AUTOMATION AND OPERATIONAL PERFORMANCE IN HYDRO-ELECTRIC POWER GENERATION SECTOR

FRANCIS K. KAWA

A RESEARCH PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF BUSINESS ADMINISTRATION (MBA), UNIVERSITY OF NAIROBI

NOVEMBER, 2013

DECLARATION

I hereby declare that this research project report is my own work and effort, and that it has not been submitted anywhere for any award.

Signature: ____________________________ Date: _______________

Name: **FRANCIS K. KAWA**

Registration No. **D61/62668/2010**

This research project report has been submitted for examination with my approval as the University Supervisor.

SUPERVISOR:

Signature: ______________________________ Date: __________________________

NAME: **DR. OWINO A. OKWIRI**

Department of Management Science,

School of Business

UNIVERSITY OF NAIROBI

ACKNOWLEDGEMENTS

Much gratitude goes especially to my supervisor Dr. Owino Okwiri for his tireless effort in guidance, advice, support and constructive criticism throughout the research project writing.

Special thanks to my family and friends for encouraging my academic pursuit up to this level. A big thank you to all those who participated in the survey for their tremendous support.

Above all thanks to the Almighty for his mercy and for giving me good health and strength to go through this very demanding study.

DEDICATION

This study is dedicated to my entire family and in particular to Simon Mutuku who offered invaluable support, prayers and encouragement. They gave me the will and determination to complete the degree course.

ABSTRACT

The purpose of the study was to determine the extent or level of automation, the nature of automation and the effect of automation on operational performance in the Kenyan hydro-electric power sub-sector. The target population was all the five major hydro-electric power generating stations of a major hydro electric power generating company in Eastern Africa. The study used primary data which was gathered by means of a self-administered questionnaire issued to respondents. Data analysis involved the use of descriptive statistics and multiple regression analysis to determine the nature of automation and the relationship between the variables respectively. The study found that two of the power plants could be classified as technology centered while the remaining three were of the fixed human centered type. None of the plants was of the adaptive human centered classification. The findings also revealed that all the plants were of the 'supervisory control, level of automation according to Endsley's level of automation classification taxonomy. The study concludes that there is a significant relationship between automation approach and operational performance and in particular automation was confirmed to have a significant effect on speed and mistake proofing which in turn have a positive impact on operational performance. The study recommends that organizations intending to implement automation strategies should consider the automation approach as it has been shown to have an effect on operational performance. A quantitative survey is also recommended to corroborate these findings.

ABBREVIATION

AA	-	Adaptive automation
DEA	-	Data Envelopment Analysis
LOA	-	Level of automation
NEA	-	Nepalese Electricity Authority

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 Background

Operations are processes that take in a set of input resources which are used to transform something into outputs or products and services. Although all operations conform to this general input transformation output model, they differ in the nature of their specific inputs and outputs. Some are manufacturing operations producing products while others are service operations producing services. The most important difference between these operations is the nature of their inputs. This has important implications on how the operation needs to be managed. Operations are a requirement to achieving the objectives of quality, cost, flexibility and speed. Cost involves eliminating waste while quality entails supplying fault free products. The imperative of speed involves operations that give short delivery times, fast flows of materials and rapid design of new products. The other operational performance measure is flexibility which requires operations that adjust to different customer tastes (Waters, 2006).

Performance is defined as the degree to which an operation fulfills the five generic objectives of quality, speed, dependability, flexibility and cost (Nigel, Stuart and Robert, 2010). Operation or production constitutes the heart of each company. Delivering goods and services in the quality, timelines and the volume required by the customer is essential for an on-going and strengthened success of a company. In the current environment it is more than ever important to focus on the value creating steps to eliminate cost while increasing delivery quality and reliability (Arthur, 2008).

Automating processes is one of the avenues organizations could consider so as to achieve the above performance objectives. It is one of the ways of improving performance through reduced costs. Technology and technological innovations have been used by nations with high labour costs to help achieve comparable production costs to those countries with low cost labour (Jones, 2007). Applications of automated systems in the service environment bring benefits through increased productivity. Automated systems in service involve mistake proofing, replacement of service interface and control of delivery processes.

Automation is the use of controlled systems such as computers to control industrial machinery and processes, replacing human operators. The drive to provide increased levels of control to electro-mechanical systems and with it a corresponding distancing of the human from direct system control, has grown out of the belief that automated systems provide superior reliability, improved performance and reduced costs for the performance of many functions (Endsley, 1996).

The classification of process technologies based on historical progression of manual, mechanization and automated is useful in comparing how each affects the competitive priorities of cost, flexibility, quality and speed (Buffa & Sarin, 1987).

1.1.1 Approaches to Automation

Automation decisions have focused on optimizing the capabilities of technology. Technology-centered automation is one of the approaches to automation which is driven by a desire to reduce costs through the reduction of human workload and thus human staffing requirements. Such efforts usually assign a computer or mechanical controller to perform those tasks technically possible and remove human operators from the control loop by placing them in the job of system monitor. A central short-coming associated with the advent of automated systems and especially the technology centered approach has been dubbed the out-of-loop performance problem due to low situation awareness on the part of the operators, which can be severely impacted by automation (Endsley, 1995a).

Situation awareness is formally defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. The effect of automated systems on situation awareness and the out-of-the-loop performance problem has been established as a critical issue that can undermine the effectiveness of human-machine performance in advanced systems. The Technology centered high automation approach has the disadvantage of inflexibity over the technology centered low configuration but guarantees consistent quality (Endsley, 1988a).

Other approaches, which redefine the assignment of functions to people and automation in terms of a more integrated team approach have been developed. One way to minimize the negative effects of automation is to devise implementation schemes that keep the human actively involved in the decision making loop while simultaneously reducing the load associated with doing everything manually. This can be accomplished through the human centered automation approach by determining a level of automation that minimizes negative impacts on operator situation awareness. Thus, even though full automation of a task may be technically possible, it may not be desirable if the performance of the joint human-machine system is to be optimized (Endsley, 1987b, 1993b).

Two approaches to human centered automation can be defined. One approach seeks to optimize the assignment of control between the human and automated system by keeping both involved in system operations. This has been labeled level of automation or level of control (Draper, 1995) and defines the level of automation. This approach ensures timely and appropriate human intervention in case of system failure.

The other approach recognizes that control must pass back and forth between the human and the automation over time, depending upon situational demands and seeks to find ways of exploiting this understanding to increase human performance. This has been labeled Adaptive Automation or Dynamic Function Allocation (Corso and Moloney, 1990). The key difference between the two approaches is that adaptive automation involves dynamic control allocations (automated or manual, varying over time) and level of control involves static function assignments (Kaber, 1997, Parasuraman et al. 2000), defining the degree to which a task is automated. One such design is Autonomation which can be described as automation with a human touch. Autonomation prevents the production of defective products and is a quality control process.

The level of automation specifying the degree to which a task is automated has also been found to have an effect on performance. It has been theorized that keeping the human involved in system operations, some intermediate Level of automation may provide better human/system performance than that found with highly automated systems (Endsley 1987, Endsley and Kiris, 1995).

1.1.2 Operational Performance

Performance is defined as the degree to which an operation fulfills the five generic objectives of quality, speed, dependability, flexibility and cost. Some kind of performance measurement is a pre-requisite for judging whether an operation is good, bad or indifferent. Performance measurement is the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from actions taken by an organization. Without performance measurement, it would be impossible to exert any control over an operation on ongoing basis. The five performance objectives can be regarded as the dimensions of overall performance that satisfy an organization's customers (Nigel, Stuart and Robert , 2010).

