MAINTENANCE PRACTICES AND POWER PLANTS OPERATIONAL PERFORMANCE IN KENYA

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BY

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DECLARATION

This research project report is my original work and has not been presented for a degree award in any other University or for any other award.

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This research report has been submitted for review with my approval as the University Supervisor:-

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DEDICATION

I dedicate this project to my beloved wife, Sophia and my children Mercyline, Rewel, Mirijed and Marksam, for their undying support during the whole period of my study.

ABSTRACT

This research was carried out on the maintenance practices and the operational performance in the state and privately owned electric power suppliers in Kenya. The study was a cross-sectional survey. Data was collected on the whole study population at a single point in time to determine the maintenance practices and investigate their relationship with the operational performance as the dependent variable measured through availability and cost per unit. It also focused on the failure distribution within the studied power plants. The research population included a total of 25 power suppliers composed of 22 state and 3 privately owned power plants.

The study was done through collection of the objective data from the plant records. Additional data was obtained from the plant managers who were the respondents in the study. Data analysis was carried out using descriptive statistics presented through spearman's rank correlation and t-value for the analysis. To enable collection of representative data for the study, the power plants 6 months operational data was used and the analysis was carried out in line with the above stated objectives.

The study found out that there existed a relationship between the maintenance practices and the power plant operational performance. Power plants that emphasized spare parts supply most among the maintenance practices studied performed better than the other plants. Additionally there was a direct relationship between the availability of the power plants and the production cost per unit.

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CHAPTER 1: INTRODUCTION

1.1 Background of the Study

The British Standard Glosary of Terms (3811:1993) defines maintenance as the combination of all technical, administrative and management actions during the life cycle of equipment intended to retain it in, or restore it to a state in which it can perform the required function. This increases the equipment operational life and productivity. Productivity is a ratio of what is produced by an operation or process to what is required to produce it, that is, the output from the operation divided by the input to the operation.

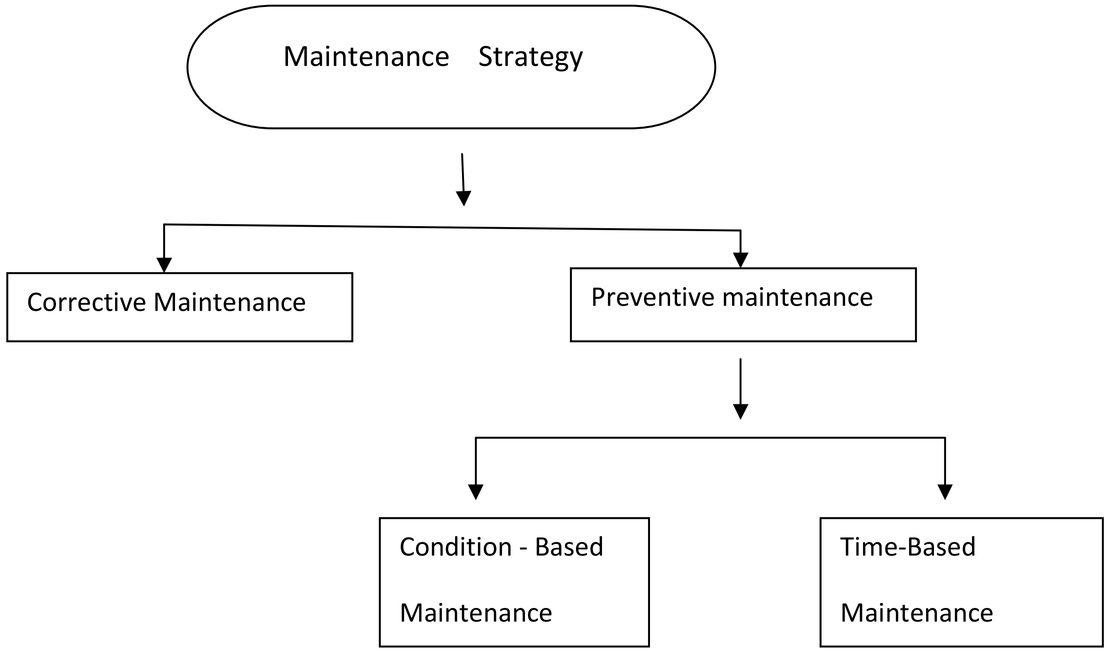
As the output increases, the firm's production cost per- unit is reduced. This is because the technology, facility costs and staff costs remain fairly constant even when units produced increases for the same quantity of brought in materials which mean more efficient utilization of the equipment. The reduced cost per Unit would lead to reduced price per unit and increased profits due to the high volume of sales and hence a competitive advantage in the industry. This benefit comes from the reduced failure rate that increases the equipment availability.

1.1.1 Maintenance Practices

The primary goal of maintenance is to avoid or mitigate the consequences of failure of equipment. In the realistic situation, all equipments are unreliable in the sense that they deteriorate with time and failure might even occur early in their life due to manufacturing defects or degradation depending on equipment age, usage and maintenance. The relative ease and cost of preventing failures (retaining an item in a specified condition) or correcting failures (restoring an item to a specified condition) can be justified through the maintenance actions.

Maintenance lengthens the life of equipment and reduces its failure rate (Jih-AN Chen, 2012). This yields a better return on investment and enhances customer satisfaction due to the increased production that meets the demand. In order to sustain high plant availability and at the same time meet the cost and regulatory requirements, appropriate maintenance practices need to be integrated with other management functions (Nakajima, 1989). In practice, maintenance strategies are grouped into two practices; these are corrective and preventive maintenance as shown in the figure below:-

Figure 1.1: Maintenance Practices



Source: Hall (1997), *Development of decision model for maintenance*

Preventive maintenance is a type of maintenance carried out at predetermined intervals or according to a prescribed criteria and intended to reduce the probability of failure or the degradation of parts. It is defined as a broad term that encompasses a set of activities aimed at improving the overall reliability and availability of an equipment (Kamran, 2003). Under preventive maintenance the equipment reliability is enhanced by replacing worn out components before they actually fail (Mitshra and Jain, 2012).

Conventional preventive maintenance policies are generally periodic and hold same time interval for preventive maintenance actions. The same time interval would however give decreasing reliabilities from one maintenance cycle to another as the equipment ages.

Condition based also known as predictive based maintenance is a set of activities that detect changes in the physical condition of the equipment in order to carry out the appropriate maintenance work so as to maximise the service life of equipment without increasing the risk of failure. Signs of failure are predicted based on the equipment important part through monitoring while the service life is predicted based on inspection or diagnosis (Mitshra and Jain, 2012).If the observed condition at an inspection exceeds the threshold deterioration level maintenance is performed, else no action is taken and the system continues to run. This maintenance practice is proposed for continuously operating equipment especially where there is un-certainty of time between failures or no known expected life.

Corrective maintenance also known as Reactive maintenance is any maintenance task performed to restore (repair or replace) the machine or component to its required function after it has failed (Rosmaini, 1995). Its major drawback is obvious i.e. the cost of repair or replacement of the equipment that is run to failure is typically much higher than if the problem were detected and fixed earlier not to mention the cost of loss in production during extended downtime. The application of corrective maintenance significantly reduces the machine performance in terms of reliability, availability, production rate and product quality (Swanson, 2001).

Maintenance infrastructure policy in an organization determines the choice between various maintenance policies that reduce frequency and severity of malfunctions. Maintenance policy has been defined as a strategy within which decisions on maintenance are taken.Optimization of the maintenance policies has been defined as a strategy within which decisions on maintenance are taken so as to achieve high plant operational performance at low maintenance cost. Power Plants operation managers emphasize preventive maintenance strategies to increase the reliability and availability of equipments. McClymonds and Winge (1987) present methods to achieve optimal preventive maintenance scheduling for nuclear Power Plants. They consider the plant availability and reliability as the objective functions and develop models based on assigning resources to preventive and corrective maintenance activities. This study contributes to the literature on the impact of maintenance practices on plant operational performance.

1.1.2 Power generation Sector in Kenya

According to the Energy Regulatory Commission, Kenya's current installed power capacity stands at 1,700 MW. The interconnected installed capacity currently stands at 1,672 MW, including the 120 MW of the emergency capacity while the supply penetration in the country is only to 15% of the total population of 40million people (World Bank report). The current national interconnected system peak demand is 1,330 MW (The East African July 13, 2013). Hydropower currently constitutes 51% of the installed capacity while Thermal, Geothermal, wind generation account for 34%, 13%, and 2% respectively.

