potential to escape are via air streams that have been used to carry cement (e.g. the mills or kiln) and directly from equipment used to transport cement (e.g. the various conveyor belts). Thus to prevent dust emissions all transport equipment is enclosed, and the air both from these enclosures and from the kiln and mills is treated in an electrostatic precipitator to remove its load of dust. Here dust-laden air passes between an electrode carrying 50 000 volts and an earthed collection plate. The electrostatic discharge between the electrode and the plate forces the dust onto the plates, from which it is removed.

The current emission limit from the main stack at Golden Bay is 250 mg m-3 and at Milburn is 150 mg m-3, while in Europe emission limits of down to 50 mg m-3 are becoming common. This poses a significant challenge to the manufacturing operation both in capital cost to emissions and monitoring of emissions to ensure compliance with existing resource consents.

2.10.2.2 Carbon Dioxide (CO_2)

Cement manufacture is an energy intensive process. One of the most significant challenges facing the industry into the 21st century is a requirement to reduce CO2 emissions. CO2 is produced during the calcinations phase of the manufacturing process and also as a result of burning fossil fuels. Opportunity to reduce emissions through increased energy efficiency is only possible on the latter of the CO2 emissions.

2.10.5.3 Quarry and Plant Water Runoff

Runoff of storm water and treatment of waste water from quarries is a problem for almost all quarry operations. Usually this is trapped in wetland areas where the water is treated in a controlled manner. Within the factory runoff can be contaminated by oils and lubricants, but the runoff is monitored and training programmes are regularly undertaken to ensure this does not happen.

2.10.5.4 Chrome Bricks

Kiln bricks used to be made of hexavalent chrome, which is a carcinogen and causes dermititus in some people. Since the problems associated with its use were identified both Milburn and Golden Bay (along with almost all cement manufacturers internationally) replaced these bricks with environmentally-sound magnesium-spinel bricks. Article written by Heather Wansbrough from the article in the previous edition by G. Slocombe (Tikipunga High School) and D. Gallop (Wilsons (N.Z.) Portland Cement Ltd.) with advice from Martyn Compton (Golden Bay Cement), Murray Mackenzie (Milburn New Zealand Ltd.) and Tim Mackay (The Cement and Concrete Association of New Zealand).

2.10.6 Reasons for Safety Problems in Maintenance

There are various reasons for safety related problems in maintenance. Some of the important reasons are shown in Fig. 2.5

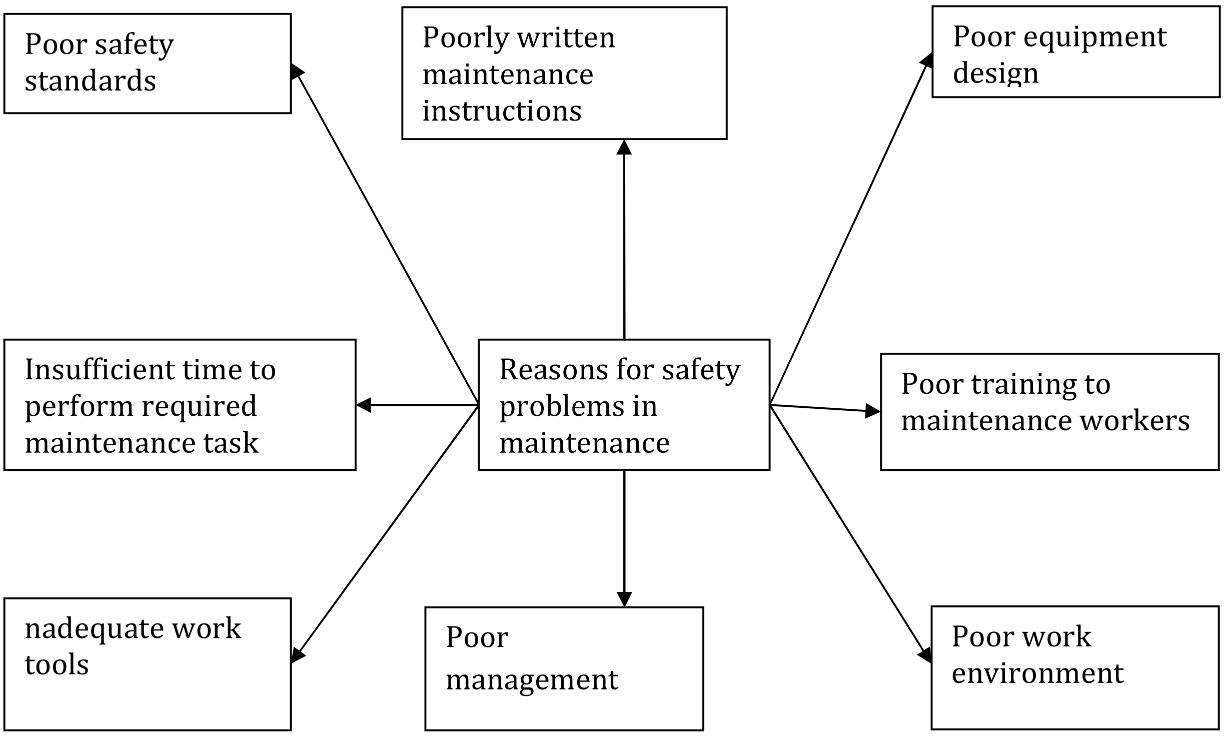

Figure2.5some important reasons for safety problems in maintenance.

2.10.7 Safety and Maintenance Tasks

In addition to the general safety considerations, other factors that influence the safety dimensions of maintenance tasks include:

- Numerous maintenance tasks or jobs are in direct response to the needs of working safely. Consequently, safety needs augment maintenance tasks or jobs.
- Numerous maintenance tasks or jobs are hazardous and lead to hazardous solutions. Thus, maintenance work is a cause of safety-related problems.

The first item may be interpreted as one result of an effective safety management system. However, the second item requires further review. Some aspects of maintenance work that give it this dubious safety reputation are as follows: (Stoneham, d., the maintenance management and technology handbook, Elsevier Science, oxford, u.k., 1998.9)

- Numerous maintenance tasks occur infrequently, e.g., machinery failures, thus fewer opportunities to discern safety-related problems and to introduce remedial measures.
- Maintenance work performed in unfamiliar surroundings means that hazards such as rusted handrails, broken light fittings, and missing gratings may pass unnoticed.
- Difficulty in maintaining regular communication with workers in some maintenance tasks.
- Some maintenance work may require performing tasks such as disassembly of corroded parts, or manhandling cumbersome heavy parts in poorly lit areas and confined spaces.
- Disassembling previously working machinery, thus working under the risk of releasing stored energy.
- Sudden need for maintenance work, allowing limited time to prepare.
- Performance of maintenance work inside or underneath machines such as air ducts, pressure vessels, and large rotating machines.
- Performance of maintenance work at odd hours, in remote locations, and in small numbers.
- Need to transfer heavy and bulky materials from a warehouse to the maintenance workplace, sometimes using lifting and transport equipment well outside a strict

2.10.8Maintenance Personnel Safety

Usually, emphasis is placed on designing safety into machines rather than on the safety of the operators, maintainers, etc. On occasion, more protection is required for maintenance workers beyond the safety designed into machines or processes. Two important areas of maintenance worker safety are respiratory protection and Protective clothing. Figure 2.6 shows four areas in which respiratory protection is required. The protective clothing includes items such as(Stoneham, d., the maintenance management and technology handbook, Elsevier Science, oxford, u.k., 1998.)

