DEVELOPMENT OF AN EFFECTIVE MAINTENANCE CONCEPT FOR ENHANCEMENT OF COMPETITIVE ADVANTAGE: A CASE STUDY OF EAST AFRICAN PORTLAND CEMENT COMPANY

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DECLARATION

I declare that this thesis is my original work and has never been presented to this institution or to any other institution for examination or for any other purpose.

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CERTIFICATION

I certify that the above-mentioned student carried out the work detailed in this report under my supervision.

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DEDICATION

This dissertation is dedicated to my wife Irene and children, Leroy and Biden for their support, inspiration and love.

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ABSTRACT

Due to global competition, many organizations are coming up with ways of sharpening their competitive edge. This has been achieved through cost leadership, differentiation of goods and services and lastly, through quick response to the needs of the customers. To respond to these market requirements, manufacturers are using high-tech equipment. They are also adopting new material control methods such as Just-In-Time philosophy. Set-up costs are also being minimized to a minimum. All these factors are shifting the focus to maintenance since unreliability and availability of manufacturing equipment will result in high maintenance costs, low profitability, low production and an increase in customer dissatisfaction. At East African Portland Cement Company, the raw mill plant has led to the above problems which in turn lead to negative feedbacks from the customers and as a result, there is need to develop a maintenance concept that will respond to the challenges mentioned above. Consequently, in this research an analysis of various the maintenance concepts were investigated.

Overall Equipment Effectiveness of the Raw mill plant was evaluated and analyzed. Downtime analysis was also done to establish the major causes of low plant availability. From the research, it can be deduced that East African Portland Cement Company requires a harmonized maintenance concept regarding inspection, regular maintenance, repair and overhaul, scheduled and preventive maintenance of the main components as well as environmental auditing during operation to ensure that the plant is fully operational and efficient. Total Productive Maintenance concept therefore has been identified as key to the meeting of organizational objectives of the company. A customized framework of Total productive maintenance deployment at East African Portland Cement Company has been developed with six step transformation steps used in embedding high performance culture. It is expected that an implementation of this project will lead to a reduction in failures, time to perform a repair and an elongation in the mean time between failures hence higher plant availability and reliability for improved productivity.

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DEFINITION OF TERMS

AVAILABILITY: The ratio of the total time a functional unit is capable of being used during a given interval to the length of the interval. Availability takes into account Down Time Loss, which includes any Events that stop planned production for an appreciable length of time (usually several minutes – long enough to log as a trackable event).

COTS: commercial-off-the-shelf is used on Technology related items that are sold and used the way they are without any element of customization and tailoring to meet the specific objectives of a given organization.

MTBS: Mean-Time-Between-Stoppages are the ratio between operated hours and the number of downtime incidents. Usually, it is a direct measure of reliability

OEE: Overall equipment effectiveness (OEE) is a hierarchy of metrics that evaluates the overall performance of equipment. This OEE includes three parameters. They are availability, performance and quality.

PERFORMANCE: The Performance portion of the OEE Metric represents the speed at which the Work Center runs as a percentage of its designed speed. The Performance Metric is a pure measurement of speed that is designed to exclude the effects of Quality and Availability

RELIABILITY: This is the probability that a given system fulfills its designed function without failure.

QUALITY: Quality takes into account Quality Loss, which accounts for produced pieces that do not meet quality standards, including pieces that require rework.

LIST OF ABBREVIATIONS/ACRONYMS

SHE	Safety Health and Environment
COTS	Commercial-Off-The-Shelf
EAPCC	East African Portland Cement Company
ISO	International Organization for Standardization
KPI	Key Performance Indicators
MTBS	Mean-Time-Between-Stoppages
OEE	Overall Equipment Effectiveness
QMS	Quality Management Systems
TPM	Total Productive Maintenance
FET	Focused Equipment Team

1 Contents

1. CHAPTER ONE: INTRODUCTION OF THE STUDY

1.1. Background of study

The ever-increasing competition in today's industry has compelled delivery commitments and operating costs to be an important consideration when securing customers. Costs associated with equipment breakdowns, degraded equipment and unavailability of spares and data, lead to downtime of the plant, production losses and wasteful activities. In order to meet increased market expectations and reduce operating costs, industries have focused efforts on reducing unplanned downtime. The maintenance department is being increasingly viewed as an indispensable function of the production system.

Maintenance has been largely considered as a support function which is none productive since it does not generate cash directly. However for industry to produce goods of the right quality and quantity for the customers and be able to deliver them at the right time, its plant or equipment must operate efficiently and accurately. For every manufacturing company the objective is to produce goods at a profit and this is only achieved by using an effective maintenance system that helps maximize availability by minimizing machine downtime due to unwarranted stoppages. Without an effective and economically viable maintenance system, equipment reliability suffers, and the plant pays the price with poor availability and increased downtime. All these mentioned poor key performance indicators (KPIs) could be as a result of poor machine condition and sometimes low employee morale. Low plant availability and overtime costs will negatively affect an industry's operational efficiency. Plant Engineers must therefore design an effective maintenance system for the plant and its equipment.

Frequent machine breakdowns, low plant availability and increased overtime are a great threat to a manufacturing plant as they increase operating costs of an industry. EAPCC has initiated a maintenance improvement plan to minimize equipment downtime and increase equipment availability. The plant's current maintenance program is reactive and plant machinery suffers from a high level of downtime.

1.2 Company background

The East African Portland Cement Company (EAPCC) has played a central role in the building of the nation. One of EAPCC products, Blue Triangle Cement, has been used as flagship for the

Vision 2030 projects such as the Thika Superhighway. In addition to that, the Blue Triangle Cement product is literally building Kenya in areas such as housing, education, health, tourism, transport and communication, as well as hydro-electric power projects such as the Chemususu Dam.

EAPCC has strategic plans to grow the business beyond the Kenyan borders, while enhancing their market share locally. EAPCC has made the commitment to its clients to deliver quality and value. EAPCC is growing rapidly and rapid growth puts a heavy load on existing processes. There is need to identify opportunities to make improvements in the areas of Maintenance, Safety, Quality and Productivity by examining EAPCC's systems, and the mindsets and capabilities of its workforce.

For more than 70 years, East African Portland Cement Company (EAPCC) has been one of Kenya's leading cement manufacturer and today is the second largest producer of cement in the country. The East African Portland Cement Company pioneered the manufacture of cement in East Africa in 1933 and it had a factory in industrial area with an initial production capacity of 600,000 tonnes of cement per annum. EAPCC Limited began as a trading company importing Cement for early construction work in East Africa and it was formed by Blue Circle industries of United Kingdom. Initially, the company had one small cement mill and used to import clinker From India to grind at the factory. This has since changed and the company now has several cement mills and it produces clinker. EAPCC is now located in Athi River, about 30 Kilometers from Nairobi. Construction of the Athi River factory begun in 1956 and it was completed in 1958. This new factory had a higher production capacity and this has kept increasing over the years. Since then the EAPCC has greatly expanded its production capacity and at present produces over 1.3 million tonnes of cement per annum.

Its vision is to be the Regional Leader in the Provision of Cement, Innovative Cement Products and Solutions while the mission is to provide Cement for Infrastructural solutions to the satisfaction of its stakeholders.

The main processes undertaken by the company include, mining, raw material preparation, clinker manufacturing, cement milling, cement packing, loading and dispatch among other customer care service functions. Cement products produced include cement building blocks, kerbstones and channels, slabs and fencing posts. EAPCC's core values include; integrity, team work and innovativeness. The company does geological surveys to establish the quality and quantity of available raw materials and from the data obtained, quarry mining plans are drawn and updated as mining progresses.

The first step in cement manufacture is the production of raw materials. The company has got three quarries namely kankur, bisel and kabini. Kunkur quarry is best known for production of kunkur that is of two qualities, high and low depending on total carbonate present by weight. After removal of the topsoil, limestone is blasted using explosives where as Kunkur is ripped using bulldozers. The material is then transported to the primary crusher for size reduction and is loaded onto trucks for transportation to the factory for further processing. The limestone is extracted from the earth's crust by the process of blasting. After blasting limestone boulders are transported to the crushing macgine and crushed to the required size. The crushed limestone is then transported through belt conveyer to the stacker-reclaimer section.

At the factory, crushed limestone and Kunkur are stacked into blending piles. The stacker-reclaimer is used for pre blending of crushed limestone. Reclaimer picks up the required quality of crushed limestone form the stock pile and feeds into the raw mill hopper through belt conveyor. Material is drawn from the piles by a carefully controlled system that cuts across the stockpile, ensuring blending takes place and a uniform raw material quality is achieved. Gypsum, iron ore and pozzolana are also stored in piles.

Laboratory quality control ensures that quality raw material standards are maintained. Crushed raw materials are conveyed to the raw mill bins, from where they are extracted in controlled quantities to the vertical roller mill. There are different hoppers for the storing of crushed limestone, iron ore and Alumina ore. The stored raw materials from the hopper are proportioned and fed to roller press and subsequently to mill for fine grinding of required fineness. The output of the raw mill grinding is stored in raw mill silo.

The mill grinds the raw material to a fine powder and dries it using hot exhaust gases from the kiln, a method that conserves energy and reduces production costs.

Cement manufacturing is a complicated, resource-intensive process in which limestone and other materials are crushed and milled, preheated to separate glass from solids, and then heated in a kiln at temperatures up to 1,450 degrees Centigrade.

The coal is fed into the coal crusher from where the crushed coal is stored in the coal stocker and reclaimer. This coal (used as fuel for burning) is crushed, pulverized in vertical roller mill (ball mill and fed into the kiln through burner pipe.

Large quantities of fuel are needed for preheating raw materials and keeping kiln temperatures high enough to produce the calcium silicate and aluminates that represent modern cement mixtures. Clinker manufacture is the most critical stage in the process. This takes place in the inclined 54 meter long rotary kiln. The raw meal is fed into the kiln pre-heater cyclones and cascades, sequentially through the four stage cyclones into the kiln, reaching a temperature of 1450°C where clinkering or conversion of the material to cement clinker occurs.

From the raw mill silo the material is extracted and conveyed to the pre-heater section. The powdered homogenized raw mill from the silo is fed to the kiln passes through pre-heaters where raw mill gets partly calcined and converted into clinker at a temperature of about 1450 degree centigrade in the sintering zone of the kiln. The material is calcined and heated in pre-heater and calcined by utilizing kiln waste gases and additional coal finding. This partially calcined material enters into the kiln where the remaining calcinations and clinkerization takes place in the kiln and clinker is discharged into the grate cooler.

The hot clinker is cooled in the grate cooler where cold atmospheric air is drawn in. The EAPCC kiln has a capacity to produce 1680 tonnes of clinker per day. The clinker from the kiln is cooled in the cooler section and is transported to the clinker stockpile by deep pan conveyor to the clinker stock pile. The clinker is transported to cement mill hopper though Deep Bucket Conveyor.

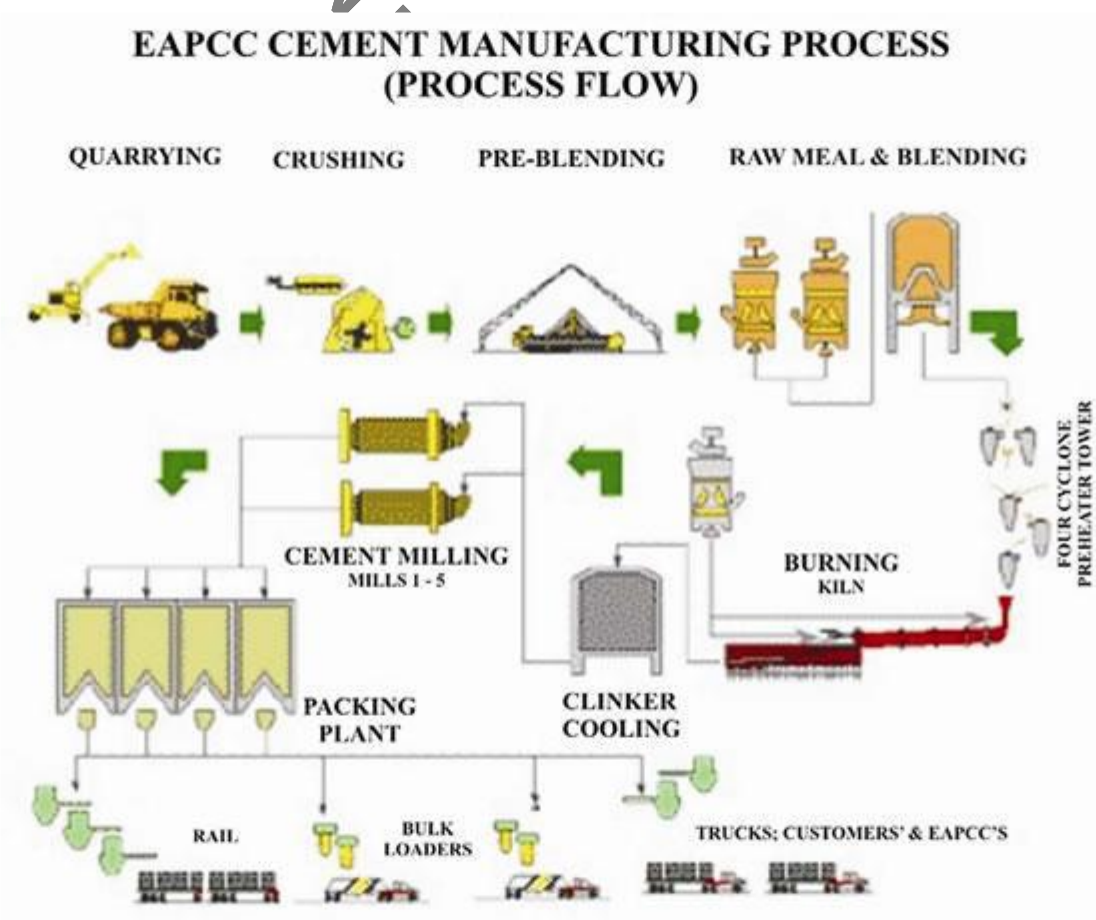
Clinker with small quantities of gypsum to control setting time, is ground in cement mills that use steel balls. Pozzolana is added to produce pozzolanic cement if desired. The clinker and gypsum are stored in the respective hopper. The clinker and gypsum are proportioned and fed to roller press subsequently to ball mill for fine grinding of required fineness.

Using compressed air, the finely ground cement is conveyed into cement storage silos, cement milling capacity is 3,000 tonnes per day. EAPCC lays strong emphasis on its quality control system to ensure the customers get quality products. Chemical and physical tests are carried out at every stage of the process to ensure proper performance of the cement. Samples collected at different stages of the process are tested and analyzed and any necessary adjustments carried out accordingly.

The cement from the mill is transported to storage silo and from there the cement is conveyed to packing plant and is packed in 50kgs bags by rotary packing machine and then directly loaded into trucks/rail rakes and transported to different locations in the country. Cement is packed into bags of 50 kg by a rotary packer then it's loaded to trucks hence transported to customers, for heavy consumers it's packed in bulk handler truck.

As shown in figure 1-1 below, the production of cement at EAPCC involves the following set of plants; the crusher, the raw mill, the kiln, the coal mill, the cement mills and packing plant.

Figure 1-1: Process flow of the cement manufacturing process at EAPCC (EAPCC, 2013)



1.3 Problem Environment

EAPCC was ISO 9001:2008 certified in June 2009, this was a corporate strategy to improve its operation efficiency and acquire a sustainable upward market share control by enhancing customer satisfaction both internal and external and improve plant efficiency and corporate image. Certification of the company was one agenda more to prestige than for accomplishment of baseline strategies/objectives. By 2008 the company market share was 40% but by January 2012 it was ranging between 17% and 20%. The 2009/2010 financial year was characterized with a loss of three hundred million shillings as a result of operation inefficiencies.

Plant availability and reliability have come out as very important aspects in meeting the organizational goals of EAPCC. This is because an improvement in any of the above factors will lead to increase in production, reduction in costs and consequently an increase in the profitability of the organization.

Pilot studies on the Overall Equipment Effectiveness (OEE), mean time between stoppages (MTBS), reliability and capacity utilization on various lines were carried out for a period of seven months. The results are summarized as shown table 1-1 below:

Table 1-1: Plant key performance indicators (August 2012 – February 2013)

Plant	OEE (%)	No of stops	MTBS (hours)	Total stop (hours)	Availability (%)	Reliability (%)	Capacity utilization (%)
Kiln	72.5	12	43.5	204.21	95.9	72.9	99.3
Raw mill	56.9	159	3.11	317.8	87	59	94
coal mill	60	54	9.69	228.7	97	67	72
cement mill 5	87.21	52	11	188	88	88	98
07PK01	51.7	23	26	129	92	96	44
07PK11	55	24	25	134	90	95	47

One thing that can be noted from table 1-1 above is that the raw mill machine is greatly affected by not only many number of stoppages, but also the least mean time between stoppages. As indicated in table 1-1 above, the raw mill had an average of 159 stoppages between August 2012 and February 2013 and 3.11 hours MTBS.