The power is supplied by KenGen the state owned Company and the Independent power producers operating in the country under license. KenGen today commands 74% of the market share which continues to decrease with the increasing market size due to the competition from the independent power producers and increased regionalization of the East African power markets. The ongoing power generation projects include 300MW Lake Turkana Wind Power project, 87MW Thika Power Limited (Thermal), 81MW Triumph Generating Company (Thermal) in Athi River zone, 280MW Olkaria Geothermal Power and 80MW Gulf Power (Thermal).

The demand growth of 8-10% has continued to outstrip supply with demand forecast to grow even further in future mainly due to the strong growth in the country's economy. The projected installed capacity by 2030 is 17,764 MW when the demand for power is expected to rise to 15,026 MW. (KenGen extract" *Utilizing Geothermal Energy in Kenya, February 20th, 2013").*

Several issues arise in the power generation sector. There are rising Operation & Maintenance costs of the plants due to the increased cost of inputs while the customers demand for clean competitively priced power which must be reliable and of high quality. There has been pressure to de-regulate the sector so as to allow other investors in the industry to promote competition and reduce electricity cost per unit. In addition the sector has continued to record rising power demand that results to periodic rationing and importation of power. The consequence is the need for efficiency and cost effectiveness in power generation for competitiveness. To survive, power suppliers must reduce maintenance costs, prioritize maintenance actions and raise reliability.

1.2 Statement of the Problem

Evidence from the literature indicates that maintenance practices activities have effect on Power Plants operational performance (Kamran, 2003). He argues that these activities retain the equipment in a state considered necessary for fulfillment of their production function. Electric utilities are confronted with challenges of competition, Operation & maintenance costs and the growing power supply demand on the system. It has also been argued that the total cost of maintenance and equipment availability varies depending on the level of maintenance and the speed of carrying out repairs (Kola and David, 2008).

The health of the equipment is of utmost importance to the industry because revenues and reliability are affected by the condition of the equipment. Therefore, the importance of the maintenance function has been greater than before due to its role in maintaining and improving availability and lengthening the equipment life (Nakajima, 1989). According to Okah-Avah (1996) all the equipment maintenance activities are concerned with preventing or responding to failure and optimization of these activities reduces the production cost per unit while improving the equipment availability. He also argued that provision of standby equipments and spare parts affects the maintenance or repair tasks duration which influences the performance. The maintenance policy applied thus becomes a factor in determining the operational performance of the equipment.

In Kenya there exists a shortfall in the country's power supply due to the low installed capacity which cannot meet the national power demand (Least cost development plan report, 2010)**.** The increasing electricity demand, the increasing requirement to supply clean reliable power and the deregulation of the power supply sector has resulted to an increased competition among the various power producers. This has led to competition as the players strive to maintain low production cost per unit that results in low unit price per unit so as to secure a high market share for their product. The players in the industry have to keep adapting to the changing business environment by changing their business strategies in order to compete effectively. To achieve this objective, focus on the optimal maintenance practices is crucial to enhance the equipment reliability and availability at the minimum cost of production to achieve market competitiveness (Alsyouf, 2007). The operation manager's decision on the maintenance policies to use determines the overall equipment availability and production cost.

An effective maintenance policy is essential to delivering safe and reliable electric power to customers economically (Anders, 1990). Additionally as equipments continue to age and gradually deteriorate the probability of service interruption due to component failure increases hence reduced availability. According to Jagadees (2010) the efficiency of maintenance determines equipment's availability and the production efficiency depends on the availability of the equipment in the process chain which is more critical when operations are running on a 24 hour basis.

Various choices in the maintenance policies could be explored to enhance the Power Plants operational performance Eti (2006). An optimum maintenance policy has to be established that yield the highest equipment availability at the highest production efficiency i.e. minimum cost per unit. Determination of the best operating level on each remains a challenge. There is therefore need for speedy repairs so as to reduce cost of interruptions in production. This requires a choice to be made on whether or not to increase the preventive maintenance frequency or provide extra machines. The option of replacing the machine parts early before failure could be made but this could increase the operational and maintenance cost per unit. Availing standby units would reduce the breakdown cost that arises due to loss in production.

Several studies have been carried out on maintenance practices and equipment operational performance. No studies have been carried out on Power Plants failures history in Kenya. The research sought to investigate the maintenance practices used in the power plants, the patterns of failure and the effects of the maintenance practices on the power plants operational. Understanding this is important for the Operation Manager's decisions on repair speed and the maintenance policies to adopt.

1.3 Objectives of the study

To answer the above questions the study sought to achieve the following specific objectives:-

(i) To identify the maintenance practices used in the power plants.

(ii) To analyse the distribution of failures in the power plants.

(iii) To establish the relationship between the maintenance practices used in the power plants and the operational performance.

1.4 Significance of the study

This study will explore the various maintenance practices used by the various Power Plants under study and the operating availability. Such information can be used by the Company in the formulation of the maintenance strategy. In addition the findings are also useful for operations management practitioners in high capital intensive operations as the guide in decision making regarding equipment maintenance.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter literature on issues relating to equipment maintenance are reviewed. The literature is reviewed along two groupings. This covers literature on maintenance practices and their relationship with the operational performance and decision analysis in maintenance Problems. Finally a conceptual framework is developed.

2.2 Decision analysis in maintenance Problems

A study by Burhanuddin (2011) on efficient failure-based maintenance decision support system for small and Medium Industries revealed that a maintenance decision support system is essential to ensure maintainability and reliability of equipments in industries. The decision support system gathers and presents data from a wide range of sources in a way that can be interpreted by tactical level managers who can use it in making tactical decisions. A quantitative approach in the decision support system model allows maintenance managers to reach decisions regarding the maintenance programme to use on each machine.

The maintenance Decision Making Grid, introduced by Labib (1998) acts as a map where the performances of the worst machines i.e. frequency of failures and downtime are placed. The matrix offers an opportunity to decide what maintenance strategies are needed for decision making such as to practice corrective maintenance, periodic preventive maintenance or Condition based Maintenance. Machines that have low frequency of failure with a short downtime are performing well and they are easy to repair, machines with high failure frequency and low downtime are easy to fix and upgrading the operator skills level in fixing the problem will help to reduce outage period. Machines that seldom fail but take long time to bring back require condition based maintenance while those with low failure frequency and medium down time require preventive maintenance. The model is able to analyze multiple criteria and is the best choice when the number of machines is less than fifty (Pascual, 2009).

Another study by Faiz and Eran (2009) on decision making for predictive maintenance in asset information management defines an asset management system as a tool for identification, design, construction, operation, and maintenance of physical assets (Wenzler, 2005). The science of asset management aims to equip engineers to become businessmen and introduces structured methods for handling reliability, performance, and maintenance (Woodhouse, 2001). The advantage of applying expert systems to assist problem solving is that the confidence in correct decisions can be greatly increased.

A Case based reasoning system stores a set of problems and answers in an organized data structure called a Case-Base or Case Archive (Clarke, 2005). He argued that a Case Based Reasoning system, upon being presented with a problem, finds the case in its knowledge base that is most closely related to the new problem and presents that case's solution as an output, with suitable modifications. In addition much of the power of decision analysis lies in its ability to effectively integrate the many factors that commonly affect a decision. Such an integrating capacity makes decision analysis a very useful means of facilitating the decision-making process. A Case Based Reasoning can help decision-makers identify what features of a problem are the important ones to remember during problem solving.

There is a widespread belief that corrective maintenance is always less economical than preventive maintenance, and all failures can be prevented. This approach to preventive maintenance firstly wastes a lot of resources in doing unnecessary tasks which will not improve equipment or system availability, and secondly it is potentially risky (Tsang, 1995). A principal argument in favor of detailed and integrated asset information management system is that accurate and unchallenged information is available to anyone with the skills to analyze and interpret it for the benefit of a company (Sherwin, 2000). Predictive scheduling relies more on information and explicit knowledge.