The five generic performance objectives, quality, speed, dependability, flexibility and cost, can be broken down into more detailed measures, or they can be aggregated into 'composite' measures, such as 'customer satisfaction', 'overall service level', or 'operations agility'. These composite measures may be further aggregated by using measures such as 'achieve financial objectives', achieve operations objectives' or even 'achieve overall strategic objectives'. The more aggregated performance measures have greater strategic relevance insomuch as they help to draw a picture of the overall performance of the business, although by doing so they necessarily include many influences outside those that operations performance improvement would normally address (Nigel, Stuart and Robert, 2010).

The more detailed performance measures are usually monitored more closely and more often, and although they provide a limited view of an operation's performance, they do provide a more descriptive and complete picture of what should be and what is happening within the operation. In practice, most organizations will choose to use performance targets from throughout the range. Some detailed performance measures are defects per unit, level of customer complaints, scrap level, mean time between failures, lateness complaints, customer querry time, order lead time, throughput time, time to market, product range, transanction costs, labour productivity and machine efficiency (Nigel, Stuart and Robert, 2010).

One of the problems of devising a useful performance management system is trying to achieve some balance between having a few key measures on one hand (straightforward and simple, but may not reflect the full range of organizational objectives), and, on the other hand, having many detailed measures (complex and difficult to manage, but capable of conveying many nuances of performance). Broadly, a compromise is reached by making sure that there is a clear link between the operation's overall strategy, the most important performance indicators that reflect strategic objectives, and the bundle of detailed measues that are used to 'flesh out' each key performance indicator. Obviously, unless strategy is well defined then it is difficult to target a narrow range of key performance indicators (Nigel, Stuart and Robert, 2010).

1.1.3 Automation and operational performance

The main objectives of automation are to control the behavior of dynamic systems and emulate the maximum physical and intellectual human capacity to improve productivity through increased accuracy. Automation can be cost effective, and can help to streamline operations with increasingly accurate production systems. The introduction of automated machines has lessened human error and in the manufacturing industry, robots have assisted with quality control, productivity and ensuring economic efficiencies.

Automation allows a company to reduce accidents and environmental impacts and also leads to improvement in workplace efficiency, production and cost-effectiveness (Juliana, Zoe, John and Magaly, 2009).

Over the last three decades a growing group of manufacturing firms in the industrialized world have been spending enormous resources in upgrading their production technology to cope with the increasing competition from non industrialized countries where production costs are much higher. As a result of this, there has been a transition in the manufacturing sector from labor intensive production to capital intensive flexible specialization in the industrialized world. For instance, in the United states the workforce employed in the manufacturing sector dropped sharply from 20 per cent in 1979 to about 11 per cent in 2006 (Deitz and Orr, 2006). At the same time the number of robots has increased to 6.5 million overall worldwide in 2007. Around 1 million of these are used in the manufacturing industry (Kromann, Skaksen and Sorensen, 2011).

Process technologies can be classified in terms of historical progression of the processes namely manual, mechanized and automated. This classification is useful in comparing how each affects the competitive priorities of cost, flexibility, quality and speed. Whereas mechanization provides human operators with machinery to assist them with the muscular requirements of work, automation greatly decreases the need for human sensory and mental requirements while increasing load capacity, speed and repeatability. The addition of automation to the service industry has led to improved performance and quality of service delivery to consumers (Buffa and Sarin, 1987).

Automated processes tend to be more consistent in quality than manual processes since machines can be continuously improved and reprogrammed to avoid defect generation and automation is used to provide quality control (Jones, 2007).

Mechanized technology on the other hand, aims at substitution of machines for human labor with the advantage of reduced labour costs. One can choose either the general or special purpose process technology depending on whether the flexibility or cost are the important competitive priorities respectively.

Autonomation, which is a form of adaptive high automation allows workers to operate two or more different machines, thus providing flexibility in processes that might precede an assembly line. This organization of multifunctional workers leads to a decrease in the number of workers required, resulting in a direct increase in productivity as a result of reduced costs (Buffa & Sarin, 1987).

In general, a key underlying factor that has emerged as a contributor to human performance problems in complex, automated systems control is human out-of-the-loop (OOTL) performance (Young 1969, Kessel and Wickens 1982). One way to minimize these negative effects of automation is to devise implementation schemes that keep the human actively involved in the decision making loop while simultaneously reducing the load associated with doing everything manually. This can be accomplished by determining a level of automation that minimizes nagative impacts on operator situation awareness (Endsley, 1987b, 1993b). Loss of situation awareness leads to serious mistakes and the right level of automation will facilitate mistake proofing.

Worker's welfare has also been found to have an impact on operational performance. Researchers who focus specifically on human factors believe that automation project failures are related to inadequate attention to human and industrial relations factors. For example, Poe and Viator (1990) argued that failure of new technology to meet organizational objectives could be the result of worker resistance to automation and hence the onus is on the employer to communicate, listen and assist workers in adjusting to the new technology. Braverman (1995) and Shaiken (1984) have argued that automation typically brings about operational performance improvement at the expense of worker well-being and often has adverse consequences on industrial relations atmosphere (Willmot, 1987).

1.1.4 Hydro-electric power generation sector

The national installed capacity in Kenya currently is 1722 MW with a peak demand of 1330 MW. The Kenya Power & Lighting Co. Ltd. and a major power generation company in Eastern Africa are the key players in this sector with Kenya Power currently being the only authorized distributor of electric power in Kenya. The major power generation company, whose main product is electric energy, accounts for about 74% of the total capacity in Kenya while the Independent Power Producers (IPPs) and emergency power plants (EPP) account for 26% of the total generation capacity (KenGen, 2012). The power generation company sells power in bulk to Kenya Power in line with the single buyer model.

The generation company utilizes various primary sources of energy to generate electricity ranging from hydro, geothermal, thermal and wind with hydro accounting for 51% of the total. Much of the hydro power comes from the hydro-electric power plants HEPP4, HEPP5, HEPP2, HEPP1 and HEPP3 so designated for purposes of this study. HEPP4 is the most upstream in the cascade with the others following as listed. These plants were installed and commissioned at diverse dates with partially automated control systems and were independently controlled until the control system was upgraded with the installation of a Supervisory Control And Data Acquisition System (SCADA) which provides monitoring and control of six of the major hydro power stations from a central dispatch center.

The supervisory system was installed in order to reduce operational costs and response time to plant failure in order to improve on plant availability. Hitherto, all the controls were localized and operational data was collected manually and reliance was partly on human intervention which at times led to serious errors. Data capture and analysis was also a key drawback to quick response to plant failure which led at times to prolonged outage times.

Power generation is a capital intensive venture and investment in power generation in Kenya comprises a large and diverse set of barriers to entry. The sector faces a number of challenges, key among them being frequent power interruptions caused by a power supply deficit that occasions delayed maintenance leading to frequent power outages , low plant availability as a result of poor maintenance practices and slow response to plant breakdowns, a poor and unreliable distribution network, over dependence on hydro power which is subject to the vagaries of weather and high operational costs resulting from operation and maintenance of aging plants, inflationary pressures and a high demand for social services by communities neighboring the plants and a regulated market that restricts the company to only one buyer.

To meet these business challenges, the power generation company needs to operate more efficiently in the current competitive environment so as to satisfy the customer demands and keep away further unbundling of the sector which would usher in more competition. This can be achieved through strengthening of its internal processes such as adopting new and emerging technologies such as plant automation and upgrades.

1.2 Statement of the Research Problem

The electric power industry plays a significant role in the Kenyan economy in general. Businesses will only thrive if there is adequate and reliable power supply in the country. The major power generating company, and in particular the hydro power generating stations along the Tana river play a key role in this respect and it is imperative that its generating processes are efficient (KenGen, 2012). One way of achieving this is through automation.