1.4 Problem statement

East African Portland Cement Company has been operating at suboptimal efficiency and effectiveness of the plant due to high rate of unplanned equipment failure and frequent stoppages. In addition to this problem, the faulty machine may be out of production for a long period of time due to shortage of spare parts. Currently the company practices breakdown maintenance, preventive maintenance and predictive maintenance with no clear cut maintenance concept for improved industrial competitiveness. The maintenance tasks are executed by maintenance personnel and the operators are not involved in carrying out basic maintenance such as cleaning, lubrication, adjustments and tightening.

The existing maintenance system in the Company is based on ineffective integration of all functions and processes with no cross-functional teams, which results into, high maintenance cost, low plant availability and reliability, frequent failure of machineries, low profit, low production and low satisfaction of workers.

Through the measure of Overall Equipment Effectiveness (OEE), the hidden problems would be exposed, analyzed and resultant countermeasures could be executed by exploring effective maintenance concept.

1.5 Research Objectives

1.5.1 Main Objective

The overall objective of this research is to investigate how to improve Overall Equipment Effectiveness of the raw mill plant through implementation of an effective maintenance concept

1.5.2 Research Objectives

i. To analyze and determine the Overall Equipment Effectiveness of the raw mill plant
ii. To establish the causes of low availability of the raw mill plant.
iii. To develop an effective customized maintenance concept along with its implementation model.

1.6 Justification

The prevailing economic environment requires companies to reduce their maintenance costs and keep pace with trends in external macro environment. Product quality, quantity and delivery targets can only be realized through an efficient maintenance management system that will yield the following benefits: improved plant availability, reliability and plant equipment utilization and hence productivity; improved operating performance (output and quality) and maintenance cost effectiveness.

The raw mill plant has the highest average number of stoppages per month (159), as compared to the other lines. Consequently, the average mean time between stops (MTBS) for raw mill is also the lowest (3.11 hours) compared with the other lines. This has led to an increase in downtime and a reduction in availability and reliability. This has resulted into low clinker and cement production thereby not meeting customer demand.

1.7 Significance of the Study

By developing an effective maintenance concept that binds together all the maintenance policies, maintenance actions and strategies for maintenance, the number of stoppages in the raw mill will greatly be reduced by increasing the mean time between stoppages. This will increase the monthly production for the company as a result of improved raw mill availability and reliability. With increased production, the revenue will be greatly increased resulting into increased profitability.

1.8 Scope of the Study

The field of maintenance engineering and management is very wide. Due to time and financial constraints, covering an integrative maintenance policy for the whole processing plant at EAPCC is not possible. Thus, this research will only focus on the raw mill because of its short MTBS and more stoppages per month. Furthermore, implementing all the concepts within one period may not be economically viable. The study focuses on improving the OEE of the raw mill plant, a case study of the East African Portland Cement Company in Kenya

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Due to increase in competition, companies are coming up with different methods to remain competitive. One of the common methods adopted by many organizations is minimizing the manufacturing costs. Another strategic thinking in improving the quality, and minimizing the cost, is through maximizing the efficiency of the production process. One of the efficient methods of reducing costs is by efficient planning and controlling of the maintenance strategies and concepts. According to Gilberts, maintenance constitutes of a set of all activities aimed at keeping an item in, or restoring it to, the physical state considered necessary for the fulfillment of its designed functions (Gilbert, 1985).

The traditional way of managing maintenance was fixing a broken item only after a failure has occurred. This practice is ineffective with disadvantages such as unscheduled downtime of the machinery, possibility of secondary damage, safety risks, production loss or delay and the need of standby machinery.

Equipment has to be reliable, efficient and cost effective. Maintenance plays a key role in the long-term profitability of an organization because it influences quality, cost and delivery. The role of maintenance has increased because high productivity and profitability can be achieved by proper maintenance concepts. As Tsang states, market forces are demanding more emphasis on customization, quick delivery and superb quality, and the success of these factors lies in maintenance strategies and concepts being adopted (Tsang, 1973). This pressure means that maintenance must be treated as a critical factor in determining the productivity and profitability of an organization.

2.2 The role of maintenance in a business strategy

As discussed in the previous section, today's international market conditions are influenced by cost, quality and response time. Thus, these three factors represent the business strategy of many companies.

To respond to these market requirements, manufacturers are using high-tech equipments. They are also adopting new material control methods such as JIT philosophy. Set-up costs are also being minimized to a minimum. All these factors are shifting the focus to maintenance since unavailability will result in serious problems (Hayes, 1988).

From being seen as a necessary-evil to now a profit contributor, maintenance can be used to sharpen the competitive edge of an organization. Breakdowns are costly and effective maintenance policies should aim at keeping them to the minimal. According to Walker, for each dollar ($ 1.00) spent on proper maintenance, the company saves the equivalent of twenty dollars ($ 20.00) of extra profit without extra needed sales when the cost of a breakdown is considered (Walker, 1994). This is because breakdowns are very expensive. According to Pintelon, the cost of maintenance is more than just labor and material used to return the failed equipment back to its normal working conditions (Pintelon, 2006). A recent survey showed that the actual cost of a breakdown is four to fifteen times that of normal maintenance costs. This is because breakdowns cause production to stop.

According to a study done by Mobley, between 15-40% of the total cost of finished goods can be attributed to maintenance activities in the factory (Mobley, 1989). Thus, the integration of maintenance actions into production is an efficient way of enhancing a company's capability of handling production losses and quality defects. However, Mobley did not put into consideration the "tip of the iceberg" as discussed by Pintelon (2006).

The role of maintenance in the long run should be seen as an essential function in the business strategy of an organization. Proper maintenance concept will increase the reliability and availability of equipment. This will lead to providing the market with higher quality goods, with low cost and less lead-times.

2.3 Maintenance strategies

2.3.1 Breakdown maintenance

In breakdown maintenance, equipment is repaired only when it breaks down. There are two main problems associated with this maintenance practice: deciding on the size of the maintenance team and loss of production time (Ayranci, 1997). When the size of the maintenance team is large, repair time is minimized. However, this condition increases the costs associated with maintenance. On the other hand, a reduction in the size of the maintenance crew may lead to an increase in the mean-time to repair (MTTR). This may lead to increase in missed opportunity costs and penalty costs. Mobley identifies three main causes of breakdowns (Mobley, 1989) as:

i. People

   Most breakdowns are caused by people who have been poorly trained, poorly supervised, or have forgotten to do some simple maintenance tasks such as lubrication of key parts. Machines do not break themselves; it takes people to do it.

ii. Deterioration

   There are two types of deterioration; natural that occurs over a period of time when the machine is well maintained and used properly and accelerated deterioration that generally occurs when equipment is not properly maintained. Accelerated deterioration occurs when an operator is not doing the job of simple daily maintenance or has not been instructed to do it properly, which shortens the life of the machinery.

iii. Machines

   As long as each part is of a machine is well taken care of there should be no problems. Minor problems on the machines on most occasions are overlooked. Larger machine problems are caused by minor problems that have gone bad.

However, Mobley (1989) fails to address the relationships that exist between the three factors. For example, the maintenance practices of the people affects the deterioration rate of the machine.

2.3.2 Preventive maintenance

This is a planned maintenance policy developed in order to minimize the number of breakdowns. It is carried out at pre-specified time intervals. Both UBM and TBM are practiced at EAPCC. UBM is determined by equipment use while TBM is determined by calendar time.

2.3.3 Predictive maintenance

Predictive maintenance (PdM) techniques help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach offers cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted (Kennedy, 2006).

The main value of predicted maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures. The key is "the right information in the right time and to the right people". By knowing which equipment needs maintenance, maintenance work can be better planned (spare parts, people etc.) and what would have been "unplanned stops" are transformed to shorter and fewer "planned stops", thus increasing plant availability. Other advantages include increased equipment lifetime, increased plant safety, fewer accidents with negative impact on environment, and optimized spare parts handling (Mobley, 1989).

To evaluate equipment condition, predictive maintenance utilizes nondestructive testing technologies such as infrared, acoustic (partial discharge and airborne ultrasonic), corona detection, vibration analysis, sound level measurements, oil analysis, and other specific online tests (Mobley, 1989).

2.4 Maintenance concepts

Pintelon defines a maintenance concept as a set of maintenance actions and policies of various types. The most common types of maintenance policies are Quick and Dirty decision charts (Q&D), Total Productive Maintenance (TPM), Life Cycle Costing (LCC), Reliability-Centered Maintenance (RCM) and customized mainteinance concepts (Pintelon, 2006).

2.4.1 Quick & Dirty decision charts (Q&D)

A quick and dirty decision chart is a decision diagram which tries to answer a series of questions. Some of the questions addressed by the Q&D charts are (Pintelon, 2006):

i. Failure behavior of equipment
ii. Replacement behavior of equipment
iii. Cost structure of maintenance operations
iv. The role of maintenance in the business context of an organization

As the name suggests, a Q&D approach allows for a quick selection of the maintenance policy to be applied in a given situation. Several Q&D charts are available as Commercial-Off-The-Shelf (COTS). However, many organizations prefer coming up with customized charts. This is done by defining specific questions affecting the organization, deleting some of the questions in the original concept, editing the decision procedures, and adding and deleting maintenance policies (Pintelon, 2006).

Pintelon (2006) argues that even if this concept is quick and easy to use, it is rarely used in the real world. This is because the basic YES/NO format often times limits the capabilities and possibilities of more concrete solutions to a given set of problems. Furthermore, the questions are very subjective (Pintelon, 2006).

On the other hand, the organizations which use this concept attribute it to the fact that it can be accomplished even with limited resources. Studies have shown that it has a potential of reducing UBM by up to 63% (Pintelon, 2006).

Pintelon (2006) developed a three step approach towards implementing this maintenance concept (Pintelon, 2006):

i. First of all, a method of identifying the criticality of equipment is developed. The methodology applied is usually developing a weighted-linear additive formula. Some of the aspects put into consideration while developing the weighted-linear additive formula are safety considerations, ergonomics, costs, loss of production, environmental considerations, hidden failures, age of the system, system complexity and reliability considerations.
ii. This is followed by the identification of the critical equipment or system is identified.
iii. The last step is usually a decision basing on the problem in question.

2.4.2 Life-cycle costing

LCC is a maintenance concept that tries to calculate the total ownership of an asset from the time of its inception to its disposal. This concept is also referred to as "cradle to grave" or "womb to tomb" costs. Blanchard warns that purchase cost of equipment is only a tip of the iceberg (Blanchard, 2003). Some of the costs that should be put into consideration are the purchase costs, installation costs, maintenance costs, replacement costs, salvage value, operational, financial charges such as loans among others. However, Blanchard did not provide a framework for analysis of the hidden costs. Some indirect costs are difficult to quantify and compute. For example, the costs associated with safety in maintenance may be very difficult to quantify.

The LCC approach consists of the following steps (Blanchard, 2003):

- Defining the decision problem and identifying all the possible alternatives

- Choosing the most effective analytical model for the problem defined. Payback period and net-present value (NPV) analysis are the most commonly used analytical models
- Acquisition of cost and performance data
- Compute the LCC and rank the alternatives
- Choose the alternative that best fulfills the problem basing on cost and performance

LCC is especially useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings. Therefore, the purpose of an LCC concept is to estimate the overall costs of alternatives and to select the design that ensures the facility will provide the lowest overall cost of ownership consistent with its quality and function. Time value of money plays an important role in the LCC concept. Therefore discounted analysis should be taken into consideration by including deflation and inflation (Riggs 1982).

Other than NPV, cost-benefit, payback and sensitivity analyses should be conducted to determine the economics of a machine across its life cycle. Several design and analysis tools have become handy in the analysis of complex projects. The use of computer programs can considerably reduce the time and effort spent on formulating the LCC, performing the computations, and documenting the study. Listed below are several LCC-related software programs:

i. Building Life-Cycle Cost (BLCC) Program—Economic analysis tool developed by the National Institute of Standards and Technology for the U.S. Department of Energy Federal Energy Management Program (FEMP).
ii. ECONPACK for Windows—an economic analysis tool developed by the U.S. Army Corps of Engineers in support of DOD funding requests.
iii. Success Estimator Estimating and Cost Management System—Cost estimating tool available from U.S. Cost

Although not mentioned anywhere, but the main set-back with computer programs is that they give a generalized solution. Most computer programs fail to provide specific solutions that are meant for that specific problem. Therefore, it is the role of the simulations and modeling engineers in the maintenance department to tailor and customize the LCC concept for their given organization.

2.4.3 Reliability by design: reliability-centered maintenance (RCM)

2.4.3.1 Introduction

RCM is a valuable maintenance concept that takes into account the system functionality and not just the system. Its focus is on reliability; safety and environmental integrity are considered more important than costs (Pintelon, 2006).

RCM provides a structured framework for analyzing the potential failures of a facility with focus on preserving the system functions instead of the facility itself (Moubray, 1997). It comprises of all processes that ensures that an asset continues to perform its designed functions.

It incorporates methods such as Failure Mode Effects and Criticality Analysis (FMECA). The main objectives of Reliability Centered Maintenance are:

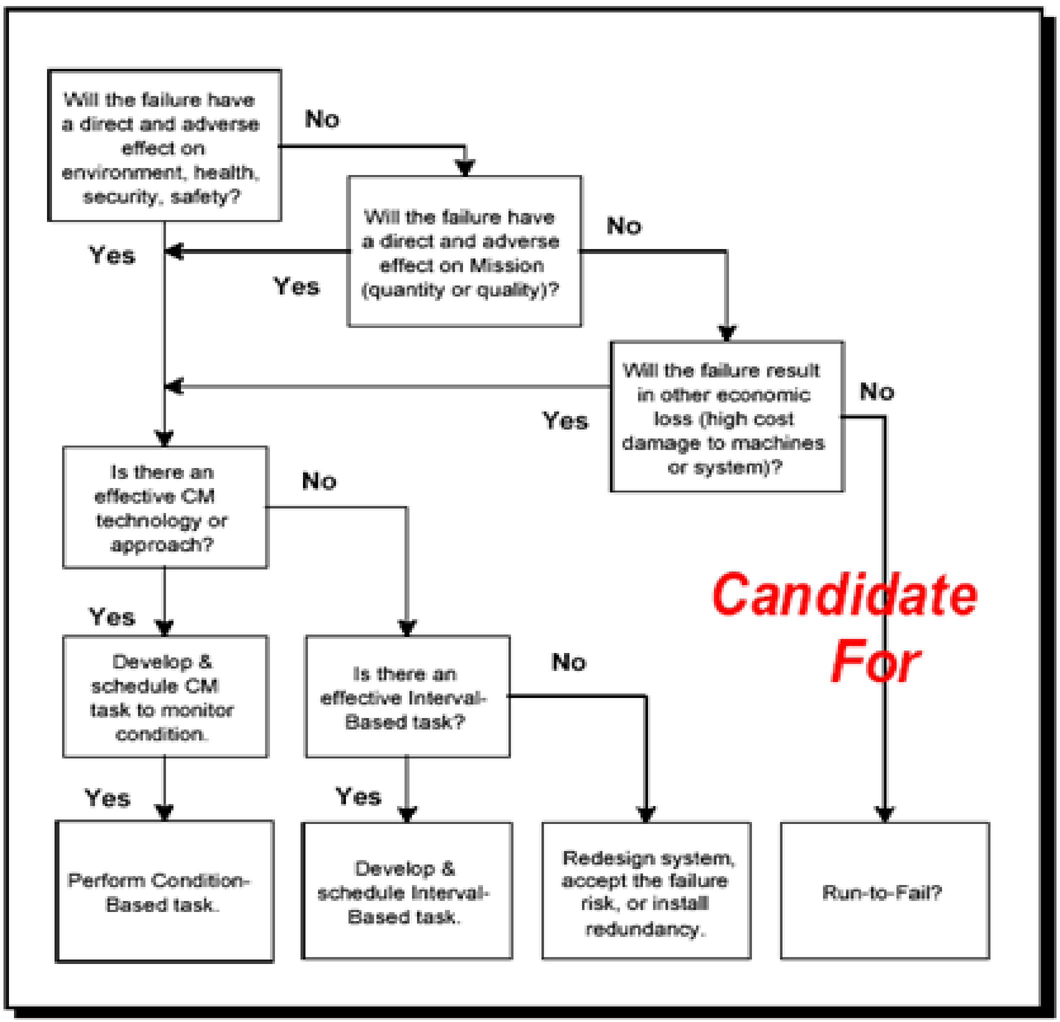
- Minimizing Costs and/or downtime
- Meeting Safety and Environmental Goals
- Meeting Operational Goals

The Reliability Centered Maintenance process begins with FMECA that identifies the importance of plant failure modes in a systematic and structured way. The process then requires the examination of each critical failure mode or cause to determine the optimum maintenance policy to reduce the severity or occurrence of each failure. This starts with the 7 questions below, worked through in the order that they are listed:

i. What is the item supposed to do and its associated performance standards?
ii. In what ways can it fail to provide the required functions?
iii. What are the events that cause each failure?
iv. What happens when each failure occurs?
v. In what way does each failure matter?
vi. What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
vii. What must be done if a suitable preventive task cannot be found?