Another consistent study by Clety Kwambai (2008) in Iceland revealed that optimum preventive maintenance policies is a logical choice if and only if the component in question has an increasing failure rate and the overall cost of the preventive maintenance action is less than the overall cost of a corrective action(Barlow and Hunter, 1960).

In conclusion Maintenance strategies are identified using the decision making grid model, based on important factors including the machines downtimes and their frequency of failures. The machines are categorized into the downtime criterions and frequency of failures, which are high, medium and low. The experimental studies are conducted using maintenance data set given by Fernandez (2003). The study however has not factored the external and internal factors of the equipments under study and it would be necessary to investigate this in another study.

2.3 Maintenance practices and their relationship with the operational performance

A study by Mulugeta (2009) on Reykjane & Nesjavellir power stations in Iceland on evaluation of maintenance practices through benchmarking for geothermal Power Plants developed a model that could help in the search for optimum methods of maintenance practices in order to improve the overall operational performance. The main objective of the study was to determine the best practices for Reykjanes power station as the benchmarked plant based on the model results.

For the five years' period considered the benchmarked Power Plant on average used 13% Emergency maintenance 26% Preventive maintenance, 41% Predictive maintenance and 20% Planned corrective maintenance while Nesjavellir Power Plant best performer used 14%, 13%, 71% and 2% of these practices respectively. The benchmarked Power Plant used a combination of different maintenance practices due to age, working condition and the complexity of the plant. In both Power Plants, predictive maintenance was preferred in delivering a flexible, dynamic and proactive maintenance procedure so as to achieve high availability, minimum down time and repair time.

The benchmarked Power Plant maintenance and operation staff consisted of 22 men who regularly attended to the 12 turbines. This flexible, co-operative and shared responsibility approach among production and maintenance personnel helped to keep a few skilled creative operators and maintenance staff. Designing the machines for maintainability and increasing the spares stocks translates to reduced maintenance duration (Wireman 2000). In addition availability of correct spare parts and materials in good condition were also found necessary so as to maintain design configuration and maintenance requirements for activities during normal operating periods and to support both planned and forced outages.

The availability of a complex system, such as a gas turbine, is strongly associated with its parts reliability and maintenance policy (Fernando and Gilberto, 2009). That policy not only has influence on the parts' repair time but also on the parts' reliability affecting the system degradation and availability. In their study based on a method for reliability and availability evaluation of gas turbines installed in an electric power station, availability analysis revealed different results for each of the two 150MW turbines studied in Brazil, one presenting 99% and the other 96% availability, indicating differences in their systems installation and operation. They argued that in a large enterprise, such as a power plant keeping asset reliability and availability and reducing costs related to asset maintenance, repair, and ultimate replacement are at the top of the management concerns.

The Reliability Centered Maintenance concept was developed to address these concerns and formally defined by Moubray (1997) as "a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context". This maintenance policy philosophy is focused on the use of predictive or preventive maintenance tasks that aim at the reduction of unexpected failures during the component's normal operation (Smith and Hinchcliffe, 2004).

In order to improve maintenance efficiency and to reduce maintenance costs, Eti (2007) proposed the use of reliability and maintainability concepts to define an availability index expressed by the ratio of the mean time to failure to the sum of the mean time to failure plus the mean time to repair. The study concluded that the data collected on field failures are particularly valuable because they are likely to provide the only estimates of the reliability and availability that incorporate the loadings, environmental and maintenance procedure effects found in practice. On both component and system levels such a database is valuable for predicting on site reliability and availability.

A similar study by Olayika (2011) in Nigeria on implementation of preventive maintenance programme in Egbin Thermal Power Plant revealed consistent results. There existed an inverse relationship between the component or equipment availability and mean time to repair or failure rate and an effective maintenance strategy was essential to delivering reliable electric power to customers at a lower production cost per unit (Anders, 1990).

In conclusion the empirical results of the study found that systematic maintenance data collection, analysis and a continued reliability study could provide valuable information about the plant performance. No studies have been in the Kenyan power generation sector to identify the operational performance of the plants based on the failure rates and the maintenance practices. The model could assist Power Plants operation managers in understanding the current performance of the plant and identification of actions to take in order to exceed identified business standards to improve performance.

2.4 Approaches to maintenance management

To reduce downtime and achieve high production capabilities, the aim should be to find ways to increase equipment reliability and extend the equipment's life through cost effective maintenance (Olayinka, 2011). Such change requires a complete shift to a Total Planned Quality Maintenance approach, which is a maintenance and management philosophy that advocates planning all maintenance (*i.e.* preventive, predictive and corrective), as well as the control of quality in maintenance operations. Training operators to carry out the routine maintenance of equipments reduces the failure rate thus increasing the equipment availability and optimization of human resources (Labib, 1998).

One of the strengths of the top performing generating companies worldwide is their successful efforts to establish a Pro-active O&M program, one that uses their equipment reliability, cost and efficiency data to supplement the recommendations of the equipment manufacturers and the utility's firsthand experience (Energy Sector Management Assistance Program reports, 2009).

Total Productive Maintenance is a well-defined and time-tested concept for maintaining plants and equipment. It was introduced to avoid waste in a quickly changing economic environment, produce goods without reducing product quality, reduce costs, produce a low batch quantity at the earliest possible time and to ensure that only non-defective parts are sent to the customers.

2.5 Summary and conceptual framework

A review of literature on equipments maintenance has revealed that a careful selection of an optimized maintenance strategy would increase the reliability and availability of equipments while reducing the operational and maintenance cost. This requires that the equipment design ensures maintainability so as to support the maintenance practices (Eti, 2007). Such an achievement would enhance the organization competitiveness as the production cost per unit would be greatly reduced. Decision analysis as relating to maintenance programmes has suggested important factors, including the machines downtimes and their frequency of failures as important tools to apply in guiding on the maintenance strategy to apply in a particular Power Plant so as to enhance operational performance. Results of the findings in the study of maintenance practices and their relationship with equipment availability indicate that predictive maintenance enhanced equipment performance and resulted to minimum equipment downtime and repair time

(Mulugeta, 2009). Operator involvement in maintenance improved operational performance as they attended to the equipment minor failures in time before serious problems developed (Labib, 1998).

Timely availability of spare parts was considered critical by the researchers to support planned and forced maintenance tasks. In Power Plants standby equipments availed during maintenance reduces the equipment downtime loses arising from reduced production, employee idle time and storage cost (Wireman, 2000). The variables identified in these studies will be represented in a conceptual framework (Fig. 2.1) to form a basis of understanding the breakdowns distribution of the various types of Power Plants and determinations of links between maintenance policies and plant operational performance.

Independent variable

Maintenance practices

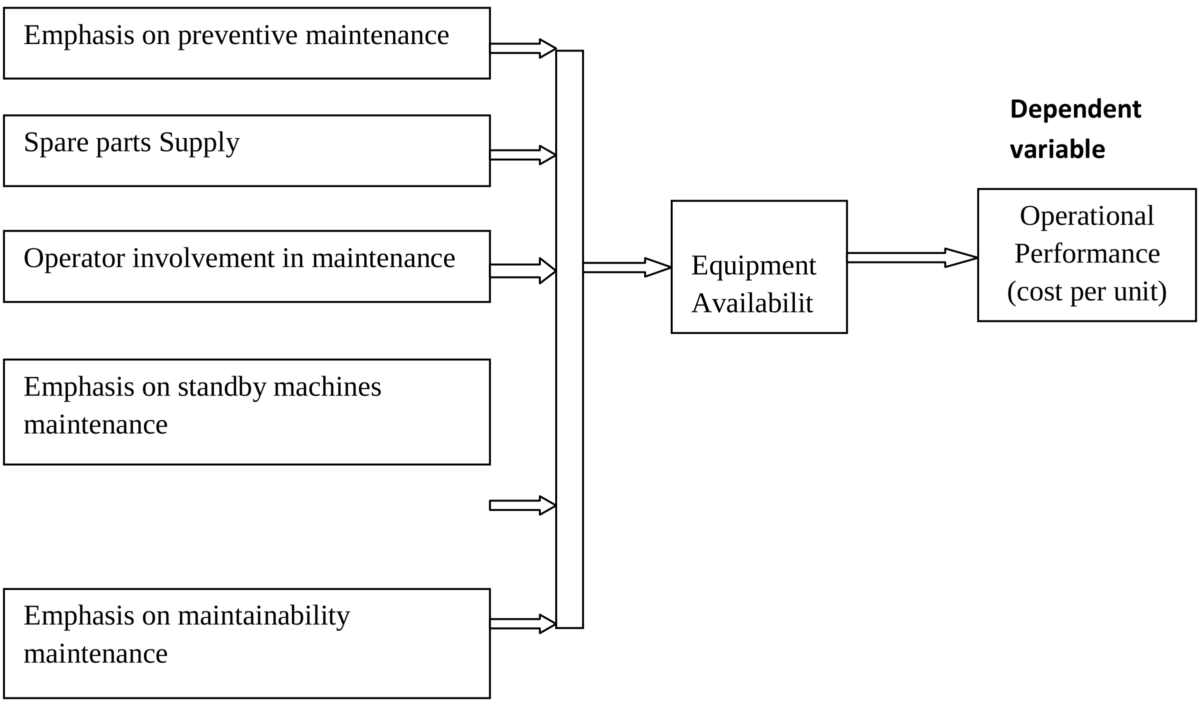


Figure 2.1 Conceptual Framework

Hypothesis

H_1 There is a significant difference between the means of those plants preferring one practice and the mean of those preferring another