- **Ear defenders**: These are necessary where machine or process noise can damage maintenance workers' ears.
- **Boots and toecaps**: well-fitting boots with steel toecaps can reduce the risk of injury in situations such as dismantling used equipment where heavy metal parts are difficult to hold and are likely to slip and drop on exposed feet.
- **helmets and hard hats**: these are useful to protect maintenance workers from head injury.

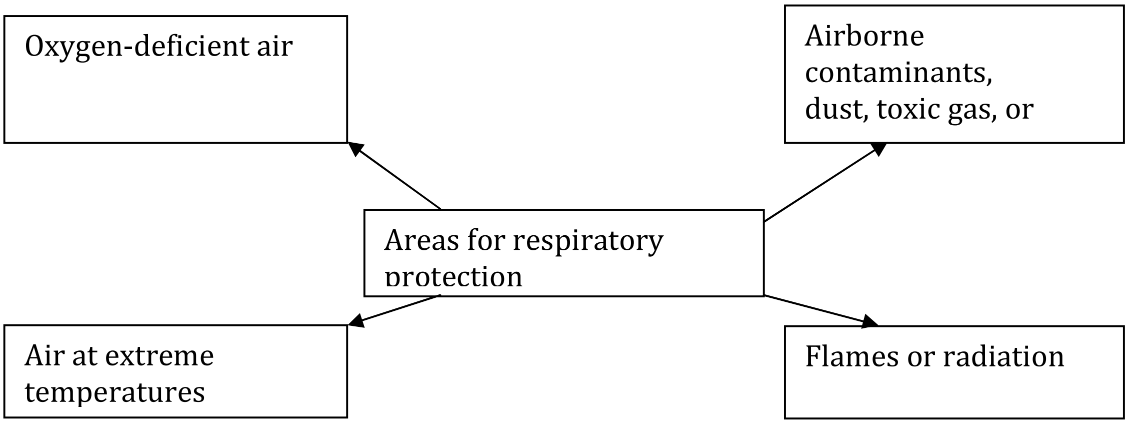

Figure 2.6Areas requiring respiratory protection.

- Gloves: These are important to protect hands from injury when performing various types of maintenance tasks.
- Goggles, visors, screens, and safety glasses: These items protect eyes from flying chips, sparks, chemical sprays, jetted hydraulic fluid, etc.

2.11Human Factors in Maintenance Management

What are 'Human Factors' in Organisations?

An organisation is a system of interdependent human beings, and their characteristics affect both its structure and its functioning. Human relations management studies the characteristics and inter-relationships of individuals and groups within organizations and takes account of these factors when designing and administering those organizations.

2.11.1Maintenance Management Behavioral Characteristics

In the previous section it has been explained that the main efforts of the human factors school have focused on identifying and understanding those elements that make an employee's work more satisfying and therefore more effective in terms of the organizational objectives. Here, we will look at human factors from a different viewpoint. We will be concerned with identifying the main ones that influence the organisation's efforts towards achieving its maintenance objectives. Some (e.g., a sense of ownership of equipment, affecting reliability performance) will affect the maintenance objective via output considerations, and some (e.g., motivation) via the efficiency of resource usage. It is important to understand that management can take actions to change human factors; the creation of plant-oriented teams, for example, might improve the sense of equipment ownership.

When identifying human factors the following points are helpful:

- It is important to differentiate between human factors and the actions that influence them (see above).
- Human factors can interact, e.g., morale affects motivation.
- Some researchers consider that some human factors, such as goodwill towards the company, can be considered as dominant.
- Some performance indicators provide a measure of certain human factors, e.g., the level of absenteeism is an indicator of morale.

I am not trying to be 'academic' about this. When auditing maintenance departments I try to get a feel for how good or bad the human factors are. There is little point in confirming that the strategy, structure and systems are good without providing corresponding information about human factors.

When seeking the key human factors in maintenance management I have found the following definition useful:

Characteristics which define the way in which an individual or group behaves or acts in an industrial setting can be called human factors. Those that influence the way the maintenance department operates are termed maintenance management human factors.

The more important of these may be divided into those that can affect individual behaviour and those that can affect the behavior of industrial groupings of people—complete companies, manufacturing units, and teams. As far as possible, industrial examples will be used to show how important these are to maintenance management.

2.11.2.2Individual Behavioral Characteristics

Equipment Ownership: a factor which involves the degree to which a trade force and/or operators and/or the team feel a sense of personal ownership for anequipment or an area of plant. This is probably the most important single factor in achieving a high level of equipment reliability. Where ownership exists the equipment tends to be operated and maintained correctly.

One of the key organisational characteristics of Total Productive Maintenance (the Japanese-developed strategic approach to maintenance management)is the move towards small, self-empowered, plant oriented operator-maintenance teams—of up to seven operator-maintainers with the responsibility for operating a definable sub-process or area of plant and carrying out simple maintenance tasks on it, such as lubrication, adjustment and minor servicing. The teams comprise operators (trained in superficial maintenance)and tradesmen (given operator training). The teams are also given considerable training in the way the plant operates and the relationship between the way it is maintained and operated and its failure or its inability to produce at its design level of quality. They are encouraged, with the help of engineers, to carry out modifications to improve operation and reliability (the so called continuous improvement or Kaizen). All of these actions engender a considerable level of plant ownership in the individuals and in the team—they care about the equipment in the same way as if it were literally their personal property.

The operators and fitters were plant oriented. However, the separation of operators and maintainers and the shift system worked against ownership. To compensate for this, individual tradesmen were made responsible for carrying out the preventive work on designated equipment—both on shifts and when they were in the weekend group.

Goodwill: 'the state of wishing well to a person, a cause or an enterprise' (a dictionary definition). This involves the tradesmen or operators feeling a sense of belonging with the company and wanting it to prosper. It is closely allied to 'loyalty' but is something more than this. The author considers it to be in many ways a key factor. When goodwill is evident at the shop floor level other problems seem to be more amenable to solution. It takes a long time to build up—perhaps many years of good relationships and trust in the management and the company. It is a function of the company treating the workforce fairly and with respect.