It has been argued that automated systems increase productivity and efficiency. By implementing new and automated technologies, companies can improve their performance. Research has it that automation leads to reduction of waste and improved quality control. Studies have shown that operations at all levels are exploring opportunities to increase efficiency, safety and production via automation (Juliana, Zoe, John and Magaly, 2009). Automation is labor saving technological change which is supposed to increase labor productivity (Kromann, Skaksen and Sorensen, 2011). It has been argued that industrial robots are technologies directly targeted at saving labor input. There are large potentials for increasing productivity through more intensive use of automation. Automation helps achieve precision and accuracy (Ankit Kumer Srivasta, 2006).The drive to provide increased levels of control to electro-mechanical systems, and with it a corresponding distancing of the human from direct system control, has grown out of the belief that automated systems provide superior reliability, improved performance and reduced costs for the performance of many functions (Endsley, 1996)

Over the years, electricity consumers in Kenya have been reported complaining of several problems associated with power supply like inadequate power supply, frequent blackouts and power rationing, poor quality supply which leads at times to customer property damage and prolonged response time to plant failure. The power supply deficit in Kenya and the continuously changing business and regulatory environment places an ever increasing burden on the key players in the industry who must keep adopting new strategies to address the perennial business challenges. High capital investment calls for efficient use of resources so as to achieve optimum operational costs. The threat of further deregulation leading to increased competitive environment requires the major generation company to maintain high reliability. Quick response to plant breakdowns, close monitoring of critical plant operating parameters and prudent maintenance practices are some of the interventions that can be put in place to achieve this. High customer demand for reliable and quality power requires mistake proofing through early detection and resolution of defects which can be achieved through use of technology.

Research by Wong and Ngin (1997) on the electronics industry in Singapore, revealed that automation was perceived to have resulted in greater improvements in operational performance and worker's wellbeing. Another study by Mailafia (2011) on the effect of automation of the trading system in the Nigeria stock exchange noted an upward trend in the performance of the exchange. A study on the effects of level of automation and adaptive automation on operational performance by Kaber and Endsley (1997) found that in general, the combined effect of the LOA and AA approaches was not additive in nature and some human manual performance is useful to overall system functioning. It was better than fully automated performance. This study was generic and there is need for further research in a realistic task situation.

No local research on automation of power generation in Kenya has been found in the literature but studies in other industries are available. For instance Njenga (2008) in his research on mobile phone banking usage experiences in Kenya found that M-banking dramatically reduces the cost of delivering financial services. The results of another study by Nyangosi, Nyan'gau and Magusa (2011) on managing banks amid information and computer technology, paradigms in Kenya, revealed that Kenyan banks are transforming their business from traditional mode of service delivery to technology based delivery systems. Omale and Adeya (2011) did a study on the use of Information Technology (ICT) in manufacturing to achieve vision 2030. Their findings were that there has been increased production volumes and speed in the Kenyan manufacturing industry through use of ICT.

It is evident from the above review that automation has a positive impact on operational performance both in service and manufacturing industry if the right automation approach and level is determined. Full automation may not necessarily lead to improved performance. The major power generation company which was the target of this study must therefore determine the status of the automation in its hydro power plants and its effect on operational performance. It should determine whether the automation approach is technology centered, fixed human centered or adaptive human centered and which automation configuration would yield the highest returns in terms of performance.

Although several studies have been done on automation and its effects, none seems to have addressed the effect of automation on hydro power generation in this company. Many of the studies have concentrated on the service industry and the normal manufacturing industry and none of them has looked at the nature of automation.

This study targeted a power company which installed a supervisory control and data acquisition system in its major hydro plants with the aim of improving controls, data capture and analysis to facilitate quick response to plant failure and it would be interesting to see the impact of this investment on its performance and in particular reduction in operation and maintenance costs and increased reliability through reduced downtime. The study attempted to determine automation approach and its effect on operational performance of the hydro power plants. It was intended at establishing answers to the following questions; what is the nature and level of automation installed in these hydro-power plants and does the automation approach significantly affect operational performance in power generation?

1.3 Research Objectives

In order to answer the research question we needed to achieve the following research objectives:

a) Determine the extent or level of automation

b) Determine the nature of automation

c) Determine the effect of automation approach on operational performance

1.4 Value of the Study

The findings of this study are expected to generate knowledge and an understanding of automation and its effect on the power generating process. It will specifically assist the power generating company under focus in appreciating the status of its automated plants and the influence this has on operational performance and whether further automation is necessary. It will enable decision makers in the power sector make the right strategic decisions on the nature and level of automation to adopt in order to reap the benefits of automation. It may also be of benefit to other industries which plan to automate their processes. The study will also be of great value to the customer as its intention is to improve the quality and reliability of electric power supply.

The study will also be beneficial to the academic world as it is expected to add to the existing body of knowledge and understanding on automation and how it can be harnessed to improve performance. It will also form the basis for further study in the subject of automation.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The relationship between automation and operational performance has been studied in the past by various researchers and in different contexts. This particular study on automation and its effect on operational performance in a major power generation company's hydro power plants was specifically focusing on the nature of automation and its relationship with operational performance. The literature review therefore covered the relevant literature pertaining to performance in power generation and its performance indicators and automation configurations.

2.1 Automation Configurations

A study on level of automation effects on performance, situation awareness and workload in a dynamic control task by Kaber and Endsley (1999) proposed the following levels of automation, manual control (MC) where the human performs all tasks including monitoring the state of the system, generating performance options, selecting the option to perform (decision making) and physically implementing it, Action Support (AS) where the system assists the operator with performance of the selected action though some human control actions are required, Batch Processing (BP) where the human generates and selects the options to be performed which are then turned over to the system to be carried out automatically, Shared Control (SHC) where both the human and the computer generate possible decision options but the human retains full control over the selection of which option to implement and carrying out the action is shared between the human and the system.

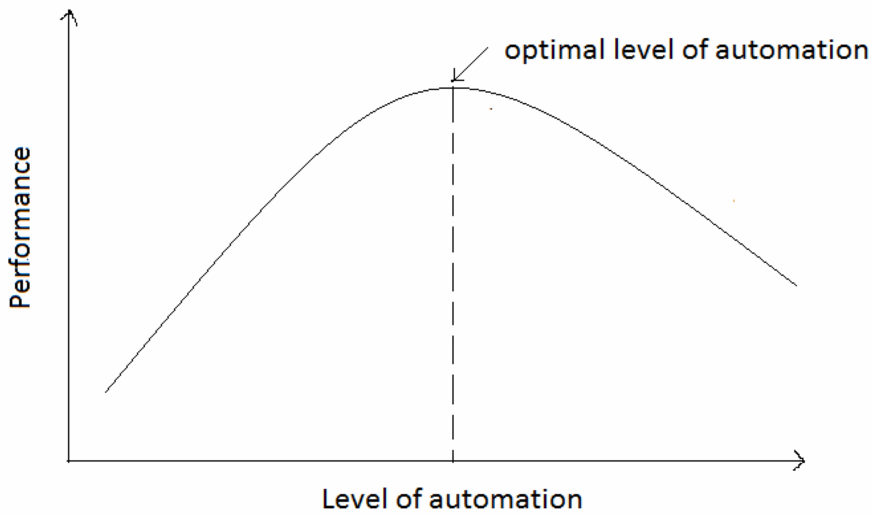
It further proposed Decision Support (DS) where the computer generates a list of decision options that the human can choose from or generate his own and once the human has selected an option it is turned to the computer to implement, Blended Decision Making (BDM) where the computer generates a list of decision options where it selects from and carries out with the consent of the human who can ignore and generate his own, Rigid System (RS) where the system presents only a limited set of actions to the operator and the operator must choose from those to be actioned by the system, Automated Decision Making (ADM) where the system chooses and implements the best option from those generated by both system and human.

