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A Baseline Knowledge on FMEA, Failure Mode and Effect Analysis on 365KVA Pump Station Generator

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ABSTRACT
*Many production or manufacturing equipment (machines) failed to operate or breakdown intermittently while production is in process, thereby causing loss of man-hour, low production, poor revenue, failed business target etc. Lokoja Pump Station was established in 1979 and it is among the seven (7) Pump Stations on System 2C Pipeline Pumping/Boosting crude oil to Kaduna Refinery and Petrochemicals (KRPC) of Nigeria Pipeline and Storage Company, NPSC a subsidiary of Nigerian National Petroleum. This paper aims to examine and provide a baseline knowledge and overview of conventional, life cost-based and fuzzy FMEA (failure mode and effects analysis) on pump station generator using 365KVA Caterpillar generator in NNPC Lokoja Pump Station as case study.***

KEYWORDS: *Baseline knowledge, Life cost-based analysis, Failure mode, Effects analysis, Pump station generator.*

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I. INTRODUCTION

Much has happened in engineering since the industrial revolution a couple of hundred years ago but perhaps the most dramatic changes have occurred in the last fifty years. These changes have of course affected how industry's plant has been maintained.

Prior to the Second World War (1939-1945) machinery was generally quite rugged and relatively slow running, instrumentation and control systems were very basic. The demands of production were not overly severe so that downtime was not usually a critical issue and it was adequate to maintain on a breakdown basis. This machinery was inherently reliable. Even today we can see examples of machines made in that period which have work very hard and are still essentially as good as the day they were made.

From the 1950's with the rebuilding of industry after the war, particularly those of Japan and Germany there developed a much more competitive market place, there was increasing intolerance of downtime. The cost of labour became increasing significant leading to more and more mechanization and automation. Machinery was of higher construction and ran at higher speeds. They wore out more rapidly and were seen as less reliable.

All equipment is designed to last for a period of time called the design life span. If the equipment does not last this long, major faults are attributed to the maintenance culture of the handler or equipment manager. In recent times research are geared towards developing models that would help select equipment maintenance intervals that are economical and have a low risk on losing the equipment.

Some of the models that proved to improve the equipment maintenance culture and system reliabilities are convention (traditional), life cost-based and fuzzy failure mode and effect analysis (FMEA). The three used models are highlighted below for more clarifications.

The traditional FMEA process is a systematic method to identify: – Primary and secondary functions of the system and the failure modes that prevent the system from completing its designed purpose.

To resolve the ambiguity of measuring detection difficulty and the irrational logic of multiplying 3 ordinal indices, a new methodology was created to overcome these shortcomings, Life Cost-Based FMEA. Life Cost-Based FMEA measures failure/risk in terms of monetary cost. