TOTAL PRODUCTIVE MAINTENANCE PRACTICES AND EQUIPMENT EFFECTIVENESS: A CASE STUDY OF BAMBURI CEMENT LIMITED

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DECLARATION

This project is my original work and has not been submitted for an award of any degree in any other university.

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DEDICATION

This project is dedicated to my mother, sisters, nieces and nephews.

ABSTRACT

The reliable performance of equipment is critical for prompt product and service delivery and eventual profitability of manufacturing organisations. In order to enhance this reliable performance of equipment, these organisations have deployed alternative models and strategies of equipment maintenance to complement the traditional strategies of equipment maintenance. Total Productive Maintenance (TPM) is one of the models of equipment maintenance whose implementation has been proposed in order to increase and sustain the effectiveness of equipment. The objective of this study was to explore the relationship between the implementation of total productive maintenance (TPM) practices and the equipment effectiveness of a typical large scale manufacturing concern in Kenya, taking the case of Bamburi Cement Limited (BCL). The study used secondary data collected from the organisation's archived records. Inferential statistics was used to analyse and present the data. The preliminary results of the analysis showed that the implementation of TPM practices at BCL caused a significant increase in the equipment effectiveness in the organisation. The analysis also showed that of the many TPM practices deployed, autonomous maintenance of equipment by production operators played the biggest role in increasing the equipment effectiveness. This study provides insights to operations managers on the strategies of implementation of various TPM practices to improve the effectiveness of their production equipment. In particular, the study recommends the implementation of autonomous maintenance in manufacturing, by ensuring that equipment operators are proficient in basic maintenance of their equipment. In the current era of global competition, implementation of these TPM practices will assist greatly in ensuring continued and sustainable production of quality products and services.

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ACRONYMS AND ABBREVIATIONS

BCL Bamburi Cement Limited

CMMS Computerised Maintenance Management System

EEM Early Equipment Management

GDP Gross Domestic Product rate

ICR International Cement Review

IMF International Monetary Fund

JIPM Japan Institute of Plant Maintenance

MI Maintainability Improvement

MP Manufacturing Performance

MTPA Million tonnes per year

OEE Overall equipment effectiveness

PM Planned Maintenance

RCA Root Cause Analysis

SIB Standard Investment Bank

SSA Sub Saharan Africa

SQRT Square Root

TPM Total Productive Maintenance

WCM World Class Manufacturing

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The efficiency and effectiveness of equipment plays a dominant role in modern manufacturing industry in determining the performance of the organization's production function as well as the level of success achieved in the organization. The performance of the production function is diminished by inefficient equipment that generate losses occasioned by equipment failure, reduced performance and defective products (Seng, Jantan, & Ramayah, 2005). To increase manufacturing productivity, production improvement strategies are employed that aim to minimize input and maximize output (Rajan & Sajumon, 2013). Total productive maintenance (TPM) is an operational strategy that aims to overcome the production losses caused by equipment inefficiency (Seng et al., 2005). TPM improves production output by increasing not just the sheer quantity produced, but also by improving quality, reducing costs and meeting delivery dates while improving safety and health conditions and the working environment in general (Nakajima, 1988).

Plant maintenance is an important service function of an efficient production system. It helps in maintaining and increasing the operational efficiency of plant facilities by decreasing the number, frequency, and severity of equipment breakdowns thereby reducing operating costs and increasing the effectiveness of production (Sethia, Shende, & Dange, 2014). TPM is a continuous improvement process of equipment maintenance whose goal is to reduce emergency and unscheduled maintenance of equipment by empowering operators to carry out basic routine maintenance of their equipment (Jain, Bhatti, & Singh, 2014). By promoting the optimal utilization of organisational resources such as machinery, men, and materials, TPM meets maintenance needs by keeping equipment in top condition so as to avoid breakdowns and delays in production (Sethia et al., 2014).

The Kenyan cement industry has seen a steady increase in production capacity driven by the entry of new cement producers into the market and extensive capacity expansion by existing players in response to increasing competition. This has led to consistent oversupply of cement in the market (Faida Investment Bank, 2014). The challenges of dampened profitability margins caused by increased competition among the existing cement producers as well as the threat of competition from cheaper imports has increased the need for cost containment through increased productivity and more efficient operations to ensure sustainable world class competitiveness (Molonket, Ombuki, & Wawire, 2014). To increase productivity, organizations develop techniques and maintenance strategies that focus on the prevention of equipment failures and increasing equipment availability for operation (Bartz, Siluk, & Bartz, 2014). Among these strategies and techniques, preventive maintenance, predictive maintenance, total productive maintenance (TPM) and more recently, the reliability-centered maintenance stand out (Khalil, Saad, & Gindy, 2009).

1.1.1 Total Productive Maintenance

Total productive maintenance (TPM) is a process of maintenance management that empowers the organization with a progressive, continuous philosophy of enabling all manpower resources to work together to accomplish the mutual goal of manufacturing efficiency (Gupta, Tewari, & Sharma, 2006). The goal of TPM is to increase the productivity of plant and equipment through the involvement of all employees in the organization in the various departments like production, maintenance, technical services, and stores (Wang, 2005). TPM was introduced into manufacturing in order to avoid wastages in a quickly changing economic environment, produce goods without reducing product quality, reduce costs and produce a low batch quantity at the earliest possible time (Hangad & Kumar, 2013).

TPM is a maintenance program philosophy which is similar in nature to total quality management (TQM) in several aspects, including the total commitment of upper-level management to the programme, empowerment of employees to take initiatives and corrective actions, and the need for continuity and long-term strategy. With the implementation of TPM, maintenance is no longer the necessary evil, but a vitally important part of the business. The general vision of TPM eliminates any "conflict of interest" between production and maintenance departments (Chan, 2005).

The goal of Total Productive Maintenance (TPM) is to increase the productivity of plants and equipment through the involvement of all employees in the organization in the various departments like production, maintenance, technical services, and stores (Wang, 2005). TPM involves maximising the utilisation of equipment to establish a comprehensive approach towards maintenance of equipment during the entire product life span, involving all employees from top management to shop-floor workers, promoting preventive maintenance through staff motivation and increasing productivity while, at the same time, improving employee morale and job satisfaction (Sharma, Kumar, & Kumar, 2006).

TPM describes a synergistic relationship among all organizational functions, but particularly between production and maintenance, for the continuous improvement of product quality, operational efficiency, productivity and safety. TPM brings maintenance into focus as a necessary and vitally important part of the business. It is no longer regarded as a non-profit activity. TPM focuses upon the entire organization for the systematic identification and elimination of wastes like planned and unplanned downtime, inefficient operation cycle time, and quality defects in manufacturing and related processes (Sharma et al., 2006).

With competition in manufacturing industries rising relentlessly, TPM has proved to be the maintenance improvement philosophy preventing the failure of an organization (Eti, Ogaji, & Probert, 2006). Wakjira and Singh (2012) argue that today, an effective TPM strategy and programs are needed, which can cope with the dynamic needs and discover the hidden but unused or underutilized resources (human brainpower, man-hours, machine-hours). A well conceived TPM implementation program will not only improve the equipment efficiency and effectiveness but also bring appreciable improvements in other areas of the manufacturing enterprise.

1.1.2 Equipment Effectiveness

Organizations should implement good equipment maintenance systems in order to continuously improve both productivity and product quality due to customer requirement of good quality product, less product delivery time and low production costs (Jain et al., 2014). To operate efficiently and effectively, manufacturing sectors need to ensure no disruption of production due to equipment breakdown, stoppages and failure (Gupta & Garg, 2012). The most efficient way to maximize equipment output is to eliminate the major causes of losses that prevent the equipment from being effective (Wang, 2005).

There are six big time losses encountered in industrial operations: equipment failure, setup and adjustment, idling and minor stoppages, reduced speed, defects in process, and reduced yield. Equipment failure and setup and adjustment are categorized as downtime time loss, and result in the reduction of availability of the equipment; idling and minor stoppages and reduced speed are categorized as speed loss, thus reducing the performance of the equipment; defects in process and reduced yields are considered as defect losses and result in reduction of the quality rate of the equipment (Nakajima, 1988).

The quantification of these accumulations of waste in time and its comparison to the total available time can give the production and the maintenance management personnel a general view of the actual performance of the plant, which can help them to focus the improvement on the bigger loss (Kocher, Kumar, Singh, & Dhillon, 2012). Nakajima (1988) proposes that the six big losses encountered in manufacturing be combined into one measure of overall equipment effectiveness (OEE). OEE is a measure of total equipment performance, that is, the degree to which the equipment is doing what it is supposed to do (Williamson, 2006). OEE is calculated by obtaining the product of the availability of the equipment, performance efficiency of the process and the rate of quality products. An OEE of 85 percent is considered as being world class and a benchmark to be established for a typical manufacturing concern (Nakajima, 1988).

1.1.3 Total Productive Maintenance and Equipment Effectiveness

Total Productive Maintenance is a strategy used to maintain equipment in optimum condition in order to prevent unexpected breakdown, speed losses, and quality defects occurring from process activities. The objective of TPM implementation is to create a sustainable competitive advantage of an organization by increasing manufacturing productivity and equipment efficiency (Gupta et al., 2006). It is a manufacturing program designed primarily to maximize equipment effectiveness throughout its entire life through the participation and motivation of the entire work force (Nakajima, 1998).

Overall equipment effectiveness (OEE) is a metric for evaluating the progress of implementation of TPM (Nakajima, 1988). It is a framework for measuring the efficiency and effectiveness of a process, by breaking it down into three constituent components; availability, performance and quality. OEE is a metric for defining equipment effectiveness in a TPM program (Vorne, 2013). The overall goal of TPM is to raise the overall equipment effectiveness (OEE) (Huang et al., 2002). TPM employs OEE as a quantitative metric for measuring the performance of a productive system (Huang et al., 2002). OEE is the core metric for measuring the success of a TPM implementation program (Jeong & Phillips, 2001).