The chosen reliability and maintenance strategy must take into account cost, safety, environmental and operational consequences. The effects of redundancy, spares costs, maintenance labor costs, equipment ageing and repair times must also be considered. Figure 2.1 below shows a classic logic tree for RCM.

Figure 2-1: The classic logic tree



2.4.3.2 Types of RCM

Two types of RCM exist: classical and streamlined RCM. Classical or rigorous RCM provides the most knowledge and data concerning system functions, failure modes, and maintenance actions addressing functional failures of any of the RCM approaches. Rigorous RCM analysis is the method first proposed and documented by Nowlan and Heap and later modified by John Moubray, Anthony M. Smith, and others. Historically, it has been based primarily on the FMEA with little, if any, analysis of historical performance data. In addition, rigorous RCM analysis is extremely labor intensive and often postpones the implementation of obvious condition monitoring tasks.

On the other hand, Abbreviated/Intuitive/Streamlined RCM approach identifies and implements the obvious, usually condition-based, tasks with minimal analysis. In addition, it culls or eliminates low value maintenance tasks based on historical data and Maintenance and Operations (M&O) personnel input. The intent is to minimize the initial analysis time in order to realize early-wins that help offset the cost of the FMEA and condition monitoring capabilities development.

2.4.4 Total Productive Maintenance (TPM)

2.4.4.1 General overview of TPM

According to Nakajima, TPM is a plant improvement methodology, which enables continuous and rapid improvement of the manufacturing process by employee involvement, employee empowerment and closed-loop measurement of results (Nakajima, 1989).It requires company-wide participation and support by everyone ranging from the top executive to the shop floor personnel.

Total Productive Maintenance (TPM) is a maintenance program with a newly defined concept for maintaining plants and equipment. It brings maintenance into focus as a necessary and vitally important part of any business or manufacturing operation. It is no longer regarded as a non-profit activity. Downtime for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process (Nakajima, 1989).

The roles and objectives of TPM have been identified by different scholars. According to Takahashi, the goal of TPM is to hold emergency and unscheduled maintenance to a minimum. This will in turn increase production and at the same time increase employee morale and job satisfaction (Takahashi, 1990).

According to Suzuki, the main purpose of TPM is to ensure that all equipment required for production is operating at almost 100% efficiency at all times. Through short daily inspections, cleaning, lubricating, and making minor adjustments, minor problems can be detected and corrected before they become a major problem that can shut down a production line (Suzuki, 1994).

In TPM, the machine operator is responsible for both the operation and the maintenance. The implementation of TPM can generate considerable cost savings through increased productivity. Nakajima noted that the cost reduction generated by TPM increases with the increase in automation (Nakajima, 1989). Nakajima states that TPM is very effective that it reduces breakdowns to almost zero (Nakajima, 1989). It also maximizes the worker productivity.

2.4.4.2 The 8 pillars of TPM

TPM is often described as a temple with different pillars. The first generation of TPM (TPM1), which was focused on equipment, consisted of 5 pillars. Later on, more pillars were added on as TPM moved to TPM2 (manufacturing process focus) and TPM3 (Company focus).The 8 pillars of TPM as identified by Suzuki are autonomous maintenance, planned maintenance system, training and education, early equipment management, focused improvement, TPM in office and support departments, quality maintenance, and safety and environmental management (Suzuki, 1994). Figure 2-2 below shows the eight pillars of TPM as suggested by Suzuki.

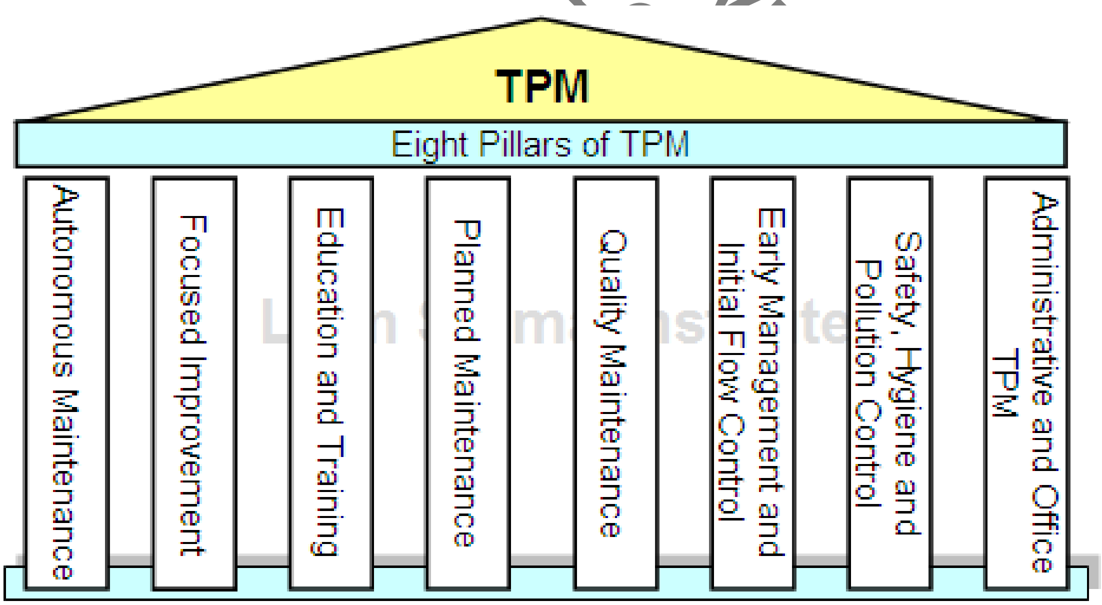


Figure 2-2: The eight pillars of TPM

i. Focused improvement**(Kobetshu Kaizen)**

This is an improvement activity performed by cross-functional departments. These activities are aimed at minimizing losses and hence maximizing the Overall Equipment Efficiency (OEE). This will eventually lead to minimization of costs.

ii. Autonomous maintenance (**JishuHozen)**

Teams of machine operators, also called TPM circles, perform routine maintenance and participate in improvement activities that halt accelerated deterioration of machines, control contamination and maintain optimal conditions. Autonomous maintenance is more than merely cleaning equipment; in doing so, it focuses on identifying and treating the problems. The operators:

- Must consider how autonomous maintenance can be performed most effectively on different types of machines
- Investigate the relative importance of different equipment parts and determine their optimal maintenance strategies, policies and actions
- Prioritize maintenance tasks
- Allocate the responsibilities accordingly between production and maintenance

iii. Planned maintenance system

Scheduled maintenance embraces three types of maintenance: breakdown, preventing and predictive maintenance. Planned maintenance activities emphasize monitoring mean time between failures (MTBF), and using the analysis to specify the intervals in annual, monthly and weekly maintenance calendars. Planned maintenance aims at maximizing reliability and availability while minimizing the costs associated with maintenance.

iv. Training and education

Implementing TPM is a continuous learning process. As a result, operators and maintenance personnel must receive regular maintenance training to upgrade their knowledge and skills about the ever-advancing technology.

v. Early management

This activity includes both early equipment management and early product management. The purpose of early management is to quickly produce products economically, and to make equipment that is easy to use and maintain. Early equipment management concerns equipment users, engineering companies, and equipment manufacturers. It addresses the following:

- Equipment investment planning
- Process design
- Equipment design, fabrication and construction
- Test operation
- Start-up management

vi. TPM in office and support department

Administration and support departments play a very important role in backing up production departments. While production and maintenance are engaged on TPM activities on the shop floor, administrative functions should aim at creating "information factories" and apply process analysis to streamline information flow. The quality and timeliness of information from the administrative department have a huge impact on the quality and timeliness of goods produced by the production department (Hartmann, 1992).

vii. Quality maintenance

These are a set of activities designed to prevent quality defects through the processes. The key is controlling variability in product quality characteristics by controlling the condition of the equipment components that affect it. Therefore, quality maintenance must be incorporated in equipment design. To apply quality maintenance in equipment design, teams must begin by identifying the components that will affect the product quality characteristics (Leflar, 2001).

viii. Safety and environmental management

This aims at achieving zero accidents, zero health hazards at works, and zero pollution Plant and Environment. Accidents cause breakdowns, which in turn leads to losses in production, quality and availability (Borris, 1994).

2.4.4.3 TPM Metrics

2.4.4.3.1 Overall Equipment Effectiveness (OEE)

The concept of overall equipment effectiveness (OEE) is included in nearly all TPM literature. OEE is calculated by multiplying the equipment availability, performance efficiency, and quality rate. The data required to determine these values is: scheduled downtime, unscheduled downtime, and throughput (both good and bad parts); which is collected by the equipment operators on a daily basis. Implementing control charts on the equipment availability, performance efficiency, and quality rate provides aggregate data that is useful for tracking any changes in equipment performance. As defined by Pintelon (2006), OEE can be represented mathematically as shown below

$$OEE = Availability * Performance * Quality$$

OEE gives a useful yardstick for tracking the progress and improvements from the TPM program; but it does not give enough detail to determine why the equipment is better or worse. For example, OEE will reflect a drop in product quality, but it will tell you nothing about why quality is suffering, or what can be done to resolve the problem.

OEE provides the means to evaluate the production process by measuring the effective utilization of the capital assets. The goal of OEE measurements is to establish a focus on eliminating the six process losses: Breakdowns, Setup and Adjustment, Idling and Minor Stops, Reduced Speed, process defects and Startup Losses.

2.4.5 Customized Maintenance Concepts

2.4.5.1 The value driven maintenance (VDM)

This methodology was proposed by Haarman and Delahay (2004). It builds a bridge between traditional maintenance philosophies and the shareholders' value. Not only does VDM simplify the boardroom discussion, it also shows that far from being a cost center, maintenance is actually a major economic value within the overall business performance. It is built on established best maintenance practices and concepts such as TPM, RCM and LCC. It shows where the added-value of maintenance lies and how an organization can be best structured to realize this value.

One of the main contributions of VDM is that it harmonizes the role of management and maintenance crew. VDM identifies four drivers in maintenance. The drivers are asset utilization, cost control, resource allocation and safety health and the environment.

2.4.5.2 CIBOCOF

Most recently, Waeyenbergh (2005) presents CIBOCOF as a framework to developed customized maintenance concepts. CIBOCOF starts out from the idea that although all maintenance concepts available from the literature contain interesting ideas, none of them is suitable for implementation without further customization. This, this concept is like a blend for all other concepts. The CIBOCOF logic is a cycle that contains the initiation phase, technical analysis, policy decision making, evaluation and continuous improvement.

2.5 Chapter conclusion

Original precepts of RCM were developed for aircraft industry where basic equipment conditions like no looseness, contamination and lubrication problems are mandatory and the operators (pilots) skill level, behavior and training are of high standard. Unfortunately in most manufacturing industry these basic equipment conditions, operator skills and behavior level do not exist thus undermining RCM application. RCM is applicable where Assets need to be highly reliable and failure of the assets can easily lead to Safety Health Environmental hazards and financial implication of one hour in downtime is very high.

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

- Basic equipment condition are established
- Equipment competent operators are developed

RCM is promoted as a maintenance improvement strategy where as TPM recognizes that maintenance function alone cannot maximize reliability. Factors such as operator lack of care, poor operational practices, poor basic equipment condition and adverse equipment loading due to change in processing requirement all impact on reliability. TPM ensures that all employees become actively involved in recognizing the need to eliminate all losses and focus on defect avoidance. Such approach improves the awareness of each employee about failures and about what to do to resolve them.

TPM is aimed to give both maintenance crew and operators the ability of finding out equipment malfunctioning and fixing them as soon as they appear. Continuous improvement is the motto of TPM. The table below shows comparison of various maintenance concepts.

Table 2-1: Comparison of the various maintenance concepts

TPM	RCM	VDM
	Advantages	
Operator involvement Productivity improvement Cost reduction. Customer satisfaction Clean work place Improved teamwork and better attitude of employees	Greater safety and environmental integrity. Reduces probability of sudden equipment failures. Focuses maintenance activities on critical system components	Focus on shareholder value Business centered Simplify boardroom discussions.
	Disadvantages	
Require culture change, top management support and commitment	Very expensive and requires a higher level skill set of operators and increased training. It is complex Extensive data base required	Complex and extensive data is required. It is built on other maintenance concepts.

From the literature and table 2-1 above it was found that RCM is focused on asset reliability, and is most suited for high risk systems. TPM is focused on people factors and organizational culture whereas VDM is focused on aligning the maintenance function with organizational or business objectives. We can therefore deduce that EAPCC needs a harmonized maintenance concept regarding inspection, regular maintenance; repair and overhaul, scheduled and preventive maintenance of the main components as well as environmental auditing during operation ensure the plant is fully operational. TPM maintenance concept therefore has been identified as key to the meeting of organizational objectives at EAPCC.

3 CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

Research design is the conceptual structure within which research would be conducted. The function of research design is to provide for the collection of relevant information with minimal expenditure of effort, time and money. The preparation of research design, appropriate for this particular research problem involved the following considerations: Objectives of the research study, method of data collection to be adopted, source of information, sample design, tool for data collection, data analysis both qualitative and quantitative.

This chapter clearly describes the layout for collecting, analyzing and interpretation of data. It also gives an overview of the research process and it also establishes data collection methods and procedures used during the research study.

3.2 Research design

According to Kerlinger (1986) research design is the plan and structure of investigation so concieved as to obtain answers to research questions. Hence it can be illustrated as a step-by-step method to develop a research. Many research designs exist and the choice determines immediate type of research findings and conclusions that the researchers can draw from the study quantitative (Creswell 2009, p. 71).

This research study is descriptive, the study is also a quantitative and a qualitative research since it gives a detailed and comprehensive report on the findings and also numerical tables and graphical representations. A detailed literature study of maintenance concepts was done to provide information for better knowledge and understanding of the theory. The main data collection method used was secondary data. Overall Equipment Effectiveness (OEE) was used to determine raw mill performance and downtime analysis was also carried out to establish the causes of low availability.

3.3 Data collection Methods

There were various modes of data collection utilized as detailed below:

Secondary Data

Kothari (2004) refers to secondary data as information already collected by someone else for the some purpose available for the present study. Secondary data was a pre-requisite for this study and was sourced from EAPCC's data room documents, archival records, journals and websites. Secondary data was used in determining metrics such as;

- OEE,
- Availability
- Performance
- Quality
- Equipment reliability
- Mean Time between failures
- Capacity Utilization
- Maintenance Effectiveness
- Cement produced

Direct observations within the raw mill plant were also used in determining parameters such as;

- Attitude of employees towards their jobs
- The level of autonomous maintenance
- The level of machine cleanliness.

3.4 Data analysis method

According to Baily (1984) data analysis procedure includes the process of packaging the collected information putting it in order and structuring in main component in a way that the findings are easily and effectively communicated. The data collected for this research study were coded, tabulated and analyzed using Microsoft Excel software. This was done with the aid of a computer and it made interpretation of the results to be more meaningful to this study. The study also contains tables and graphs that were used to capture numerical details and represent them diagrammatically.

4 CHAPTER FOUR: PROBLEM ANALYSIS

4.1 Introduction

In this section, data will be analyzed in order to compare the different metrics associated with each maintenance concept with the company target and world-class target. The Overall Equipment Effectiveness (OEE) will be used as a metric for TPM analysis, machine reliability will be used to for the comparison of Reliability Centered Maintenance (RCM) and downtime analysis will be used to establish the causes of low availability of the raw mill plant.

4.2 Maintenance KPIs

Different organizations use different KPIs in their maintenance department. At East Africa Portland Cement Company, the KPIs used in the maintenance department include the OEE metric and its three components, reliability, maintenance cost, maintenance effectiveness, Mean Time to Repair (MTTR) and Mean Time Between stoppages (MTBS).

4.2.1 OEE metric as a maintenance KPI

4.2.1.1 Introduction

In the evaluation of a maintenance performance, OEE is used as a metric to evaluate the manufacturing capability. OEE is a function of equipment availability, performance efficiency and quality. An 85% OEE is considered as being world class and a benchmark to be established for a typical manufacturing capability. As defined by Pintelon (2006), OEE can be represented mathematically as shown below

$$OEE = Availability * Performance * Quality$$

4.2.1.2 Availability analysis

Availability is essentially a measure of the equipment's actual up-time, relative to the planned up-time. Availability and downtime have a strong negative relationship. A lower availability means the downtime of the equipment is higher. Downtime is any appreciable length of time the equipment is not working as a result of lack of input materials, lack of operators and machine failure. Usually, availability is given as a ratio between the operating time and the total loading time.

$$Availability = \frac{Operating\ time}{Loading\ time}$$

The table below shows a summary of the calculated monthly availability of the raw mill from the year 2010 to 2013.

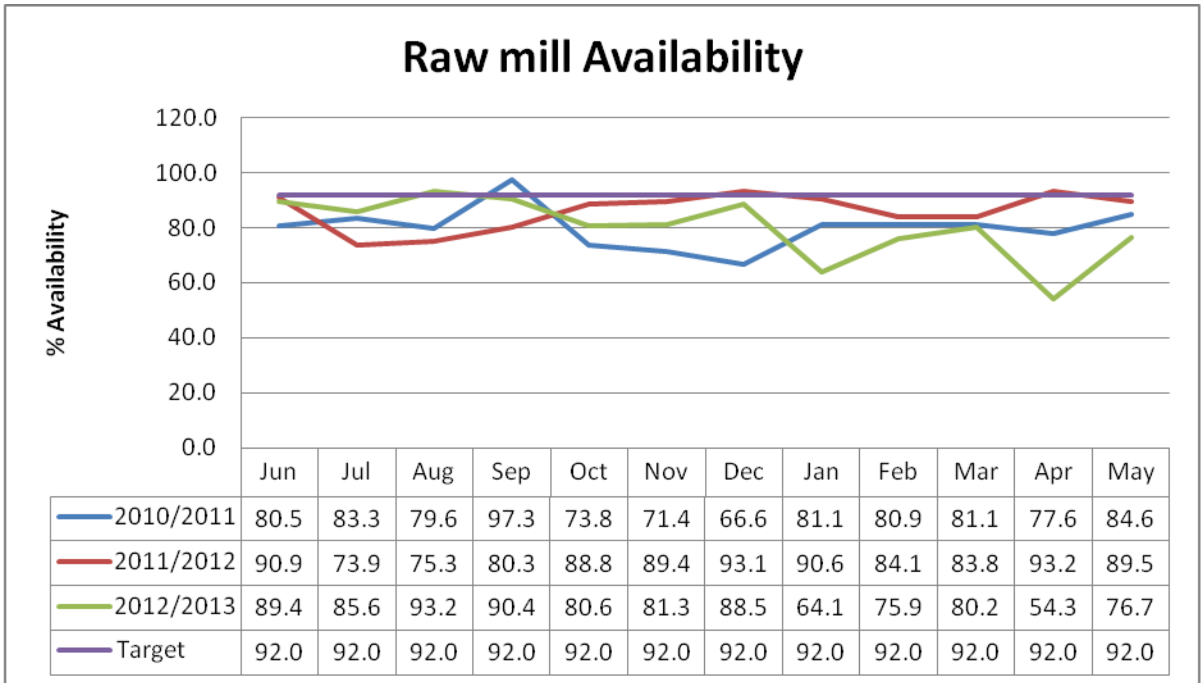
Table 4-1: **The calculated monthly availability for three years**

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	80.5	83.3	79.6	97.3	73.8	71.4	66.6	81.1	80.9	81.1	77.6	84.6
2011/2012	90.9	73.9	75.3	80.3	88.8	89.4	93.1	90.6	84.1	83.8	93.2	89.5
2012/2013	89.4	85.6	93.2	90.4	80.6	81.3	88.5	64.1	75.9	80.2	54.3	76.7
Target	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0

Availability = (Total month hrs-Eng hrs)/Total month hrs

The figure below shows the monthly availability for the last 36 months as compared to the organizational target of 92%.

Figure 4-1: The comparison of plant availability and the target



From figure 4-1 above, we can note that the achieved availability of the raw mill has been below the targeted value, except for September 2010, April 2012, December 2011 and September 2012. This can be attributed to the short Mean Time Between Stoppages (MTBS), a higher Mean Time To Repair (MTTR) and the higher frequency of breakdowns on the raw mill as shown in the table below.

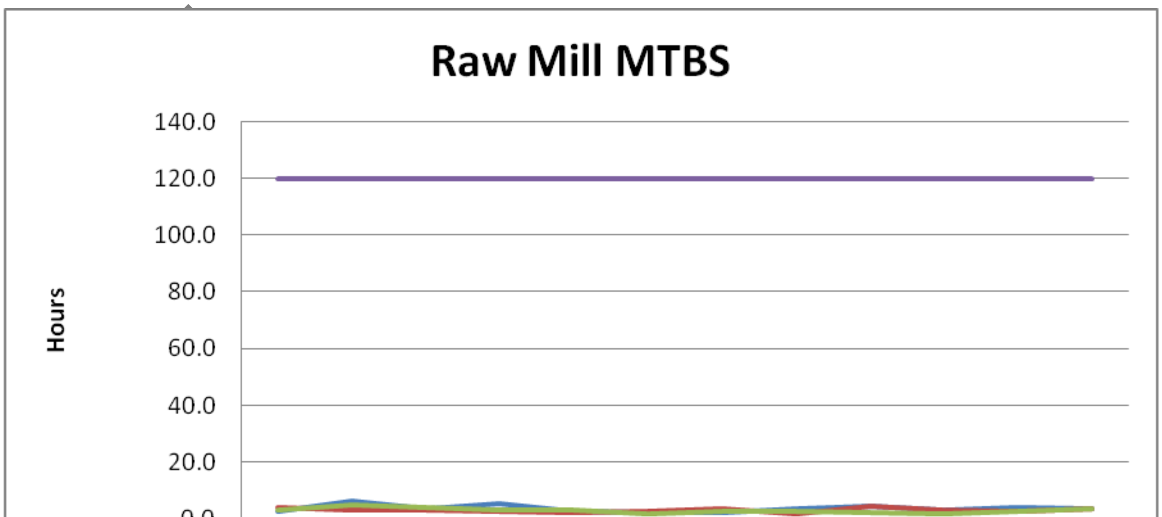
Table 4-2: MTBS for the raw mill

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	2.6	6.3	3.7	5.5	2.7	2.2	2.2	3.6	4.4	3.3	3.8	3.5
2011/2012	3.9	2.9	3.1	2.7	2.1	2.6	3.4	1.8	4.4	3.2	2.8	3.7
2012/2013	2.9	5.0	3.9	3.1	3.0	1.5	2.4	2.4	2.0	1.7	2.7	3.7
Target (hours)	120	120	120	120	120	120	120	120	120	120	120	120

From table 4-2 above, we can notice that the MTBS is much smaller as compared to the targeted figure of more than 120 hours. The MTBS is usually calculated by dividing the run hours and the total number of stoppages. Therefore a low MTBS at EAPCC can be attributed mainly to the higher number of stoppages on the raw mill. The figure below shows a comparison between the targeted MTBS and the achieved.

Mean Time Between failures (MTBS) = Operating time/No. of failures

Figure 4-2: The variation of achieved and targeted MTBS with time



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	2.6	6.3	3.7	5.5	2.7	2.2	2.2	3.6	4.4	3.3	3.8	3.5
2011/2012	3.9	2.9	3.1	2.7	2.1	2.6	3.4	1.8	4.4	3.2	2.8	3.7
2012/2013	2.9	5.0	3.9	3.1	3.0	1.5	2.4	2.4	2.0	1.7	2.7	3.7
Target	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.

4.2.1.3 Performance analysis

Performance reflects whether the equipment is running at its designed full capacity. Performance is the ratio between the actual quantities produced during the actual running speed and the quantities that could have been produced if the equipment was running at its designed capacity; it takes into account speed losses. Speed losses are losses that make an equipment to operate below the rated capacity. Therefore, a low output means fewer quantities are produced. It is given by the equation below

$$Performance = Operating\ speed\ rate * net\ operating\ rate$$

The operating speed rate is a ratio between the theoretical cycle time and the actual cycle time

$$OS\ rate = \frac{Theoretical\ cycle\ time}{Actual\ cycle\ time}$$

The net operating rate is given by the following equation

$$NO\ rate = \frac{Actual\ processing\ time}{Operating\ time}$$

The table 4-3 below shows the summary of the performance factor as achieved by EAPCC on the raw mill for the last 36 months.

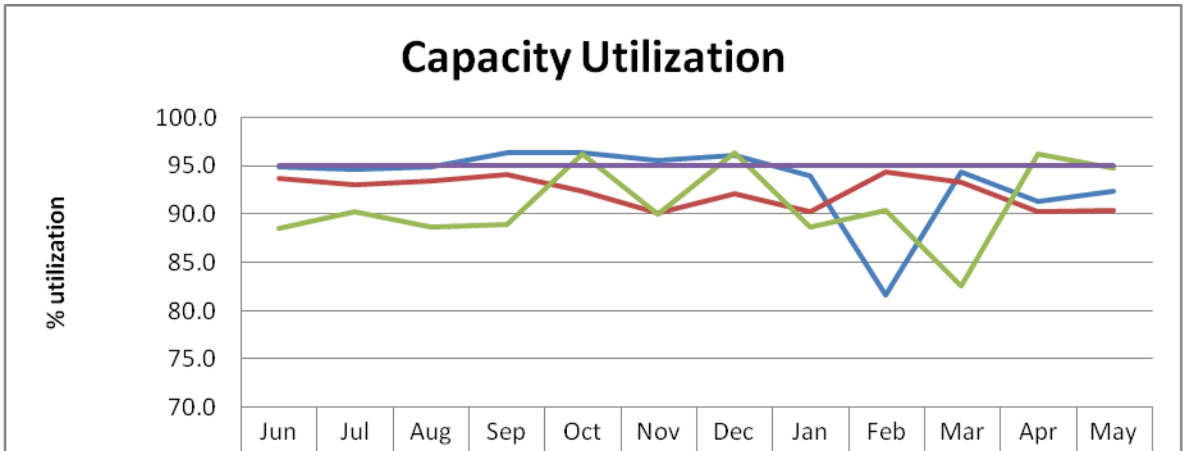
% CAPACITY UTILIZATION = Prod. Rate per hrs/Design capacity per hrs *100

Table 4-3: The performance factor on the raw mill

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	**95.0**	**94.7**	**95.0**	**96.4**	**96.4**	**95.7**	**96.1**	**94.0**	**81.7**	**94.4**	**91.3**	**92.4**
2011/2012	**93.7**	**93.1**	**93.5**	**94.1**	**92.5**	**90.2**	**92.1**	**90.4**	**94.4**	**93.3**	**90.3**	**90.5**
2012/2013	**88.5**	**90.3**	**88.6**	**88.9**	**96.2**	**90.0**	**96.4**	**88.7**	**90.5**	**82.5**	**96.2**	**94.9**
Target	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**	**95.0**

By comparing the achieved values tabulated in the table 4-3 above and the targeted world-class value of 95%, the figure below was drawn to highlight the differences.

Figure 4-3: The achieved and the targeted values for the performance of the raw mill



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	95.0	94.7	95.0	96.4	96.4	95.7	96.1	94.0	81.7	94.4	91.3	92.4
2011/2012	93.7	93.1	93.5	94.1	92.5	90.2	92.1	90.4	94.4	93.3	90.3	90.5
2012/2013	88.5	90.3	88.6	88.9	96.2	90.0	96.4	88.7	90.5	82.5	96.2	94.9
Target	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0

From figure 4-3 above, we can conclude that performance is not a serious problem on the raw mill. This is because in some months the achieved performance is much greater than the targeted performance.

4.2.1.4 Reliability as a KPI

Reliability is also used as a KPI in the maintenance department at EAPCC. The information about reliability can be used in RCM analysis. The table below shows the monthly reliability of the raw mill for the last 36 months. Reliability is calculated as follows

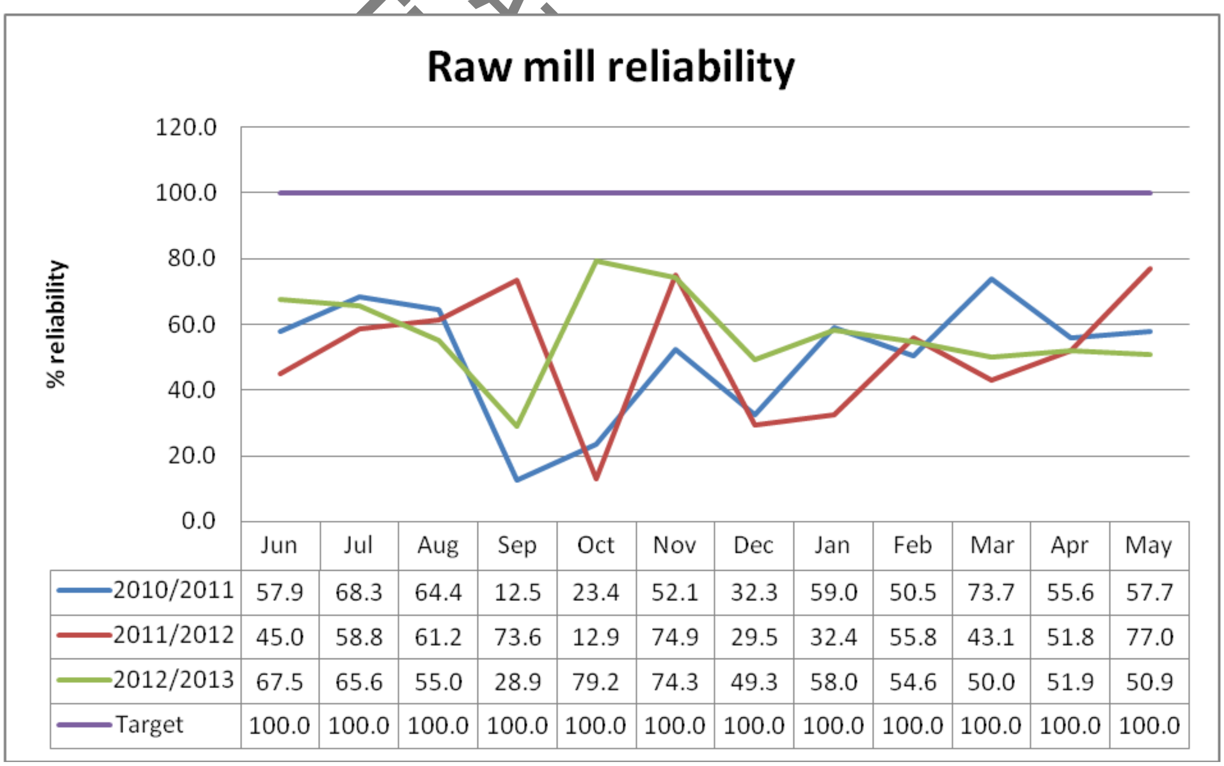
% RELIABILITY = Total run time/ (Total hrs) - (Planned time)-(Power)-(Sales)-(Idle)-(Admin) *100

Table 4-4: The monthly reliability of the raw mill

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	57.9	68.3	64.4	12.5	23.4	52.1	32.3	59.0	50.5	73.7	55.6	57.7
2011/2012	45.0	58.8	61.2	73.6	12.9	74.9	29.5	32.4	55.8	43.1	51.8	77.0
2012/2013	67.5	65.6	55.0	28.9	79.2	74.3	49.3	58.0	54.6	50.0	51.9	50.9
Target %	100	100	100	100	100	100	100	100	100	100	100	100

The figure 4-4 below shows the comparison between the achieved reliability and the targeted reliability at EAPCC (100%) for a period of 36 months.

Figure 4-4: The achieved and targeted reliability for the raw mill



4.2.1.5 The quality factor

The quality factor is a measure of the processes ability to produce products without producing defective parts. It measures the actual yield of the process by excluding availability and performance of the production equipment. It takes into account scraps, wastes and the components that were reworked.

$$Q = \frac{Total\ throughput - Defects}{Total\ throughput}$$

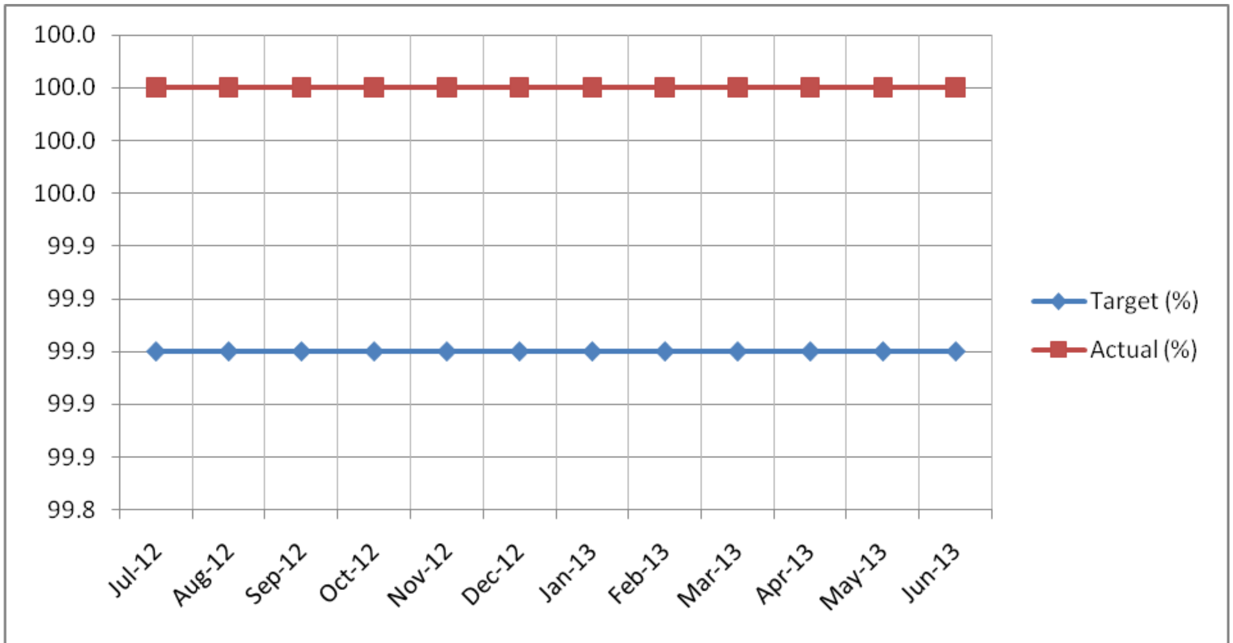
The table below shows a summary of the quality rate at EAPCC on the raw mill for the last 12 months.

Table 4-5: The monthly quality factor

Quality	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13
Target (%)	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
Actual (%)	100	100	100	100	100	100	100	100	100	100	100	100

A comparison between the achieved quality factor and the world-class target is as shown in the figure below.

Figure 4-5: The achieved and the targeted quality factor in the OEE analysis



From the figure above, we can note that quality is not a major problem at EAPCC because the achieved target is higher the world-class metric of 99.9%.

4.2.1.6 OEE calculation

As mentioned above, the OEE is a product of the availability, performance and the quality factors. However, at EAPCC OEE is a calculated using capacity utilization, quality and reliability factor. The table below shows the OEE calculated for the raw mill during the last 36 months.

OEE = Capacity utilization (U)*Reliability (R)*Quality factor (Q)

Table 4-6: The OEE for the raw mill for 36 months

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	56.5	67.1	63.4	12.5	23.4	51.7	32.2	57.6	42.7	72.2	52.7	55.2
2011/2012	43.7	56.7	59.4	71.8	12.4	70.1	28.2	30.3	54.7	41.8	48.5	72.2
2012/2013	62.0	61.4	50.6	26.7	79	69.3	49.3	53.4	51.2	42.8	51.8	50.1
Target	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0

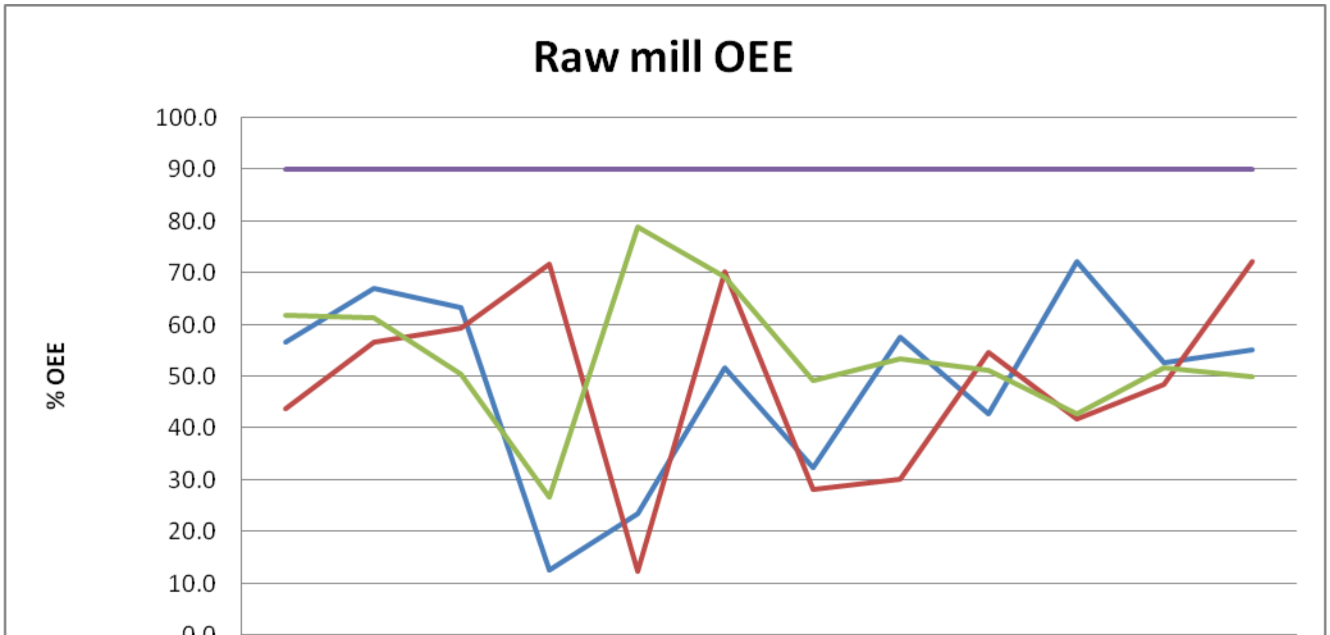
The world-class value for OEE is 85.41%. This value is arrived at by multiplication of the factors shown in the table below

Table 4-7: The world-class OEE

OEE metrics	World-class value (%)
Availability	90.00
Performance	95.00
Quality	99.90
OEE	85.41

A comparison between the world-class OEE, company target and the achieved OEE on the raw mill at EAPCC is as shown in the figure 4.6 below

Figure 4-6: The targeted and achieved OEE on the raw mill



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2010/2011	56.5	67.1	63.4	12.5	23.4	51.7	32.2	57.6	42.7	72.2	52.7	55.2
2011/2012	43.7	56.7	59.4	71.8	12.4	70.1	28.2	30.3	54.7	41.8	48.5	72.2
2012/2013	62.0	61.4	50.6	26.7	79	69.3	49.3	53.4	51.2	42.8	51.8	50.1
Target	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0

The achieved OEE value has a huge variance with the targeted OEE value. By comparing with the world-class value for OEE which is 85.41%, there was no single month for the last 36 months in which the targeted OEE value was achieved as shown in figure 4-6 above

4.2.1.7 Cost analysis as a maintenance KPI

Maintenance cost plays a very important role in LCC concept analysis. Maintenance costs should be less than 15% of the total cost of production in a typical manufacturing organization. At EAPCC two KPIs are used in regard to cost:

i. Percentage maintenance cost per unit output, which is given by

$$\%\ mainteinance\ per\ unit\ output = \frac{cost\ per\ output}{mainteinance\ cost} * 100$$

ii. Percentage maintenance cost per unit input

$$\% \; mainteinance \; per \; unit \; input = \frac{cost \; per \; input}{mainteinance \; cost} * 100$$

The table 4-8 below shows the different cost KPIs in the maintenance department at EAPCC for the last five months.

Table 4-8: Cost KPIs at EAPCC

Month	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13
Target Maintenance cost (Ksh)	16,000,000	16,000,000	16,000,000	16,000,000	16,000,000	16,000,000
Actual Maintenance cost (Ksh)	14,836,138	8,901,043	27,556,147	31,280,603	15,381,309	18,863,796
Production (Tones)	73,250	63,604	70,765	62,174	65,469	67,958
Maint cost/Tone	203	140	389	503	235	278

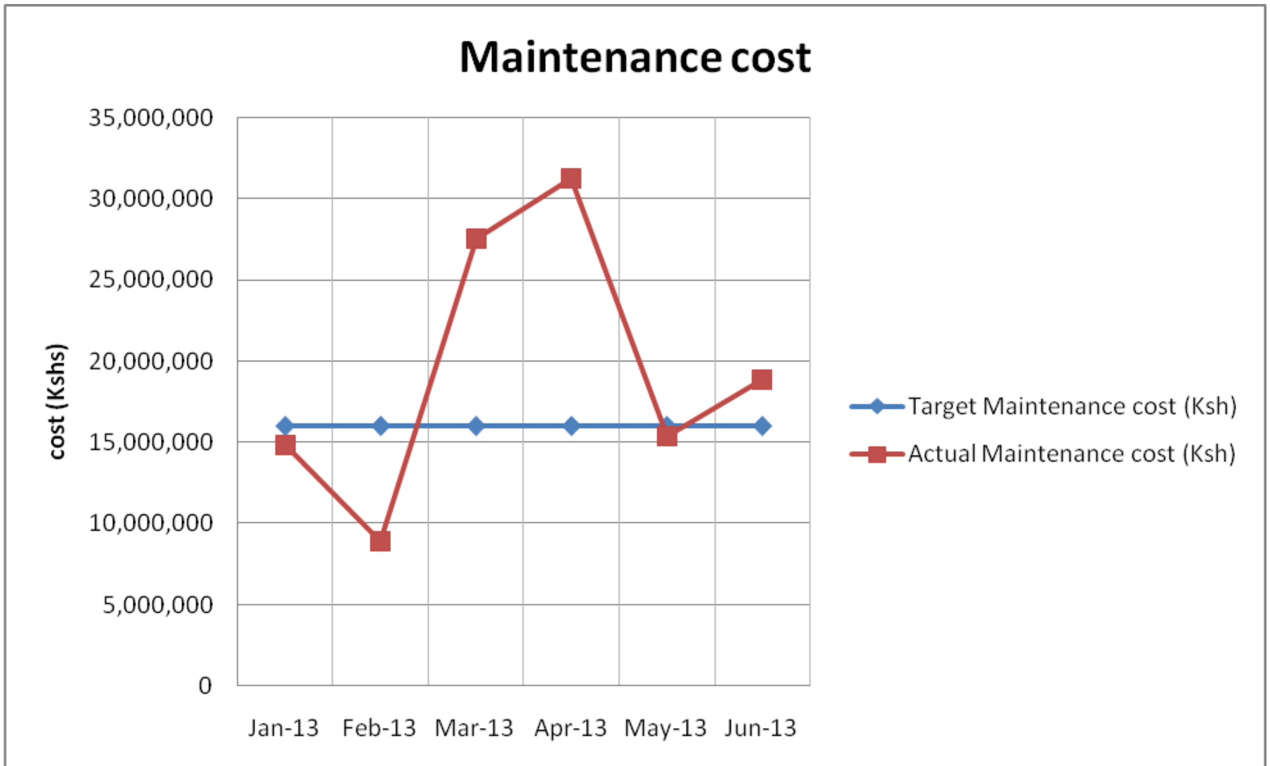
The different target level for the key Performance Indicators (KPIs) is as shown in table 4-9 below.

Table 4-9: Key Performance Indicators with the different target levels

Key Performance Indicator	**Target level**
Maintenance cost (Ksh)	16,000,000
Maintenance cost/unit output	6-8%
Maintenance cost/total sales	6-8%

The figure 4-7 below shows the relationship between the target level and the maintenance cost that was actually spend in the maintenance department for a period of six months.

Figure 4-7: Maintenance cost as a KPI



From figure 4.7 above, the maintenance cost for three months is below the targeted monthly cost of 16,000,000 during the six months period.

4.2.1.8 Raw mill production output

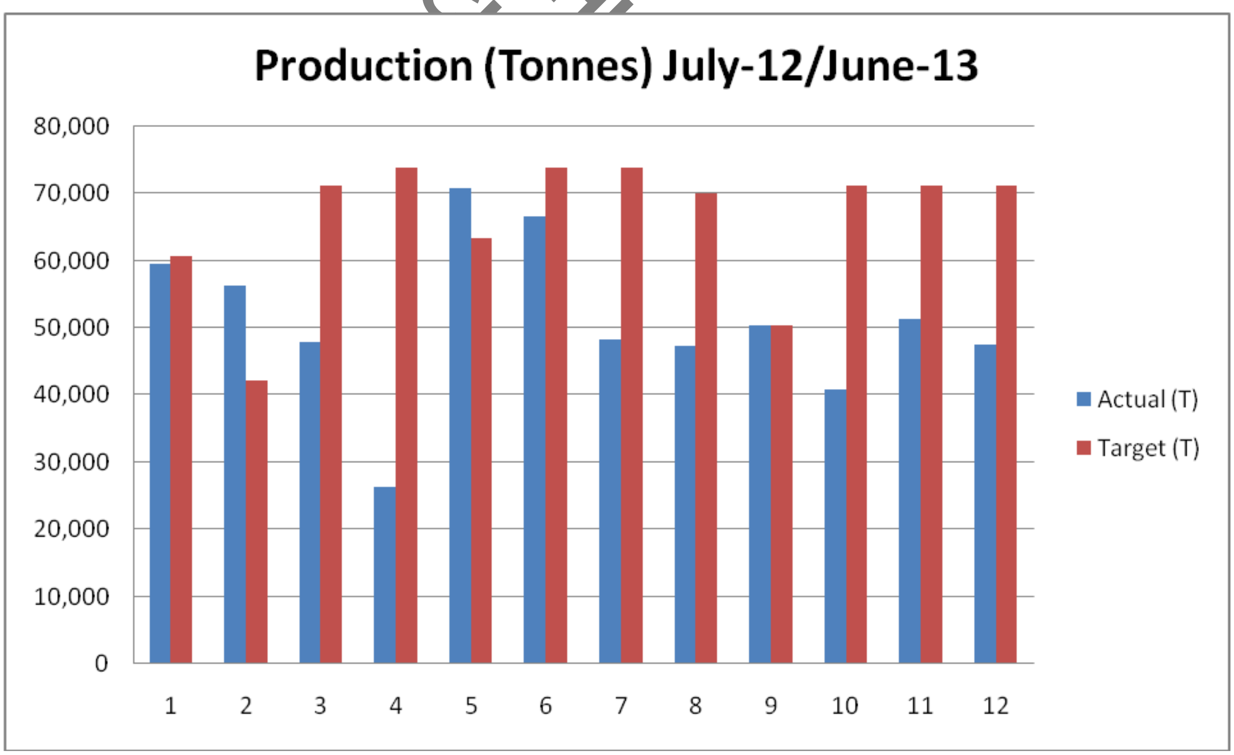
The production of the raw mill for the year 2012/2013 is as shown in table 4-10 below

Table 4-10: Raw mill Production for Financial Year 2012/2013

	12-Jul	12-Aug	12-Sep	12-Oct	12-Nov	12-Dec	13-Jan	13-Feb	13-Mar	13-Apr	13-May	13-Jun	Total
Actual (T)	59,497	56,334	47,925	26,389	70,893	66,571	48,266	47,376	50,449	40,784	51,411	47,557	613,452
Target (T)	60,720	42,240	71,280	73,920	63,360	73,920	73,920	70,125	50,490	71,280	71,280	71,280	793,815

Using the information in table 4.10 above, figure 4.8 below was drawn

Figure 4-8: Raw Mill Production for Financial Year 2012/2013

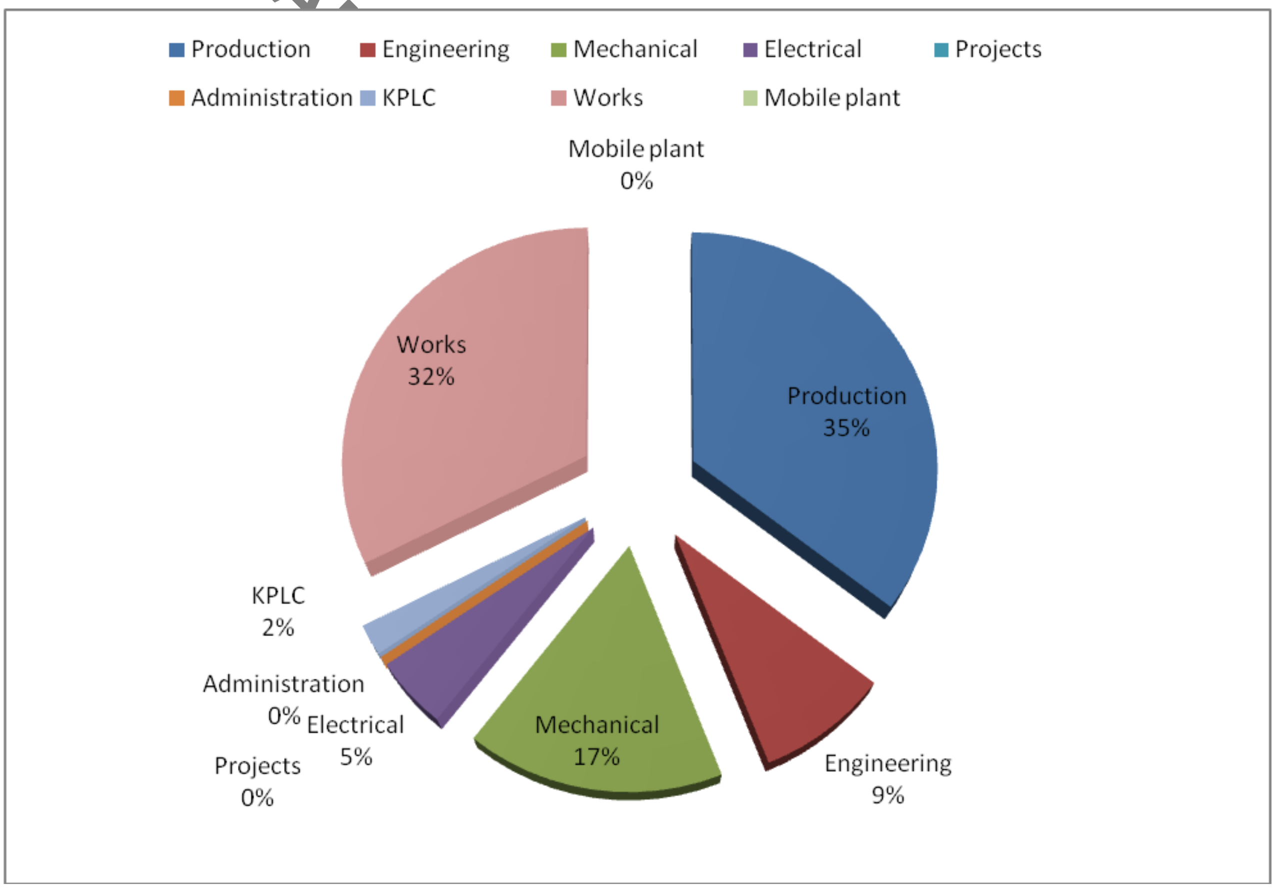


From figure 4-8 above it can be noted that due to plant inefficiencies the production target was largely not met.

4.3 Raw mill downtime analysis

On the raw mill plant at EAPCC, the downtime ownership is grouped into eight categories: downtime due to production (scheduled cleaning, start ups, rework), engineering (planned maintenance), electrical breakdown, mechanical breakdown, projects, Kenya Power (power outage), administration and works (planned shutdown maintenance). The figure below shows a summary for the contribution of each factor to the downtime on the raw mill.

Figure 4-9: Raw mill downtime June 2012 – July 2013



From the figure 4.9 above, we can conclude that production plays a big role in downtime of the raw mill (35%). It is followed by works at 32% and mechanical at 17%. A Pareto analysis reveals that by a reduction in the downtime of the three can greatly reduce the overall downtime of the raw mill.

Table 4-11: Downtime ownership June 2012 – July 2013

Downtime ownership	Hours
Production	788.9
Engineering	190.8
Mechanical	368.3
Electrical	107.7
Projects	0
Administration	0
KPLC	47
Works	721.9
Mobile plant	0

Using pareto analysis the following are the root-causes of raw mill downtime.

Table 4-12: Root causes of major downtime June 2012 – July 2013

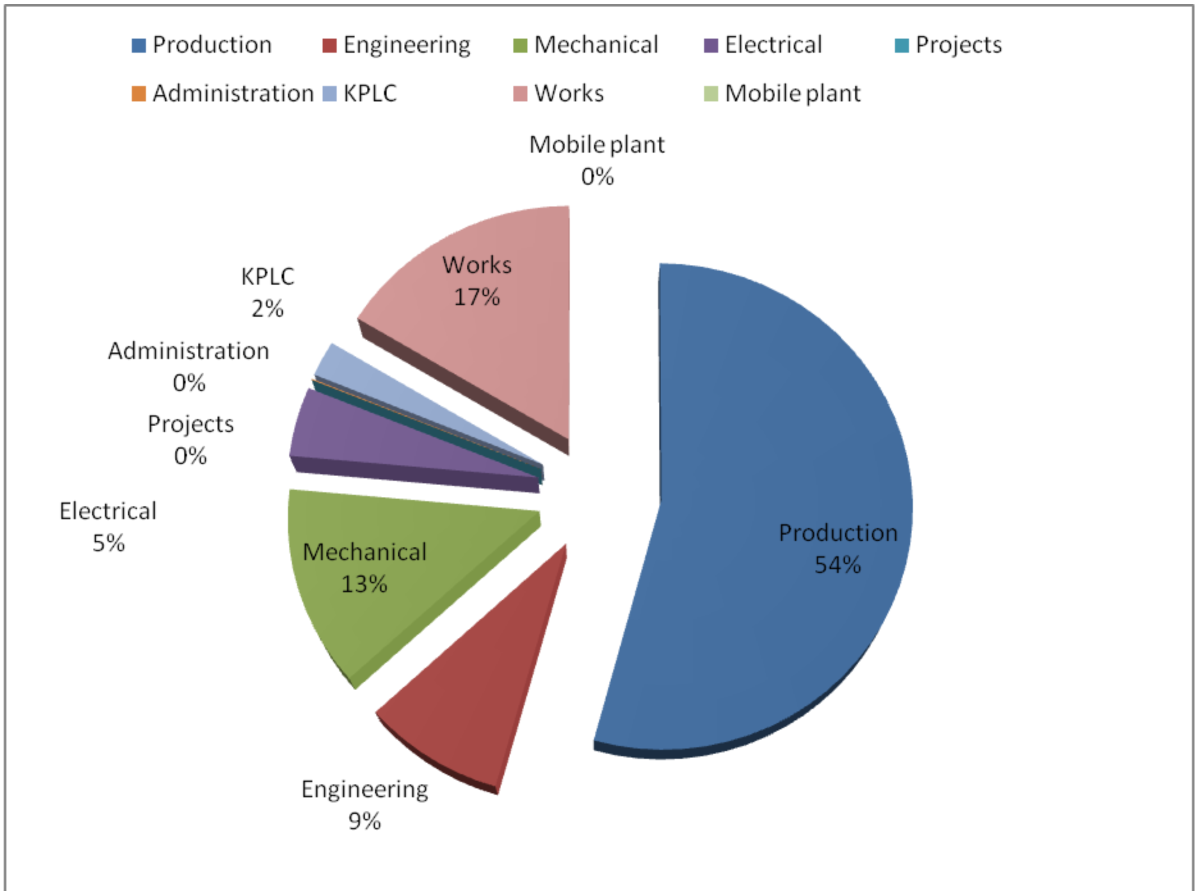
Production losses	Hours
Lack of sufficient hot gases	521.96
Deblocking Rotary feeder	179.91
LCP3 Low thrust pad	46.79

Works	Hours
Major shutdown	873.3
Replacing Roller 1 seals	157
03RF01 worm wheel	124.46

Mechanical failures	Hours
03RM01 fallen segment	161.61
03FN01 Drive end bearing failure	145.07
LCP1 maximum cylinder	85.87
Broken tension bolts	78.98

Most significant time loss is due to lack of sufficient Kiln hot gasses and restarting after run interruption. Fallen segment of the mill was also major mechanical failure

Figure 4-10: Raw mill downtime June 2011 – July 2012



From the figure 4.10 above, we can conclude that production plays a big role in downtime of the raw mill (54%). It is followed by works at 17% and mechanical at 13%. A Pareto analysis reveals that by a reduction in the downtime of the three can greatly reduce the overall downtime of the raw mill.

Table 4-13: Downtime ownership June 2011 – July 2012

Downtime ownership	Hours
Production	2483.8
Engineering	406.4
Mechanical	604.2
Electrical	212.8
Projects	0
Administration	3.3
KPLC	109.3
Works	751.9
Mobile plant	0

Using Pareto analysis below are the main root-causes of downtime

Table 4-14: Root causes of major downtime June 2011 – July 2012

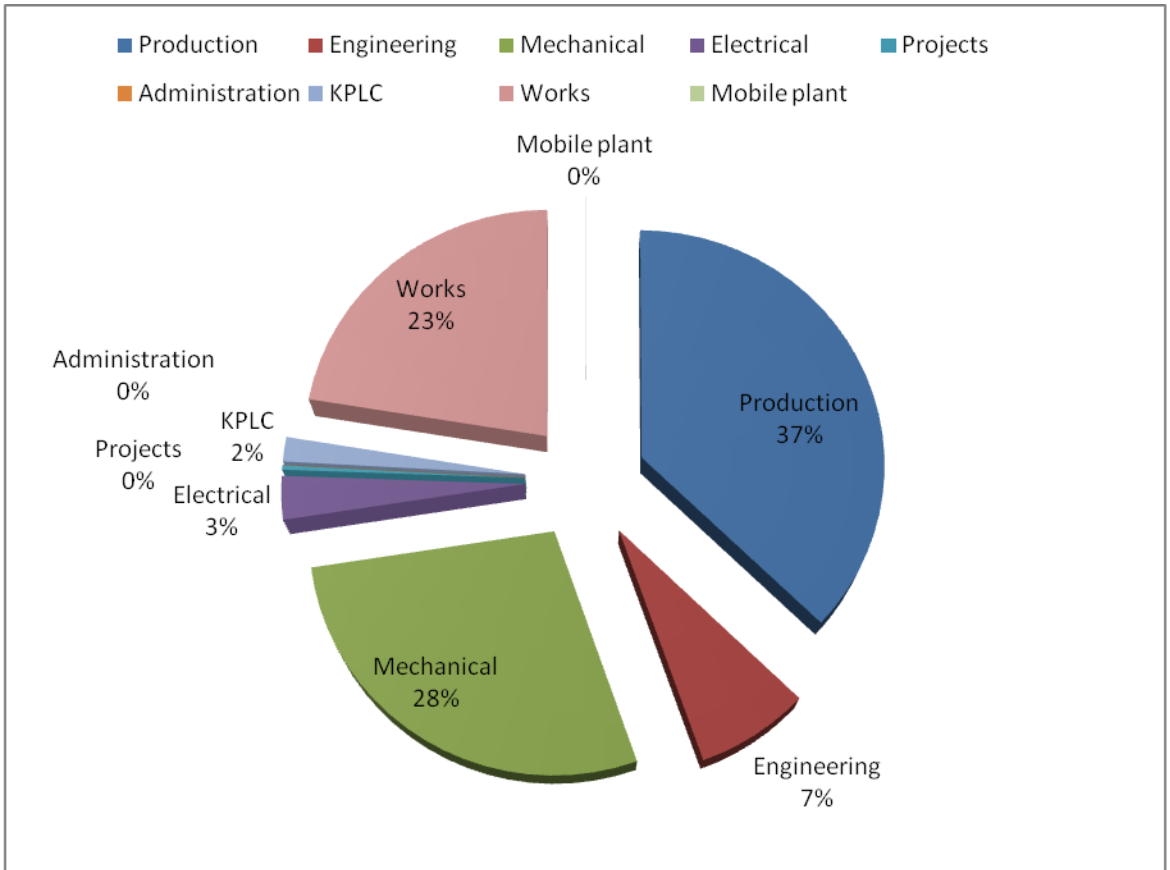
Production failures	Hours
Lack of sufficient hot gases	1624
Union strike	333

Works	Hours
Planned shutdown	751

Mechanical	Hours
03RMRL01 Tripped on LCP 2 min	42
03PL01repair raw meal transport pipeline	38
03RMHY01 Tripped on LCP 1 min'	36
03RM01 Replaced tension bolts	30

Most significant time loss is due to lack of sufficient Kiln hot gasses and restarting after run interruption. Mill is currently dependant on Kiln running

Figure 4-11: Raw mill downtime June 2010 – July 2011



From the figure 4.11 above, we can conclude that production plays a big role in downtime of the raw mill (37%). It is followed by mechanical at 28% and works at 23%. A Pareto analysis reveals that by a reduction in the downtime of the three can greatly reduce the overall downtime of the raw mill.

Table 4-15: Downtime ownership June 2010 – July 2011

Downtime ownership	Hours
Production	1701.7
Engineering	338.9
Mechanical	1279.1
Electrical	136.7
Projects	14.5
Administration	0
KPLC	77
Works	1025.4
Mobile plant	1.3

Using Pareto analysis below are the main root-causes of downtime

Table 4-16: Root causes of major downtime June 2010 – July 2011

Production failures	Hours
03RM01 Lack of kiln hot gases	1002
02BI22 Empty alumina bin	123
LCP3 low thrust pad	120

Works	Hours
Plant Major shutdown	964
Lack of milling room	58.25

Mechanical failures	Hours
03RMRL01 leaking roller 3	275
clogged 03RF02 airslide	222
LCP minimum cylinder	165

Most significant time loss is due to lack of sufficient Kiln hot gasses and restarting after run interruption. Mill is currently dependant on Kiln running. Leaking roller 3 also contributed significantly to the mechanical downtime.

4.4 Maintenance effectiveness as a KPI at EAPCC

Mathematically, maintenance effectiveness at EAPCC is a ratio given by the equation below

Table 4.11 below shows a summary of the maintenance effectiveness for the last 12 months

Table 4-17: Maintenance Effectiveness

Maintenance Effectiveness	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13
Target (%)	95	95	95	95	95	95	95	95	95	95	95	95
Actual (%)	94	87	89	75	79	69	84	61	70	71	53	69

The figure 4-12 below shows the comparison between the achieved maintenance effectiveness and the targeted maintenance effectiveness for a period of 12 months. It illustrates that for the entire twelve months maintenance effectiveness was not met and it is in linear declining trend as indicated in the graph below.

Maintenance Effectiveness= {(Operating time/ (operating time+Downtime)}

Figure 4-12: The achieved and targeted maintenance effectiveness for the raw mill

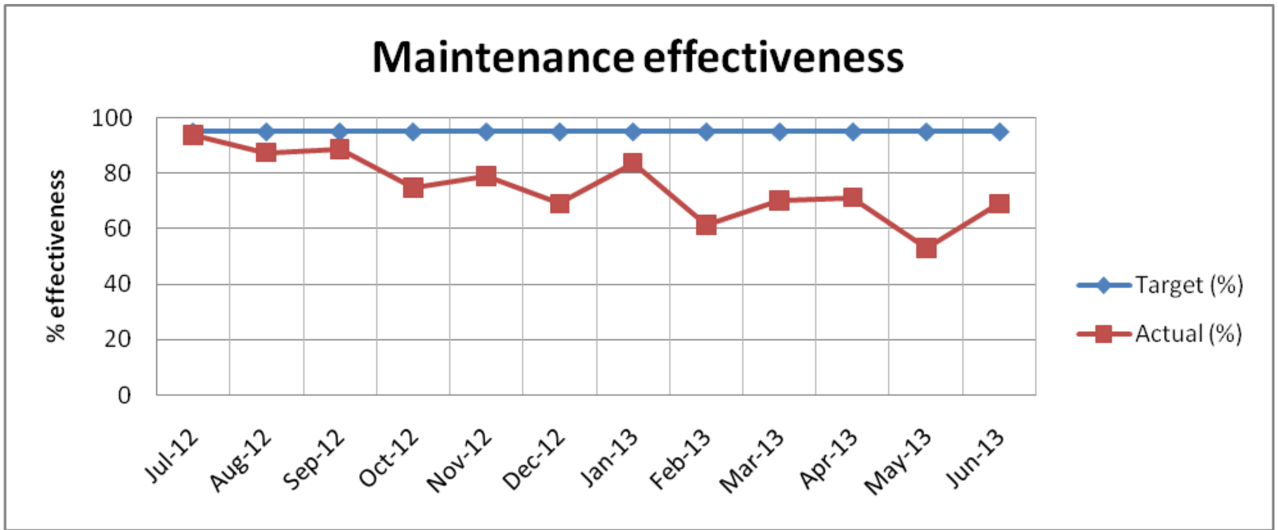


Table 4-18: The percentage of unplanned downtime as compared to the planned downtime

	Jul-12	**Aug-12**	**Sep-12**	**Oct-12**	**Nov-12**	**Dec-12**	**Jan-13**	**Feb-13**	**Mar-13**	**Apr-13**	**May-13**	**Jun-13**	**Total**
Maintenance planned hrs	80	80	80	80	80	80	80	80	80	80	80	80	960
Mechanical breakdown (hrs)	28	51	34	51	57	86	61	217	9	131	331	45	1101
Electrical breakdown hours	21	13	5	10	34	18	8	24	152	12	9	116	420
Total (Mechanical &Ele) hrs	49	64	39	61	91	103	69	241	161	143	340	161	1521
Total maintenance (planned+unplanned) hours	129	144	119	141	171	183	149	321	241	223	420	241	2481
% Planned maintenance	62	56	67	57	47	44	54	25	33	36	19	33	39
% Unplanned maintenance	38	44	33	43	53	56	46	75	67	64	81	67	61

From the table 4-12 the average unplanned maintenance is 61% and planned maintenance is at 39%

4.5 Conclusion

A best practice blend of maintenance strategies is 10% corrective, 30% preventive, 50% predictive, and 10% proactive. Current practice, however, has much room for improvement, with an average unplanned maintenance being over 60%.

From the analysis, we can conclude that OEE and MTBS metrics are the KPI that has a wide variation between the expected and the targeted value. TPM would be used to improve equipment reliability by redesigning the workforce in equipment care and improve maintenance function for continuous improvement.