H_0 There is no significant difference between the means of those plants preferring one practice and the mean of those preferring another

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter highlights the issues relating to the research design and methodology for the present study. Consequently it contains a brief description of the research design, study area, target population, sampling technique, research instruments, data collection procedure and analysis.

3.2 Research design

The study was a cross-sectional survey where data was collected on the whole study population at a single point in time to examine the relationship between the independent variables with the dependent variable. According to Mugenda and Mugenda (2003), a survey design is an attempt to collect data from an identified group of objects, with the objective of determining the current status given the specified variables, in this case, the maintenance practices with respect to specified variables. This design was adopted since it facilitated the collection of original data necessary to realize the research objectives. The design was also appropriate in collecting useful data that could be quantified and reported as a representation of the real situation or characteristic in the study population.

3.3 Population

A survey was conducted and the researcher considered the state owned and the independent power producers in Kenya. The plants were identified through correspondence with National Control Center where all the transmission network is managed. A total number of 25 power plants were contacted in this study. 23 of these power plants have offices in Nairobi but the other 2 have their offices outside Nairobi where they are located. The power plants generate power using various methods i.e. 9No. thermal, 1No. wind, 3No. geothermal and 12No. hydro, and all the power is sold to Kenya Power the main power distributor in the country. The study was restricted to the mentioned local power plants.

3.4 Data collection Method

The respondents of the study were the plant managers or their representatives who have the role of managing the operations of the plants and maintain the plant records. The researcher introduced himself to the plant managers through the contacts availed by Kenya Power and those available in the plant head offices in Nairobi. The data collection was accomplished using self- administered questionnaires, which sought information on maintenance practices in the respective plants. The questionnaire used paired comparison, where each practice was compared with the others. The indicators of each of the variables were statements that were closely used in practice. This data represented the independent variables in the study. Secondary data from the plant records on power plant operations was collected from the plant records. The information was related to the units generated(Mwhr), operation and maintenance costs per unit (ksh/kwhr), plant availability(%), breakdown reports and the outage hours for the previous 6months (March-August 2013). In order to ensure that the respondents provided accurate information, the researcher assured them of the confidentiality with which the information was to be treated. The respondents were also informed of the need to provide accurate information as the results of the study would assist those in operation management roles in decision making. The information given would also be coded before use.

3.5 Data Analysis

After collecting the raw data it was edited to correct any errors before coding and interpreting to facilitate analysis. The power plant identities were coded numerically, while the maintenance practices were coded alphabetically. The coded data was presented in tables and figures where the means of the quantitative variables studied were used. The interest of the study research was to find out whether the group of independent variables in this case the maintenance practices predicted a given dependent variable in this case the operational performance given in cost-per unit and measured through availability. The results obtained were presented in paired comparison worksheets for each plant. The degree of preference for each option in the power plant was calculated based on its score against the other practices. Scores of 0 and 1 were used for the less and most preferred options respectively. Descriptive statistics in form of mean, variance and frequencies were generated from the coded data. The interval scale was applied and analysis using paired comparison for maintenance practices was done. Ranking was done so as to establish some type of priority among the variables studied. For the first and third objectives studied, T-test and spearman's factor correlation at 95% confidence level was applied. Binomial test was applied on the analysis of the distribution of failures.

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CHAPTER 4: RESULTS, DATA ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents the results, data analysis and discussion as per the data collected using the researcher's questionnaires which were issued to the plant managers in all the 25 power plants in Kenya. The first part of this section, presents the response rates, while the second and subsequent sections present the results and findings obtained with regards to the objectives of the study.

4.2 Response

The researcher issued 25 questionnaires to the respondents from the various identified power generating plants in Kenya. Out of these questionnaires, 22 were returned, indicating 88 percent response rate. The response is as indicated in table 4.1 below.

Table 4.1 Respondents response rate

Power plants category	Total sent	Total received back	Response rate
State owned	20	20	100%
Privately owned	5	2	40%
	25	22	88%

Table 4.2 Objective data from plant records

Power plants category	Total plants participating	Total plants submitting objective data	Response rate
State owned	20	20	100%
Privately owned	5	2	40%
	25	22	88%

There was a very good response (100%) from the state owned companies.

Table 4.3 Power production by ownership

Power plants category	Generated energy(Mwhrs)	% of Total in Kenya
State owned	2,934,433	87.58%
Privately owned	416,016	12.42%
	3,350,449	

The state owned plants generate the bulk of the electrical energy (87.58%) in the country while the privately owned plants generate only 12.42%.

4.3 Results

The aim of the study was to identify the maintenance practices used in the power plants, to establish the relationship between the maintenance practices used in the power plants and the operational performance and finally to analyse the distribution of the failures. Paired comparison analysis was applied to analyse the maintenance practices from the various power plants.The tables below present the individual power plants operational data for the period of the study.

Table 4.4 Individual power plant operation data

PP1	% Availability	Generated Units in (MWhrs)	O&M cost(ksh)	Production Cost per kwhr (ksh)	Outage hours	No. of failures
March	100.0	3,958	1,088,742	0.3	1.0	1
April	100.0	4,048	1444340	0.4	0.0	0
May	99.7	4,089	1,082,987	0.3	23.0	7
June	100.0	4,537	1,221,941	0.3	0.0	0
July	100.0	4,785	1,360,940	0.3	0.0	0
August	100.0	2,899	911,145	0.3	0.0	0
TOTAL	**99.7**	**24,316**	**7 ,110,095**		**24.0**	**8**
AVERAGE	**99.9**			**0.3**		

PP2	% Availability	Generated Units in (MWhrs)	O&M cost(ksh)	Production Cost per kwhr (ksh)	Outage hours	No. of failures
March	99.3	28,874	4,448,000	0.1540487	36	2
April	97.9	25,918	3,416,000	0.1317987	104	3
May	99.3	23,894	169,000	0.0070730	36	1
June	93.0	22,806	4,020,000	0.1762711	352	2
July	99.4	27,083	276,000	0.0101909	31	2
August	99.8	27,342	3,427,000	0.1253397	12	0
TOTAL		**155,917**	**15,756,000**		**570**	**10**
AVERAGE	**98.1**			**0.1007870**		

PP 3	% Availability	Generated Units(Mwhrs)	O&M Cost(ksh)	Cost per kwhr produced(ksh)	Outage hours	No. of failures
March	98.8	32,273	31,615,887	0.98	62.19	7
April	98.2	48,368	38,057,019	0.79	88.94	17
May	99.0	53,115	108,840,741	2.05	55.66	21
June	99.5	52,332	50,488,362	0.96	22.67	9
July	97.7	52,599	35,150,436	0.67	130.43	7
August	94.1	46,743	86,833,656	1.86	293.99	6
TOTAL		**285,430**	350,986,101		**653.88**	**67**
AVERAGE	**97.9**			**0.913291507**		