TPM practices aim to make the improvement of OEE and labor productivity, and eventually to secure zero equipment failure, zero defects and rework and zero industrial accidents (Shirose, 1999). The strategic objective of TPM implementations is to reduce the occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which, according to Gosavi (2006), can exceed millions of dollars annually. TPM practices enable improvement of the performance of production facilities by continuously and systematically addressing the sources of major losses and wastes inherent in the production systems (Gupta, Sonwalkar, & Chitale, 2001). The OEE measure is central to the formulation and execution of a TPM improvement strategy (Ljungberg, 1998). TPM has the standards of 90 per cent availability rate, 95 percent performance efficiency rate and 99 percent rate of quality. This results in an OEE measure of 85 percent (Sohal, Olhager, O'Neill, & Prajogo, 2010).

TPM is a strategic change management approach that has a considerable impact on the internal efficiency of manufacturing organization by increasing the effectiveness of the production environment, especially through increasing the effectiveness of equipments (Sharma, Gera, Kumar, Chaudhary, & Gupta, 2012). Its implementation can significantly contribute towards improvement in organizational behavior in the manufacturing enterprises leading to world class competitiveness (Ahuja, Khamba,& Choudhary, 2006).

1.1.4 Bamburi Cement Limited

Bamburi Cement Limited (BCL) was founded by Felix Mandl (a director of Cementia Holdings A.G. Zurich) in 1951. Cementia later partnered with Blue Circle PLC (UK). Cementia was acquired by Lafarge in 1989, making Lafarge an equal shareholder with Blue Circle in BCL. In 2001, Lafarge acquired Blue Circle to become BCL's principle shareholder (Collomb, Brenneisen, Groom, & Hillenmeyer, 2004). In July 2015, Lafarge merged with Holcim to form LafargeHolcim, the biggest producer of building materials in the world (International Cement Review, 2015).

According to Ecobank Research (2014), cement producers in Sub Saharan Africa (SSA) are facing serious challenges to their competitiveness and commercial viability, the most significant being the risk of overcapacity following the wave of investment in new plants expected over the next five years. The sector is also vulnerable to rising production costs, which are among the highest in the world. Given Africa's poorly developed power networks, cement companies depend on costly fuel imports for power generation, exposing the sector to volatility in international energy prices. High energy costs reduce the competitiveness of locally produced cement, especially when compared with cheaper imports from Asia.

By early 1995, Kenya's economy became substantially liberalised, bringing with it new opportunities and new threats, particularly in the form of imports to threaten the domestic market. It was the realisation in 1993/4 that imports were going to pose a serious threat to the future profitability of BCL that drove many of the actions that took place in BCL from 1995 onwards. Although BCL was profitable, and looked like becoming more so over the next few years, it was evident that, in the long run, the company's very existence would be threatened unless its cost base was substantially reduced (Collomb et al., 2004).

The challenges of dampened profitability margins caused by fierce competition among the existing cement producers in the region as well as the threat of competition from cheaper imports has increased the need for cost containment through increased productivity and more efficient operations to ensure sustainable world class competitiveness (Molonket et al., 2014). To this end, organizations have developed techniques and maintenance strategies that focus on the prevention of equipment failures, and increasing equipment availability for operation and reliability when in use (Bartz, Siluk, & Bartz, 2014). Among these strategies and techniques, preventive maintenance, predictive maintenance, total productive maintenance (TPM) and more recently, the reliability-centered maintenance stand out (Khalil et al., 2009).

BCL's management then started preparing the company for adapting to a continually changing environment and to increasing labour costs. By introducing new working practices, streamlining operations, re-training managers and instilling the concept of delegation, BCL was able to halve its workforce, reduce overtime levels, achieve safety records and increase running times, efficiencies and output (Collomb et al., 2004).

1.2 Research Problem

The main objective of total productive maintenance (TPM) is to enhance the overall effectiveness of factory equipment, and the provision of an optimal group organization approach for the accomplishment of system maintenance practices. In manufacturing industries, TPM is one of the very important factory maintenance methodologies that are used throughout a product life cycle that try to optimize the effective use of production installations (Wang, 2005). This effectiveness can be measured in terms of the overall equipment effectiveness (OEE), which is a function of equipment availability, performance efficiency, and quality rate (Huang et al., 2002).

According to Standard Investment Bank (2013), excess capacity in the East African cement sector is likely to suppress any price increase, and the cement producing companies will have to continue absorbing increasing production costs. To deal with the risk of increased local and global competition, BCL has been forced to radically rethink its strategy and focus on reduction of operational costs (Molonket et al., 2014). Faced with the phenomenon of globalization, equipment maintenance becomes focused under the vision of quality and productivity management. In that sense, the adoption of a model of strategic maintenance management such as TPM has been increasingly accepted in industrial organizations (Bartz et al., 2014).

Past studies have been conducted on the effects of TPM practices on equipment effectiveness. For instance, Sharma et al. (2006) conducted a case study to establish the various issues related with TPM implementation in a semi-automated cell in an Indian manufacturing firm. They found that TPM not only leads to an increase in efficiency and effectiveness of manufacturing systems, measured in terms of OEE, by reducing the wastages but also prepares the plant to meet the challenges put forward by globally competing economies to achieve world class manufacturing (WCM) status.

Wakjira and Singh (2012) conducted a study to evaluate the contributions of TPM initiatives towards improving manufacturing performance in the Ethiopian malt manufacturing industry. Their study established that focused TPM implementation can strategically contribute towards realization of significant manufacturing performance enhancements. Bartz et al. (2014) conducted a study on the implementation of a maintenance management model based on (TPM) in a production line of a metallurgical company in Brazil. They observed that after the implementation of TPM, there was a significant improvement of the performance indicators of the production lines. They thus concluded that the TPM assists in improving industrial performance and competitiveness of the production line studied.

Some local researchers have investigated TPM practices in Kenyan firms, but none on the effects of TPM on equipment effectiveness. Induswe (2013) for example investigated the challenges, success factors and benefits of TPM implementation in large manufacturing firms in Kenya. Ateka (2013) examined the adoption of TPM practices in large manufacturing firms located in Mombasa County. Matuga (2013) conducted a study to establish the contribution of TPM strategy on Unilever Kenya's competitive advantage.

The researcher is not aware of any studies that have focused on the effects of the implementation of TPM practices on equipment effectiveness of the Kenyan manufacturing industry and specifically in the Kenyan cement industry. This is significant because the cement industry in Kenya is facing a very challenging future due to increased competition from emerging local manufacturers and from imports SIB (2013). This study made an attempt to fill that gap.

Eti et al. (2006) have argued that with competition in manufacturing industries rising relentlessly, TPM has proved to be the maintenance improvement philosophy preventing the failure of organizations. The researcher therefore studied the effects of the implementation of TPM practices on equipment effectiveness in the Kenyan cement industry, taking the case of Bamburi Cement Limited. This leads to the research question; does the implementation of TPM practices affect the equipment effectiveness of a manufacturing firm?

1.3 Research Objective

The objective of the study was to establish the relationship between the implementation of TPM practices and the availability rate, performance rate, quality rate and the overall equipment effectiveness (OEE) rate at Bamburi Cement Limited (BCL).

1.4 Value of the Study

This study is valuable to researchers, scholars, managers and policy makers both in the private and public sectors. To the researchers and scholars, the study highlights the relationship between the implementation of the various TPM practices and the overall equipment effectiveness of a Kenyan cement manufacturing enterprise.

The study is useful to professionals and managers in Kenyan cement companies in highlighting the benefits in equipment effectiveness occasioned by adoption of TPM practices and the success factors required for successful TPM implementation, which can help them justify the need for implementing TPM practices in their respective organisations, and improve the equipment effectiveness of these organizations.

To policy makers it is hoped the study provides insights into ways of increasing industrial productivity and competitiveness to enable them formulate policies that may help create maximum value from their industries by using their resources creatively to increase performance and guarantee survival in the face of increasing global competition.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review. First, the theoretical foundation of the study is discussed. The strategies of implementation of TPM are then discussed, followed by the equipment maintenance practices that comprise the implementation of a TPM program. A summary of the empirical review of the relationship between TPM and operational performance is then presented. Finally, the conceptual framework that was adopted by the study is presented.

2.2 Theoretical Foundation of Total Productive Maintenance

Maintenance of facilities and equipment in good working condition is essential to the attainment of the specified level of quality and reliability and efficient working. Maintenance is defined as activities that retain the performance of equipment. The number, frequency, and severity of equipment breakdowns can be decreased with proper maintenance. Maintenance includes repairing current deficiencies in equipment performance and taking action to prevent future problems. The major categories of maintenance include breakdown maintenance (where people wait until equipment fails before repairing it), preventive maintenance (PM) (where a system is created for diagnosing equipment condition and taking action to prolong the service life of the equipment), corrective maintenance (where equipment with design weaknesses are redesigned to improve reliability or maintainability) and maintenance prevention (MP) (which involves design of new equipment while focusing on improving reliability) (Sethia et al., 2014).

Preventive maintenance is the daily maintenance of equipment that involves cleaning, inspection, oiling and retightening, done in order to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. Maintenance prevention is the design of new equipment that involves studying the weaknesses of current equipment and incorporating in the new equipment failure prevention techniques while enabling easier maintenance and prevention of product defects.

TPM is an equipment maintenance philosophy where preventive maintenance is performed by the equipment operators in a practice called autonomous maintenance and maintenance prevention is done by a dedicated maintenance crew to improve equipment reliability (Venkatesh, 2007). The objective of implementing TPM in manufacturing is to eliminate losses and wastes by ensuring employee participation in equipment maintenance (Vorne, 2013). The underlying TPM concept is that if plant machinery is maintained properly, there will see a sharp decline in machine breakdowns, safety and quality problems (Sethia et al., 2014).