5 CHAPTER FIVE: DEVELOPMENT OF A MAINTENANCE CONCEPT

5.1 Introduction

The study reveals that successful implementation of TPM requires top management support and commitment, a greater sense of ownership and responsibility from operators, cooperation and involvement of both operators and maintenance workers and an attitude change from "not my job" to "this is what I can do to help". The study shows how TPM can significantly contribute to improve the productivity, quality, safety and morale of workforce. In EAPCC, if there was any practice of TPM and team working between the maintenance and production people, this practice only existed informally, based upon personal relationship rather than taking it as TPM initiative. The study reveals the need for a more proactive approach to maintenance management and greater integration between maintenance and production departments. In EAPCC, the driving force came mainly from the maintenance department, which was keen to transfer some of basic maintenance tasks to their production fellows. But production operators resisted towards these changes as they have productivity pressure from middle management and they treat it as an additional workload. The study shows that implementing TPM is by no means an easy task without strong backup from the top management.

The implementation process of the Total Productive Maintenance program should be performed in phases. The following phases are recommended by (Keneddy, 2002):

i. Awareness phase: This phase involves TPM education and training. This includes developing of the Total Productive Maintenance introduction strategy.

ii. Learning phase: This involves the introduction of the TPM to two or more pilot areas. This should incorporate the focused equipment, process improvement, work area management and operator equipment management pillars.

iii. Assessment phase: This involves development of a site-wide implementation plan based on the learning phase above.

iv. Site-wide implementation phase: This involves the cascade of TPM throughout the entire site.

Companies that have been successful in TPM implementation usually follow an implementation plan that includes the following 12 steps:

Step 1: Announcement of TPM. Top management needs to create an environment that will support the introduction of TPM. Without the support of management, skepticism and resistance will kill the initiative.

Step 2: Launch a formal education program. This program will inform and educate everyone in the organization about TPM activities, benefits and the importance of contribution from everyone.

Step 3: Create an organizational support structure. This group will promote and sustain TPM activities once they begin. Team-based activities are essential to a TPM effort. This group needs to include members from every level of the organization – from management to the shop floor. This structure will promote communication and will guarantee everyone is working toward the same goals.

Step 4: Establish basic TPM policies and quantifiable goals. Analyze the existing conditions and set goals that are SMART: Specific, Measurable, Attainable, Realistic and Time-based.

Step 5: Outline a detailed master deployment plan. This plan will identify what resources will be needed and when for training, equipment restoration and improvements, maintenance management systems and new technologies.

Step 6: TPM kick-off. Implementation will begin at this stage.

Step 7: Improve the effectiveness of each piece of equipment. Project teams will analyze each piece of equipment and make the necessary improvements.

Step 8: Develop an autonomous maintenance program for operators. Operators' routine cleaning and inspection will help stabilize conditions and stop accelerated deterioration.

Step 9: Develop a planned or preventive maintenance program. Create a schedule for preventive maintenance on each piece of equipment.

Step 10: Conduct training to improve operation and maintenance skills. The maintenance department will take on the role of teachers and guides to provide training, advice and equipment information to the teams.

Step 11: Develop an early equipment management program. Apply preventive maintenance principles during the design process of equipment.

Step 12: Continuous improvement. As in any lean initiative, the organization needs to develop a continuous improvement mind-set.

5.2 Customized Framework of TPM deployment at EAPCC

The following six step transformation approaches will be used in embedding high performance TPM culture within EAPCC.

Step 1: Workplace Review

Reviewing existing maintenance and asset management systems, processes, performance and maintenance data. The obtained data to be benchmarked against best practices and also compare with design capacity and subsequently make recommendation and develop action plans for improvement to bridge the gap. The gap analysis involves interviews with staff, data analysis and shop floor observations. This will help in understanding the layout of operational activities and look for opportunities for improvement. Also to observe the conduct which employees are demonstrating, specifically the presence or absence of safe behavior, focus of attention of the job, sense of urgency and standard of housekeeping.

Step 2: Change management process

This requires substantial management support and commitment and participation at the operational level to be successful. Change management approach must be incorporated to minimize resistance by ensuring top management support and cultivating acceptance and ownership at operational level. This will involve;

- On-job coaching to identify and resolve organization critical issues,
- Building skills and confidence through FET teams
- Formal training
- Establishment of steering committee

Step 3: Leadership workshop for senior managers

The Managing Director and some of his direct reports as well as senior leadership team in maintenance department need to understand the TPM principles and develop the key pillars of a successful TPM transformation strategy and implementation plan, this is one of the most important factors for success. Additionally leaders are involved in policy deployment process and become responsible and accountable for the outcomes. Policy starts with the vision and mission of the implementation and then the objectives are cascaded down to individual KPIs. This step is the most important of all. The primary reason that TPM implementation fail is when senior managers are not fully supporting and driving the process.

Step 4: Translate strategy into a roadmap workshop

TPM deployment defines maintenance' strategic mission, determine what commitment is inherent in that mission, set goals for each commitment and determine how the company should measure performance against those goals. The aim of these programs is to enable more senior personnel to use the workshop outcomes and develop plans for their group input into the project. By the end of these programs participants will have:

- Understood the TPM impact on the organization
- Translated the project vision, strategies and goals into their groups
- Identified internal and external support and resources required to implement their plan
- Explored ways to inspire people to want to achieve the vision
- Developed the leadership competencies necessary to achieve the above goals
- Cascaded down the metrics to the organization with a single point of accountability
- Created a TPM transformation plan or policy deployment
- Developed the project charters for each planned rapid improvement
- Reported the project to the executive team

Step 5: Training – A Focused Equipment Team (FET) will be established

An FET should consist of;

- Operators
- Technicians
- Electricians
- Electrical Engineer
- Mechanical Engineer
- Stores representative
- Electrical supervisor
- Mechanical supervisor

The above group develops action plans and teams necessary to fix two top issues identified during the review process. The members in these teams must be given the time necessary to lead, organize and communicate changes to the practices and equipment. Improvement should be expected almost immediately (within two weeks to two months). Improvement team should report on fortnightly or monthly basis to senior management. This meeting would be used to monitor progress, show commitment of senior management team to the project, act as a development opportunity for the frontline team.

The training includes the following:

- Autonomous maintenance
- Planned maintenance (Moving from reactive to proactive maintenance)
- Attack Six Big Losses
- Quality maintenance
- Equipment Design and start-up management
- New assets meet production needs – design right, buy right and build right
- Safety and Environment

Step 6: Piloting area (Raw mill plant)

Raw mill plant will be used for piloting. Once successful the same process will be used for other areas. FET members gain practical experiences of TPM as they apply, adapt the concepts and tools. The practical experience forms the bedrock of the TPM learning not only for the individual team but also for the organization as a whole. The benefits of a TPM rapid improvement event are; all employees including floor workers are engaged in making improvements and multiple minds work together from perspectives to develop the best possible solutions. Most importantly, the rapid improvement manufacturing is fast and delivers results.

Step 7: Plant-wide roll out – Implement and standardize

Managers of each of each area will introduce the vision and the burning platform to team leaders and staff. Leaders need to demonstrate their commitment to the transformation, clarify and reach consensus on key lead and lag indicators that measure progress and actively engage workforce to deliver the outcome

Underpinning these programs are these key principles;

- People need to work together to identify barriers and reach consensus on the way forward.
- Success comes from building on what currently works and creating a critical mass at different levels of the organization
- Leaders need to lead effectively by planning and implementing strategies with their work teams to achieve the desired outcome

- People need to be competent, confident and committed to meet the challenge

Sustain knowledge transfer

The goal of the strategy is to build the internal capacity of EAPCC so that it can drive the transformation process long after the initial intensive period has passed.

Table 5-1: Proposed TPM implementation work plan at EAPCC

Phases	Key Result Area	Invention Design Principle	Responsibility Level	Deliverable	Task
Leaders map out the vision and goals	Leadership team aligned	Aligned performance vision across the organization	CEO, Maintenance Manager, Procurement Manage, finance Manager and Production Manager Head of HR Electrical	Diagnostic Workshop. TPM Leadership & Leadership development Align the vision with the	Alignment of culture Coaching and mentoring Develop strategic goals, timeline to meet the

			Engineer Mechanical engineer Superintendent	performance culture. Cascading and coaching	vision Agree on ways to inspire people to want to achieve the vision Governance model selected &Basic metrics agreed
Manager translate the visions and goals to a roadmap	Strong team performance	Translate the vision, KPIs to a roadmap Development of all levels to share responsibilities and accountabilities	All Maintenance Manager/Procurement Superintendent and Production Superintendent /Supervisors	Translate strategy into a roadmap Cascading coaching plan Lean Impact on organization Get the resources required for the implementation	TPM overview Develop a performance culture Cascade the organization vision into a roadmap Project Charters for each planned TPM Dates for each TPM

				Complete a plan on a page	Report-Out Sessions for the Executive
FET Team training	TPM and how to attack 6 big Loses and wastes	Knowledge and understand on how to implement	Operators Maintenance technicians Electrician Engineer Stores/Procurement rep Supervisors Operators OEM rep.	TPM Training Kaizen	5 days training, lean, 5 S, Information, TPM , Poke Yoke and FMEA,
Pilot an area and Quick Wins	Fully integrated performance manager Visual quick wins	High Performance standard Benchmarking	FET Team & area personnel's	TPM Training Start with the Raw mill Performance metric and measure Implement 5S program, information centres, OEE	Ensure individual team understands the vision Develop ability to lead others Communication plan Manage and mitigate risk Visible leadership

Group 01 Quarries (Kabini hill and Kunkur Quarry) Group 02 Raw Materials preparations Group 03 Raw Meal preparation Group 04 Raw Meal Homogenization Group 06 Cement Milling Group 07 Cement packing Group 08 Utilities (compressed air supply and cooling water	Clear accountabilities & responsibilities aligned	Take action today that have long term impact	Group 01 Quarries (Kabini hill and Kunkur Quarry) Group 02 Raw Materials preparations Group 03 Raw Meal preparation Group 04 Raw Meal Homogenization Group 06 Cement Milling Group 07 Cement	TPM Training Performance metric and measure Implement 5S program, Information centres, OEE	Ensure individual teams understand the vision Visible leadership

Sustain and knowledge transfer	Change management	Audit and coaching	Leadership Team	Lean Progress Internal Lean Capacity Lean Governance Lean Metrics &Reporting Sharing best practice & recognizing excellence	Revised Lean Transformation plan Review Culture Change plan Internal Lean Capacity plan (Learning Matrix) Lean Governance review Review of Lean Metrics and Reporting KPIS achieved

Six step transformations begin with the senior management group and cascades through other levels of management to individuals functioning within multi-disciplinary project teams as indicated in Figure 5-1 below. This process engages people at different levels in the principle organization and its contractors in a way which has them identifying what needs to be done and to close the gaps that have been identified during the workplace review whilst ensuring high safety standards. It will also help to clarify their roles and accountability in achieving this outcome and the indicators by which success will be measured.

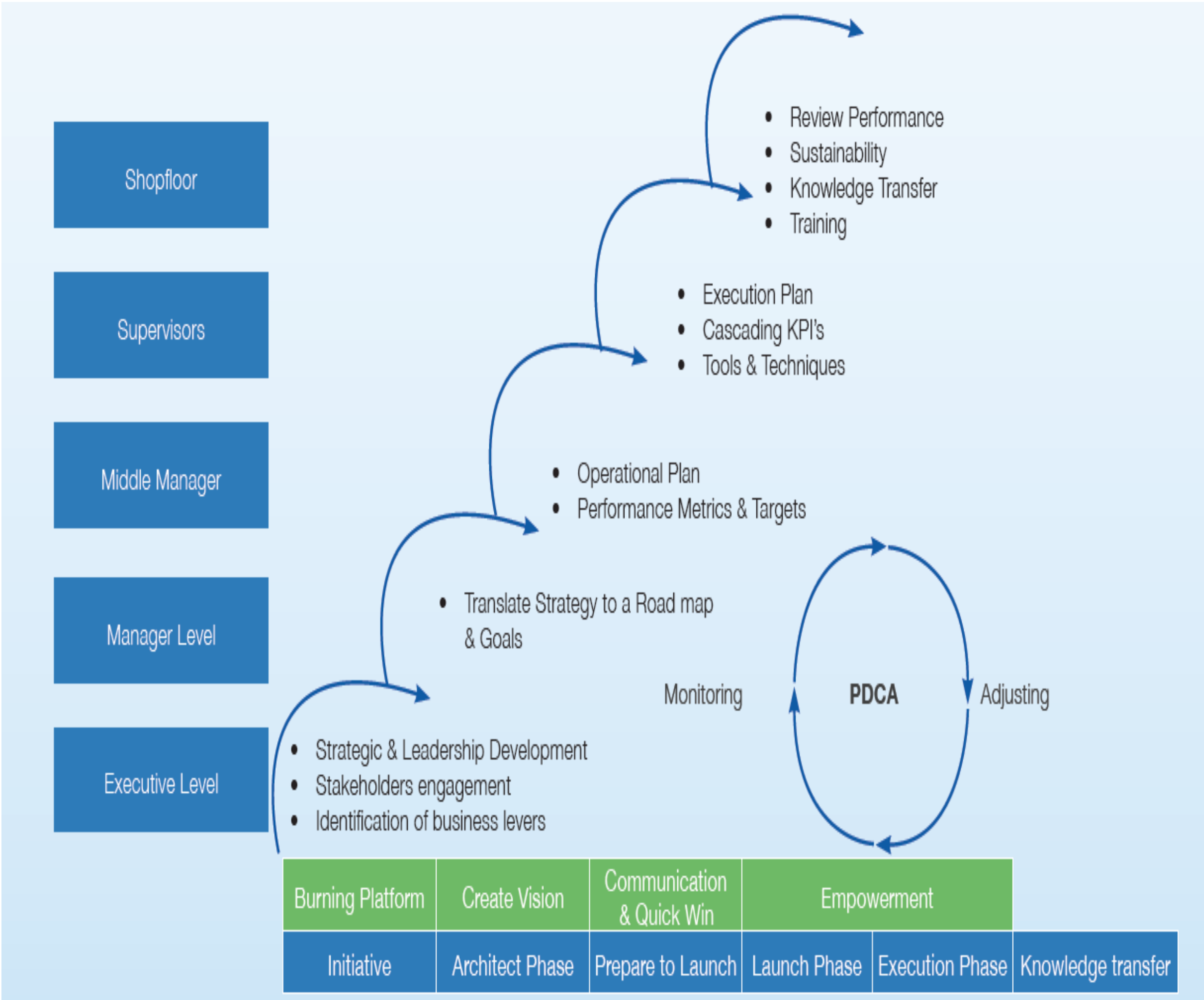


Figure 5-1: Multilevel Involvement and commitment

Chapter conclusion

Deployment of TPM aims to help EAPCC maximize return on investment from their assets by ensuring:

- The maintenance processes will be optimized and preventive and corrective maintenance activities on site will be scheduled and executed efficiently.
- Performance gets measured by using standard maintenance indicators.
- Increased productivity due to improvement on all factors of Overall Equipment Efficiency- Availability, performance and quality
- Health Safety and Environment improvement by mitigation of associated hazards and preserving the integrity of assets to prevent harm to people and the environment.

- Securing employee ownership of the changes, especially among formal and informal leadership
- Bringing to bear world-class techniques from superb organizations that have undergone similar transitions
- Preventing problems before the more expensive and sometimes embarrassing contingent actions must be used
- Teams will be empowered to manage their business
- Move away from the “fire-fighting” culture to problem solving culture.

6 CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Review of Research objectives

- The Overall Equipment Effectiveness (OEE) has been analyzed for three financial years (2010/2011, 2011/2012, 2012/2013) and it was established that the achieved OEE value has a huge variance compared with the targeted OEE value of 90%. By comparing with the world-class value for OEE which is 85.41%, there was no single month in which the targeted OEE value was achieved for the 36 months period
- It was also established that the three major causes of low availability of the Raw mill plant are downtime due to production (scheduled cleaning, start ups, rework), works (planned shutdown maintenance) and mechanical breakdown. A Pareto analysis reveals that a reduction in the downtime of the three can greatly reduce the overall downtime on the raw mill hence resulting into improved availability
- A customized framework of TPM deployment at EAPCC has been developed to improve Overall Equipment Effectiveness (OEE) to 85% and this will result into improved productivity and profitability.

6.2 Results and key findings

The business scenario across the world is going through a process of change and Companies are drawing business strategies to achieve customer delight by ensuring timely delivery of reliable products and services at highly competitive prices. Hence the focus is on supply of quality goods and services at prices which are competitive. Therefore, in order to be successful in today's world-class manufacturing environment, companies have to fulfill these requirements effectively. Maintaining a reliable manufacturing process is a key success factor in doing so, which can be achieved through implementing a proper maintenance concept, because maintaining an efficient and effective maintenance strategy is crucial to keeping high-level process quality, achieving high machine and labor force efficiency.

This scenario has necessitated bench marking of EAPCC maintenance strategy with global best practices. This has led the company to adapt time-tested philosophy of TPM, concentrating on productivity improvement, primarily by way of maximizing the availability of equipment.