The study also proposed Supervisory Control (SC), where the system generates options, selects the option to implement and carries out the action and the human mainly monitors the system and intervenes only when necessary and lastly Full Automation (FA) where the system carries out all actions and the human is completely out of the control loop and cannot intervene. The results of the empirical study suggest that, in terms of performance, human operators benefit most from automation of the implementation portion of the task, but only under normal operating conditions. In contrast, removal of the operator from task implementation is detrimental to performance recovery if the automated system fails.

Endsley and Kaber (2003) in a later study proposed a similar LOA taxonomy. They carried out an empirical study on the effects of level of automation and adaptive automation on performance. The objective of this study was to investigate the interaction of the two human centered approaches and their effect on performance. An experiment was conducted in which a dual task scenario was used to assess the performance, Situation Awareness and workload effects of low, intermediate and high LOAs and the results indicated that in general, the combined effect of the LOA and AA approaches was not additive in nature and some human manual performance is useful to overall system functioning. It was better than fully automated performance as shown in figure 1 below. This study was generic and there is need for further research in a realistic task situation.

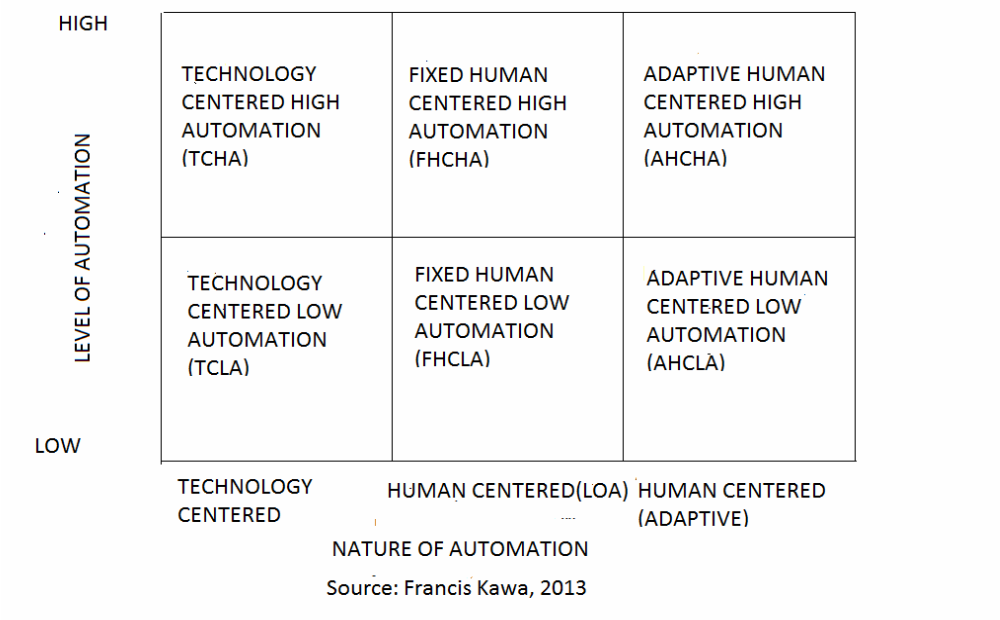
Several configurations of automation level and approach are possible and the matrix in figure 2 below depicts six combinations that can be used to determine the configuration that leads to the highest performance. It takes into account two levels of automation, low and high and three approaches to automation namely, technology centered, fixed human centered and adaptive human centered.

Figure 1: Automation vs performance



Source: Endsley, 1987)

Figure 2: Automation configurations



Norman (1990), in a study on 'the problem of automation: inappropriate feedback and interaction, not over-automation' suggested that automation should not be blamed for causing harm and increasing the chance of human error when failures occur. He proposed that the problem is not the presence of automation, but rather its inappropriate design. The problem is that the operations under normal operating conditions are performed appropriately, but there is inadequate feedback and interaction with the humans who must control the overall conduct of the task. When the situations exceed the capabilities of the automatic equipment, then the inadequate feedback leads to difficulties for the human controllers.

Norman (1990) further suggested that the automation is at an intermediate level of intelligence, powerful enough to take over control that used to be done by people, but not powerful enough to handle all abnormalities. He concluded that inappropriate level of automation leads to problems but it is possible to reduce error through appropriate design considerations. Appropriate design should assume the existence of error, it should continuously provide feedback and interact with operators in an effective manner.

Starter and Billings (1994) made similar conclusions in a study on automation surprises. In a variety of domains, the development and introduction of automated systems has been successful in terms of improving the precision and economy of operations. At the same time, however, a considerable number of unanticipated problems and failures have been observed. These new and sometimes serious problems are related for the most part to breakdowns in the interaction between human operators and automated systems. It is sometimes difficult for the human operator to track the activities of their automated partners. The result can be situations where the operator is surprised by the behavior of the automation asking questions like, what is it doing now, why did it do that, or what is it going to do next (Wiener, 1989).

2.2 Performance in Power Generation

A study by Deependra and Yoshifumi (2010) on Nepalese hydro plants owned by Nepalese electricity Authority (NEA) found that some of the hydro plants were inefficient. The number of employees and annual operation and maintenance expenditure was very high, resulting in poor efficiency scores of the plants. The objective of the empirical study was to analyze the operational performance of the hydropower plants in Nepal India using a modified Data Envelopment Analysis model. It proposed a sufficient number of variables reflecting the electricity production process which were incorporated in the analysis for a more comprehensive comparison of the hydropower plants and the model represents a move from measurement of technical efficiency to measurement of overall efficiency.

This wide range of variables includes, installed capacity of the plant (MW), Annual operation and maintenance cost, number of permanent and temporary staff, plant tripping, unit tripping, annual energy generation, energy generated in the driest month, summer and winter season peaking capacity. The modified model has led to significantly different results from those based on the classical model and it is believed that these results are far comprehensive than the previous ones as a wide range of operational data has been included. The study identified some improvement directions. A sensitivity analysis was done to confirm the robustness of the results.

Another study by Alice and Pun-Lee-Lam (2009) used the data envelopment analysis (DEA) approach to measure the productivity performance of China's state-owned power sector. The empirical results of this study revealed that the state-owned enterprises in China's power industry are grossly unproductive. The study proposed electricity generated in each plant as the output variable while capital, fuel and labour were the three inputs used for power generation. Capital is measured in terms of installed generating capacity. This study seems to support another one on the Nepalese electricity Authority which also included these variables amongst others. The study however, did not give the significant levels of the variables considered.

Obioma and Obioma (2012) also carried out an empirical analysis of productivity of the Nigerian power sector whose objective was to evaluate the performance of the country's power generation stations over a period of some time and make recommendations on how to improve its performance. The basic idea was to analyze and investigate the productivity of Nigeria's power plants and to evaluate the impact of reform on Nigeria's power sector. This work employed the Stochastic Frontier model and Malmquist index.

The study proposed the following production characteristics, load factor, utilization factor and capacity factor which is the degree of plant failure. Human labour and installed capacity were proposed as the input variables and total electricity energy produced, average load generated and maximum load generated as the output variable in the stochastic frontier model. Over ally results obtained showed that the 2005 national electric power reform act produced slight technical improvement.

Kromann, Skaksen and Sorensen (2011), in an empirical study on automation, labor productivity and employment, found that automation has a significant impact on labor productivity both in the short and long run since overall less labor input is used to produce the same amount of products. However, the study found that automation tends to reduce employment in the short run but raises it in the long run. They used cross country and cross industry data on the use of industrial robots to analyze how automation affects productivity and employment in manufacturing. The study used stock of industrial robots as a more direct measure of technology. The typical measures of technological change in economic analyses are expenditure on R&D, patents, ICT capital or the answers to survey questions on innovation activities (Hall (2011) and Hall et al (2010).

The above studies show that there are many factors that affect productivity in any organization but the authors appear to agree on the critical ones. The studies show that productivity is key to any organization and those who wish to excel must take these factors into consideration. The social-economic status of the three countries above is varied with China taking the lead, followed by India, Nigeria and Kenya in that order. However, the margins are not very big and the issues prevalent in them are likely to be found in Kenya.