TPM consists of three words: total; this signifies to consider every aspect of equipment maintenance and involving everybody from top to bottom, productive; emphasis is on trying to do maintenance while production goes on and minimize troubles for production, maintenance; means keeping equipment in good condition autonomously by production operators – repair, clean, grease, and accept to spend necessary time on them (Ahuja & Khamba, 2007). TPM is “a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team based participation of employees across all levels of the operational hierarchy" (Pomorski, 2004, p. 6).

TPM implementation involves the adoption of life cycle approach for improving the overall equipment effectiveness (OEE) of production equipment, improvement of equipment productivity by highly motivated workers through job enlargement, and the use of voluntary small group activities for identifying the causes of failure, and performing equipment modifications to prevent these failures (Venkatesh, 2007). TPM emphasizes proactive and preventative maintenance to maximize the OEE of equipment. The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by equipment operators in preventive maintenance (Vorne, 2013).

2.3 Strategies of Implementation of Total Productive Maintenance

In order to achieve a successful implementation of TPM in a manufacturing organization, two approaches or strategies are employed; Human-oriented strategy and Process-oriented Strategy (Varotaria & Barelwala, 2014). Human-oriented strategy factors are important while formulating the foundation prior to TPM implementation; whereas the process oriented strategy factors are important in the subsequent phase of achieving a successful TPM implementation within an organization (Pathak, 2015).

2.3.1 Human-oriented Strategy

Human-oriented strategies are strategies that actively involve the administrative application of management methods in implementing TPM practices in order to achieve a high implementation of TPM (Varotaria & Barelwala, 2014). The application of human oriented strategy involves three important aspects; Top management commitment and leadership, Total Employee Involvement and Cultural transformation (Pathak, 2015).

Top management commitment and leadership is crucial to the successful implementation of TPM (Tsang & Chan, 2000). The top management establishes a strategic direction for TPM implementation by formulating a master plan for effective TPM implementation within the organization, enabling cultural transformation, communicating TPM goals and objectives throughout the organization, providing sufficient resources for influencing process improvements, providing appropriate training and education for the workforce to develop TPM related competencies, encouraging cross functional working within the organization by enhancing inter-departmental synergy, and promoting proactive maintenance initiatives (Pathak, 2015).

Total employee involvement is achieved when all employees to have a common understanding of the basic principles of TPM. Shop floor operators have the most hands-on experience with the machines they operate daily. In order to achieve successful autonomous maintenance by the shop floor operators, high levels of maintenance awareness and simple routine maintenance tasks are integrated into their daily duties (Varotaria & Barelwala, 2014).

The TPM implementation process requires a radical transformation in the organization's culture to enhance total employee involvement towards manufacturing performance enhancement. The top management has to make concerted efforts to enhance motivation within the organization by creating awareness about the true potential of TPM philosophy and effectively communicating to the employees the direct benefits of TPM implementation. Organizations should ensure buy-in from all employees during the planning and execution phases of TPM implementation by addressing employees' behavioural barriers towards TPM and developing a consciousness that TPM implementation will generate additional skill sets and competencies thereby making the employees more valuable to the organization (Pathak, 2015).

2.3.2 Process-oriented Strategy

Process-oriented Strategy includes all kinds of technical approaches to maximize the overall equipment efficiency by quantitatively, increasing the equipment availability and qualitatively, eliminating all production losses resulting from inefficient equipment (Varotaria & Barelwala, 2014). Process-oriented strategy factors include conventional and proactive maintenance strategies, training and education, and failure prevention and focused production system enhancement (Pathak, 2015).

Majority of the equipment failures can be attributed to the lack of standard operating procedures for business functions including production systems. It is therefore imperative to develop standard work practices and safe operating procedures to be implemented by a competent and motivated workforce. Processes and procedures for collecting and analyzing data associated with manufacturing performance should be developed. To enhance manufacturing performance, the organization should endeavour to influence continuous improvements in the production systems (Pathak, 2015).

The ability of the organization to implement TPM practices successfully depends on the competencies of the workforce. To implement TPM, the entire workforce in the organization needs to acquire new knowledge, skill and abilities related to TPM. Employee training encompasses systematic development of competencies, knowledge and mindset essential for task execution and work performance (Varotaria & Barelwala, 2014). They should develop and implement a loss-elimination process that involves identifying failures and analyzing causes, setting improvements to eliminate the failures, and confirming and consolidating the results (Seng et al., 2005).

2.4 Total Productive Maintenance Practices

The aim of TPM is to increase the availability and effectiveness of existing equipment in a given situation, through the effort of minimizing input (improving and maintaining equipment at optimal level to reduce its life cycle cost) and the investment in human resources which results in better hardware utilization (Afefy, 2013). TPM maximizes the effectiveness of equipment through the use of autonomous maintenance by production operators and the use of small group activities to improve equipment reliability, maintainability and productivity (Sharma et al., 2006).

There is a complexity and divergence of TPM programs adopted throughout industry (Bamber et al., 1999). Infact, Aspinwall and Elgharib (2013) argue that there is no single correct method for the implementation of a TPM program. There are many frameworks for implementing TPM in different organizations having varying environments for garnering suitable manufacturing competencies in order to achieve organizational goals and objectives (Ireland & Dale, 2001).

TPM provides a comprehensive company-wide approach to maintenance management, which can be divided into long-term and short-term TPM practices or elements. Long-term TPM efforts focus on new equipment management and elimination of sources of lost equipment time. Short term TPM activities include an autonomous maintenance program for the production department and a planned maintenance program for the maintenance department (McKone et al., 2001).

2.4.1 New Equipment Management

New equipment management is a system whereby shop-floor personnel participate in the concept and design phase of new equipment in order to develop equipment that requires less maintenance, and is more easily maintained when maintenance is required (Japan Institute of Plant Maintenance, 1996). New equipment management variables assess how the plant directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment, so as to ensure that new equipment reaches planned performance levels much faster due to fewer start up issues (Venkatesh, 2007).

New equipment management entails design activities that are carried out during the planning and construction of new equipment, that impart to the equipment high degrees of reliability, maintainability, economy, operability, safety, and flexibility, while considering maintenance information and new technologies, and to thereby reduce maintenance expenses and deterioration losses (Pomorski, 2004). Sethia et al.,

(2014) describe new equipment management as a maintenance strategy which involves design of new equipment while focusing on improving reliability and refer to the practice as maintenance prevention (MP).

2.4.2 Elimination of Sources of Lost Equipment Time

Lost equipment time variables assess the incorporation of error detection and prevention strategies into the production process and the creation of small groups of employees to work together proactively to achieve regular, incremental improvements in equipment operation (Vorne, 2013). In order to eliminate the sources of lost equipment time, root cause analysis is applied to eliminate recurring sources of equipment failures and quality defects.

To ensure elimination of sources of lost equipment time, the organization targets quality issues with improvement projects focused on removing root sources of defects. The practice reduces maintenance costs by catching equipment defects early. Recurring problems are identified and resolved by cross-functional teams. The practices combine the collective talents of a company to create an engine for continuous improvement (Vorne, 2013). Manufacturing organizations should make intensive efforts to improve the performance of production systems by developing failure prevention initiatives and enhancing the focus on manufacturing system improvements (Pathak, 2015).

2.4.3 Autonomous Maintenance

Autonomous Maintenance places responsibility for routine maintenance, such as cleaning, lubricating, and inspection, in the hands of operators. More responsibility for maintenance gives operators greater "ownership" of their equipment, increases operators' knowledge of their equipment, ensures equipment is well-cleaned and lubricated and helps identify emergent issues before they become failures. It also frees maintenance personnel for higher-level maintenance tasks (Venkatesh, 2007).

There are four elements of autonomous maintenance: focus on housekeeping on the production line, cross-training of personnel, creation and utilization of teams of production and maintenance personnel, and operator involvement in the maintenance delivery system (McKone et al., 2001). Housekeeping of the production line involves creation of a work environment that is clean and well-organized. It consists of the five elements of sort (eliminate anything that is not truly needed in the work area), set in order (organize the remaining items), shine (clean and inspect the work area), standardize (create standards for performing the above three activities) and sustain (ensure the standards are regularly applied) (Vorne, 2013).

Cross-training of personnel ensures operators develop skills to routinely maintain equipment and identify emerging problems and that maintenance personnel learn techniques for proactive and preventive maintenance. Creation and utilization of teams of production and maintenance personnel ensures employees work together proactively to achieve regular, incremental improvements in equipment operation (Vorne, 2013).

2.4.4 Planned Maintenance

Planned Maintenance (PM) is a system where maintenance tasks and equipment stoppages are scheduled based on predicted and/or measured failure rates. PM efforts are evolved from a reactive to a proactive method. The objectives of PM are to achieve and sustain availability of machines, optimize maintenance cost, reduces spares inventory and improve reliability and maintainability of machines (Venkatesh, 2007).

Implementation of a PM system reduces instances of unplanned down time significantly. It enables equipment maintenance to be planned for periods when the equipment is not scheduled for production and reduces inventory by enabling better control of wear-prone and failure-prone parts (Vorne, 2013). JIPM (1996) suggest three elements of planned maintenance: disciplined planning of maintenance tasks, information tracking of equipment and process conditions, and compliance to the maintenance schedule.

2.5 Empirical Review

Several studies have been conducted that seek to establish the relationship between the implementation of TPM practices in an organization and the operational performance of the organization. According to Venkatesh (2007), the direct benefits of TPM implementation include increase in productivity and overall equipment efficiency (OEE), reduction in customer complaints, reduction in the manufacturing cost by 30%, satisfying the customers' needs by 100 % (delivering the right quantity at the right time, in the required quality) and reduced accidents.

