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Analyzing the effectiveness of overhaul maintenance in the energy sector: A critical review

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Abstract

Regardless of the overhaul outages planned with the aim of preventing failures on the energy plants in South Africa, it is witnessed not to be effective based only on the production ratio outcomes. The production ratio, as per the South African power enterprise is 80:10:10. The ratio is based on 80 % availability, the only fixed figure of 10% planned maintenance and 10 % unplanned maintenance of the power plants. The production ratio on most South African power station is not close to the above mentioned ideal ratio as witnessed on some stations whereby the station's ratio is recorded at 55:10:35. Overhaul maintenance on equipment are ideally rolled out as a failure preventative measure to prevent unplanned maintenance and thus ensure satisfactory availability of the power generating plant. In this paper, we illustrate the effectiveness and benefits of maintenance operations or strategies. Although numerous studies have been conducted over the past two decades to analyze effectiveness of maintenance strategies, there remains a gap in the current overview. Therefore, the objective of this paper is to conduct a theoretical assessment on the effectiveness of overhaul maintenance in the energy sector. The results of the critical analysis of the current literature on the subject matter, clearly demonstrates that there are flaws in the current body of knowledge related to a lack of boiler and quantitative studies.

Keywords

Energy Sector, maintenance strategies, boilers

1.0 Introduction

Electricity generators and manufacturers around the world are continuously faced with mounting challenges posed by globalization and the fast-paced changes within the business landscape. To remain competitive and optimize turnovers; it remains optimum goal to enhance production performance (Goh et al., 2007; Muthiah & Huang, 2006).
Nevertheless, numerous uncertainties influence production performance; processing times, machine breakdowns, customer demands and quality failures to mention a few. For an example, production losses and production costs increases as a result of machine and quality failures due to a production of defective parts. These uncertainties have triggered numerous studies into the field of production and the control of maintenance in pursued of a coping mechanism (Wang & Liu, 2013; Pan et al., 2010). Considering constraints of man power, material availability and cost to mention a few; to achieve favourable performance, production control is used to predict, plan and schedule maintenance activities (Kenneth & Vincent, 2004) Its objective is to maximize production rate and minimize its costs as much as possible. However, from time to time, production is interrupted due to the various uncertainties covered above. Thus, maintenance remains unavoidable to ensure uninterrupted production. Maintenance consist of a set of activities including inspection of machine defects, repairs and replacement which when put in place assist assuage

deterioration and reinstate systems or machines in a state of design performance specification (Jin et al., 2009; Colledani & 15 Tolio, 2012). Therefore, in principal, production performance can be improved by maintenance. A balance between maintenance and production plan should be maintained as excessive maintenance may result in decreased production rate due to the interruption of processing; hence a balance between production control and maintenance management should be optimised. Over the years integrated control and maintenance management has gained increasing attention from many researchers with an objective of designing the control parameters of maintenance and production to minimize cost and completion time (Pan et al., 20 2010; Chen & Subramaniam, 2012; Yang & Yang, 2010; Tseng et al., 1998; Sheu & Zhang, 2013; Schutz et al., 2009; Yao et al., 2009; Zhou et al., 2012; Gharbi et al., 2007; Berthaut et al., 2010, 2011; Aghezzaf et al., 2016; AlDurgam & Preprint submitted to Computers & Industrial Engineering October 16, 2017 Duffuaa, 2013; Dhouib et al., 2012; Song, 2009).

1.1 Background

Maintenance's ultimate objective is to quickly correct failures caused by a law of system changes. Maintenance management's aim is to firstly ensure availability and reliability of the systems or equipment, and secondly, to ensure optimization of maintenance resources. In addition, a theoretical definition of maintenance is activities carried out on equipment or facilities with aim to maintain the original state of operating conditions (Pintelon and Gelders 1992; Brook 1998; Reason 2000; Dhillon and Liu 2006). This definition however does not recognize how carrying out repairs on equipment periodically can extend their productive life by reducing standing time and maximising reliability, but rather concentrates on the maintenance of the equipment's design characteristics (Endrenyi et al. 2001; Dhillon and Liu 2006; Muchiri et al. 2011). "Maintenance" was in 1995 defined by The Maintenance Engineering Society of Australia (MESA) as "the achievement of required asset capabilities within an economic or business context" (Muchiri et al., 2011).