Motivation: much researched and much written about, because of its importance to all industrial personnel. I consider the behaviorist theories (see Table 2.3)to be too general and insufficiently dynamic to describe the motivational characteristics of the shop floor. To quote from one of my earlier books:

'In general the industrial worker sees his job as a means of obtaining money, a lower order need, in order to satisfy elsewhere his other, higher order, needs. This view is based on the observation that people are only truly motivated when they are doing something (work, hobby, sport, home repairs) that they really want to do. Most often the worker does not experience this at work. The nature of the work is such that it is normally difficult to institute changes sufficiently to arouse true motivation'.(Kelly, A.,1984)

Applying these ideas to the maintenance tradesman is not without difficulty. To a certain extent, maintenance work has many of the ingredients needed to provide Herzberg's idea of worker satisfaction and motivation. It has autonomy, craftsman status, pride in the quality of the work, varied and interesting job content etc.—all of this reinforced with the movement in many companies to self empowerment. These work ingredients also emphasise how important trade force motivation is to maintenance management. Maintenance workers are among the few on the shop floor who still have considerable autonomy as regards their day-to-day actions. Thus it is difficult to check how well a preventive maintenance inspection routine has been carried out. It is also difficult to judge how well a repair has been carried out and, in some cases, whether the spares used have been the best from the company's point of view. Maintenance workers know that if they carry out inferior work the consequences of their actions take time to surface and often will be difficult to attribute to them.

In the case of the maintenance tradesman, the most realistic indicators of his level of motivation are :-a) the extent to which he knows what is wanted from him, and b) the level of his effort to provide it with a minimum of external control.

When trying to influence, understand or audit motivation within a maintenance department the following aspects must be taken into consideration:

- The shop floor's industrial relations history, its present position and its deficiencies.
- The factors that influence job content and job environment.
- The external social and political environment and its influence (because this governs the extent to which internal change is possible).
- The trade force's identification with the maintenance objectives (the most important factor in their motivation).

Morale: defined in the Oxford Dictionary as—'the mental state of an individual with regard to confidence and discipline.' Finding a definition in a management text proved difficult; the best was 'an individual's satisfaction and confidence with membership of an organisation'.(Hicks, F.E., and Rosenzweig, J.E., 1985) The same work pointed out that production is not a function of morale and therefore morale is not a very meaningful concept in management thought! My own auditing experience, however, has convinced me that poor morale, whether of individuals or trade groups, most certainly affects both the quantity and the quality of maintenance work.

Morale within the maintenance department may be defined as: an individual's perception, which may be positive or negative, of his future work prospects, and which may be induced by the success or failure of the company employing him and the ability (leadership, organisational and engineering performance) of its management.

As this implies, the negative factors affecting morale may be those that appear to threaten the individual's or group's future work security, e.g.,

- a company's poor economic performance;
- poor company organisation and systems, inducing problems with product quality, for example;
- recent workforce redundancies and the threat of more to come.

Resentment: defined in the dictionary as 'a strong feeling of ill will against the perpetrator of a wrong or affront.' The following example, drawn from one of my own auditing exercises, explains this in the context of the maintenance tradesman: 'Hell hath no fury like a fitter scorned.' A small power station, supplying a chemical plant, consisted of a number of large diesel generators. It was maintained by five fitters, one of them a leading hand. One of the younger (very bright) fitters had been promised promotion to supervisor level but this had not materialised—and did not 'look like doing so. He had become resentful and obstructive (the bad apple) and this feeling had spread to two of the other, younger, fitters. They were using every IR trick in the book (bad backs, badarms etc.) to avoid work and undermine the rest of the trade group. Weak management had allowed this situation to fester for about a year. The condition of the diesel units was deteriorating and this was likely to have a considerable effect on the overall operation of the plant.

Protectionism: can be defined in the maintenance context as 'resistance to sharing knowledge and information;' it can be affected by other human factors such as insecurity and low morale.

A typical example is provided by the technician who has built up considerable knowledge over many years about specific equipment but is reluctant to document this knowledge or convey it to other employees.

Parochialism: the dictionary definition is 'local narrowness of view and attitude.' many organizations have encountered this. It can occur, for example, within the manufacturing units of a decentralized organization.

A power station, which I was auditing, provided electricity to an alumina refinery. It was set up as a semi-autonomous manufacturing unit. There was considerable narrowness of view exhibited by its manager. He was an ex-marine engineer and ran the station as if it were a ship. On each visit I felt that the gangway had to be lowered before I could go on board. The attitude of the staff was that they were set apart and different. The refinery senior management seemed to know little about the way the power station was being operated and maintained. I established that two out of the three generating units were needed at all times for full refinery operation. However they were all in poor condition and in need of major overhaul. It was difficult to take a unit out because of the unreliability of the two left in service. Before leaving the site I insisted that the refinery general manager discuss this problem with the power station manager.

Organizational design creates the boundaries between departments and it is management's job to minimize parochialism and its effects. It generates other human factor problems, e.g., polarization.

Other human factors: which I do not audit directly but are covered indirectly during the one-to-one interviews which make up the bulk of the audit programme. Some of these are as follows:

Jealousy: of those on shifts exhibited by those on days, or vice versa.

Attitude: a positive trade force attitude towards data collection.

Envy: of those promoted.

Resistance to change: to the introduction of new working methods, team working, or computer systems.

Pride: in an individual's trade and in the quality of work carried out.

Prejudice: a pre-conceived, biased, opinion or position on a subject, e.g., the maintenance view of production "they break it, we mend it;" the production view of maintenance "They don't understand our objectives we give them a line for four hours they keep it for twelve."

2.11.2.3Group Behavioral Characteristics

Culture: has been defined as "the collective mental programming of people in an environment" (Hicks, F.E., and Rosenzweig, J.E., 1985) It is not a characteristic of individuals, it encompasses a number of people who are conditioned by the same education and life experience. Thus, when auditing it is important to recognize and understand the culture of the country. For example, that of Saudi Arabia is very different from that of Australia and this can influence the organization—most of the tradesmen in Saudi Arabia are expatriates.

A company can have its own culture.

A food processing plant which I audited was part of a USA multi-national that had been operating in Australia and the UK for many years. It had developed a company culture that I had observed in both of these countries, one that put a very high premium on success, hard work, fairness, tight scheduling and efficiency of thought—it could almost be "felt." Johnson (1968)

Further down the organization a culture can also develop within departments.

A petrochemical complex used a functional organizational structure in which the maintenance department was large and carried out all the maintenance, even the major shutdowns. Over many years the culture within this department had developed a mix of norms, standards and behavior weighted much more towards maintaining equipment for engineering excellence rather than achieving organizational efficiency. The department was considerably over-manned.

Esprit de corps: defined as "a spirit of regard for the company or group honors and interest, and for those of each member belonging to it."Clearly a concept of military origin and one which I observed in the major Japanese companies during visits to that country in the late 1960s. During my auditing of some fifty companies world-wide I have not come across any other companies, departments or manufacturing units which have had an esprit of the kind defined above. It has been suggested that one of the reasons for breaking down large functional organizations into semi-autonomous manufacturing units is to generate esprit de corps in each of those units (although I have not, as yet, observed this actually occurring to any extent).(Johnson, A.v.,1968)

Horizontal polarization: has been defined as "having opposite views and attitudes across departmental boundaries."Conflict builds up across the boundaries of the main departments—viz. Production, Maintenance, Engineering, Stores—and to a lesser extent across the sub-departments, e.g., Electrical Maintenance and Mechanical Maintenance.