Sharma et al. (2006) conducted a case study to examine the need to develop, practice and implement such maintenance practices, which not only reduce sudden sporadic failures in semi-automated cells but also reduce both operation and maintenance costs in a semi-automated cell in an Indian manufacturing firm. The findings indicate that TPM leads to increase in efficiency and effectiveness of manufacturing systems, measured in terms of OEE index, by reducing the wastages. The availability of the cell improved by 17 percent, while performance efficiency improved by 8 percent and quality rate by 20 percent. The OEE measure had increased from 39 to 69 percent.

Ahuja and Khamba (2007) established through a case study of the Indian manufacturing industry that there has been significant improvement in overall equipment effectiveness of all the production facilities as a result of TPM initiatives. The benefits realized through effective TPM implementation program included OEE improvement by 14 - 45 per cent, reduction in customer rejections by 50-75 per cent, reduction in accidents by 90-98 per cent, reduction in maintenance cost by 18-45 per cent, reduction in defects and rework by 65-80 per cent and a reduction in breakdowns by 65-78 per cent.

Bartz et al. (2013) conducted a study of a maintenance management model based on TPM in a production line of a metallurgical company in Brazil, with high-precision equipment requiring effective maintenance to maintain the quality of the production process. The study concluded that TPM assists in improving industrial performance and competitiveness of the production line studied. It was observed that the rate of production efficiency improved from 79.25 to 83.72 percent, and the rate of rework was reduced from 4.6 to 2.3 percent.

Paropate and Sambhe (2013) performed a study on the implementation of TPM in a midsized cotton spinning plant in India. The study found that TPM enables improvement in the availability, performance efficiency and the quality rate of the carding machine, resulting in improvement of the overall equipment effectiveness of the equipment. The values for availability, quality rates, performance efficiency and overall equipment effectiveness before TPM implementation were 89.6832%, 79.29%, 96.4783% and 68.9866% respectively and the values after TPM implementation were 91.96%, 79.758%, 97.177% and 71.465% respectively.

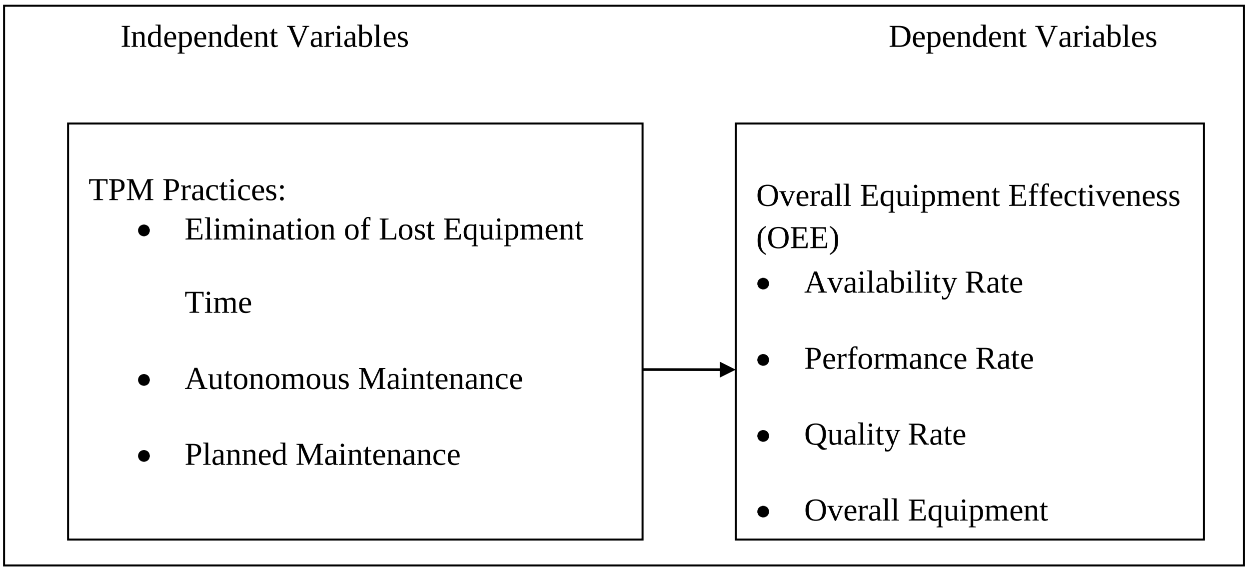
Some local researchers have investigated TPM practices in Kenyan firms, but none on the effects of TPM on equipment effectiveness. Ateka (2013) for example conducted a study to examine the adoption of TPM practices in large manufacturing firms located in Mombasa County. His study identified increased quality and improved productivity as the key benefits resulting from TPM implementation. The study results also showed that the most important critical success factor of TPM is co-operation and involvement of both the operators and the maintenance workers. Induswe (2013) conducted a study to investigate the challenges, success factors and benefits of TPM implementation in large manufacturing firms in Kenya. His study found the benefits of implementing TPM to be elimination of waste and losses, reduction of equipment breakdown, reduction of maintenance costs, optimization of equipment reliability, improvement of operator skills and boosting of the morale of employees.

Matuga (2013) conducted a study to establish the contribution of total productive maintenance strategy to the competitive advantage of Unilever Kenya Limited. Her study found that increased profit margins, reduced accidents in the factory, reduced customer complaints resulting from better quality products, reduced machine breakdown, reduction in maintenance costs and maintenance workforce costs through reduction of overtime labour cost, better planning and scheduling, improved equipment efficiency and availability, employee recognition and empowerment through improved capabilities and competencies, better relationships between operators and maintenance personnel and better competitive edge in global arena were the contributions that Total Productive Maintenance strategy has brought to Unilever Kenya Limited.

2.6 Conceptual Framework

This study attempts to investigate the impact of implementation of Total Productive Maintenance (TPM) practices on operational performance, given by Overall Equipment Effectiveness (OEE). As shown in Figure 2.1, the dependent variable of the study is the OEE which is the product of the equipment availability, performance and quality rates. The independent variables are the various practices of TPM. The independent variables used in this study are elimination of lost equipment time, autonomous maintenance and planned maintenance.

Figure 2.1: Conceptual Framework of the study



CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology of the study. It describes the procedure that was used in conducting the study. It comprises of the research design, justification of selecting the case, the data collection procedure that was used in the study, operationalization of the study variables, and the data analysis techniques that were employed in the study.

3.2 Research Design

The research employed a longitudinal case study design. According to Yin (2003), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between the phenomenon and the context are not clearly evident. Case study design is used when the focus of the study is to answer how and why questions, when the behavior of those involved in the study cannot be manipulated, when it is necessary to cover contextual conditions believed to be relevant to the phenomenon under study, and when the boundaries between the phenomenon and the context are not clear. Eisenhardt (1989) describes the case study as a research strategy which focuses on understanding the dynamics present within single settings. In-depth single-company case studies help develop theories and are particularly suitable for understanding phenomena that are dynamic in nature.

The longitudinal case method provides the opportunity to examine continuous processes in context and to draw in the significance of various interconnected levels of analysis. Furthermore, a longitudinal case study can often better capture firm dynamics over time (Pettigrew, 1990). Longitudinal data collected gives a better guide to long-term processes and outcomes and are more informative about the causal relations that are the drivers of disadvantage or success. Longitudinal studies offer causality – why and how things happen (Kuula & Putkiranta, 2012).

3.3 Case selection

In order to determine the effect of implementation of TPM practices on the equipment effectiveness of manufacturing firms, the study took the case of Bamburi Cement Limited (BCL), focusing on their Mombasa plant. BCL is owned by LafargeHolcim, the biggest producer of building materials in the world (ICR, 2015). According to Molonket et al., (2014), BCL is not only the largest cement producer in Kenya but also the most efficient cement plant in the country, resulting in larger profit margins relative to its competitors.

By early 1995, Kenya's economy became liberalised, bringing new opportunities, and also new threats, particularly in the form of imports to threaten the domestic cement market. It was the realisation that imports were going to pose a serious threat to the future profitability of BCL that drove many of the actions that took place from 1995 onwards. Although BCL was profitable, it was evident that in the long run, the company's very existence would be threatened unless its cost base was substantially reduced (Collomb et al., 2004).

BCL's management then started preparing the company for adapting to a continually changing environment and to increasing labour costs. By introducing new working practices, streamlining operations, re-training managers and instilling the concept of delegation, BCL was able to halve its workforce, reduce overtime levels, achieve safety records and increase running times, efficiencies and output (Collomb et al., 2004). The study sought to establish the impact of implementation of various TPM practices in BCL on the equipment effectiveness of the organization.

3.4 Operationalization of Study Variables

This section describes the variables in the study and how they were operationalized. The independent variables of the study were elimination of sources of lost equipment time, autonomous maintenance and planned maintenance. The dependent variables of the study were the plant performance indicators measured using equipment availability, performance and quality rates to give an overall measure of overall equipment effectiveness (OEE).

Availability rate is the ratio of the actual production time to the potential production time (Vorne, 2013). In this study, equipment availability for BCL was defined as the percentage of the time the kiln shop (Kilns 1 and 2) was available for operation, weighted for Kilns 1 and 2 to give a global availability rate. Performance rate is the ratio of the actual output produced by equipment while in operation to the theoretical output of the equipment during that operation time (Kocher et al., 2012).

Equipment performance of BCL was defined as the ratio of the amount of clinker produced by the kiln shop to the rated production capacity of the shop, weighted to give a global performance rate. Quality rate is the percentage ratio of the number of units produced to the number of the units produced that meet specifications (Nakajima, 1988). Quality rate for BCL was used to refer to the measured value of the compound tri calcium silicate (abbreviated C3S) in the clinker produced in the kiln shop as compared to a set target of C3S, expressed as a percentage, and weighted to give an overall value of global quality rate.