The concept of Total Production Maintenance (TPM) integrated within that of Total Quality Management (TQM) is one effective and strategic concepts that numerous organisation has implemented as a continuous improvement methodology aimed at improving the efficiency and availability of existing equipment by reducing input and minimizing its life cycle costs (Medhat et al. 2008; Pintelon and Parodi-Herz 2008). This method is implemented more in industrial organisations than service organisations due to its prominence on the necessity of continuous productivity improvement. Terotechnology is a combination of management, engineering, financial and other related practices functional to physical assets with an objective of economic costs in their life cycle. These practices are furthermore concerned by the maintainability, design and specification for the reliability of the plant or machinery or structures, their replacement and refurbishment, their performance and cost implications. This approach was developed by the UK Department of Trade and Industry to aid continuous improvement of productive maintenance (Checkland 1979; Levery 1998; Shahanaghi and Yazdian 2009), (Pintelon and Gelders 1992; Levery 1998; Belak 2004; Belak and Cicin-Sain 2005). There is a vast availability of employed maintenance strategies in the industry, which vary in their allied costs and effectiveness. A selection of the right strategy and balance of appropriate appointed resources result in an effective control of facility maintenance. Poor implementation of a maintenance strategy tends to have a low success rate in the delivery of business objectives. Operations are generally stuck in a "reactive zone" when a strategy based on corrective maintenance is implemented. In this zone, operations reflect uncertainties figuring out what to do next due to high production loss, higher maintenance cost as a result of repetitive common failures of equipment leaving them out of service under most cases.

Reactive maintenance restricts our resources from being effective and inhibits the organisation to meet production targets with a cost implication. Many companies' perceptions conclude maintenance as a compulsory burden. Such perceptions obscure many of these companies from benefits presented by proactive and integrated approaches to maintenance, Facility Integrity Excellence Model (FIEM) operations and Facility Integrity and reliability (FI & R).
In contribution to profitability for companies, maintenance can have a significant contribution if viewed as a cooperative partnership with other facility teams. Furthermore, the commitment of the maintenance teams remains crucial through training as to embrace an approach that is risk based and a cooperation with other facilities. Interface between these facilities can be achieved by the use of up-to-date systems such as computerized maintenance management system (CMMS), as an upgrade of maintenance systems and common practices in support of new proactive approach. The plant's overall performance is impacted by systems put to place and the reliability and integrity of our facility equipment. Great emphasis on the integration of integrity, maintenance and reliability is revealed by the Facility Integrity Excellence Model (FIEM). The proactive approach includes relations with

maintenance, operations and FI & R groups. It is crucial that besides the inter-relations that facility maintenance, operations, integrity and reliability have; there is need to understand each other's roles and appreciate their abilities.

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2. Gap identification in the current literature

The objective of this section is to assess current literature currently present in the energy sector. To achieve to derive a critical analysis, the ICISI of Science database was used with "maintenance of power plants" as key words. The time frame was between 1997 and 2017. The search focused on purely reviewed articles published in English fulfilling certain research areas. The search resulted in 289 documents that were critically assessed by means of title and abstract with the purpose of creating additional boundaries and eliminating incorrect or unrelated entries (screening phase). Throughout this phase, groups of inclusion and segregation standards were established, against which individually, every single journal article was evaluated. Precisely, articles assessed are those which concentrate on maintenance of power plants. It should be highlighted that studies that did not meet these requirements were not considered. At this point, the results generated reduced to 141 studies focusing on maintenance in power plants. These studies were categorized on the basis on a set of standards, for instance, in this paper the studies were selected based on the citation. To this end, the table below illustrates the fifteen best studies in the field of power plant maintenance, that were critical assessed to identify a gap.

Table 1. Gap analysis of current literature

Authors	Country of study	Source of energy	Methodology	Plant Focus
Yeh and Rubin (2006)	United States of America	Fossil Fuel	Quantitative	Boiler
Xiong et al (2012)	People's Republic of China	Fossil Fuel	Qualitative	Overall Power Plant
Chattopadhyay and Momoh (1999)	United States of America	Thermal and Nuclear	Quantitative	N/A
Zhao et al (2006)	United States of America	Fossil Fuel	Quantitative	Turbine
Pekka Pyy (2001)	Finland	Nuclear	Qualitative	Overall Power Plant
Ekpenyong et al (2012)	South Africa	Fossil Fuel	Qualitative and Quantitative	Generator
Hans Christian Gils (2014)	Europe	Nuclear	Qualitative	N/A
Carazas et al (2009)	Brazil	Fossil Fuel	Qualitative	Turbine
Hu et al (2009)	PR China	Fossil Fuel	Qualitative	N/A
Viswanathan et al (2005)	United States of America	Fossil Fuel	Qualitative	Boiler

Feng and Wang (2010)	PR China	-	Qualitative	Operating
Campbell et al (2000)	United Kingdom	Fossil Fuel	Qualitative	Overall Power Plant
Al-musleh et al (2014)	United States of America	Renewable	Quantitative	Powerlines
Krishnasamy et al (2005)	Canada	Thermal	Quantitative	Overall Power Plant
Wang et al (2012)	PR China	Fossil Fuel	Quantitative	N/A

As per table above, Yeh and Rubin (2006) compiled a quantitative study on the history of pulverized coal power stations, that is aimed at filling a gap of century scale trends based on the current studies of technological transformation in this field. Their study is based on historical data of the United States of America's power plants that was used to draw up long term experience graphs and curves to prove an inclusive thermal efficiency of power stations and capital cost and operation cost of boilers. After quantifying such data their paper comes to conclusion that these fossil fuel power plants will continue to advance and be a crucial part of the power generation sector.