The Production–Maintenance conflict has been well documented. The maintenance view is that 'Production built it and we mend it.' In other words 'theymal-operate and never let us have the equipment for proper maintenance.' The production view is that 'we make the money and maintenance do not understand our objectives—we give them the plant for a shift and they keep it for a day.'

I was consulting on the maintenance of a paper-making machine. A production supervisor pointed out that a machine came down every three to four weeks for the replacement of a wire belt (a task of eight hours duration which the production operators carried out). When asked if this provided a window for maintenance work the supervisor replied 'we don't tell them when the machine is coming down otherwise we lose it for more than eight hours—we keep this information to ourselves.'

I often observe polarization across the Maintenance-Stores interface when these functions are the responsibility of different departments. From the company point of view the spares holding objective would be to minimize the sum of the holding and stockout costs. Maintenance try to keep the inventory high, Stores Management try to keep it low—hence conflict and polarization.

The organization can develop the 'us and them' syndrome across the horizontal boundaries. 'We' are mechanical maintenance and everybody else (including electrical maintenance)is a 'them'—the larger the number of 'themes' the greater the polarization. Once severe polarization develops, information might flow but communication and understanding is lost. Vertical Polarization: considerable antipathy can build up between the various levels of an organization, especially if these are many and the organization is large.

The greatest degree of antipathy is often between the shop floor and the higher levels of management—a conflict in objectives and attitudes. Not only does such conflict affect communication but it also negatively affects some of the more important individual behavioral characteristics, e.g., goodwill and motivation.

The other important vertical maintenance interface is that which lies between the maintenance supervisors and their professional engineering managers. Supervisors mostly come from the trades, do not have professional engineering qualifications and only rarely move into the upper reaches of management. They are, however, unique in that they constitute the only level of management that looks downwards to non-management personnel. In addition, they tend to be less mobile within the organization than professional engineers and are the main source of trade and plant-oriented knowledge. More recently, their direct man management role has been threatened by the introduction of self-empowered teams. In many industries their role has changed to that of technical advisor, planner and team leader. They have become uncertain and defensive. This has led to conflict and polarization.

The 'us and them' syndrome (of both the vertical and horizontal varieties)is most evident in large organizations which are highly functionalized at the top, with long chains of command down to operators and maintainers. Severe polarization in such organizations can cause complete lack of communication, organizational contraction and eventual failure. (Johnson, A.v., 1968)

3- RESEARCH METHODOLOGY

In this chapter the researcher discusses what approaches and strategies have been chosen in order to be able to answer the purpose. A clarification of how the data was collected is included as well as who interviewed and what method was used. Finally the study presents how the data was analyzed and the issue of reliability and validity are brought up.

3.1 Selection of Appropriate Research Methodology

The methodology which is used in this research is a descriptive, analytical and operational along with a question based case study of Derba MIDROIC cement. With the exercise of question based study, the maintenance management of DMC is analyzed and recommendations forwarded.

Case study research focuses on obtaining practical knowledge through research which emphasizes the analysis of limited details within individual cases. Case study aids in examining real-life and real-work condition situations. "Robert K. Yin defines the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real- life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin, R.K., 1984).

Due to emergence of new entrants with bigger capacities in the cement sector of the national market, maintenance management function is one of the key success factors to be used as a tool for competitive and a rapidly growing national markets, so the reason for the company understudy to properly manage its maintenance management function. An overview of the company is provided, and its weakness and strengths are analyzed.

In a nut shell, the research

- Theoretically approaches the problem statement.
- Analyzes and understands the company's maintenance management function.
- States DMC's weakness and strengths.
- Examines whether the objectives of the maintenance management function are aligned with strategies of the company.

Although the case study method has been chosen as the approach of the research, it certainly faces some major issues that most case studies do. Case study method has some advantages as having detailed research analysis of certain issue within an organization, possible proposals of solutions for the observed and analyzed issues as well as the benefits of the simplicity in sample and data collections, more specifically in relation to the organization. In the mean time, the case study of DMC is facing few disadvantages not having straight forward answers to most of the questions, interviewees also have provide either wrong information, wrong answers, or simply made minimal attention to the research questions, in which case the result of the study may be completely wrong. Since the conclusions of this study are based on analysis of the collected data and the responses collected through questionnaires and interviews in this particular case, and since it will not be easy to collect similar information and responses from similar scenario in another organization, therefore the accuracy of these findings may not be verified and the study may not be replicated. Amid all the above considerations, the researcher hopes to establish the best possible results through this method.

3.2Research Philosophy

Research philosophy leads to develop knowledge during the research process. (Saunders, M., et al, 2003).Since the intention of the researcher is to evaluate and examine the current situation of the company, the best way of getting a more reliable result is the case using an interpretive approach. (Ann, C.L., 1998) explains that "positivist work seeks to identify qualitative data with proportions that can then be tested or identified in other cases, while interpretive work seeks to combine those data in to systems of belief whose manifestations are specific to a case" This approach helps to understand the peoples experiences, and view points through exploratory their terminology and symbols. (Saunders, M., et al, 2003)

A qualitative approach is used because the researcher is seeking to grab the reality from the interviewee's point of view who is dealing with the issues in the top company position. According to (Bryman, A., and Bell, E., 2003) "The qualitative method is the process where researcher and respondents interact."

When writing a research paper it is important to decide up on which research approach to use. The design of the research project is determined by the use of deductive approach, inductive approach or a combination of the two. in the deductive approach you develop a theory and hypothesis as well as designing a research strategy to test the hypothesis , if you instead decide to choose an inductive approach you collect data and develop theory as a result of your data analysis (Saunders, M., et al, 2003), it can often be advantageous to do so.

The researcher choose the inductive approach since there was no pre defined theory that was trying to proof that. Instead researcher collected data and made a conclusion based on that. The model is then tested through the conduction of in depth interviews in order to see the connection and relation between two perspectives. This followed by qualitative data analysis of the empirical findings to be able to draw conclusions on whether the suggestions will function or even be applied to the chosen company of our case study.

3.3 Research Method

Research can be divided in to two sections; qualitative and quantitative research. Qualitative research can be defined as where the researcher develops concepts, insights, and understanding from patterns in the data. In qualitative studies researchers follow a flexible research design as for example with vague formulated research questions (Taylor & Bogdan, 1984). Rist (1977) clarifies the concept by stating that the qualitative methodology is more than a set of data gathering techniques; it is a way of approaching the empirical world (cited in Taylor & Bogdan, 1984)

One of the major reasons for doing qualitative research is to become more experienced with the phenomenon you are interested in. Many qualitative researchers believe that the best way to understand any phenomenon is to view it in its context (Trochim, 2006). This perception is closely related why the researcher chose a qualitative research study by doing a case study. This choice is in accordance with Sekran (2003) who states that case studies usually provide qualitative data rather than quantitative data for analysis and interpretation. In order to fulfill our purpose the researcher needed to make in-depth interviews with those whom he thought represent the different levels of management. The case study is based on inductive approach and qualitative data collection, the researcher intended to interpret interviewees' word to see the success of the maintenance management function of the organization. Researcher has used a qualitative method through the open ended and close ended questionnaire .See appendix A, for the questions used in the study.