Lost equipment time variables assess the incorporation of error detection and prevention strategies into the production process (Venkatesh, 2007). The error detection and prevention strategy employed at BCL is Root Cause Analysis (RCA). RCA is a structured method of determining the root causes of equipment failures and quality defects in order to prescribe solutions and prevent recurrence of the failures (Japanese Institute of Plant Maintenance, 1996). Elimination of lost equipment time at BCL was measured as the ratio of the number of RCAs conducted by the plant every year to the number of failures in the major equipment line (kiln shop) during that year, expressed as a percentage.

Autonomous maintenance variables include measures for cross-training of employees, use of cross-functional problem-solving teams, and operator involvement in basic equipment maintenance (McKone et al., 2001). The extent of cross-training of employees at BCL was measured as the ratio of the number of employees in operations (either the production or the maintenance departments) who were trained to perform cross functional roles, to the total number of employees in that particular department. The extent of use of cross-functional problem-solving teams at BCL was measured as the ratio of the number of operations employees trained and proficient in RCA who are members of cross functional RCA teams in the plant to the total number of employees in operations at a particular time.

Operator involvement at BCL was measured as the ratio of the number of times a dedicated maintenance team was called into the plant during silent hours of operation (at night and during holidays) for a less than 2 hours kiln stoppage to the total number of such stoppages in the kiln shop. The three measures of autonomous maintenance were weighted equally into one measure that was used an indicator of the extent of implementation of autonomous maintenance at BCL.

Measures of planned maintenance include disciplined planning, information tracking, and schedule compliance (JIPM, 1996). The extent of planned maintenance at BCL was measured as the ratio of the number of kiln stoppages on planned condition-based maintenance to the number of kiln stoppages on incidents (unplanned stoppages) in one year. This measure was used to assess two of the planned maintenance variables: the level of implementation of disciplined planning as well as the level of compliance to the maintenance schedule (schedule compliance).

3.5 Data Collection

The study employed secondary data both for the independent and the dependent variables. Bi-annual data for the independent variables (elimination of lost equipment time, autonomous maintenance and planned maintenance) were collected from records of number of RCAs conducted after failures, creation and use of cross-functional problem-solving teams, cross training of employees, operator involvement in daily equipment maintenance, disciplined planning of maintenance tasks, tracking of information on production performance, and compliance to maintenance schedules for a period of fifteen years from the year 2000 to 2014.

Bi-annual data for the dependent variables (equipment availability, performance and quality rates) was collected using a data collection table from documented and archival records of equipment availability, performance and quality rates of the kiln shop in BCL's Mombasa Plant over the review period. The data was used to calculate the overall equipment effectiveness of the equipment during the review period.

3.6 Data Analysis

The analysis focused on understanding the relationship between the adoption of the TPM practices of elimination of sources of lost equipment time, autonomous maintenance and planned maintenance and equipment effectiveness of BCL. The study was a longitudinal case study and the data was quantitative in nature. Inferential statistics was used to analyze the data. Overall Equipment Effectiveness (OEE) performance was measured in terms of equipment availability, performance and quality rates as well as the overall computed OEE rate. OEE is the product of the equipment availability, performance and quality rates (Vorne, 2013).

Multivariate linear regression analysis was used to analyze the effect of implementation of the TPM practices on equipment availability, performance and quality rates as well as the overall equipment efficiency (OEE) rate. According to Weisberg (2005), regression analysis can be used to determine the dependence of a response variable on one or more predictors, including prediction of future values of a response, discovering which predictors are important, and estimating the impact of changing a predictor on the value of the response. The linear regression model used took the form:

$Y_1 = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon$

$Y_2 = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon$

$Y_3 = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon$

$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon$

Where: Y_1, Y_2, Y_3 were the equipment availability, performance and quality rates respectively and Y the overall equipment effectiveness (OEE); β_0 being a constant, and $\beta_1 - \beta_3$ being the regression coefficients. X_1, X_2 and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively, and ε the error term.

CHAPTER FOUR: DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

The objective of this study was to determine the effect of adoption of TPM practices on the equipment effectiveness at Bamburi Cement Limited (BCL). This chapter presents the findings of the study and the analysis of the findings with regard to the objectives of this research, and a discussion of the same.

4.2 Implementation of TPM Practices and Equipment Effectiveness

The bi-annual data for the availability, performance and quality rates of BCL as well as the bi-annual data for the TPM practices considered in the study (elimination of sources of lost equipment time, autonomous maintenance and planned maintenance) were collected and recorded. The data were for a period of fifteen years from the year 2000 to 2014 and were summarised in table 4.1.

Table 4.1: TPM Practices and Equipment Effectiveness Data

Year	Month	Y_1	Y_2	Y_3	Y	X_1	X_2	X_3
2000	Jan - June	90.93	78.50	90.02	64.25	0.00	9.74	0.00
2000	June - Dec	89.80	79.07	89.40	63.48	0.00	11.22	0.00
2001	Jan - June	88.92	80.38	89.92	64.27	42.11	13.12	0.00
2001	June - Dec	90.94	77.65	89.35	63.10	48.00	18.85	0.00
2002	Jan - June	91.21	78.72	91.25	65.52	42.86	15.62	28.57
2002	June - Dec	91.10	78.99	91.02	65.50	41.18	14.44	40.00
2003	Jan - June	89.68	78.58	94.54	66.62	57.89	22.78	50.00
2003	June - Dec	90.18	80.57	93.29	67.78	50.00	26.34	40.00
2004	Jan - June	87.14	77.95	94.90	64.46	26.67	27.39	33.33
2004	June - Dec	86.63	80.23	94.00	65.33	53.85	19.42	50.00
2005	Jan - June	92.49	77.89	93.26	67.19	31.58	30.58	66.67
2005	June - Dec	91.88	75.22	93.54	64.65	52.94	27.86	25.00
2006	Jan - June	91.19	79.69	95.25	69.22	26.67	29.87	28.57
2006	June - Dec	93.36	71.06	96.43	63.97	28.57	31.83	66.67
2007	Jan - June	92.22	76.18	93.31	65.55	54.55	27.52	40.00
2007	June - Dec	92.74	77.89	94.68	68.39	45.00	27.52	33.33
2008	Jan - June	93.75	80.62	94.98	71.79	29.63	31.99	50.00
2008	June - Dec	93.18	81.90	95.47	72.85	44.00	26.52	40.00
2009	Jan - June	94.83	81.90	95.02	73.80	50.00	35.64	66.67
2009	June - Dec	93.95	96.41	94.83	85.89	38.46	35.49	66.67
2010	Jan - June	91.28	83.73	97.96	74.87	47.06	36.51	50.00
2010	June - Dec	91.94	83.11	97.32	74.37	57.89	37.41	40.00
2011	Jan - June	96.96	83.11	97.86	78.86	60.00	35.96	66.67
2011	June - Dec	97.08	88.19	98.92	84.70	50.00	37.83	60.00
2012	Jan - June	93.08	88.19	90.01	73.89	38.10	36.62	66.67
2012	June - Dec	92.33	81.04	95.45	71.42	63.64	29.20	50.00
2013	Jan - June	94.08	83.81	98.01	77.27	50.00	40.33	40.00
2013	June - Dec	94.19	84.94	98.46	78.78	52.94	40.64	66.67
2014	Jan - June	94.68	85.20	99.25	80.05	65.22	49.08	50.00
2014	June - Dec	95.20	86.09	98.84	81.01	61.11	45.59	66.67

Where $Y_{1,}$ was the equipment availability rate at BCL measured as the ratio of the actual production time of the kiln shop to the total potential production time; $Y_{2,}$ was the equipment performance rate at BCL measured as the ratio of the amount of clinker produced by the kiln shop to the rated production capacity of the shop; and Y_3 the quality rate at BCL measured as the value of the compound tri calcium silicate (abbreviated C3S) in the clinker produced in the kiln shop as compared to a set target of C3S, expressed as a percentage. Y was the value of overall equipment effectiveness (OEE) rate at BCL, obtained by calculating the product of the availability, performance and quality rates at BCL. X_1, $X_{2,}$ and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively.

There is a general increase in the level of implementation of the three TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance during the period under consideration. Correlation and regression analyses were conducted to evaluate the relationship between the implementation of TPM practices and the equipment availability, performance and quality rates as well as the overall equipment effectiveness (OEE) of BCL. The results of the analyses are summarized in the sections below.

4.2.1 Nature and Degree of the Relationship between TPM Practices and Equipment Effectiveness

A Pearson's correlation analysis was run to determine the nature of the relationship between the implementation of the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance and the equipment availability, performance and quality rates as well as the overall equipment effectiveness (OEE) of BCL. The results of the analysis are summarised in table 4.2.

Table 4.2 Correlations between TPM Practices and the Availability, Performance, Quality and OEE Rates of BCL

Correlations

		Y_1	Y_2	Y_3	Y	X_1	X_2	X_3
Availability rate (Y_1)	Pearson Correlation	1						
	Sig. (2-tailed)							
Performance rate (Y_2)	Pearson Correlation	.447*	1					
	Sig. (2-tailed)	.013						
Quality rate (Y_3)	Pearson Correlation	.569**	.348	1				
	Sig. (2-tailed)	.001	.060					
OEE rate (Y)	Pearson Correlation	.756**	.867**	.719**	1			
	Sig. (2-tailed)	.000	.000	.000				
Lost Equipment Time (X_1)	Pearson Correlation	.315	.245	.535**	.424*	1		
	Sig. (2-tailed)	.091	.192	.002	.020			
Autonomous Maintenance (X_2)	Pearson Correlation	.688**	.520**	.838**	.799**	.535**	1	
	Sig. (2-tailed)	.000	.003	.000	.000	.002		
Planned Maintenance (X_3)	Pearson Correlation	.567**	.420*	.642**	.631**	.453*	.736**	1
	Sig. (2-tailed)	.001	.021	.000	.000	.012	.000	

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

From the analysis, it is observed that there is a weak, positive and insignificant relationship between implementation of elimination of lost equipment time and the availability rate (r = 0.315, n = 30, p = 0.091). There is a strong, positive and significant relationship between implementation of autonomous maintenance and the availability rate (r = 0.688, n = 30, p = 0.000). There is a moderate, positive and significant relationship between implementation of planned maintenance and the availability rate (r = 0.567, n = 30, p = 0.001).