As per table above**,** Xiong et al (2012) carried out a study addressing CO2 seizure from generation power stations for confiscation based on the fast developed oxy-combustion technology. They compiled a qualitative study on thermos-economic cost investigation of a 600 MWe oxy-combustion coal fired power station in the People's Republic of China to comprehend both the economic and thermodynamic process. A comparison of the differently developed systems is established in the paper and moreover the paper demonstrates a new decomposition method for exergy cost that was found to be the most important factor affecting the unit's boiler cost, which is proposed to explore the forming mechanism of exergy cost and the economic cost.

As per table above**,** Chattopadhyay and Momoh (1999) in their paper presented a modelling framework for effective planning for generation and transmission over a cycle of a year that includes the dynamic restrictions on generator outputs and the static transmission limitations. They further compiled a case study to quantify the results of a 120-bus test system carried out in the transmission energy lifecycle of thermal and nuclear power sector of The United States of America A case study for a 120-bus, to demonstrate the use of the anticipated modelling framework.

As per table above**,** Zhao et al (2006) carried out a quantitative study in the fossil fuel plants of the United States of America to address the bypassed preventative maintenance of generation gas turbines due to the economic effects of carrying out such maintenance and that the turbine is a repairable failing system and that the preventative maintenance usually just restores only a portion of its original performance. The paper presents an idea that economic factors drive maintenance frequency and cost to more regular repairs and more expenses as equipment deterioration is introduced. To establish the probability of the anticipated sequential preventative maintenance scheduling procedure, a conceptual level study is achieved by means of a base load combined cycle power station with a sole gas turbine unit.

As per table above**,** Pyy (2001) covers a study that compromises of a trend of faults on nuclear power plants caused by maintenance activities. The aim of the qualitative study is to conclude on unplanned maintenance on the overall plant's safety and the system availability. To achieve the objective of the study, 4400 maintenance history reports over two years at the Finland power plant of Olkiluoto BWR NPP were assessed together with the maintenance team at the power generation station. Furthermore, the paper discusses the results of a statistical analysis of the gathered data. Majority of the failures identified came up as human error, while some came up in outages and the operation of the power plant. This data is concluded to be crucial as a good source of human reliability information and should rather be used more effectively for future instances.

As per table above**,** Ekpenyong et al (2012) conducted a study on a coal fired power generation plant's turbine on South Africa's Arnot power station, to address the maintenance schedule of generators to match the electricity demand on the grid and to also ensure the reliability thus availability of the plant at a minimized operation cost. Two maintenance models are compared with added constraints whereby one comes out with a more reliable result, which then drives the study to put the modified generator maintenance scheduling (MGMS) model to test at Arnot power plant to illustrate its robustness.

As per table above**,** Hans Christian Gils (2014) compiled a study on the demand response of a nuclear-powered system on a plant in Europe. The study's objective is to improve the use of power plant and grid volumes. The paper illustrates an analysis of the theoretical demand response of the transmission energy cycle of the concerned plants and attentive eye is given to the availability and the geographic dispersal of the flexible loads. The analysis furthermore identifies overall potential features of substantial variations during the year, which are distinctive for specific customers and countries.

As per table above**,** Carazas et al (2009) study of Brazil's fossil fuel power generation' turbine, illustrates a decision-making technique based on concepts analysis of risks for maintenance strategies selection of power plants machinery. The paper breaks down the method in two steps, one identifying critical machinery and their availability based on risk, and the other step incorporates the suggestion of a possible maintenance strategy that could be applied to critical machinery to bring up the availability of the plant. This qualitative study is based on a decision criterion to reduce the equipment fee of breakdowns, considering the costs and prospect of existence of failure possibilities. This method adapted from the study is illustrated in the examination of a lubrication oil system used in gas turbines journal bearings on power plants. A design alteration with the installation of a laid off oil pump is proposed for lubricating oil system availability enhancement.

As per table above**,** Hu et al (2009) study is based on a fossil fuel plant based in the People's Republic of China focused on Risk-based maintenance (RBM) strategies that can be utilised in creating a cost-effective maintenance plan to make financial and safety optimization in a petrochemical plant. The case of a remodelling reaction system in a petrochemical plant is analysed using the enhanced RBM approach. Results of the qualitative study indicates most equipment in this scheme is poorly repaired. The imperfect nature of the episodic preventive maintenance indicates a dire need to carry out maintenance routines more frequently.