3.4 Source of Data

There is no single way to conduct a case study and a combination of methods (e.g., unstructured interviewing, direct observation) can be used (Trochim, 2006). The researcher have chosen to conduct semi structured in-depth interviews to collect primary data i.e. data collected for the first time, specifically for the purpose at hand (Saunders, M., et al, 2003). In-depth interviews include both individual interviews (e.g., one-on-one) as well as "group" interviews.

The researcher has mainly focused on one-on-one face- to-face interviews. The purpose of the interview is to explore the ideas of the interviewees about the phenomenon of interest (Trochim, 2006). The major advantages of face-to-face interviews allow for researcher to adapt questions, make clarifications and repeat or rephrase questions if necessary. However their might be geographical limitations, nationally or internationally, and a large amount of resources demanding activities could be travel costs and training of the researcher to minimize biases (sekaran, 2003).

Additional interview methods, telephone and e-mail were also used. The quality of data obtained by telephone can be comparable to data collected through personal interviews. Zikmund (2003) even argues that respondents may be more willing to provide detailed and reliable information on personal topics over the telephone over personal interviews. Another advantage of the telephone interview method technique is that a large number of different people can be reached in a relatively short period of time. On the other hand, the respondents could without warning or explanations hang up the phone and terminate the interview. There is also a greater risk of non response problems with telephone interviews (Sekaran, 2003).

Sending respondents questions via e-mail share some of the advantages of telephone interviews such as: geographically spread at a relatively low cost. It is also convenient for the respondent to fill them out whenever he/she has time. The interviewer's absence can be seen as a disadvantage to this approach, not being able to state follow-up questions, make clarifications and no social interaction. However, the interviewer's absence can also induce the respondents to reveal sensitive or socially undesirable information (Zikmund, 2000)

As secondary data sources, data that already have been collected for another purpose (Saunders ,M., et al. 2003), we have used written documents from the company, such as strategy documents, policy, procedures, business plans, schedules, and reports from different sections of the organizations, manufacturers manuals, hand books, and journals articles from the organization and broachers from related organizations in the cement industry, to gain basic understanding of the organization and the industry.

Additional external information was collected from websites. In the theoretical framework, back ground section and in the problem discussion we have used documentary secondary data, which can include written documents such as books, journals, magazine articles, and news papers (Saunders, M., et al, 2003). The researcher has explored and collected this data mainly from books and articles related to search terms including maintenance management, maintenance hand book, previous research works by different researchers in related areas.

3.5 Data Gathering Tools

The purpose of this study is to do a case study analysis. Naturally the means to fulfill this purpose is to conduct a case study. Usually case studies refer to research that investigate a few cases, often just one, being an intensive and depth study of a specific organization, individual, institution or a whole national society (Gomm, Hammersley& Foster, 2000)

Case study research is used in order to give an understanding of a complex issue or object and can extend experience or add strength to what is already known through previous research.

Case studies emphasize contextual analysis of a limited number of events or conditions and their relationship (Soy, 1977). Researcher Robert K. Yin (1984) defines the case study research as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; and in which multiple source of evidence are used" (cited in Soy, 1977). A case study can give you several indications to what factors might be operating in the current situation and how the problem might be solved. Picking the right case for the study, understand and correctly translating the research findings are critical for successful problem solving (Sekaran, 2003).

The purpose of the case method is to obtain information from one or few situations that are similar to the researchers problem situation (Zikmund, 2000), in this study the best the best suited data are collected from the usage of literature, questionnaire, and examination of existing information resource from the industry.

Unstructured questionnaires and observation were used in order to access the data respective to organizations maintenance management function, analysis of weakness and strengths of the organization as perceived by the interviewed. The case study strategy becomes a natural choice for us since our purpose, more or less, builds on conducting a case study analysis.

Finally a collected data is reported in an exploratory way that would transform most complicated issues in to readable and digestible material by average readers or stakeholders. While this report often refers to detailed observation and analysis, it also portrays the major conclusion and presents an overall image of the study.

3.6 Research Sample

Sampling Techniques provide a range of methods that enable to reduce the amount of data needed to collect by considering only data from a sub-group rather than all possible cases or elements. Non-probability sampling is done without chance selection procedures. Purposive sampling or Judgmental sampling is a non-probability sampling method that basically allows the researcher to select cases that seems to be best suited to answer the research questions. The form of sampling is often used when working with small samples, especially in a case study when a researcher is looking for cases that are particularly informative.

The non-probability judgmental sampling will be used for this study. Each case should have some characteristics to give relevant and accurate data. The first sampling criterion is to have information about the formulation maintenance objectives, strategies, and implementation of them. The second criterion is about the interviewee; s/he'd been better from bottom middle and top executives of the company because the maintenance strategy formulation and following the implementation usually are the responsibility of top managers of the company, planning organizing scheduling coordinating and controlling are the maintenance managers responsibility, and execution of the maintenance tasks is the responsibility of operation level managers and operators.

In order to have different ideas and perspectives, interviewees were chosen from all levels of management and operators, total number of interviewees were thirty. And the Questionnaires are designed in such a way that opinions of researcher the interviewees can only be applicable to every particular section of the study which interviewees have been interviewed for. In other words, since this is a case study based research, solutions may be only applicable to the problem in question and may not be relevant to all situations.

3.7Reliability and Validity of Data

When it comes to the discussion concerning the external validity, or as it is also referred to as generalizability, or one's research design, we are aware of that this is not applicable on a case study (Saunders, M., et al, 2003). The purpose wit this thesis is not to generalize the results in any way. Validity also refers to the extent to which the researcher gains access to the participants knowledge and experience; qualitative interviews usually show a high level of validity (Saunders, M., et al, 2003).

The reliability of a measure indicates the extent to which it is without biases such as interviewee or interviewer biases. The stability and consistency of the thesis is also measured in level of reliability (sekaran,2003). Interviewer biases are characterized by the comments, ton or non verbal behavior of the interviewer during the interview situation (Saunders, M., et al, 2003).According to (Bryman, A., and Bell, E., 2003) reliability refers to extent to which a concept reach the result, and validity is ensured by having access to best information and data. Therefore the researcher acknowledges that the study is reliable and the same result woud come up if it was done by another researcher and the collected data through interviews and questionnaire ensured the validity and reliability of data is full field.

4- DATA PRESENTATION, DISCUSSION, AND FINDINGS

To conduct the survey, questionnaire was delivered to DMC including, document review, and field visits. The purpose of data collection is to obtain information about maintenance management in DMC factory. The questionnaire was designed with unstructured questions in which the respondent could tell about his experience and observation. Pretest a questionnaire was done with maintenance manager in DMC and academics draft tests. All their comments were considered in a revised version.

Due care is taken while designing the Questionnaire. Keeping the questionnaire as short as possible, use simple and clearly worded questions, start with demographic questions to help respondents get started comfortably. Using open-ended questions cautiously and Avoiding using leading-questions.

Statistical techniques were used to analyze collected data in order obtain answers to questions. All questions of the survey are open ended questionnaires .Achieving accurate data and understanding the maintenance processes and parameters that are being measured. The data analyses help the best practices which lead to superior performance and identify the poor practices that need to be improved. The best practices are practices that enable a company to be become a leader in its marketplace.