There is a weak, positive and insignificant correlation between implementation of elimination of lost equipment time and the performance rate (r = 0.245, n = 30, p = 0.192). There is a moderate, positive and significant correlation between implementation of autonomous maintenance and the performance rate (r = 0.520, n = 30, p = 0.003). There is a moderate, positive and significant correlation between implementation of planned maintenance and the performance rate (r = 0.420, n = 30, p = 0.021).

There is a moderate, positive and significant correlation between implementation of elimination of lost equipment time and the quality rate (r = 0.535, n = 30, p = 0.002). There is a very strong, positive and significant correlation between implementation of autonomous maintenance and the quality rate (r = 0.838, n = 30, p = 0.000). There is a strong positive correlation between implementation of planned maintenance and the quality rate (r = 0.642, n=30, p = 0.000).

There is a moderate, positive and significant correlation between implementation of elimination of lost equipment time and the OEE rate, r = 0.424, n = 30, p = 0.020. There is a very strong, positive and significant correlation between implementation of autonomous maintenance and the OEE rate (r = 0.799, n = 30, p = 0.000). There is a strong, positive and significant correlation between implementation of elimination of planned maintenance and the OEE rate (r = 0.631, n=30, p = 0.000).

4.2.2 TPM Practices and Availability Rate

A regression analysis was performed to determine the relationship between the implementation of the TPM Practices of elimination of lost equipment time, autonomous maintenance and planned maintenance and the availability rate of BCL. The results are summarized in table 4.3.

Table 4.3 Regression results of TPM Practices and the Availability Rate of BCL

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.697[a]	.486	.427	1.86528

a. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

b. Dependent Variable: Availability rate

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	85.587	3	28.529	8.200	.001[b]
	Residual	90.461	26	3.479		
	Total	176.048	29			

a. Dependent Variable: Availability rate

b. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	87.642	1.168		75.033	.000
	Lost Equipment Time	-.013	.026	-.087	-.520	.608
	Autonomous Maintenance	.154	.054	.628	2.850	.008
	Planned Maintenance	.017	.024	.144	.691	.496

Coefficients[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	Lost Equipment Time	.315	-.101	-.073	.706	1.417
	Autonomous Maintenance	.688	.488	.401	.407	2.457
	Planned Maintenance	.567	.134	.097	.453	2.206

a. Dependent Variable: Availability rate

From Table 4.3, the results of the regression indicated a strong, positive relationship between TPM practices and the availability rate of BCL (R = 0.697). Adjusted R^2 shows that 42.7% of the variation in the availability rate of BCL is explained by the linear combination of the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance.

To determine the significance of correlation coefficient r for TPM practices and the availability rate of BCL, a test of significance was done as follows.

H_0: r = 0 (The coefficient of correlation is not significant)

H_1: r $\neq$ 0 (The coefficient of correlation is significant)

It was a two tailed test of 5% level of significance df = n-2 = 30-2 = 28.

The decision rule therefore was to reject H_0 if computed t is greater than 2.048 (Garcia, 2010).

Computed t = r*SQRT [((n – 2) / (1 – r^2))] = 0.697*SQRT [((30-2) / (1-0.697^2))] = 5.1434. Decision: since the computed t (5.1434) is greater than critical t (2.048), the null hypothesis is rejected implying that the coefficient of correlation between TPM practices and the availability rate of BCL is significant.

The independent variables of the study were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance. The VIF values for the independent variables were 1.417, 2.457 and 2.206. Since the VIF values are less than 5, there is no multicollinearity among the independent variables of the study (Hair, Ringle, & Sarstedt, 2011).

The regression equation for predicting the availability rate of BCL was:

$Y_1 = 87.642 – 0.013X_1 + 0.154X_2 + 0.017X_3$

Where Y_1 was the equipment availability rate and X_1, $X_{2,}$ and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively.

The regression equation above establishes that taking all factors into account constant at zero, the availability rate of BCL will be at 87.62%. It also establishes that a 1% increase in implementation of lost equipment time practices would actually result in a .013% decrease in the availability rate of BCL. A 1% increase in implementation of autonomous maintenance practices would result in a .154% increase in the availability rate of BCL, while a 1% increase in implementation of planned maintenance practices would result in a .017% increase in the availability rate of BCL. The analysis shows that of the three TPM practices, it was only the implementation of autonomous maintenance practices that statistically predicted the availability rate of BCL significantly, $p = .008$.

4.2.3 TPM Practices and Performance Rate

A regression analysis was performed to determine the relationship between the implementation of the TPM Practices of elimination of lost equipment time, autonomous maintenance and planned maintenance and the performance rate of BCL. The results are summarized in table 4.4.

Table 4.4 Regression results of TPM Practices and the Performance Rate of BCL

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.525[a]	.276	.192	4.24653

a. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

b. Dependent Variable: Performance rate

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	178.520	3	59.507	3.300	.036[b]
	Residual	468.859	26	18.033		
	Total	647.379	29			

a. Dependent Variable: Performance rate

b. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	74.489	2.659		28.012	.000
	Lost Equipment Time	-.016	.059	-.054	-.272	.788
	Autonomous Maintenance	.227	.123	.484	1.851	.076
	Planned Maintenance	.019	.054	.088	.356	.724

Coefficients[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	Lost Equipment Time	.245	-.053	-.045	.706	1.417
	Autonomous Maintenance	.520	.341	.309	.407	2.457
	Planned Maintenance	.420	.070	.059	.453	2.206

a. Dependent Variable: Performance rate

From Table 4.4, the results of the regression indicated a moderate, positive relationship between TPM practices and the performance rate of BCL (R = 0.525). Adjusted R^2 shows that 19.2% of the variation in the performance rate of BCL is explained by the linear combination of the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance.

To determine the significance of correlation coefficient r for TPM practices and the performance rate of BCL, a test of significance was done as follows.

H_0: r = 0 (The coefficient of correlation is not significant)

H_1: $r \neq 0$ (The coefficient of correlation is significant)

It was a two tailed test of 5% level of significance df = n-2 = 30-2 = 28.

The decision rule therefore was to reject H_0 if computed t is greater than 2.048. Computed t = r*SQRT $[((n-2) / (1-r^2))]$ = 0.525*SQRT $[((30-2) / (1-0.525^2))]$ = 3.264. Decision: since the computed t (3.264) is greater than critical t (2.048), the null hypothesis is rejected implying that the coefficient of correlation between TPM practices and the performance rate of BCL is significant.

The regression equation for predicting the performance rate of BCL was:

$Y_2 = 74.489 – 0.016X_1 + 0.227X_2 + 0.019X_3$

Where Y_2 was the equipment performance rate and X_1, X_2, and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively.

The regression equation above establishes that taking all factors into account constant at zero, the performance rate of BCL will be at 74.49%. It also establishes that a 1% increase in implementation of lost equipment time practices would actually result in a .016% decrease in the performance rate of BCL. A 1% increase in implementation of autonomous maintenance practices would result in a .227% increase in the performance rate of BCL, while a 1% increase in implementation of planned maintenance practices would result in a .019% increase in the performance rate of BCL. The analysis shows that none of the three TPM practices statistically predicted the performance rate of BCL significantly, $p > .05$.

4.2.4 TPM Practices and Quality Rate

A regression analysis was performed to determine the relationship between the implementation of the TPM Practices of elimination of lost equipment time, autonomous maintenance and planned maintenance and the quality rate of BCL. The results are summarized in table 4.5.

Table 4.5 Regression results of TPM Practices and the Quality Rate of BCL

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.845[a]	.713	.680	1.72230

a. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

b. Dependent Variable: Quality rate

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	191.849	3	63.950	21.559	.000[b]
	Residual	77.124	26	2.966		
	Total	268.973	29			

a. Dependent Variable: Quality rate

b. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	86.776	1.079		80.459	.000
	Lost Equipment Time	.022	.024	.118	.943	.354
	Autonomous Maintenance	.225	.050	.746	4.533	.000
	Planned Maintenance	.006	.022	.039	.250	.805

Coefficients[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	Lost Equipment Time	.535	.182	.099	.706	1.417
	Autonomous Maintenance	.838	.664	.476	.407	2.457
	Planned Maintenance	.642	.049	.026	.453	2.206

a. Dependent Variable: Qualityrate

From Table 4.4, the results of the regression indicated a strong, positive relationship between TPM practices and the quality rate of BCL (R = 0.845). Adjusted R^2 shows that 68.0% of the variation in the quality rate of BCL is explained by the linear combination of the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance.

To determine the significance of correlation coefficient r for TPM practices and the quality rate of BCL, a test of significance was done as follows.

H_0: r = 0 (The coefficient of correlation is not significant)

H_1: r ≠ 0 (The coefficient of correlation is significant)

It was a two tailed test of 5% level of significance df = n-2 = 30-2 = 28.

The decision rule therefore was to reject H_0 if computed t is greater than 2.048. Computed t = r*SQRT [((n – 2) / (1 – r^2))] = 0.845*SQRT [((30-2) / (1-0.845^2))] = 8.361. Decision: since the computed t (8.361) is greater than critical t (2.048), the null hypothesis is rejected implying that the coefficient of correlation between TPM practices and the quality rate of BCL is significant.

The regression equation for predicting the quality rate of BCL was:

$Y_3 = 86.776 + 0.022X_1 + 0.225X_2 + 0.006X_3$

Where Y_3 was the equipment quality rate and X_1, X_2, and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively.