Over the years, EAPCC has been practicing reactive maintenance, routine/planned maintenance and condition based maintenance. All these modes of maintenance are only carried out by maintenance department and therefore not holistic.

The increased dependence on the production equipment to reliably and repeatedly manufacture high quality products has created the need for a new approach to equipment management at EAPCC. Among various maintenance strategies and concepts, Total Productive Maintenance (TPM) has widely been accepted as an effective strategy for improving maintenance in the manufacturing companies. Raw mill plant has been analyzed to study TPM implementation methodology, calculations of OEE, and difficulties in implementation, the roadmap to be followed and key benefits as a result of TPM implementation. There have been attempts by management and the maintenance workers to involve the production staff in basic maintenance work, but success has been limited for reasons discussed earlier, with negative effects.

For effective implementation of TPM at EAPCC, employee contributions and achievements need to be recognized and applauded. This will help motivate employees to a large extent and ensure changes in attitudes. To improve ownership of processes, management needs to empower all the employees to make decisions affecting their work environment. This implies that all employees need to be actively involved in the decision making process. This will also drive the necessary changes in attitude, motivate employees and establish a culture of teamwork. In addition to that the maintenance, production and quality departments at EAPCC need to be restructured in such a way that all personnel fall under one department. By restructuring these departments, everyone will become actively involved in driving the TPM program and achievement of performance objectives. This will eliminate the barriers that exist amongst all these departments. Therefore all employees will share the same responsibility without necessarily shifting blame amongst each other.

6.3 Research contribution

The developed customized framework of TPM deployment at EAPCC could be adopted by other similar manufacturing plants and also be used along other literature. Comparative analysis of the various maintenance concepts has been done and OEE methodology explored to determine the need for TPM deployment. By developing an effective maintenance concept that binds together all the maintenance policies, maintenance actions and strategies for maintenance, the number of stoppages in the raw mill will greatly be reduced by increasing the mean time between stoppages. This will increase the monthly production for the company as a result of improved raw mill availability and reliability. With increased production, the revenue will be greatly increased resulting into increased profitability.

6.4 Research Limitations

The field of maintenance concepts has not been widely studied and not many researchers have documented relevant articles in cement manufacturing and this demanded extra work in search of similar information from other sources like internet.

6.5 Further research

In this research a framework for development of a TPM framework was proposed. A natural extension of this work is to initiate further studies on the effectiveness of TPM implementation at EAPCC. This would enable a comparison of the applicability of the implementation of TPM at EAPCC.

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Appendices

Appendix 1: plant maintenance cost data

Equipment	Jan-2013	Feb-2013	Mar-2013	Apr-2013	May-2013	TOTAL (KSHS)
Crusher	2,161,000	108,000.00	339,000.00	3,290,000.	342,000.00	6,240,000
coal mill	37,000.00	171,000.00	54,000.00	137,000.00	134,000.00	533,000
Raw mill	3,720,000.	274,000.00	2,973,000.	16,798,000.	1,963,000.	**25,728,000**
kiln	700,000.00	216,000.00	2,694,000.	411,000.00	260,000.00	4,281,000
Cement mill	84,000.00	1,950,000.	77,000.00	1,827,000.	730,000.00	4,668,000
packer 1	746,000.00	649,000.00	311,000.00	453,000.00	934,000.00	3,093,000
packer 2	970,000.00	77,000.00	334,000.00	225,000.00	17,000.00	1,623,000

Appendix 2: Raw mill data June 2010 – July 2011

Total stop Days	**14.25**	**11.21**	**13.11**	**27.14**	**23.17**	**15.48**	**21.56**	**12.40**	**15.68**	**9.15**	**14.17**	**13.30**
Downtime ownership, Hrs												
Production	184.80	144.40	115.20	8.70	15.70	155.00	249.30	161.70	231.10	75.30	157.60	202.90
Engineering	43.30	48.80	79.40	0.00	10.50	25.70	33.80	28.70	12.20	33.10	4.10	19.30
Mechanical	86.30	63.70	58.60	14.90	158.20	168.90	208.00	92.50	113.80	79.80	151.60	82.80
Electrical	15.80	12.10	8.60	3.90	6.70	18.10	6.50	5.90	16.40	23.10	11.00	8.60
Projects	0.00	0.00	0.00	1.10	13.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KPLC	5.40	0.00	11.00	0.00	9.30	3.90	8.50	8.70	2.70	8.20	13.70	5.60
Works	5.20	0.00	41.80	622.70	342.30	0.00	11.40	0.00	0.00	0.00	2.00	0.00
MOB	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total stop hrs	**342.10**	**269.00**	**314.60**	**651.30**	**556.10**	**371.60**	**517.50**	**297.50**	**376.20**	**219.50**	**340.00**	**319.20**
Total No. of stops	154.00	76.00	109.00	17.00	61.00	172.00	104.00	103.00	84.00	153.00	107.00	114.00
No. of stops due to power	2.00	0.00	4.00	0.00	3.00	6.00	6.00	7.00	3.00	5.00	5.00	7.00
Running Days	**16.75**	**19.79**	**16.89**	**3.86**	**6.83**	**15.52**	**9.44**	**15.60**	**15.33**	**20.85**	**16.83**	**16.70**
Atox Run factor,%	**54.0**	**63.8**	**56.3**	**12.5**	**22.8**	**50.1**	**30.4**	**55.7**	**49.4**	**69.5**	**54.3**	**55.7**
MTBS ,hrs	2.6	6.3	3.7	5.5	2.7	2.2	2.2	3.6	4.4	3.3	3.8	3.5
Availability	80.5	83.3	79.6	97.3	73.8	71.4	66.6	81.1	80.9	81.1	77.6	84.6
Reliability	57.9	68.3	64.4	12.5	23.4	52.1	32.3	59.0	50.5	73.7	55.6	57.7
Capacity utilization @135	98.5	98.2	98.5	100.0	100.0	99.2	99.7	97.5	84.7	97.9	94.7	95.8
Capacity utilization @140	**95.0**	**94.7**	**95.0**	**96.4**	**96.4**	**95.7**	**96.1**	**94.0**	**81.7**	**94.4**	**91.3**	**92.4**
Quality factor,%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
OEE	56.5	67.1	63.4	12.5	23.4	51.7	32.2	57.6	42.7	72.2	52.7	55.2
Average Daily Output	**3191.4**	**3181.7**	**3191.4**	**3240.0**	**3240.0**	**3214.1**	**3230.3**	**3159.0**	**2744.3**	**3172.0**	**3068.3**	**3103.9**
Avg daily output (reconciled stks)	**3163.1**	**3182.5**	**3192.0**	**3323.0**	**3311.4**	**3214.4**	**3229.2**	**3160.6**	**2743.5**	**3172.2**	**3069.6**	**3103.1**
Power consumed, raw milling , Kwh	1,085,300	1,209,800	1,063,300	249,400	499,300	1,081,200	712500.0	1,070,400	952,800	1,357,700	1,108,700	1,148,000
Power consumed, Raw mtl handling	57990	55180	39640	11680	18210	46540	44060	47270	81,350	87,030	77,320	76,650
Total Kwh	**1,143,290**	**1,264,980**	**1,102,940**	**261,080**	**517,510**	**1,127,740**	**756,560**	**1,117,670**	**1,034,150**	**1,444,730**	**1,186,020**	**1,224,650**
Kwh/t	**21.6**	**20.1**	**20.5**	**20.3**	**22.9**	**22.6**	**24.8**	**22.7**	**24.6**	**21.8**	**23.0**	**23.6**
Total Potential R/meal o/p calc'ed	**53,442.7**	**62,970.8**	**53,908.1**	**12,514.5**	**22,126.5**	**49,871.8**	**30,485.8**	**49,293.6**	**42,056.1**	**66,148.6**	**51,649.4**	**51,835.5**
Actual R/meal Prod. (reconciled)	52,968.0	62,987.0	53,919.0	12,835.0	22,614.0	49,876.0	30,476.0	49,319.0	42,044.0	66,153.0	51,671.0	51,821

Appendix 3: Raw mill June 2011 – July 2012

Total stop Days	**17.26**	**13.46**	**13.66**	**11.50**	**26.16**	**8.24**	**21.99**	**19.68**	**16.21**	**18.46**	**15.41**	**8.45**
Downtime ownership, Hrs												
Production	112.90	121.70	144.70	96.00	20.90	111.80	473.20	402.70	257.60	313.70	305.50	123.10
Engineering	9.90	20.30	74.20	74.50	0.00	7.70	7.20	0.00	94.70	65.20	8.30	44.40
Mechanical	46.10	163.10	100.10	55.30	48.40	39.40	39.40	47.50	12.40	18.00	15.60	18.90
Electrical	11.90	10.50	3.50	16.80	32.20	31.70	4.90	17.70	11.00	33.60	26.50	12.50
Projects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Administration	3.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KPLC	0.90	7.40	5.40	33.50	3.70	7.10	3.00	4.40	13.40	12.60	13.90	4.00
Works	229.30	0.00	0.00	0.00	522.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total stop hrs	**414.30**	**323.00**	**327.90**	**276.10**	**627.80**	**197.70**	**527.70**	**472.30**	**389.10**	**443.10**	**369.80**	**202.90**
Total No. of stops	85.00	143.00	128.00	172.00	43.00	212.00	64.00	122.00	80.00	87.00	135.00	139.00
No. of stops due to power	2.00	5.00	6.00	12.00	2.00	14.00	3.00	6.00	10.00	9.00	9.00	4.00
Running Days	**13.74**	**17.54**	**16.34**	**19.50**	**3.84**	**22.76**	**9.01**	**8.32**	**14.79**	**11.54**	**15.59**	**21.55**
Atox Run factor,%	**44.3**	**56.6**	**54.5**	**62.9**	**12.8**	**73.4**	**29.1**	**29.7**	**47.7**	**38.5**	**50.3**	**71.8**
MTBS ,hrs	3.9	2.9	3.1	2.7	2.1	2.6	3.4	1.8	4.4	3.2	2.8	3.7
Availability	90.9	73.9	75.3	80.3	88.8	89.4	93.1	90.6	84.1	83.8	93.2	89.5
Reliability	45.0	58.8	61.2	73.6	12.9	74.9	29.5	32.4	55.8	43.1	51.8	77.0
Capacity utilization @135	97.2	96.5	97.0	97.6	95.9	93.5	95.5	93.7	97.9	96.8	93.6	93.8
Capacity utilization @140	**93.7**	**93.1**	**93.5**	**94.1**	**92.5**	**90.2**	**92.1**	**90.4**	**94.4**	**93.3**	**90.3**	**90.5**
Quality factor,%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
OEE	43.7	56.7	59.4	71.8	12.4	70.1	28.2	30.3	54.7	41.8	48.5	72.2
Average Daily Output	**3149.3**	**3126.6**	**3142.8**	**3162.2**	**3107.2**	**3029.4**	**3094.2**	**3035.9**	**3172.0**	**3136.3**	**3032.6**	**3039.1**
Avg daily output (reconciled stks)	**3151.6**	**3124.6**	**3142.8**	**3163.2**	**3111.4**	**3030.1**	**3095.0**	**3403.5**	**3174.0**	**3138.4**	**3032.5**	**3039.0**
Power consumed, raw milling , Kwh	931,500	1,175,800	1,043,200	1,285,400	293,800	1,472,800	58390 0.0	621,500	931,000	785,200	1,074,200	1,446,900
Power consumed, Raw mtl handling	86650	82820	76550	83710	16260	46060	23320	33090	36,160	35,920	42,670	52,110
Total Kwh	**1,018,150**	**1,258,620**	**1,119,750**	**1,369,110**	**310,060**	**1,518,860**	**607,220**	**654,590**	**967,160**	**821,120**	**1,116,870**	**1,499,010**
Kwh/t	**23.5**	**23.0**	**21.8**	**22.2**	**25.9**	**22.0**	**21.8**	**23.1**	**20.6**	**22.7**	**23.6**	**22.9**
Total Potential R/meal o/p calc'ed	**43,263.2**	**54,845.8**	**51,345.5**	**61,650.5**	**11,936.7**	**68,956.7**	**27,886.5**	**25,261.1**	**46,905.4**	**36,185.3**	**47,283.9**	**65,480.4**
Actual R/meal Prod. (reconciled)	43,295.0	54,811.0	51,346.0	61,669.0	11,953.0	68,973.0	27,894.0	28,320.0	46,936.0	36,209.0	47,281.0	65,478

Appendix 4: Raw mill data June 2012 – July 2013

Total stop Days	**11.00**	**12.42**	**13.91**	**22.17**	**8.07**	**8.97**	**16.15**	**12.10**	**14.40**	**15.29**	**15.10**	**15.09**
Downtime ownership, Hrs												
Production	182.00	169.70	93.40	78.20	47.10	77.50	141.00	34.80	35.70	60.90	13.80	184.70
Engineering	30.10	43.20	9.70	10.50	48.50	32.10	16.70	0.00	8.80	0.00	0.00	6.90
Mechanical	27.80	51.20	34.40	50.80	57.20	85.70	61.20	217.10	151.70	130.80	331.30	44.70
Electrical	21.10	12.70	4.80	10.10	33.70	17.60	7.70	24.10	18.90	0.00	8.70	116.30
Projects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.90	0.00	0.00
Administration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KPLC	3.00	21.30	8.30	0.90	7.10	2.40	4.00	14.50	5.60	14.30	8.70	9.50
Works	0.00	0.00	183.20	381.60	0.00	0.00	157.10	0.00	124.80	149.10	0.00	0.00
MOB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total stop hrs	**264.00**	**298.10**	**333.80**	**532.10**	**193.60**	**215.30**	**387.70**	**290.50**	**345.50**	**367.00**	**362.50**	**362.10**
Total No. of stops	165.00	89.00	98.00	68.00	176.00	363.00	150.00	159.00	203.00	209.00	142.00	96.00
No. of stops due to power	6.00	9.00	9.00	3.00	17.00	8.00	11.00	9.00	8.00	12.00	4.00	5.00
Running Days	**20.00**	**18.58**	**16.09**	**8.83**	**21.93**	**22.03**	**14.85**	**15.90**	**16.60**	**14.71**	**15.90**	**14.91**
Atox Run factor,%	**64.5**	**59.9**	**53.6**	**28.5**	**73.1**	**71.1**	**47.9**	**56.8**	**53.6**	**49.0**	**51.3**	**49.7**
MTBS ,hrs	2.9	5.0	3.9	3.1	3.0	1.5	2.4	2.4	2.0	1.7	2.7	3.7
Availability	89.4	85.6	93.2	90.4	80.6	81.3	88.5	64.1	75.9	80.2	54.3	76.7
Reliability	67.5	65.6	55.0	28.9	79.2	74.3	49.3	58.0	54.6	50.0	51.9	50.9
Capacity utilization @135	91.8	93.6	91.9	92.2	99.8	93.3	100.0	92.0	93.8	85.6	99.8	98.4
Capacity utilization @140	**88.5**	**90.3**	**88.6**	**88.9**	**96.2**	**90.0**	**96.4**	**88.7**	**90.5**	**82.5**	**96.2**	**94.9**
Quality factor,%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
OEE	62.0	61.4	50.6	26.7	79	69.3	49.3	53.4	51.2	42.8	51.8	50.1
Average Daily Output	**2974.3**	**3032.6**	**2977.6**	**2987.3**	**3233.5**	**3022.9**	**3240.0**	**2980.8**	**3039.1**	**2773.4**	**3233.5**	**3188.2**
Avg daily output (reconciled stks)	**2974.9**	**3032.2**	**2978.2**	**2988.8**	**3232.2**	**3022.3**	**3251.1**	**2980.4**	**3038.3**	**2772.8**	**3234.2**	**3189.1**
Power consumed, raw milling , Kwh	1,375,400	1,235,900	1,039,400	590,100	1,421,000	1,456,800	1019000.0	1,019,500	1,106,900	982,900	1,100,400	1,006,100
Power consumed, Raw mtl handling	51530	58570	49040	26240	42630	47320	35910	32410	33,350	24,260	31,760	32,700
Total Kwh	**1,426,930**	**1,294,470**	**1,088,440**	**616,340**	**1,463,630**	**1,504,120**	**1,054,910**	**1,051,910**	**1,140,250**	**1,007,160**	**1,132,160**	**1,038,800**
Kwh/t	**24.0**	**23.0**	**22.7**	**23.4**	**20.6**	**22.6**	**21.9**	**22.2**	**22.6**	**24.7**	**22.0**	**21.8**
Total Potential R/meal o/p calc'ed	**59,486.4**	**56,343.9**	**47,913.9**	**26,375.2**	**70,921.9**	**66,592.4**	**48,100.5**	**47,382.3**	**50,462.1**	**40,792.7**	**51,399.5**	**47,543.4**
Actual R/meal Prod. (reconciled)	59,498.0	56,335.0	47,925.0	26,389.0	70,892.0	66,578.0	48,266.0	47,376.0	50,449.0	40,784.0	51,410.0	47,557