As per table above**,** Viswanathan et al (2005) covers a study on the deterioration behaviour of tubes transporting steam in power plant boilers at very supercritical temperatures. The aim is to address operators' great concern on the corrosion noticed on these tubes. Oxide films built up on the steam side of these tubes leads to catastrophic failures reducing the plants overall availability. The study furthermore exhibits the type of failures, mostly causing premature creep failures and at a later stage the material builds up in these tubes is proven to cause blockages on the sensitive turbine side of the power plant, going through turbine nozzles and blades and poses a high safety risk to the generation plant overall. A wide variety of similar incidents have been reported throughout plants in the United States of America and this study develops its qualitative method's results from analysis of this data reported.

As per table above**,** Feng and Wang (2010) published a paper proposing a novel method for unit maintenance scheduling (UMS) in the derestricted environment in the People's Republic of China, based on the diverse functions of power generators and the independent system operator (ISO). The objective of the scheme is to obtain a trade-off between making sure the generators' benefits and maintaining the system reliability. This scheme furthermore demonstrates a three-step mechanism, which encourages evaluation of the probable benefits of energy-selling returns versus maintenance cost and anticipated renewal costs for each outage available window, bearing in mind the effects of unpredicted unit failures. In this paper the IEEE-RTS system is utilised to illustrate the fundamental features of the proposed mechanism in everyday applications, counting its equality, simplicity and efficiency.

As per table above**,** Campbell et al (2000) compiled a study based on United Kingdom and Spain's supercritical fossil fuel power generating plants using a qualitative model to qualify data demonstrating optimised efficiency, decreased costs and an improved availability of the plant. These studies remove the variances caused by the feedstock and the climatic circumstances and then go on to look at a progressive IGCC (Integrated gasification combined cycle) concept that has been established based on procedures, components and resources that are now available.

As per table above**,** Al-musleh et al (2014) takes on an energy storage and thus distribution challenged faced in the renewable energy sector in a couple of case studies in the United States of America. The paper proposes an effective way of implementing carbon recirculation cycle that permit dense energy storing. By means of process simulations they illustrate that these cycles have a likelihood to provide GWh of electricity conforming to an overall energy storage efficiency of 55–58% at much compact storage volumes related to other options.

As per table above, Krishnasamy et al (2005) compiled a paper on a major problem in any process plant, which are the unexpected breakdowns, the down time linked with such failures, the loss of the targeted production and most importantly the associated higher maintenance costs. This paper introduces Risk based Maintenance (RBM) method as of great assistance in designing another strategy to decrease risk resulting from equipment failures. A case study of a power-generating unit in the Holyrood thermal power generation plant of Canada is used to quantify the data and illustrate the maintenance strategy proposed. The results prove that the strategy is successful in recognizing the critical equipment and in decreasing the risk following failure of the equipment. Risk lessening is attained through the implementation of a maintenance strategy which not only increases the reliability of the equipment but also decreases the cost of maintenance including the cost of catastrophe.

As per table above, Wang et al (2012) study is based on petrochemical facilities and plants of the People's Republic of China's. They are outlined as requiring crucial ongoing maintenance to ensure adequate levels of reliability and safety. They propose that a risk based maintenance strategy (RBM) is a useful tool to design a cost-effective schedule bearing in mind to subsequently decrease the risk in the operating facility of the plants. In this paper, a failure mode and effects analysis (FMEA) is used to quantify the seriousness of personnel injury and environmental pollution. A case study of an ongoing catalytic reforming plant is used to demonstrate the proposed approach. The outcomes specify that FMEA is constructive to identify critical facilities; and that the RBM maintenance strategy can increase the reliability of high-risk facilities, and corrective maintenance is the ideal method for low-risk facilities to decrease maintenance cost.

Conclusion

Regardless of the overhaul outages planned with the aim of preventing failures on the energy plants in South Africa, it is witnessed not to be effective based only on the production ratio outcomes. The production ratio, as per the South African power enterprise is 80:10:10. The ratio is based on 80 % availability, the only fixed figure of 10% planned maintenance and 10 % unplanned maintenance of the power plants. The production ratio on most South African power station is not close to the above mentioned ideal ratio as witnessed on some stations whereby the station's ratio is recorded at 55:10:35. Overhaul maintenance on equipment are ideally rolled out as a failure preventative measure to prevent unplanned maintenance and thus ensure satisfactory availability of the power generating plant. In this paper, we illustrate the effectiveness and benefits of maintenance operations or strategies. Although numerous studies have been conducted over the past two decades to analyze effectiveness of maintenance strategies, there remains a gap in the current overview. Therefore, the objective of this paper is to conduct a theoretical assessment on the effectiveness of overhaul maintenance in the energy sector. The results of the critical analysis of the current literature on the subject matter, clearly demonstrates that there are flaws in the current body of knowledge related to a lack of boiler and quantitative studies.

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