PP 4	% Availability	Generated Units in (MWhrs)	O&M cost(ksh)	Production Cost per kwhr (ksh)	Outage hours	No. of failures
March	100.0	82,908	8 ,825,922	0.11	0	0
April	99.8	88,980	10,358,200	0.12	5.34	3
May	99.6	104,560	1 0,829,199	0.10	9.08	3
June	99.6	90,219	1 2,244,057	0.14	8.96	0
July	89.6	86,569	9 ,309,397	0.11	223.8	1
August	97.5	82,753	11,665,679	0.14	53.9	1
TOTAL		**535,989**	**6 3,232,454**		**301.08**	**8**
AVERAGE	**97.7**			**0.12**		

PP 5	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	100.0	56,502,000	21,387,865.18	0.3785329	-	-
April	87.1	36,508,000	18,007,854	0.4932578	185.60	5
May	99.4	47,893,000	22,912,610	0.4784125	9.12	4
June	99.3	45,189,000	25,678,517.94	0.5682471	10.39	2
July	94.0	50,302,000	13,305,160.20	0.2645056	86.54	4
August	96.7	52,685,000	17,568,725.00	0.3334673	47.68	-
TOTAL		**289,079,000**	**118,860,732**		**339.33**	15
AVERAGE	**96.1**			**0.4194039**		

PP6	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	83.1	42,871	9,047,392.31	0.21	366.03	2
April	97.3	43,787	9,016,726.60	0.21	57.55	2
May	98.8	51,096	9,036,376.46	0.18	25.79	1
June	98.4	47,093	12,131,990.52	0.26	34.69	1
July	97.0	42,694	10,610,730.50	0.25	64.63	1
August	99.5	41,715	10,340,208.42	0.25	10.70	0
TOTAL		**269,255**	**60.183,425**		**559.39**	**7**
AVERAGE	**95.7**			**0.22**		

PP 7	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	99.8	94,970	8,650,000.00	0.0910814	2	0
April	100.0	93,889	7,610,000	0.0810532	-	0
May	99.9	102,354	10,390,000	0.1015104	1	1
June	98.6	98,150	11,620,000.00	0.1183902	20	2
July	99.7	101,422	8,530,000.00	0.0841040	5	1
August	75.2	86,947	8,530,000.00	0.0981057	357	2
TOTAL		**577,732**	**55,330,000**		**385**	**6**
AVERAGE	**95.5**			**0.0957075**		

PP8	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	85.1	58,450	23,719,569	0.41	331.8	9
April	96.0	64,900	22,967,884	0.35	86.79	2
May	96.2	66,580	28,638,530	0.43	91.23	7
June	100.0	67,360	25,114,973	0.37	0	0
July	97.7	67,570	21,296,922	0.32	52.45	6
August	95.9	66,580	23,094,922	0.35	92.9	3
TOTAL		**391,440**	**144,832,800**		655.17	**27**
AVERAGE	**95.1**			**0.37**		

PP 9	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	94.6	1,933,832	2,779,420	1.4	289	0
April	91.8	1,786,187	4,720,194	2.6	336	0
May	99.2	1,764,268	3,522,466	2.0	32	0
June	96.0	1,709,774	4,374,075	2.6	151	0
July	98.1	1,812,216	2,080,943	1.1	78	0
August	83.7	1,824,551	5,619,831	3.1	745	0
TOTAL		**10,830,828**	**23,096,929**		**1,631**	0
AVERAGE	**93.9**			**2.1**		

PP10	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	91.3	30,460	58,672,072	1.93	187.87	14
April	99.3	31,055	71,106,975	2.29	14.53	4
May	98.5	30,733	79,145,447	2.58	32.08	15
June	97.1	29,792	63,387,823	2.13	61.97	25
July	76.8	24,009	90,673,541	3.78	501.91	4
August	97.0	29,897	64,002,457	2.14	64.42	14
TOTAL		**175,946**	**426,988,315**		**862.78**	**76**
AVERAGE	**93.3**			**2.47**		

PP11	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	99.7	16,284	2,225,000	0.1366365	13	6
April	96.2	13,944	3,463,000	0.2483461	165	19
May	79.7	12,125	3,185,000	0.2626830	906	41
June	95.2	11,906	3,635,000	0.3053065	210	16
July	93.4	13,769	3,741,000	0.2717068	297	20
August	94.6	13,528	3,699,000	0.2734268	241	26
TOTAL		**81,556**	**19,948,000**		**1,831.26**	**128**
AVERAGE	**93.1**			**0.2496843**		

PP12	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	99.9	4,738	10,243,743	2.16	0	2.12
April	98.9	10,322	10,515,953	1.02	8	15.36
May	89.7	6,932	70,426,988	10.16	9	148.47
June	93.5	13,153	10,682,467	0.81	2	94.22
July	83.6	10,993	10,612,644	0.97	0	235.71
August	90.2	12,780	71,277,008	5.58	7	140.99
TOTAL		**58,918**	**183,758,803**		**26**	**636.87**
AVERAGE	**92.6**			**3.45**		

PP13	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	98.9	23,152	8,573,967	0.37	1.00	1
April	72.6	6,039	7,872,568	1.30	2.00	2
May	99.6	3,803	7,829,889	2.06	4.00	4
June	99.3	7,801	10,614,124	1.36	1.00	1
July	85.7	21,501	8,583,148	0.40	1.00	1
August	98.2	26,254	8,816,461	0.34	3.00	3
TOTAL		**88,550**	**52,290,157**		**12.00**	**12**
AVERAGE	**92.4**			**0.97**		

PP14	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	87.7	15,753	64,924,191	4.12	176.53	3
April	93.8	34,027	51,218,756	1.51	88.85	2
May	70.3	24,766	51,278,062	2.07	427.41	5
June	98.5	42,555	105,156,248	2.47	21.97	2
July	98.7	36,530	52,031,582	1.42	18.19	0
August	100.0	42,643	50,796,566	1.19	0.49	2
TOTAL		**196,274**	**375,405,405**		**733.44**	**14**
AVERAGE	**91.5**			**2.13**		

PP15	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Total outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	76.4	1,811	1,112,360	0.6	1018.0	0
April	77.2	561	2,323,747	4.1	987.0	0
May	79.2	729	1,441,429	2.0	900.0	0
June	85.5	600	2,669,581	4.5	624.6	0
July	93.9	692	1,635,422	2.4	262.0	0
August	91.3	997	1,577,269	1.6	376.0	0
TOTAL		5,390	**10,759,808**		4167.6	0
AVERAGE	**83.9**			**2.5**		

PP16	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	26.8	282,488	800,000	2.8319787	1,633	0
April	95.0	859,360	3,400,000	3.9564327	107	61
May	96.4	1,029,575	2,730,000	2.6515795	6	33
June	98.5	1,015,515	4,510,000	4.4410964	33	25
July	99.7	907,862	3,350,000	3.6899881	6	39
August	99.9	916,025	3,320,000	3.6243552	69	32
TOTAL		**5,010,825**	**18,110,000**		**1,854**	**190**
AVERAGE	**86.0**			**3.5325718**		

PP17	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	95.0	660	5 ,297,426	8.023	252.26	3
April	85.2	599	3 ,913,454	6.534	747.65	6
May	81.8	556	3 ,576,231	6.428	940.87	5
June	79.4	531	3,605,139	6.792	874.39	9
July	80.8	579	4,313,746	7.455	774.86	3
August	78.7	613	7,211,208	11.77	888.4	4
TOTAL		**3,538**	**2 7,544,345**	7.786	**4478.43**	**30**
AVERAGE	**83.5**			**6.8485**		

PP 18	% Availability	Generated Units(Mwhrs)	O&M cost(ksh)	Cost per kwhr produced(ksh)	Total outage hours	Total No. of failure
March	83.7	2,292,401	3,880,000	1.6925486	367	0
April	71.6	3,153,213	2,090,000	0.6628160	933	0
May	67.4	3,330,021	2,180,000	0.6546505	1,200	0
June	78.1	3,828,304	2,520,000	0.6582549	436	0
July	92.5	4,725,703	610,000	0.1290813	161	0
August	65.6	3,486,819	2,120,000	0.6080040	707	38
TOTAL		20,816,461	**13,400,000**		**3,804**	**38**
AVERAGE	**76.5**			**0.7342259**		