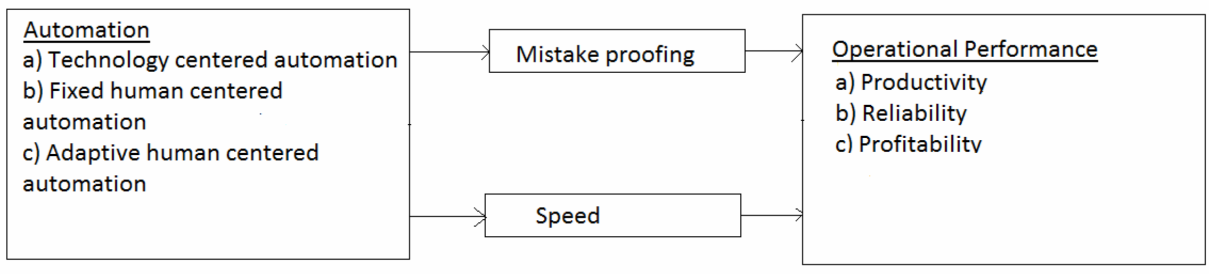
2.3 Summary

Available literature has shown that different automation configurations have different effects on the various aspects of operational performance. In particular, the nature and level of automation of any function have been shown to affect performance and that full automation does not necessarily lead to improved performance. Indeed over automation can lead to serious errors. There is therefore need to determine the optimum combination that lead to this. The key variables here are the nature and level of automation. Literature on productivity has also helped in identifying the key factors in the power generation sector that influence performance. The performance variables are plant reliability and productivity all of which lead to improved operational performance. This can be conceptualized as per figure 3 below with speed and mistake proofing as intervening variables..

While there is a lot of literature on the impact of automation configurations on performance, a lot of it has been simulated and this study intended to fill this gap by conducting a survey in an actual industrial set-up. To the best of the knowledge of this researcher, no studies have been done on the effect of automation approach on the performance of hydro power generation sector in Kenya and this study was to fill this gap.

2.4 Conceptual Framework

Figure 3: Conceptual Framework



This relationship can be tested using the hypotheses:

H1: There is a significant relationship between automation approach and mistake proofing.

H2: There is a significant relationship between automation approach and speed of processing time.

H3: There is a significant relationship between automation approach and operational performance.

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

This chapter introduces the methodology that was followed in order to achieve the objectives of the study. It covers the research design, target population, sampling approach or design, data collection and analysis.

3.1 Research Design

This study employed a descriptive research technique in order to achieve the set objectives which were to determine the nature and level of automation in the target plants and also establish if there is any relationship between automation approach and operational performance which fits the descriptive framework. According to Donald R. (2011), research design is the plan and structure of investigation so conceived as to obtain answers to research questions. It expresses the structure of the research problem, the framework, organization or configuration of the relationships among variables of a study and the plan of investigation used to obtain empirical evidence on those relationships.

A case study design based on cross-sectional approach was adopted because case studies place more emphasis on a full contextual analysis of fewer events or conditions and their interrelations. This type of design was chosen as it provides opportunity for more depth and the emphasis on detail provides valuable insight for problem solving, evaluation and strategy. The study focused on only one organization which has its headquarters in Nairobi and in particular, its hydro-electric power plants were identified for this study as they contribute the largest percentage of the power consumed in Kenya and are thus a good representation of hydro power generating facilities in the country.

The population of study was all the five major hydro-electric power generating stations of this power generating company designated HEPP4, HEPP5, HEPP2,HEPP1 and HEPP 3 for purposes of this study. HEPP4 is the most upstream followed by 5,2,1 and 3 in that order. These plants generate power using hydro resources which is sold in bulk to the Kenyan sole power distributing company, Kenya power.

3.2 Data Collection

The study used primary data which was gathered by means of a self-administered questionnaire (appended) issued to respondents. The questionnaires were administered personally by the researcher using the drop and pick method. Hard copies were grouped into six batches one for each station and for the scada engineers and dispatched to the respective respondents with clear instructions to answer the questions as accurately and truthfully as possible and return them to the researcher within an agreed pre-determined period. An assurance of confidentiality and anonymity was extended to boost the truthfulness of the responses.

The indicators of automation configuration were based on statements drawn from the study by Kaber and Endsley (2003), on effects of level of automation and adaptive automation on performance. The indicators of operational performance on the other hand were plant availability, productivity and profitability proxied by operational costs. The respondents included operations managers, maintenance engineers, technicians and selected operation and maintenance staff of at least secondary school level of education in the target stations who are involved in control matters and all scada engineers.

3.3 Data Analysis

The collected data was initially prepared for correctness and possible editing. According to Donald R. (2011), data preparation includes editing, coding and data entry and is the activity that ensures the accuracy of the data and their conversion from raw form to reduced and classified form that are more appropriate for analysis. Editing detects errors and omissions, corrects them where necessary, and certifies that maximum data quality standards are achieved.

Coding involves assigning numbers or other symbols to answers so that the responses can be grouped into a limited number of categories to facilitate analysis. When codes are established in the instrument design phase of the research process you can pre-code the questionnaire at the design stage. The questionnaire in this study included scaled items for which respondents were to indicate to what extent they agreed or disagreed with the statements. The likert scale employed in this study had the ratings of Strongly Disagree(1), Disagree(2), Neutral(3), Agree(4), Strongly agree(5).

Descriptive statistics in form of means and standard deviations were computed from the responses and tabulated to facilitate analysis. These were analyzed as groups of related items whose scores were summed up to create a score for a group of statements. Multiple regression analysis was used to determine the nature of automation and the relationship between the variables.

The regression equation took the following form:

$Y = C + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$

Where Y is the dependent variable (mistake proofing, speed, overall performance)

C = Y-intercept

β_1, β_2, β_3 = slope and

X_1 = Technology centered automation

X_2 = Fixed Human centered automation

X_3 = Adaptive Human centered automation

Three sets of hypotheses were tested by checking the significance of the coefficients β_1, β_2, β_3

CHAPTER FOUR: RESULTS, DATA ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents the research findings, analysis and presentation of data gathered from questionnaires. The findings are presented mainly in form of tables. Data is summarized into mean scores and standard deviations. This research studied a total of five hydro-electric power generating plants in Kenya that are managed by a major power generation company. The research set out to determine the automation approach in each plant and the effect it has on operational performance. The results are presented in four sections. The first section presents the response rate, the second section presents the type of automation in each plant, the third section presents the benefits of automation and lastly the data analysis and discussion.

4.2 Results

Completed and returned questionnaires were 89 out of 114 sent to respondents representing a response rate of 78.1 %. A high response rate assures more accurate results and validity of data according to Warner, (1988). The table below shows the response per power plant.

Table 4.1: Response Rate per Power plant

Power plant	Sample	Responses	Response rate in %
HEPP 4	15	15	100 %
HEPP 5	38	28	73.7 %
HEPP 2	24	19	79.2 %
HEPP 1	21	15	71.4 %
HEPP 3	17	12	70.6 %
Total	114	89	78.1 %

Source: Research Data, 2013

The study covered five hydro-electric power generating plants HEPP4, HEPP5, HEPP2,HEPP1 and HEPP3,and sought to establish the type of automation deployed in each and the relationship of this automation approach with operational performance. The results covering the different automation approaches and performance indicators are tabulated in Appendix 2 in measures of means and standard deviation.

To help in determining the type of automation deployed in each plant, the lower limit of the confidence interval at 95% confidence level was computed for each plant and type of automation and the results are tabulated in Appendix 3.