The regression equation above establishes that taking all factors into account constant at zero, the quality rate of BCL will be at 87.78%. It also establishes that a 1% increase in implementation of lost equipment time practices would result in a .022% increase in the quality rate of BCL. A 1% increase in implementation of autonomous maintenance practices would result in a .225% increase in the quality rate of BCL, while a 1% increase in implementation of planned maintenance practices would result in a .006% increase in the quality rate of BCL. The analysis shows that of the three TPM practices, it was only the implementation of autonomous maintenance practices that statistically predicted the quality rate of BCL significantly, $p < .001$.

4.2.5 TPM Practices and OEE Rate

A regression analysis was performed to determine the relationship between the implementation of the TPM Practices of elimination of lost equipment time, autonomous maintenance and planned maintenance and the OEE rate of BCL. The results are summarized in table 4.6.

Table 4.6 Regression results of TPM Practices and the OEE Rate of BCL

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.802[a]	.643	.601	4.25740

a. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

b. Dependent Variable: OEE rate

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	846.985	3	282.328	15.576	.000[b]
	Residual	471.262	26	18.125		
	Total	1318.247	29			

a. Dependent Variable: OEE rate

b. Predictors: (Constant), Planned Maintenance, Lost Equipment Time, Autonomous Maintenance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	55.602	2.666		20.856	.000
	Lost Equipment Time	-.006	.059	-.013	-.094	.926
	Autonomous Maintenance	.492	.123	.735	4.001	.000
	Planned Maintenance	.030	.055	.096	.551	.587

Coefficients[a]

Model		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	Lost Equipment Time	.424	-.018	-.011	.706	1.417
	Autonomous Maintenance	.799	.617	.469	.407	2.457
	Planned Maintenance	.631	.107	.065	.453	2.206

a. Dependent Variable: OEE rate

From Table 4.4, the results of the regression indicated a strong, positive relationship between TPM practices and the OEE rate of BCL (R = 0.802). Adjusted R^2 shows that 60.1% of the variation in the OEE rate of BCL is explained by the linear combination of the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance.

To determine the significance of correlation coefficient r for TPM practices and the quality rate of BCL, a test of significance was done as follows.

H_0: r = 0 (The coefficient of correlation is not significant)

H_1: r ≠ 0 (The coefficient of correlation is significant)

It was a two tailed test of 5% level of significance df = n-2 = 30-2 = 28.

The decision rule therefore was to reject H_0 if computed t is greater than 2.048. Computed t = r*SQRT [((n – 2) / (1 – r^2))] = 0.802*SQRT [((30-2) / (1-0.802^2))] = 7.105. Decision: since the computed t (7.105) is greater than critical t (2.048), the null hypothesis is rejected implying that the coefficient of correlation between TPM practices and the OEE rate of BCL is significant.

The regression equation for predicting the OEE rate of BCL was:

$Y = 55.602 - 0.006X_1 + 0.492X_2 + 0.030X_3$

Where Y was the equipment OEE rate and X_1, $X_{2,}$ and X_3 were the TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance respectively.

The regression equation above establishes that taking all factors into account constant at zero, the OEE rate of BCL will be at 55.6%. It also establishes that a 1% increase in implementation of lost equipment time practices would actually result in a .006% decrease in the OEE rate of BCL. A 1% increase in implementation of autonomous maintenance practices would result in a .492% increase in the OEE rate of BCL, while a 1% increase in implementation of planned maintenance practices would result in a .030% increase in the OEE rate of BCL. The analysis shows that of the three TPM practices, it was only the implementation of autonomous maintenance practices that statistically predicted the OEE rate of BCL significantly, $p = .000$.

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter discusses the overall findings of the study, with the aim of answering the research questions. The chapter also presents conclusions and recommendations drawn from the study on the objectives of the study and gives suggestions for future possible studies.

5.2 Summary of the Findings of the Study

The study established that the implementation of various TPM practices at Bamburi Cement Limited (BCL) had a significant effect on the availability, performance and overall equipment effectiveness (OEE) rates achieved by the organization. With the gradual implementation of the three TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance, the OEE rate of BCL increased from an average rate of 65.03% in the years from 2000 to 2005 to an average rate of 77.52% in the years from 2006 to 2014. The implementation of the three TPM practices increased the equipment availability rate from 89.65% to 94.08%, the performance rate from 79.06% to 84.74% and the quality rate from 91.77% to 97.21% through the same time period.

Of the three TPM practices studied, autonomous maintenance was found to be the biggest contributor to changes in the availability, performance and quality rates of BCL, with a 1% increase in the implementation of the autonomous maintenance practices of operator involvement, cross training of employees and creation of multidisciplinary problem solving teams resulting in a 0.154%, 0.227% and a 0.225%

increase in the availability, performance and quality rates of BCL respectively. Implementation of the planned maintenance practices of disciplined planning and schedule compliance was found to be the second largest contributor to the changes in the availability, performance and quality rates of BCL, with a 1% increase in planned maintenance practices resulting in a 0.017%, 0.019% and a 0.006% increase in the availability, performance and quality rates of BCL respectively.

Further, the study determined that the implementation of elimination of lost equipment time actually resulted in a decrease in the availability and performance rates of BCL, with a 1% increase in the elimination of lost equipment time practice of conducting root cause analyses (RCA) for equipment failures resulting in a 0.013% and 0.016% decrease in the availability and performance rates of BCL respectively. One possible explanation of this observation is that the RCAs conducted at BCL did not address the true causes of equipment failures, and could therefore not be useful in preventing recurrence of the failures and so would add little value to the maintenance process. The study however showed that a 1% increase in the implementation of elimination of lost equipment time resulted in a 0.022% increase in the quality rate of BCL.

Autonomous maintenance was found to be the biggest contributor to changes in OEE rate of BCL, with a 1% increase in the implementation of the autonomous maintenance practices of operator involvement, cross training of employees and creation of multidisciplinary problem solving teams resulting in a 0.492% increase in the OEE rate of BCL. Implementation of the planned maintenance practices of disciplined planning and schedule compliance was found to be the second largest contributor to the increases OEE rate of BCL, with a 1% increase in planned maintenance practices resulting in a 0.030% increase in the OEE rate of BCL. The study also established that a 1% increase in the implementation of elimination of lost equipment time resulted in a 0.006% decrease in the OEE rate of BCL.

5.3 Conclusions

This study concludes that there is a significant relationship between the implementation of total productive maintenance (TPM) practices at BCL from the year 2000 to 2014 and the improvement in the availability, performance, quality and overall equipment effectiveness (OEE) rates that was witnessed in the organisation during that time period. The combined effect of the implementation of the three TPM practices of elimination of lost equipment time, autonomous maintenance and planned maintenance was an increase in all of the indicators of equipment effectiveness.

Of the three TPM practices considered, autonomous maintenance of plant equipment by the production teams was found to have the biggest effect in the OEE of the equipment in the kiln shop of BCL, followed by the planned maintenance of the equipment. The study did not find the implementation of elimination of lost equipment time at BCL to have any effect on the OEE of the organisation.

The findings of the study agree with the findings of Paropate and Sambhe (2013) who performed a study on the implementation of TPM in a midsized cotton spinning plant in India and established that TPM enables improvement in the availability, performance and the quality rates of the carding machine, by increasing the availability, quality, performance and overall equipment effectiveness rates from

89.6832%, 79.29%, 96.4783% and 68.9866% respectively before TPM implementation to 91.96%, 79.758%, 97.177% and 71.465% respectively after TPM implementation.

The findings of the study also agree with those of Sharma et al. (2006) who established that TPM leads to increase in efficiency and effectiveness of manufacturing systems, measured in terms of OEE index. The study findings also agree with the findings of Ahuja and Khamba (2007) who established through a case study of the Indian manufacturing industry that there had been an improvement in overall equipment effectiveness of all the production facilities as a result of TPM initiatives notably OEE improvement by 14 - 45 per cent.

The findings of the study are also consistent with the findings of Ateka (2013) who examined the adoption of TPM practices in large manufacturing firms located in Mombasa County and identified increased quality and improved productivity as the key benefits resulting from TPM implementation. His study also established that the most important critical success factor of TPM is co-operation and involvement of both the operators and the maintenance workers in equipment maintenance.

5.4 Recommendations

In order to realize significant gains in the reliability, performance and quality rates of their equipment, manufacturing organizations should consider implementing the TPM practices outlined in this study. Specifically, organisations should invest their resources in creating a culture of autonomous maintenance of their production equipment by the production operators. They should endeavour to create a strong production team that is knowledgeable in the basic skills of equipment maintenance.

A strong production team would be able to identify emerging operational problems early on and correct them or seek assistance from more knowledgeable employees before major breakdowns occur. This in turn would increase the availability of the equipment to continue with production and ensure that the highest quality product is produced, and at the optimal production capacity. Prevention of major equipment breakdowns would also increase the lifetime of the equipment and reduce the costs associated with their maintenance, thereby increasing the profitability of the organizations.

Organizations should also ensure that a regular equipment maintenance schedule is created for all their production equipment in consultation with the equipment manufacturer. The schedule is followed diligently by the maintenance team. Creation of a regular maintenance schedule and adherence to a disciplined maintenance plan will ensure that all emerging problems with the equipment are addressed promptly. This in turn will increase the equipment availability, performance and quality rates by enabling the equipment to run without any unnecessary stoppages due to breakdowns and at the correct speed while producing the best quality product.

5.5 Limitations of the Study

The study used secondary data of the availability, performance and quality rates achieved by BCL for a period of fifteen years. Due to the sensitivity of the information, and the obligations placed on the researcher and the custodians of the information, the study was not able to establish more data points, and to obtain data for a longer time period, thereby limiting the scope of the period under the study.

Due to the amount and complexity of the data needed for the study and the time constraints placed on the researcher, the researcher could not be able to obtain and analyze data for the whole production line at BCL, from the quarrying stage of cement production to the finishing stage. This limited the scope of the study to the clinker production shop (kiln shop) of the organization.