Benchmarking process in maintenance used the following steps. Conduct internal analysis, identify areas for improvement, develop questionnaire, perform site visits, compile results, develop and implement improvements and do it again. The goal of internal analysis is to identify weaknesses and areas that need improvement in company. Goals of maintenance organization are maximum production at lowest cost, highest quality, and within the optimum safety standard.

4.1 **General information about the Interviewees**

A total of 30questionnaires were distributed, all were filled and returned to the researcher. The researcher has taken due care in selecting the respondents so that all key informants from different levels of management are represented.

Table 4.1 respondents and their composition

No	Level of management	Number of respondents
1	Top management	6
2	Middle management	6
3	Operation level management	8
4	Operators and Mechanics	10

Appropriate analysis for the data collection; lead to obtain a general view or different maintenance parameters at DM Cement Production Company.

Table 4.2 responses of the interviewees, how they perceive the maintenance function, to add value for the organization.

Criteria for evaluation	Highly perceived	Fairly perceived	Medium perceived	Low perceived	Don't know	Total
The necessity of the maintenance function for the organizations objectives	60 %	30 %	10 %	-		100 %
Maintenance helps the organization to provide high quality low cost products for customers	40 %	20 %	20 %		10 %	100 %
Maintenance lowers down time maximizes availability of plant and equipment and hence increases productivity	40 %	-	-	40 %	20 %	100 %
Maintenance reduces expenditure and maximizes life time profitability	70 %	10 %	20 %	-	-	100 %

Source field survey : august 2013

Table 4.2 above reveals,

- the maintaining function is perceived as value added by all interviewee whatever the level of perception varies and every interviewee proudly words out the vision set for maintenance by saying "To maintain assets to meet customers' needs cost effectively; to continuously improve skills and process to optimize asset life, using best fit methods and technologies; to work safely and be environmentally responsible". Even though most of the managers talk about the maintenance strategies, however the only person who has told the researcher, how the strategy is formulated is the production operations manager who was the chief representative of DMC from the inception to commissioning of the project, but all members of the management whom the researcher interviewed has ascertained they participate in the quarterly evaluation of the strategy. Maintenance is included in production and process scheduling meetings.

Table 4.3 below and written documents reveal,

- Even though the difference in the level of education among the interviewees affected the reply to the questionnaire, more than 80 % have said the company uses the preventive maintenance program which includes lubrication checklists and inspection checklist. Some diagnostic procedures such as heat, oil and vibration analysis are used. There are specific personnel to execute preventive maintenance on each crew. The preventive maintenance results are checked quarterly for material cost and time. Corrective action work orders are generate from the inspection plane. The inspections tasks include safety information, material requirements, time and number of labors. The frequency of inspection task interval in all equipment depends on fixed interval chart and equipment run time. More than 90% from important equipment's follow up by preventive maintenance. More than 90% of PM program are completed within one week of the required date. More than 90% of an equipment items are checked by PM program.

- Predictive maintenance program is also used, includes vibration analysis, thermograph, sonic techniques' and oil analysis for all equipments for criticality. Predictive maintenance program utilizes sonic techniques only for criticality. The computer maintenance management system (CMMS) is tied into predicative maintenance system. The data of predictive maintenance is used to build work orders for preventive corrective maintenance and to improve maintenance performance. And it assigns specific technicians to work in the predictive maintenance program. Weekly work schedule includes tasks for predictive maintenance.

Table 4.3 responses of the interviewees, how they perceive objectives and strategies of the organization.

Criteria for evaluation	Highly perceived	Fairly perceived	Medium perceived	Low perceived	Don't know	Total
Ensuring the highest possible health safety and environment, highest possible production, and highest possible cost effectiveness	60 %	10 %		10 %-	20%	100 %
Enhancing over all equipment effectiveness	40 %	20 %		20 %	20%	100 %
Extending the useful life of an asset	40 %	40%	-	20 %	20 %	100 %
To ensure operational readiness,safety of personnel, and to achieve all the above with minimum cost	70 %	10 %	20 %	-	-	100 %
The company uses preventive maintenance	60%	30%	10%	-	-	100 %
The company uses predictive maintenance	10%	10%	10%	20%	50%	100 %

Source field survey: august 2013

Table 4.4below and written documents reveal,

- All maintenance operation utilizes CMMS. Maintenance activity are planned and scheduled through a CMMS. Maintenance inventory and purchasing uses CMMS. The production scheduling system, the payroll, timekeeping system, financial accounting system and CMMS are integrated. More than 80% of maintenance personnel are using the system for their job functions with a high level of performance. CMMS data is used to make cost effective decisions and verify the progressive return of investment. The whole organization focused on asset utilization and optimization.

- Maintenance automation showed that the percentage of all maintenance operation utilizes CMMS is more than 80%. More than 75% of maintenance activity are planned and scheduled through a CMMS. More than 75% of the maintenance Inventory and purchasing include. More than 90% of maintenance personnel are using the system for their job functions with a high level of performance. Maintenance planning and scheduling showing that, more than 90% of overall equipment availability is calculated on key assets, processes and facilities. More than 90% of operational decisions are made taking into account equipment reliability and availability. From 75% to 89% of non-emergency work orders are completed within four weeks of initial request. From 75% to 89% of time is an actual measure compared to the estimate for monitoring planning effectiveness. Maintenance organization showing that, maintenance organization chart is current and complete. The job descriptions are available for all maintenance positions including supervisors. Maintenance personnel are tied to pay incentive plan based on output. Maintenance inventory and purchasing show that from 80% to 95% of time are stored materials.

Table 4.4responses of the interviewees, how they perceive computerized maintenance management system of the organization.

Criteria for evaluation	**Highly perceive**	**Fairly perceive**	**Medium perceive**	**Low perceive**	**Don't know**	**Total**
Maintenance activity are planned and scheduled through a CMMS.	60 %	10 %		10 %-	20%	100 %
Maintenance inventory and purchasing uses CMMS	40 %	40 %		-	20%	100 %
The production scheduling system	40 %	40%	-		20 %	100 %
the payroll, timekeeping system, financial accounting system and CMMS are integrated	40%	40%	20 %	-	-	100 %

Source field survey: august 2013

Table 4.5responses of the interviewees, how they perceive maintenance management planning of the organization.