PP19	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	59.0	18,694	8,825,922	0.39	862.79	0
April	62.7	20,357	10,358,200	0.36	833.74	11
May	61.1	22,805	10,829,199	0.33	874.54	4
June	69.1	21,943	12,244,057	0.35	695.76	6
July	64.1	22,966	9,309,397	0.43	763.43	7
August	97.7	20,436	11,665,679	0.45	24.70	4
TOTAL		**127,201**	**63,232,454**		4,054.96	32
AVERAGE	**69.0**			**0.39**		

PP 20	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	45.2	4,151,000	7,200,000.00	1.7345218	1,654	0
April	80.9	7,398,000	2,590,000	0.3500946	1,381	28
May	70.7	8,852,000	920,000	0.1039313	965	0
June	76.3	7,990,000	2,340,000.00	0.2928661	758	4
July	71.4	7,898,000	1,010,000.00	0.1278805	840	10
August	64.2	6,285,000	2,960,000.00	0.4709626	1,028	20
TOTAL		**42,574,000**	**17,020,000**		**6,626**	**62**
AVERAGE	**68.1**			**0.5133762**		

PP 21	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	50.0	0	1,421,260	-	720.00	0
April	49.4	103,602	2,796,946	0.05	728.00	0
May	47.9	102,715	4,773,935	0.05	750.00	0
June	50.0	112,560	4,690,619	0.04	720.00	0
July	47.9	113,210	1,308,000	0.04	750.00	0
August	47.8	106,205	4,089,263	0.04	752.00	0
TOTAL		**538,292**	**19,080,023**		**4,420.00**	0
AVERAGE	**48.8**			**0.04**		

PP22	% Availability	Generated Units	O&M cost(ksh)	Production Cost per	Outage hours	No. of failures
		in (MWhrs)		kwhr (ksh)		
March	50.0	1,962	1,421,260	0.72	720.00	0
April	8.3	196	4,796,946	24.47	1,320.00	0
May	50.0	652	4,773,935	7.32	720.00	0
June	50.0	110	4,690,619	42.64	720.00	0
July	49.2	132	4,308,057	32.64	732.00	0
August	47.6	892	4,089,263	4.58	755.00	0
TOTAL		**3,944**	**24,080,080**		**4,967.00**	0
AVERAGE	**42.5**			**18.73**		

4.4 Analysis and findings

Power plants operated by one plant manager were found to use the same maintenance practices at the same preference levels. All the power plants studied reported that all the maintenance practices were adopted in the power plants to enhance performance. 13 power plants emphasized on spare parts as the maintenance practice preferred most with a mean score of 25% followed by preventive maintenance which ranked highest in 6 power plants at a mean score of 23%. Operator involvement was rated low in comparison with the other maintenance practices a mean score of 14.1% with no power plant rating it as the most preferred maintenance option among all the alternatives.

A=Emphasis on preventive maintenance B=Spare parts supply C=Operator involvement in maintenance

D=Emphasis on standby machines E=Emphasis on maintainability

Most preferred option= 1 Less preferred option=0

Table 4.5 Combined power plants summarized operational data

	most preferred practice	score	Outage hours	% Availability	Cost per kwhr	No. of failures
PP1	B	8	24	99.9	0.3	8
PP2	B	7	570	98.1	0.1	10
PP3	B	7	653.88	97.9	0.91	67
PP4	B&D	5	301.08	97.7	0.12	8
PP5	E	6	339.33	96.1	0.42	15
PP6	A	7	559.39	95.7	0.22	7
PP7	B&A	6	385	95.5	0.1	6
PP8	B	8	622.26	93.7	0.37	27
PP9	B	7	1,631	93.6	2.1	0
PP10	D	6	862.78	93.3	2.5	76
PP11	B	7	1,831.26	93.1	0.25	128
PP12	A	7	636.87	92.6	3.5	26
PP13	A	8	12	92.4	7.1	12
PP14	A	7	733.44	91.5	2.13	14
PP15	A	6	4167.6	86.6	2.5	0
PP16	B	6	1,854	86	3.53	56
PP17	D	6	746	83.5	6.85	30
PP18	B	6	3,804	76.5	0.73	38
PP19	B	6	4,054.96	69	0.39	32
PP20	B	6	3313	68.1	0.51	62
PP21	A	6	2210	48.8	8.4	0
PP22	B	6	2483	42.5	18.73	0

4.4.1 Comparison of Maintenance practices

The mean scores of the plants preferring one practice were computed in table 4.6 below. The difference of these means was investigated using the paired sample T-test and forecasting software at 95% confidence level and the results obtained were given in table 4.7. The study compared two practices at a time and in case of a T-score of more than 1.96, the null hypothesis would be rejected.

First the study compared the mean of the various maintenance practices as presented in table 4.6 below.

Table 4.6 Maintenance practices mean scores comparison

Practices compared	Practice 1 mean score (X1)	Practice 2 mean score X2	Mean Difference
AB	6.71	6.23	0.48
AC	6.71	0	6.71
AD	**6.71**	**5.67**	1.04
AE	6.71	6	0.71
BC	6.23	0	6.23
BD	6.23	5.67	0.56
BE	6.23	6	0.23
CD	0	5.67	-5.67
CE	0	6	-6
DE	5.67	6	-0.33

The mean score of practice C was zero as no power plant ranked it as the most preferred in enhancing operational performance.

The study further sought to establish the paired T-test of practice A and B. These findings were presented in table 4.7.

Table 4.7: T test on And B

T-Test		
Difference: Mean1 - Mean2	0.48	
T Statistic	2.481	
P-value	0.5103	

As seen in table 4.7, it is evident that the mean those preferring B is significantly different from those preferring A, therefore the null hypothesis was rejected. This therefore means that B is most preferred than A. The study therefore dropped A and sought to compare the mean of B and C using the paired sample T-test. It was established in the study, there was mean score for C was 0 and therefore it indicates that none of the respondents preferred to use C, the study thus compared the means of B and D as presented in table 4.8.

Table 4.8: T-Test on B and D

T-Test		
Difference: Mean1 - Mean2	0.56	
T Statistic	2.493	
P-value	0.7496	

As seen in the table 4.8, the mean those preferring B is significantly different from those preferring D, therefore the null hypothesis was rejected. This shows that B practice was most preferred than D, with a T-statistic of 2.493, in this regard therefore D was dropped and B was further compared with E, as seen in table 4.9.

Table 4.9: T-Test for B and E

T-Test		
Difference: Mean1 - Mean2	0.023	
T Statistic	2.007	
P-value	0.5002	

As seen in the table 4.9, it is evident that the mean those preferring B is significantly different from those preferring E, therefore the null hypothesis was rejected. It means therefore that B is the most preferred maintenance practice.