4.2.1 Automation approach

This section sought to establish the type of automation in each plant. Appendix 3 gives a summary of the determination of the most emphasized type of automation in each plant using the lower limit of the confidence interval at 95% confidence level. The results of the nature and level of automation in each plant are tabulated below;

Table 4.2: Type of Automation Approach

Plant	Automation			Level	
	Type	**Mean**	**S.D**	**Mean**	**S.D**
HEPP 1	Human	2.87	1.55	4.00	1.438571
HEPP 2	Technology	2.82	1.576	3.37	1.411429
HEPP 3	Human	2.79	1.690	4.00	1.28
HEPP 4	Technology	2.47	1.5	3.67	1.29
HEPP 5	Human	2.90	0.958	3.36	1.01

Source: Research Data, 2013

Perceptual data obtained from the study and tabulated in appendix 3 and table 4.2 found that the plants can be classified into two mutually exclusive categories of automation. Two of the plants HEPP2 and HEPP4 have adopted technology centered automation while the rest, HEPP1, HEPP3 and HEPP5 have adopted human centered automation. None of the plants can be classified as adaptive human centered automation. A confidence interval (C.I) of 3.15 was considered a reasonable threshold but in its absence the highest value of the lower limit was considered in identifying the type most emphasized.

The level of automation was determined according to the ten level classification taxonomy by Kaber and Endsley (1999). The level with the highest mean score was considered most emphasized per plant and is as given above. All the plants returned a high mean score on item 24 of the questionnaire depicting a supervisory level of automation. This is consistent with Endsley's proposed supervisory control level of automation where the system generates options, selects the option to implement and carries out the action.

4.2.2 Benefits of Automation

The third objective of the study was to establish the effect of automation on operational performance. The following subsection presents a summary of the findings with regard to the various performance measures that have been considered in the study.The mean scores of the intervening variables of speed of processing and mistakeproofing together with the operational performance indicators of productivity, reliability and profitability are given in table 4.3 below.

Table 4.3: Benefits of Automation

Plant	Mistake Proofing		Speed	
	Mean	S.D	Mean	S.D
HEPP 1	4.33	1.83	4.33	1.84
HEPP 2	4.25	1.231	4.09	1.21
HEPP 3	4.52	1.505	4.39	1.066
HEPP 4	4.47	1.488	4.55	1.357
HEPP 5	4.40	1.343	4.52	1.432

Source: Research Data, 2013

It is evident from the results that automation improves mistake proofing and response speed as indicated by the respective means which are above 4.None of the plants appears to have a particularly outstanding impact on both mistake proofing and speed though plant no. 3 which is human centered has scored the highest in mistake proofing while plant no. 4 which is technology centered has scored the highest in speed. From the responses, it is

clear that the Scada system has indeed enabled faster response to plant failure as data analysis takes a much shorter time with automation. There are also fewer errors in operations.

4.2.3 Operational Performance

The study further sought to establish the effect of automation approach on operational performance using the indicators of productivity, profitability and reliability. This is presented in table 4.4 below.

Table 4.4: Operational Performance

Plant	Productivity		Reliability		Profitability (Cost)	
	Mean	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
HEPP 1	4.01	1.326	4.24	1.224	4.10	1.085
HEPP 2	3.97	1.214	3.96	1.310	4.11	1.225
HEPP 3	4.20	1.543	4.36	1.432	4.50	1.116
HEPP 4	3.92	1.279	4.30	1.432	4.20	1.325
HEPP 5	4.15	1.531	4.24	1.443	4.02	1.323

Source: Research Data, 2013

The study shows that generally the different automation approaches have a positive impact of the three elements of operational performance. However, plant 3 which is technology centered has the highest scores in all the aspects. As seen in the table, plant

HEPP 3 was the highest in terms of reliability with a mean of 4.36, followed by plant HEPP 4 (mean 4.30) and then plant HEPP 1 and HEPP 5 with a mean of 4.24 each and finally plant HEPP 2 with a mean of 3.96. Cost was considered the indicator for profitability. Specifically plant HEPP 3 had the highest mean of 4.50, followed by plant HEPP 4 (mean (4.20), then plant HEPP 2 (mean, 4.11), plant HEPP 1 (mean, 4.10) and finally plant HEPP 5 (mean, 4.02). It is again evident that automation has a positive impact on operational performance as exhibited by the high mean scores.

This is consistent with the assertion that Automation represents one of the major trends of the 20th century. The drive to provide increased levels of control to electro-mechanical systems, and with it a corresponding distancing of the human from direct system control, has grown out of the belief that automated systems provide superior reliability, improved performance and reduced costs for the performance of many functions (Endsley, 1996).

4.3 Data Analysis and Discussion

The following subsection presents the data analysis and discussion of the results. Table 4.5 presents a correlation matrix for all variables, on how different approaches relate to performance. The relationship amongst them is established by regression analysis.

Table 4.5: Correlation Matrix

	Human	Technology	Adaptive
Mistake proofing	x	x	x
Speed	x	x	x
Overall performance	x	x	x

x- To be determined

4.3.1 Regression Analysis

To establish the relationship between the variables in the above matrix, multiple regression analysis was carried out. The regression model was as follows:

$Y=C+B_1X_1+B_2X_2+B_3X_3$ Where:

Y=Dependent variable which could be mistake proofing, speed and performance.

$X_{1=}$Technology Centered automation

$X_{2\ =}$Fixed Human Centered automation

$X_{3=-}$ Adaptive Human centered automation

In order to test the relationship between mistake proofing and the automation approach, the following regression equation was used.

$Y_m=C+B_1X_1+B_2X_2+B_3X_3$

Table 4.6: Mistake Proofing

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.976	4.638		24.575	.000
	Technology	.719	.005	.578	28.5	.000
	Human	-.014	.005	.449	.115	.452
	Adaptive	.030	.002	.029	5.266	.003

a. Dependent Variable: Mistake Proofing

As shown in table 4.6 the multiple regression model equation can be expressed as:

Y =1.976+0719 (Technology centered) - 0.14 (Human centered)+ 0.030 (adaptive).

The results indicate that both technology centered automation and adaptive automation have a positive relationship with mistake proofing while fixed human centered automation has returned a weak negative relationship meaning that mistake proofing depends on the type of automation deployed. This effectively means that those plants which have adopted technology centered automation may experience reduced mistakes, while human centered approach may not necessarily lead to the same due to the presence of the human operator. The null hypothesis is therefore rejected.

In order to test the relationship between speed and automation approach, the following regression equation was used.

$Ys=C+B_1X_1+B_2X_2+B_3X_3$

Table 4.7: Speed

Coefficients[a]

Model		Unstandardized Coefficients	Standardized Coefficients	T	Sig.
		B	Beta		
1	(Constant)	3.34		21.20	.000
	Technology	.695	.399	19.7	.000
	Human	-.225	.225	.203	.000
	Adaptive	.130	.179	3.001	.005

a. Dependent Variable: Speed

As shown from table 4.7 the multiple regression model equation can be expressed as:

Y =3.34+695 (Technology centered) - 0.225(Human centered)+ 0.130 (adoptive).

This again indicates that indeed speed has a positive relationship with technology centered and adoptive approaches while the relationship with human centered is negative confirming that automation approach should be considered for improved performance. This means therefore that implementing technology centered and adaptive approaches helps increase response speed, unlike the human centered approach. The null hypothesis is therefore rejected.

In order to test the relationship between operational performance and the automation approach, the following regression equation was used.

$Ypef=C+B_1X_1+B_2X_2+B_3X_3$

Table 4.8: Operational Performance

Coefficients[a]

Model		Unstandardized Coefficients	Standardized Coefficients	T	Sig.
		B	Beta		
1	(Constant)	4.311		18.900	.000
	Technology	.771	.405	21.5	.000
	Human	-.134	.211	.278	.000
	Adaptive	.050	.204	0.998	.000

a. Dependent Variable: Performance

As shown in table 4.8 the multiple regression model equation is expressed as:

Y =4.311+0.771 (Technology centered) - 0.134 (Human centered)+ 0.050 (adoptive)

This indicates that indeed there is a positive relationship between performance and technology centered approaches as well as adaptive. In this regard therefore the null hypothesis is rejected and the positive one is retained, indicating that there is a significant positive relationship between automation approach and performance.