Criteria for evaluation	Highly perceive	Fairly perceive	Medium perceive	Low perceive	Don't know	Total
Have clearly stated maintenance policy by which maintenance planning is guided.	70 %	30%				100 %
Maintenance activity are planned, scheduled, and controlled to conform to the original plan	40 %	40 %		20%		100 %
Feedback is used to provide direction for future maintenance plan	40 %	40%	-	20%		100 %
Maintenance and production work hand in hand in planning and scheduling times	80%	10%	10 %	-	-	100 %

Source field survey: august 2013

Table 4.5above and written documents reveal,

- The maintenance data collection system is utilized by management. Operators are used for first line maintenance functions in some areas. Overall equipment availability is calculated on key assets, processes and facilities. Operational decisions are made taking into account equipment reliability and availability. More than 75% from the right soft skills training classes (such as leadership) have been conducted for maintenance supervisors. Less than 59% from the right technical training have been conducted for appropriate personnel. The Financial effect of equipment availability is not observed by everyone.
- From 75% to 89% of non- emergency work orders are completed within four weeks of initial request. Work order planning specific job instructions or job plan. From 10% to 20% of planned work orders experiencing delays due to poor or in complete plans. The maintenance planner is responsible for planning the work orders. Maintenance job schedules are issued biweekly. Maintenance and production/facilities are scheduled for daily meeting. The backlog of maintenance work is available by date needed. After of the job is completed, the actual time, material, downtime and other information is reported

by the supervisor of the group. From 75% to 89% of time are actual measure compared to that estimated for monitoring planning effectiveness. Both of planner and supervisor are report to same maintenance manager. Routine supervision and periodic inspection of equipment are handled by the operating personal, whereas overhauls and major repairs are done by the maintenance department.

Table 4.6 response of the interviewees, how they perceive maintenance store management system of the organization.

Criteria for evaluation	**Highly perceive**	**Fairly perceive**	**Medium perceive**	**Low perceive**	**Don't know**	**Total**
Inventory purposes, types, and basic inventory related decisions	60 %	10 %		10 %-	20%	100 %
Inventory control policies	40 %	40 %		-	20%	100 %

Source field survey: august 2013

Table 4.6above and visit made by researcher to the areas covered by inventory reveals, From 80% to 95% of time are materials in stores when required by maintenance organization. From 75% to 80% of items in inventory appears in maintenance stores catalog. A person from maintenance staff control stocked as maintenance inventory items. The maintenance store catalog is produced by alphabetic and numeric listing. More than 95% of aisle and bin location is specified for the stores. More than 95% of maintenance stores items are issued to a work order or account number upon leaving the store. Maximum and minimum levels for the maintenance stores items are specified for more than 95% of the inventory. More than 80% of critical maintenance material is stock in the warehouse ore in a location readily accessible when the material is required. More than 95% from maintenance stores inventory level are updated daily upon receipt of materials. More than 90% from items are checked for at least one issue every year.

More than 95% of aisle and bin location is specified for the stores. More than 95% of maintenance stores items are issued to a work order or account number upon leaving the store. Maximum and minimum levels for the maintenance stores items are specified for more than 95% of the inventory. More than 95% from maintenance stores inventory level are updated daily upon receipt of materials. More than 90% from items are checked for at least one issue every year. Operations and facilities involvement showed that from 75% to 89% from operations personnel generate work order requests.

Table 4.7response of the interviewees, how they perceive the maintenance organization of DMC.

Criteria for evaluation	**Highly perceive**	**Fairly perceive**	**Medium perceive**	**Low perceive**	**Don't know**	**Total**
The place of maintenance function in the overall organization structure.	60 %	20 %		10 %-	10%	100 %
Maintenance organization structure	40 %	40 %		10%	100%	100 %
Maintenance organization HRD policies	40 %	40%	-		20 %	100 %

Source field survey: august 2013

Table 4.6above and visit made by researcher reveals. Maintenance organization chart is current and complete. The job descriptions are available for all maintenance positions including supervisors. Maintenance organizational assignments responsibility fully documented. Maintenance shop and work area from the point of layout and locations is perfect. Maintenance tools and equipment from the point of quality and quantity is perfect. The maintenance personnel are tied to pay incentive plan based on output. From 75% to 89% of the time are the maintenance reports distributed on timely basis to the appropriate personnel. From 75% to 89% of time are the reports distributed within one day of the end of the time period specified in the report. Equipment reports include the equipment downtime in order of highest to lowest total hours weekly or monthly. Preventive maintenance report include the PM hours verses total maintenance hours per item expressed as a percentage. The personnel reports include the time showing hours worked by employee divided by work order. The planning reports include the backlog report showing the total hours ready to schedule versus the craft capacity per week.

Here is a strong support visible management support for continuous improvement effort. The organization strong support continuous improvement effort in maintenance. The spirit of cooperation between plant management and labor is excellent. On continuous improvement the company focused on management, maintenance, stores and purchasing. Management support training designed to enhance employee skills. The continuous improvement efforts tied to reliability engineering. From 60% to 89%, competitive forces affect improvement efforts. The site's document management system is electronic and interfaced with other systems. Document control procedures and associate work process exist for the system.

The maintenance personnel are in process of being trained to use the document management process. The document management system has detailed indexing and search capabilities that make document simple and easy to find the quality and level of document version control is excellent. A document management system is used by managers and supervisors only. About 75% of maintenance man-hours are reported to work order and 75% of maintenance materials are charged against a work order number when issued. About 75% of total jobs performed by maintenance are covered by work order.. About 25% of the work orders are opened under a priority that would be identified as emergency or urgent and 75% of work orders are available for historical data analysis. About 50% of work orders are checked by a qualified individual for work quality and completeness. From 75% to 89% from operations personnel generate work order requests. From 60% to 74% from facilities generate work order requests.

Operations work order priority is set for maintenance daily in a joint operation and maintenance meeting. Facility work order priority is set for maintenance daily in a joint facility and maintenance meeting. Operators are involved in the upkeep and asset performance. Operators are trained and certified to perform equipment

Inspections. From 40% to 59% of time operators follow up and sign off on completed work order.

Downtime duration is consistently tracked for all assets. For key areas only the downtime cost is clearly identified. For all assets downtime causes are accurately and consistently tracked. Maintenance costs are clearly and accurately tracked for key assets only. All other maintenance costs such as energy, quality, and contractors are available. Total operation costs are compared when making decisions for all cost factors. Efficiency loss cost is available and accurate for 75% to 89% of time. Personnel are not dedicated to financial costs analysis.

The majority is offered and attends supervisory training, which is offered on an infrequent or irregular basis. All maintenance planer receive one on the job training for at least one month. Maintenance planers received scheduling practices training program. General quality and productivity training includes upper management and line supervision. Formal job experience for maintenance craft training is required before hire. Formal maintenance craft employees training is provided in irregular intervals for some employee only. All training program instructors is all on the job training only. Training program instructor is done only supervisors. Quality and skill level of maintenance work force group is good and need to some improvement. Quality and skill level of supervisory group still need some improvement.

Data of predictive maintenance is used to build work orders for preventive and corrective maintenance and to improve the maintenance performance.

Table 4.7 Response of the interviewees, how they perceive DMC's maintenance management to wards safety and environment.

Criteria for evaluation	**Highly perceive**	**Fairly perceive**	**Medium perceive**	**Low perceive**	**Don't know**	**Total**
Regular inspection of plant and equipment.	60 %	40 %				100 %
Police for conducting health, safety and environmental commitments.	40 %	40 %		20%		100 %
Participation of workers in any health and safety training.	40 %	40%	-	20%		100 %
Documentation and investigation of accidents	40%	40%	20 %	-	-	100 %

Source field survey: august 2013

Table 47above and visit made by researcher reveals. At the early stage of the project implementation, DMC had commissioned HOLTEC, to carry out the following environmental studies:

i. Environmental and Social Impact Assessment (ESIA)

ii. Resettlement Action plan (RAP) and

iii. Environmental and social Management Plan (ESMP).