4.4.2 Analysis of availability and cost per unit

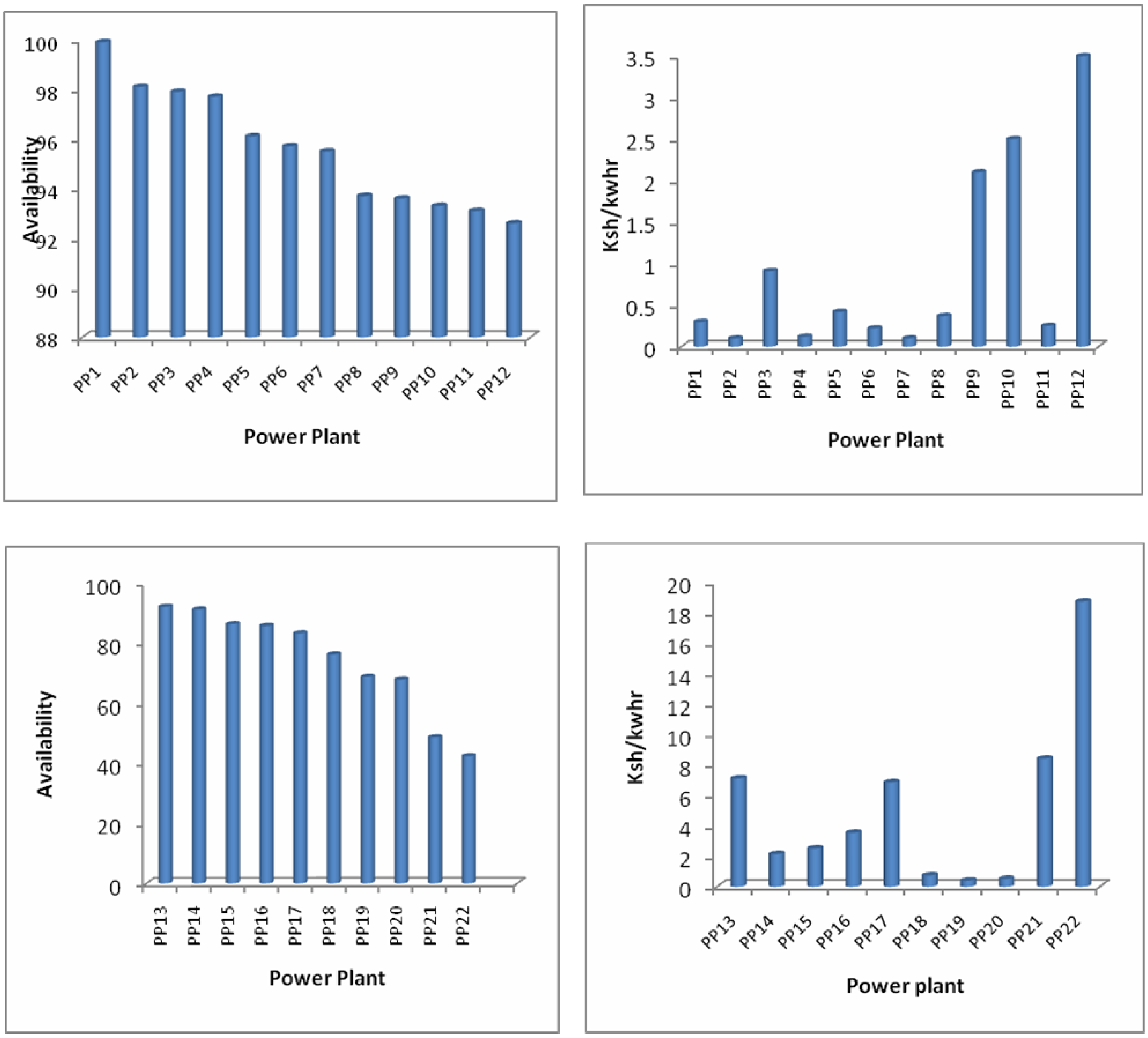
The power plants availability and production cost per unit analysis was carried out at 95% confidence level using the spearman's correlation and table 4.10 indicates the outcomes.

Table 4.10 Spearman rank correlation between availability and cost per unit

Spearman Rank Order Correlation - Ungrouped Data	
Statistic	Value
Correlation (not corrected)	-0.429136
Correlation (corrected)	-0.429944
Degrees of Freedom	20
Observations	22

The sign of the Spearman correlation indicates there was a negative relationship between availability and cost per unit in the negative direction of association between the availability (independent variable) and the cost per unit (dependent variable). Spearman correlation coefficient is negative implying that the cost per unit reduces when the plant availability increases.

Figure 4.1: Comparison of Cost per unit and availability



The figure 4.1 indicates that the cost per unit increases when the availability reduces. This is because of the reduced energy production while some inputs contributing to the production cost i.e. rents, salaries etc remains fairly constant.

4.4.3 Maintenance practices and availability

The mean availabilities for the plants operating using the various practices i.e. Emphasis on preventive, spare parts supply, Operator involvement in maintenance emphasis on standby equipments, and maintainability were calculated as in table 4.11 below. The mean availability for all the power plans studied was 72.62% at a standard deviation of 40.852. The standard deviation (SD) gives an idea of how close the entire set of data is to the average value. This large standard deviation implied a wide variation between availabilities between plants using the various practices.

Table 4.11: Availability variation with maintenance practice

Maintenance practice	**No. of plants**	**Mean plants availability**		**Parameter**	**Value**
A	7	92.4		Mean	72.62
B	11	83.5		SD	40.852
C	0	0.0		SEM	18.269
D	3	91.5		N	5
E	1	96.1		90% CI	33.673 to 111.567
	22			95% CI	21.896 to 123.344
				99% CI	-11.494 to 156.734
				Minimum	0
				Median	91.5
				Maximum	96.1

A=Emphasis on preventive maintenance B=Spare parts supply C=Operator involvement
D=Emphasis on standby machines E=Emphasis on maintainability

4.4.4 Distribution of the power plant failures

The *binomial distribution* describes the behavior of a count variable *X* if the following conditions apply:

1: The number of observations n is fixed.

2: Each observation is independent.

3: Each observation represents one of the two outcomes ("success" or "failure").

4: The probability of "success" p is the same for each outcome.

In this study, the number of observations were fixed, each observation was independent. Additionally, each plant is expected to operate at a minimum of 90% availability, and therefore a plant that does not operate at this level is considered a failure while the one that operates at or above 90% is considered a success. The expected hours are calculated based on 90% of the ideal operational hours. Table 4.12 shows the percentage availability for each plant.

Table 4.12: Analysis of Observed and Expected Failures

	Outage hours	Availability hours	Observed failures	Expected hours	% Availability	100% Availability (hours*
PP1	24	4296	8	3888	99%	4320
PP2	570	3750	10	3888	87%	4320
PP3	653.88	3666.12	67	3888	85%	4320
PP4	301.08	4018.92	8	3888	93%	4320
PP5	339.33	3980.67	15	3888	92%	4320
PP6	559.39	3760.61	7	3888	87%	4320
PP7	385	3935	6	3888	91%	4320
PP8	622.26	3697.74	27	3888	86%	4320
PP9	1,631	2689	0	3888	62%	4320
PP10	862.78	3457.22	76	3888	80%	4320
PP11	1,831.26	2488.74	128	3888	58%	4320
PP12	636.87	3683.13	26	3888	85%	4320
PP13	12	4308	12	3888	100%	4320
PP14	733.44	3586.56	14	3888	83%	4320
PP15	4167.6	152.4	0	3888	4%	4320
PP16	1,854	2466	56	3888	57%	4320
PP17	746	3574	30	3888	83%	4320
PP18	3,804	516	38	3888	12%	4320
PP19	4,054.96	265.04	32	3888	6%	4320
PP20	3313	1007	62	3888	23%	4320
PP21	2210	2110	0	3888	49%	4320
PP22	2483	1837	0	3888	43%	4320

In order to test for binomial distribution, table 4.13 presents a summary of the findings.

Table 4.13: Binomial Distribution of Failures

Binomial Test						
		Category	N	Observed Prop.	Test Prop.	Exact Sig (2-tailed)
Success or Failure	Group 1	1.00	5	.23	.50	.014
	Group 2	.00	17	.77		
	Total		22	1.00		

As seen in the table 4.13, N=22; Success is 17, and p is .90. Calculating the results shows that the probability of getting 5 or more successes is 0.014, in a 2 tailed probability value.

4.5 Discussion

Out of the 22 power plants studied 13 power plants emphasized on spare parts as the maintenance practice preferred most with an average availability of 83.5%. The 6 plants which emphasized on preventive maintenance indicated an availability of 92.4%. The high performing power plants were also found to record low cost per unit. This is in is consistent with the findings in literature review by (Mulugeta, 2009) that predictive maintenance enhanced equipment performance and resulted to minimum equipment downtime and repair time.

The study revealed that plants which emphasized supporting supply of spare parts performed better than all the others. Careful choice of the practice to emphasis in the power plant was therefore of vital importance in improving performance. The study also found that the number of outage hours affected the equipment performance as this resulted to low production. This is consistent with the findings by Jih-AN Chen, 2012 that maintenance lengthens the life of equipment and reduces its failure rate.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents summary of findings as discussed in chapter four and interpretations of the data analysis, conclusions and recommendations based on the findings.

5.2 Summary of the findings

The objectives of the study were to identify the maintenance practices and to analyse the distribution of failures in the power generating plants in Kenya. In addition the study was also carried out to establish the relationship between the maintenance practices and the operational performance in these power plants. The research was conducted on the 25 major operating power plants in Kenya where the plant managers were the respondents. Responses were received from 22 plants managers which gave a response rate of 88%. An effective maintenance practice policy reduces the equipment failure rate and increases the equipment availability which leads to low production cost per Unit and hence a competitive advantage in the industry.