In order to test the relationship between overall performance and level of automation, the following regression equation was used.

Y=C+*BL*

Coefficients[a]

Model		Unstandardized Coefficients	Standardized Coefficients	T	Sig.
		B	Beta		
1	(Constant)	1.04		16.5	.000
	Level of Automation	.209	.113	2.001	.000

a. Dependent Variable: Overall Performance

This indicates that indeed there is a positive relationship between performance and the level of automation depicted by the positive coefficient..

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Automation represents one of the major trends of the 20th century. The drive to provide increased levels of control to electro-mechanical systems, and with it a corresponding distancing of the human from direct system control, has grown out of the belief that automated systems provide superior reliability, improved performance and reduced costs for the performance of many functions (Endsley, 1996). In many cases automation has provided the desired benefits and has extended system functionality well beyond existing human capabilities. However, the biggest challenge is in determining the appropriate technology to deploy.

The study set out to investigate the automation configuration in terms of its nature and level in five major hydro-electric power generating plants in Eastern Africa and its effect on operational performance. This chapter provides a summary of the findings, conclusions and recommendations.

5.2 Summary of the Findings

The main objective of the study was to analyze the relationship between automation and operational performance in the hydro-electric power generation sector in Kenya and in particular the effect of automation approach on performance.. The study was guided by the following objectives: to determine the extent or level of automation, to determine the nature of automation and to determine the effect of automation on operational performance.

The study found two of the plants had adopted technology centered automation while the rest was classified as human centered. The study further revealed that none of the plants could be classified as adaptive human centered. The study further revealed that all the plants were at supervisory control level of automation where the automation makes all the decisions and implements with the operator only intervening in cases of failure. This is in line with the assertion that humans have remained a critical part of most automated systems. They must monitor for failures of the automated system and the presence of conditions the system is not designed to handle. Furthermore, as most automation has been piece-meal covering certain functions but not others, humans have remained in the system as integrators- monitoring the automation for some functions and performing others themselves (Endsley, 1997)

The study further showed that automation has generally improved the response time to plant failure as a result of easier and accurate data capture and analysis. The occurrence of operational mistakes and errors has also reduced with the introduction of automation. Staffing levels and operational costs have also gone down as a result of automation as hitherto manned operational areas have been automated and operator work load has reduced. This is consistent with Jones (2007) assertion that technology and technological innovations have been used by nations with high labour costs to help achieve comparable production costs to those countries with low cost of labour.

Generally customer and worker satisfaction has improved and with it overall operational performance. A significant relationship between automation approaches and operational performance was found.

5.3 Conclusion

The study sought to identify the automation approach in hydro power plants and its effect on operational performance. The findings revealed that two of the plants are of the fixed human centered automation classification while the rest are technology centered. None of the plants has adopted the adaptive human centered approach. The study further revealed that all the plants were at the supervisory control level of automation. The study concludes that there is a significant relationship between automation approach and operational performance and in particular automation was confirmed to have a significant effect on speed and mistake proofing which in turn have a positive impact on operational performance.

5.4 Recommendations

It is recommended that the major power generation company in this study undertakes a quantitative survey to determine the actual impact of the scada system in terms of reduction in response time, operational mistakes and errors and actual staffing levels.

The organization should also compare its automation policy with best practice to determine whether to retain, improve or reduce or downgrade the current automation status to attain the optimal level. This should form the basis of rolling out similar undertakings to the rest of its power plants. Companies wishing to implement automation systems in their processes must take into account the automation configurations for optimal performance.

5.5 Limitations of the Study

This was a case study which focused only on one organization's hydro power plants with limited scope. Expanding the scope would possibly include plants of varying levels of automation which would enable comparative analysis and determination of the optimum level of automation. The study findings are based on perceptual data which could lead to erroneous conclusions..

5.6 Recommendation for Further Research

Further research will be necessary to determine at which level of automation the performance begins to decline as indicated by Endsley in his study of automation and situation awareness which concluded that there is an optimal level of automation beyond which the performance suffers. This comparison was not possible in this study as the results clearly revealed that the automation in the focus plants is of the same level. Application of adaptive human centered automation in the hydro plants can be explored by studying the characteristics of the tasks and their suitability for this type of automation and whether it would lead to significantly better performance.

Further study should incorporate other factors that could influence the above outcomes eg profitability is dependent on other factors and plant reliability could also be affected by poor maintenance practices.

REFERENCES

Almas H., Subal C. K, (2013), *Estimation of Productivity in Korean Electric Power plants: A Semiparametric Smooth Coefficient Model*

Arthur (2008), *Operational performance Excellence*

Alice Shiu, Pun-Lee Lam, (1998), *Total factor productivity growth in China's power generation*

Carlos P. B., Walter B. and Nicolas P., (2001), *Productivity Growth and Biased Technological Change in Hydroelectric Dams*

Carlos Pestana Barros, Ade Ibiwoye and Shunsuke Managi, (2001) *Nigeria' Power Sector: Analysis of Productivity*

David B. K., Jennifer M. R. and Kheng-Wooi T., Mica R. E. (2001), *On the Design of Adaptive Automation for Complex Systems*

Deependra Kumar Jha, Naoto Yorino;Yoshfumi Zoka, (2009), A *Modified DEA Model for Benchmarking of Hydropower plants*

Donald W.,*(2000), Automation in Manufacturing*

Donald R. C, Pamela S. S. (1997), *Business Research Methods 11th edition*

Donald A. N., (1990), *The problem of automation: inappropriate feedback and interaction, not over-automation*

Elwood S. B., Rakesh K. S. (1987), *Modern production/operations management 8th edition*

Endsley, M. R. (1996), *Automation and Situation awareness.*

Iwuamadi O. C., Dike Damian O., (2000), *Empirical Analysis of Productivity of Kenya Power Sector*

John M. Nicholas (2001), *Competitive manufacturing management, Tata McGraw-Hill Edition*

Kaber D. B, Riley M.J, M.R Endsley (2001), *On the Design of Adaptive Automation for Complex Systems.*

Lene, K., Skaksen J., Sorensen A. (2011), *Automation, labour productivity and employment- a cross country comparison.*

Mica R., David B. Kaber (1999), *Level of automation effects on performance, situation awareness and workload in a dynamic control task*

Michael A. G., Erwin R. B., (2000), *Designing Human-Centered Automation: Tradeoffs in Collision Avoidance System Design*

N.B. Sarter, D.D. Woods, and C.E. Billings,(1997), *Automation Surprises*

Nigel S., Stuart C., Robert J. (2010), *Operations Management 6th Edition*

Norman A. D (1990), *The problem of Automation: Inappropriate feedback and interaction, not over-automation*

Parasuraman, R. (1993), *Effects of adaptive function allocation on human performance*

Parreira, Juliana, Zoe, Magaly (2009), *How Automation and Key Performance Indicators (KPI's) Contribute to Sustainable Development in the Mining Industry*

Parker, Sally (1996): *Measuring up! Automation variables is no obstacle to Benchmarking for competitive advantage; Rochester Business Journal, vol. 8*

Raja P., Toufik Bahri, (1995), *Theory and design of adaptive automation in aviation systems*

Sarter. N. B, Woods D.D, and Billings C. E (1997), *Automation surprises*

S. Gupta (2012), *Statistical Methods,* 42nd revised edition. Regression Analysis.

Stevenson, William (1996): *Productions/operations management*, *Irwin publishing company, 5th edition*

William J., (2007), *Modern manufacturing techniques*

Wickens, C. D. (1992), *Engineering psychology and human performance, 2nd edn.*

Yin-Fang Z., David P. and Colin K., (2006), *Electricity sector reform in developing countries: an economic assessment of the effects of privatization, competition and regulation.*

APPENDIX 1: RESEARCH QUESTIONNAIRE

Introduction

Please answer the following questions by crossing with (x) or tick (√) the relevant column. You may also make comments if considered necessary in the space provided at the back of the questionnaire, clearly indicating the section and row. This questionnaire is designed for the sole purpose of gathering information on the effects of automation on operational performance for academic purposes only. The responses will remain anonymous and that the information they provide will be treated as confidential at all times.