The studies have been submitted to the Environmental Protection Authority (EPA) of the Federal Democratic Republic of Ethiopia for review and endorsement. EPA has issued DMC the Environmental Permit. The environment studies are in compliance with the Environment and Social Standards of the lending banks and accordingly IFC has posted the ESIA in its web site www.ifc@org In line with Environmental and Social Management Plan, DMC has fulfiled its obligation. It has building up its environmental and safety management capacity and has, as part of ESMP carried out, the following:

- Made payment amounting over Birr 42 million to compensate farmers displaced due to the project.

- Built over 20 kms of open access road from junction point (near Derab town) to mine site, which is open for public use.

- Built a health center to the local community, at the cost of Birr 3.2 million.

- Set up a revolving fund amounting Birr 2.5 million. The fund is used for income generation activities by persons affected due to the project. The Suluta Wereda Office of the Oromiya Regional state in collaboration with Chancho branch of the Oromiya Credit and saving Association will manage the fund.

- Bought and donated to project affected persons dewatering system for crop farming at a cost Birr 100,000.

- Efforts are underway to cover 8 ha of land with tree seedlings as buffer zone between the factory and neighboring colony.

- In the coming few years DMC will plant 1,000,000 tree seedling in the surrounding areas.

- Created and will create awareness on preventable diseases such as HIV /AIDS and malaria.

- Donated over 200,000 ETB to Farmers Skill Training Center at Chancho Town, Oromiya Regional state.

DMC has installed bag filters and electrostatic precipitator (ESP) to mitigate the emission of dust particulates to the European standard. Dust collectors are working in different areas of the production line to absorb the fine dust particles. It will also leverage innovative strategies to cut emissions and waste across the factory. It will continue participating in Carbon Market for emissions trading to supplement its clean investment aspiration. Through the partnership it has with an emission trading company six projects have been originated among which two of them are in the advanced stage of international accreditation.

The potential annual emissions reduction anticipated is estimated at 1,000,000tCO2e. The total emissions reduction from all activities may amount 3,000,000 tCO2e. The water, which is coming out of the plant, is neutralized not to be harmful when it is discharged. The limit of the gases coming out of the system from the fossil fuel and limestone is controlled during the mix design and operation of the kiln. DMC has installed a water treatment plant with a reverse osmosis (RO) membrane type. The treated water would be used for human consumption, cooling of machinery, laboratory and general purposes. Compressed dry air is supplied to the packing plant, instrumentation and control systems, bag filters and other pneumatic organs.

5-CONCLUSIONS AND RECOMENDATIONS

The areas those need to improvement such as training programs in maintenance show that the majority is offered and attended supervisory training on an irregular basis. All instructors depend on the job training only. It is not a mix of classroom and lab exercises. Quality and skill level of maintenance work force group is good but need to some improvement. Training is done by supervisors while it must be by an outside contract expert staff. Quality and productivity training includes upper management and line supervision only without workers. Formal job experience for maintenance craft training is required before hire but it is not tied to a pay and progression programs. Operations and facilities involvement show that operators are trained and certified to perform equipment inspections. It must content lubrication, minor maintenance task and assist in maintenance repair task.

Maintenance reporting shows that equipment reports include the equipment downtime in order of highest to lowest total hours weekly or monthly. It is preferable to include also maintenance cost for equipment in order of highest to lower weekly or monthly. The purchasing reports include price performance, showing the quoted and actual prices, it preferably to include also buyer or purchasing agent performance report. Non stock report showing all direct items not carried in stock for a specified period. Administrative maintenance reports including monthly maintenance costs versus monthly maintenance budget with a year to date total. It is preferable to include also the comparison of labor and material costs as a percentage of total maintenance cost and total costs of outside contractor usage. The finances of maintenance showing that, downtime costs is clearly identified for key area only, it preferably to include all area. Maintenance costs are clearly and accurately tracked for key assets only, it preferably to include all assets. A dedicated individual or team is not assigned to analyze financial costs. Maintenance documents show that maintenance personnel are in process of being trained to use document management.

Although the application is conducted to one company, this work can be extended to more companies

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APPENDIX

A. Questionnaire Scope and Confidentiality

Dear participant,

Your help is needed for a maintenance management function evaluation in your organization for the fulfillment Master's Degree in Business Administration of this researcher.

The following questionnaire is prepared to study maintenance management function at DMC. Please answer the questionnaire as best you can with as complete details as possible. If a question is not relevant, just tell me N/A (Not Applicable). If the practice suggested in a question is not done in your company say 'Not done at present'. If you do not have answers to a question, or you do not understand the question, do not concern yourself. You can ask me for elaboration and we can take time and discuss.

Thank you for your assistance

1. Describe how you view the maintenance function in your organization to meet the objectives of the organization.

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2. Are there a maintenance vision, objective, and strategy for the operation? If yes, describe one. And explain how the maintenance strategy is arrived at.

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3.Who is involved in 1) determining the maintenance objectives and strategy and 2) reviewing its effectiveness?

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4.Describe the level of involvement provided by the Operations and Maintenance groups during the detailed designing of maintenance objective and strategy?

5.What is the maintenance objectives set by the organization?

6. How many maintenance strategies do you employ? Do you rely on predictive technologies, condition based principles, preventive maintenance, when do you use each one and why?

7. Does your organization use a computerized system for maintenance activities (CMMS)?

8. Describe how maintenance work is planned and scheduled and controlled. Who does the planning?

9. What maintenance activities are performed by the plant and equipment operators?

10. Describe how equipment parts are purchased, issued and replenished.

11. What proportion of maintenance materials used annually are kept and provided direct from suppliers instead of keeping them in your own store?
<20%, 20%-30%,30%-40%,40%-50%, 50%-60%,60%-70%, >70%

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12. How often in a year are stocked materials, or parts delivered to-site for a job, not available or not found when required? Describe a recent example.

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13. Where is the place of maintenance function on the overall organization structure of DMC, does this position makes the function to achieve organization strategies and goals?

____

14. Does maintenance organization structure show the various parts of maintenance organization including defining responsibilities and roles of units and individuals?

____

15. Does the maintenance organization is well equipped with resources i.e. people material and technology

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16. Is there any Career Path, Opportunities, and Incentives for Maintenance for Developing the contribution of maintenance work towards increase in production ?

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17. What level of training is given to a maintenance person and plant and equipment operators provided and by whom? Describe how operators are trained and tested.

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18. Does your organization have a policy for conducting health, safety and environmental commitment?

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19. Have workers of your organization participated in any health and safety training?

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20. Have your organization ever been convicted of any Work Health and Safety WHS or environmental offences in the past five years, or are there any proceedings underway or pending?

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21. Have your organization ever received any WHS or environmental inspector notices in the past? (I.e. improvement or prohibition notices.)

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22. Does your organization record and investigate incidents? /accidents?

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