The data received indicated that all the practices in the administered questionnaire were adopted in those power plants. These practices were applied at varying levels from one plant to the other. Plant managers operating more than one plant applied the same practices across these plants. Emphasis on spare parts was reported in 7 of the 10 highest performing power plants. 13 out of the 22 power plants studied rated supply of spare parts highest in operational performance improvement followed by emphasis on preventive maintenance which was rated highest by 6 power plants. 4 power plants highly emphasized maintainability of equipments while none of the plants rated operator involvement in maintenance as the most effective practice to enhance operational performance.

On analysis the power plants operating at high availability recorded lower production cost per unit. High outage hour's plants were observed to have low availability and high cost per unit. This was because of the reduced production volume which reduced sales while some facility costs i.e. rent, salaries, security etc were maintained. The number of failures recorded varied between the plants but this was not related to the plant availabilities recorded. The average per unit cost of the various energy sources based on the study were thermal sh4.7/Kwhr, wind ksh2.5/Kwhr, hydro ksh2.3/Kwhr and geothermal sh1.3/Kwhr.

5.3 Conclusion

Based on the findings above it is concluded that there exists a link between the maintenance and the plant operational performance. For the highest operational plant performance adequate spare stocks supply in the power plants is very critical. Preventive maintenance also leads to high operational performance. It is defined as a broad term that encompasses a set of activities aimed at improving the overall reliability and availability of an equipment (Kamran, 2003). Standby equipments and maintainability of equipments also have an effect on the plant performance while involvement of operators in maintenance has a very low effect on the plant performance. Each practice is important in operational performance improvement from the findings of the study. Low cost per unit is realized by increasing production volume and the equipment availability. The mode of generation and the plant availability affect the energy generation cost per unit. This arises from varying cost of inputs and the different volumes of production. Decision makers should strive to improve on the studied maintenance practices, however high emphasis should be placed on the supply of spare parts, given that it has shown high influence on plant performance.

5.4 Recommendations

Varying levels of application of the maintenance practices was found between the power plants studied. The study recommends the need for plant managers to emphasize on supply of spare parts, for good performance. Additionally, there is need to maintain good plant records to enhance performance assessment. The study further recommends the need to benchmark with other firms in related industries in order to improve the maintenance practices.

5.5 Limitations of the study

The study required collection of data which was considered confidential by most of the plant managers. Time was required by some of the managers to obtain authorities to provide the required information. Poor accuracy in the operation and maintenance data obtained in some plants was noted due to poor records especially where information technology in operations was not adequately applied. Editing was done on such data, before it was used in the research. In addition some of the power plants studied were located far away from each other and only the data provided by the plants managers on mail was used. The researcher had travelled out of the country for some time during the time of study, and this increased the data collection period.

The study was cross-sectional in nature; a longitudinal study would have given a better representation of the variables studied.

5.6 Suggestions for further Research

The study was carried out in power plants generating power from various sources i.e. wind, hydro and thermal which had also different capacities. The effect of other underlying factors like age of the power plants, generation mode, human and environmental factors were not considered in this study. A similar research is recommended to establish whether these variables affect the power plant operational performance. Further research need to be done on power plants of the same type and approximately the same rating to investigate whether the same results are obtained. Some power plants were not operational during the time of the study. In this regard, it is recommended that a similar study be carried out for a longer period in order to establish if the same relationship is maintained due to possible changes in the studied power plants load profiles. Finally the study recommends for a similar research to be carried out but in a different industry, i.e. manufacturing to establish how maintenance practices affect performances in such industries.

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APPENDICES

RESEARCH QUESTIONAIRE

Power Plant operating data for the period March-August 2013

Please provide the operating data of the generator (s) in your power plant. In-case the power plant has more than four generators an extra sheet will be required. "**Type**" means mode of generation i.e. thermal while "**Unit identity**" is the unit name i.e. **ST1**. The sum total of the standby, system, forced and planned hours will be the total hours in the month less the operating hours.

(a) Individual Units monthly operating Data

Unit identity:		Rating (MW):		Year commissioned:			Type:
	Standby hours	System outage hours	Forced outage hours	Planned outage hours	Number of failures	Energy generated(Mwhrs)	Availability (%)
March							
April							
May							
June							
July							
August							
TOTAL							

Unit identity:		Rating (MW):		Year commissioned:			Type:
	Standby hours	System outage hours	Forced outage hours	Planned outage hours	Number of failures	Energy generated(Mwhrs)	Availability (%)
March							
April							
May							
June							
July							
August							
TOTAL							

Unit identity:		Rating (MW):		Year commissioned:			Type:
	Standby hours	System outage hours	Forced outage hours	Planned outage hours	Number of failures	Energy generated(Mwhrs)	Availability (%)
March							
April							
May							
June							
July							
August							
TOTAL							

Unit identity:		Rating (MW):		Year commissioned:			Type:
	Standby hours	System outage hours	Forced outage hours	Planned outage hours	Number of failures	Energy generated(Mwhrs)	Availability (%)
March							
April							
May							
June							
July							
August							
TOTAL							

(b) Power plant monthly expenditures for the period March-August 2013

Month	March	April	May	June	July	August
O&M cost (ksh)						

Note: This excludes any capital investments.

(c) Power plant maintenance practices

Please tick [√] the statement in each pair that is closest to what happens in your station.

1.	[ ]	In my power plant maintenance programmes for the equipments form a critical work tool.	[ ]	In my power plant adequate spare stocking guarantees low equipments downtime.
2.	[ ]	In my power plant equipments required for preventive maintenance are adequate.	[ ]	In my power plant maintainability is emphasized at the equipment design stage.
3.	[ ]	In my power plant Preventive maintenance is the focus for performance improvement.	[ ]	In my power plant Operator technical skills development is highly emphasized.
4.	[ ]	In my power plant Regular periodic maintenance is done.	[ ]	In my power plant Auxiliary standby equipments are provided.
5.	[ ]	In my power plant frequent stores audit for stocks control is carried out.	[ ]	In my power plant equipments that are not maintainable are replaced.
6.	[ ]	In my power plant an inventory management system is used in the Power Plant.	[ ]	In my power plant operator qualification is highly considered during recruitment.
7.	[ ]	In my power plant re-order level for spare parts ensures no stock-outs.	[ ]	In my power plant the working condition of the standby equipment is regularly checked.
8.	[ ]	In my power plant adequate spare stocking guarantees low equipments downtime.	[ ]	In my power plant maintenance programmes for the equipments form a critical work tool.
9.	[ ]	In my power plant a budget is provided for replacements of non repairable equipments.	[ ]	In my power plant operator on job training is done immediately on employment.
10.	[ ]	In my power plant maintainability of equipments is tested early in the life cycle.	[ ]	In my power plant review of the number of standby equipment is done regularly.
11.	[ ]	In my power plant maintainability is emphasized at the equipment design	[ ]	In my power plant equipments required for preventive maintenance are adequate.

		stage.		
12.	[ ]	In my power plant regular stock count is carried out to ensure there are good stocks.	[ ]	In my power plant quotations offering non maintainable equipments are rejected.
13.	[ ]	In my power plant operator training needs are regularly reviewed and implemented.	[ ]	In my power plant obsolete standby equipments are replaced with latest equipments.
14.	[ ]	In my power plant the operators are held accountable in the plant operations.	[ ]	In my power plant the standby equipments provided are adequate and serviceable.
15.	[ ]	In my power plant operator on job training is done immediately on employment.	[ ]	In my power plant a budget is provided for replacements of non repairable equipments.
16.	[ ]	In my power plant the operators are held accountable in the plant operations.	[ ]	In my power plant in my power plant Preventive maintenance is the focus for performance improvement.
17.	[ ]	In my power plant standby equipments are regularly operated to check performance.	[ ]	In my power plant methods of improving preventive maintenance are regularly explored.
18.	[ ]	In my power plant standby equipment status is captured in the monthly reports.	[ ]	In my power plant approvals for emergency spares procurement are easily arranged
19.	[ ]	In my power plant review of the number of standby equipment is done regularly.	[ ]	In my power plant maintainability of equipments is tested early in the life cycle.
20.	[ ]	In my power plant performance benchmarking is done with the best local performing power plants.	[ ]	In my power plant the status of spare parts forms the agenda in our weekly meetings.