SECTION A Automation configuration

The following statements are in reference to the Supervisory, control and data acquisition system (Scada) used in your station. Please indicate the extent to which you agree or disagree with the statement as it relates to how the system in your station works.

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
	Technology centered					
2	In my station the scada does all the control activities without assistance from the operator					
3	In my station the operator`s role is to monitor the scada control system only					
7	In my station the plant runs independently without human assistance except in abnormal situations					

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
10	In my station the control system only reverts to manual when there is a problem					
12	In my station the plant is remotely controlled					
13	In my station there is a possibility of the operator getting bored because all activities are carried out by the scada					
15	In my station there is adequate and timely feedback from the scada system in case of a fault					
16	In my station there are incidences when it is difficult to know what the scada system is doing					
18	In my station too much unnecessary information is displayed on the computer screens					
	Fixed human centered					
1	In my station the operator does all the control activities without assistance from the scada system					

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
4	In my station the operator shares the control activities with the scada in equal measure					
5	In my station the scada does more than 50% of the control activities/tasks					
6	In my station the scada does less than 50% of the control activities/tasks					
8	In my station the tasks allocated to the operator and those allocated to the scada remain fixed throughout (except when the system reverts to manual due to a fault)					
11	In my station the operator remains involved in system operations throughout					
14	In my station the operator is always aware of what the Scada system is doing					
17	In my station there is no time that the operator is not involved in control activities					

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
19	In my station the operator is able to take control immediately the automatic control/scada fails					
	Adaptive human centered					
9	In my station certain control tasks/activities keep switching /changing from scada to operator and back to scada even when the system is functioning normally.					
20	In my station the automation is designed in a way that it cannot operate without the operator					
	Level of automation					
21	In my station the scada decides everything and acts autonomously, ignoring the operator					
22	In my station the scada informs the operator of plant status only if it decides to					
23	In my station, the scada informs the operator of plant status only if asked					

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
24	In my station the scada executes tasks automatically, then informs the human operator					
25	In my station the scada allows the operator restricted time to veto before automatic execution					
26	In my station the scada executes a suggestion only if the operator approves it					
27	In my station the scada suggests only one alternative					
28	In my station the scada narrows the selection options to a few and suggests one alternative					
29	In my station the scada offers a complete set of decision/action alternatives					
30	In my station the scada offers no assistance: the operator must take all decisions and actions.					

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
31	In my station the operators are also involved in controlling plants in other stations					
20	In my station the automation is designed in a way that it cannot operate without the operator					
21	In my station the scada decides everything and acts autonomously, ignoring the operator					
22	In my station the scada informs the operator of plant status only if it decides to					
23	In my station, the scada informs the operator of plant status only if asked					
24	In my station the scada executes tasks automatically, then informs the human operator					
25	In my station the scada allows the operator restricted time to veto before automatic execution					

		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
26	In my station the scada executes a suggestion only if the operator approves it					
27	In my station the scada suggests only one alternative					
28	In my station the scada narrows the selection options to a few and suggests one alternative					
29	In my station the scada offers a complete set of decision/action alternatives					
30	In my station the scada offers no assistance: the operator must take all decisions and actions.					
31	In my station the operators are also involved in controlling plants in other stations					

Section B: Effects of automation on operational performance

The following statements are in reference to the Supervisory, control and data acquisition system (scada) used in your station. Please indicate the extent to which you agree or disagree with the statement as it relates to the impact of the system in your station.

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
	Speed					
1	In my station automation/scada has had a major impact on plant break down response time					
6	In my station data analysis has become easier with automation/scada					
7	In my station it takes a shorter time to analyze data and resolve problems with automation/scada					
15	In my station scada has enabled faster response to machine breakdowns					
	Mistakes					
2	In my station automation/ scada has reduced the number of mistakes made in operations					

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
14	In my station errors in data capture have reduced with introduction of automation/scada					
16	In my station data capture and analysis has become easier and more accurate with automation/scada					
	Reliability					
3	In my station plant availability has improved with automation / scada.					
4	In my station automation /scada has led to reduced machine sudden outages					
8	In my station scada has led to superior reliability					
11	In my station scada has led to fewer machine trips					
	Profitability					
9	In my station automation/ scada has led to reduction of operational staff					
10	In my station automation/scada has led to reduction of operational costs					

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
	Overall performance					
5	In my station automation/scada has reduced operator workload					
12	In my station monitoring plant status on the computer screen constitutes additional workload					
13	In my station, controlling plants in other stations (where applicable) does not affect performance					
17	In my station customer complaints have reduced with automation/scada					
18	In my station worker satisfaction and hence performance has increased with automation/scada					
19	In my station automation/scada has led to consistent quality of power					
20	In my station profitability has improved with the introduction of automation/scada					

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
21	In my station automation/scada has overally led to improved performance					

APPENDIX 2: RESULTS

Plant	Technology Centered		Human Centered		Adaptive		Level of Automation		Mistake Proofing		Speed		Productivity		Reliability		Profitability	
	Mean	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
HEPP1	2.688	1.54	3.230	1.747	2.88	1.55	4.00	1.438571	4.33	1.83	4.33	1.84	4.01	1.326	4.24	1224	4.10	1.085
HEPP2	3.138	1.57153846	3.008	1.566	2.160	1.8	3.37	1.411429	4.25	1.231	4.09	1.21	3.97	1.214	3.96	1.310	4.11	1.225
HEPP3	3.123	1.690769	3.116	1.591	2.085	1.63	4.00	1.28	4.52	1.505	4.39	1.066	4.20	1.543	4.36	1.432	4.50	1.116
HEPP4	2.771	1.43	2.726	1.5	2.200	1.07	3.67	1.29	4.47	1.488	4.55	1.357	3.92	1.279	4.30	1.432	4.20	1.325
HEPP5	2.841	1.055385	3.100	0.958	2.64	1.34	3.36	1.01	4.40	1.343	4.52	1.432	4.15	1.531	4.24	1.443	4.02	1.323

Source: Research Data, 2013

APPENDIX 3 TYPE OF AUTOMATION DEPLOYED

Plant	Technology Centered		95% CI		Human Centered		95% CI		Adaptive Centered		95% CI	
	Mean	S.D	Lower Limit	Upper Limit	Mean	S.D	Lower Limit	Upper Limit	Mean	S.D	Lower Limit	Upper Limit
HEPP1	2.688	1.54	2.29	3.09	3.230	1.747	2.87	3.59	2.800	1.55	**2.48**	3.12
HEPP2	3.138	1.576	2.82	3.46	3.008	1.566	2.65	3.37	2.160	1.8	**1.79**	2.53
HEPP3	3.123	1.690	2.77	3.47	3.116	1.591	2.79	3.45	2.085	1.63	**1.75**	2.42
HEPP4	2.771	1.43	2.47	3.07	2.726	1.5	2.41	3.04	2.200	1.07	**1.98**	2.42
HEPP5	2.841	1.055	2.62	3.06	3.100	0.958	2.9	3.3	2.64	1.34	**2.36**	2.92

Source: Research Data, 2013