5.6 Suggestions for Further Research

The study focused on the effects of implementation of the TPM practices on the OEE rate of the equipment in the kiln shop of BCL. It did not consider the effect of implementation of the practices on the OEE rates of the other equipment in the organization. A follow-up study should be conducted that will consider the effects of implementation of the TPM practices on the other equipment in the production line of BCL.

The study focused on the effects of the implementation of TPM practices on the overall equipment efficiency (OEE) of BCL. It was limited to one organization and the results are limited to the organization. They therefore cannot be generalized for other cement companies in the country and elsewhere without considering the context due to differing management philosophies employed and capabilities of the workforce. The study therefore recommends further work on the effects of the implementation of TPM practices in other Kenyan cement manufacturing organizations to be conducted.

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APPENDICES

APPENDIX 1: FORMULAE FOR CALCULATING EQUIPMENT EFFECTIVENESS

Availability rate (%) = Valuable operating time / Available operating time

Where:

Valuable operating time = Operating time + Breakdown time

Available operating time = Total time available for production (Jain et al., 2014)

Performance rate (%) = [(Cycle time x Number of final goods produced) / Valuable operating time]

Where:

Cycle time = Time taken to produce one unit = 1/Capacity per hour (Jain et al., 2014)

Quality rate (%) = [(Total production – Rejection) / Total production] (Jain et al., 2014)

OEE rate (%) = Availability rate x Performance rate x Quality rate (Jain et al., 2014)

APPENDIX 2: DATA COLLECTION TABLE

TPM PRACTICE	**YEAR**									
	2000	2000	2001	2001	2002	2002	2003	2003	2004	2004
	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec
LOST EQUIPMENT TIME										
Total number of incidents in Kiln shop	21	26	19	25	21	17	19	14	15	13
Total number of Root Cause Analyses done			8	12	9	7	11	7	4	7
Lost Equipment Time Score (%)	**0.00**	**0.00**	**42.11**	**48.00**	**42.86**	**41.18**	**57.89**	**50.00**	**26.67**	**53.85**
AUTONOMOUS MAINTENANCE										
Cross-training of employees										
Maintenance personnel trained in basics of cement production			10	10	14	14	14	14	19	19
Total number of Maintenance personnel	115	115	110	110	113	113	109	109	107	107
Maintenance cross-training rate (%)	0.00	0.00	9.09	9.09	12.39	12.39	12.84	12.84	17.76	17.76
Production personnel trained in basics of equipment maintenance	11	11	13	13	15	15	17	17	14	14
Total number of Production personnel	89	89	87	87	85	85	87	87	84	84
Production cross-training rate (%)	12.36	12.36	14.94	14.94	17.65	17.65	19.54	19.54	16.67	16.67
Global cross-training rate (%)	**7.58**	**7.58**	**12.68**	**12.68**	**15.61**	**15.61**	**16.95**	**16.95**	**17.09**	**17.09**

Cross-functional problem-solving teams										
Number of operations employees trained in RCA and in RCA team				15	18	18	27	31	24	33
Number of Operations employees trained in RCA (%)	**0.00**	**0.00**	**0.00**	**7.61**	**9.09**	**9.09**	**13.78**	**15.82**	**12.57**	**17.28**
Operator involvement										
Total number of less than 2 hour incidents (minor incidents) in Kilns 1 & 2 during silent hours	41	53	48	57	53	42	47	51	45	49
Number of times Maintenance team is called into the plant for minor incidents	32	39	35	36	41	34	29	27	21	37
Operator involvement (%)	**21.95**	**26.42**	**27.08**	**36.84**	**22.64**	**19.05**	**38.30**	**47.06**	**53.33**	**24.49**
Autonomous Maintenance Score (%)	**9.74**	**11.22**	**13.12**	**18.85**	**15.62**	**14.44**	**22.78**	**26.34**	**27.39**	**19.42**
PLANNED MAINTENANCE										
Disciplined planning and Schedule compliance										
Number of budgeted shutdown stoppages (2 shutdowns per kiln shop per year)	2	2	2	2	2	2	2	2	2	2

Total number of stoppages on planned condition-based maintenance on Kilns 1 & 2					7	5	4	5	6	4
Planned Maintenance Score (%)					28.57	40.00	50.00	40.00	33.33	50.00

TPM PRACTICE	**YEAR**									
	2005	2005	2006	2006	2007	2007	2008	2008	2009	2009
	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec
LOST EQUIPMENT TIME										
Total number of incidents in Kiln shop	19	17	15	21	22	20	27	25	12	13
Total number of Root Cause Analyses done	6	9	4	6	12	9	8	11	6	5
Lost Equipment Time Score (%)	**31.58**	**52.94**	**26.67**	**28.57**	**54.55**	**45.00**	**29.63**	**44.00**	**50.00**	**38.46**
AUTONOMOUS MAINTENANCE										
Cross-training of employees										
Maintenance personnel trained in basics of cement production	19	19	25	25	25	25	29	29	34	34
Total number of Maintenance personnel	103	103	104	104	107	107	105	105	102	102
Maintenance cross-training rate (%)	18.45	18.45	24.04	24.04	23.36	23.36	27.62	27.62	33.33	33.33
Production personnel trained in basics of equipment maintenance	15	15	15	15	20	20	20	20	27	27

Total number of Production personnel	84	84	81	81	81	81	83	83	78	78
Production cross-training rate (%)	17.86	17.86	18.52	18.52	24.69	24.69	24.10	24.10	34.62	34.62
Global cross-training rate (%)	**18.09**	**18.09**	**20.65**	**20.65**	**24.18**	**24.18**	**25.46**	**25.46**	**34.12**	**34.12**
Cross-functional problem-solving teams										
Number of operations employees trained in RCA and in RCA team	31	34	35	40	40	45	45	49	61	61
Number of Operations employees trained in RCA (%)	**16.58**	**18.18**	**18.92**	**21.62**	**21.28**	**23.94**	**23.94**	**26.06**	**33.89**	**33.89**
Operator involvement										
Total number of less than 2 hour incidents (minor incidents) in Kilns 1 & 2 during silent hours	50	54	53	48	58	51	61	52	35	43
Number of times Maintenance team is called into the plant for minor incidents	21	28	26	22	36	33	32	37	21	26
Operator involvement (%)	**58.00**	**48.15**	**50.94**	**54.17**	**37.93**	**35.29**	**47.54**	**28.85**	**40.00**	**39.53**
Autonomous Maintenance Score (%)	**30.58**	**27.86**	**29.87**	**31.83**	**27.52**	**27.52**	**31.99**	**26.52**	**35.64**	**35.49**
PLANNED MAINTENANCE										
Disciplined planning and Schedule										

compliance										
Number of budgeted shutdown stoppages (2 shutdowns per kiln shop per year)	2	2	2	2	2	2	2	2	2	2
Total number of stoppages on planned condition-based maintenance on Kilns 1 & 2	3	8	7	3	5	6	4	5	3	3
Planned Maintenance Score (%)	66.67	25.00	28.57	66.67	40.00	33.33	50.00	40.00	66.67	66.67

TPM PRACTICE	**YEAR**									
	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014
	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec	Jan - June	June - Dec
LOST EQUIPMENT TIME										
Total number of incidents in Kiln shop	17	19	15	18	21	22	20	17	23	18
Total number of Root Cause Analyses done	8	11	9	9	8	14	10	9	15	11
Lost Equipment Time Score (%)	**47.06**	**57.89**	**60.00**	**50.00**	**38.10**	**63.64**	**50.00**	**52.94**	**65.22**	**61.11**
AUTONOMOUS MAINTENANCE										
Cross-training of employees										
Maintenance personnel trained in basics of cement production	36	36	36	36	37	37	38	38	41	41
Total number of Maintenance personnel	99	99	98	98	95	95	92	92	96	96

Maintenance cross-training rate (%)	36.36	36.36	36.73	36.73	38.95	38.95	41.30	41.30	42.71	42.71
Production personnel trained in basics of equipment maintenance	27	27	25	25	28	28	30	30	33	33
Total number of Production personnel	75	75	73	73	69	69	65	65	64	64
Production cross-training rate (%)	36.00	36.00	34.25	34.25	40.58	40.58	46.15	46.15	51.56	51.56
Global cross-training rate (%)	**36.14**	**36.14**	**35.21**	**35.21**	**39.95**	**39.95**	**44.28**	**44.28**	**48.14**	**48.14**
Cross-functional problem-solving teams										
Number of operations employees trained in RCA and in RCA team	63	63	61	61	65	65	68	68	74	74
Number of Operations employees trained in RCA (%)	**36.21**	**36.21**	**35.67**	**35.67**	**39.63**	**39.63**	**43.31**	**43.31**	**46.25**	**46.25**
Operator involvement										
Total number of less than 2 hour incidents (minor incidents) in Kilns 1 & 2 during silent hours	47	39	42	48	51	45	52	45	46	48
Number of times Maintenance team is called into the plant for minor incidents	29	23	26	27	35	41	34	29	21	27
Operator involvement (%)	**38.30**	**41.03**	**38.10**	**43.75**	**31.37**	**8.89**	**34.62**	**35.56**	**54.35**	**43.75**
Autonomous Maintenance Score (%)	**36.51**	**37.41**	**35.96**	**37.83**	**36.62**	**29.20**	**40.33**	**40.64**	**49.08**	**45.59**

PLANNED MAINTENANCE										
Disciplined planning and Schedule compliance										
Number of budgeted shutdown stoppages (2 shutdowns per kiln shop per year)	2	2	2	2	2	2	2	2	2	2
Total number of stoppages on planned condition-based maintenance on Kilns 1 & 2	4	5	3	4	3	4	5	3	4	3
Planned Maintenance Score (%)	50.00	40.00	66.67	50.00	66.67	50.00	40.00	66.67	50.00	66.67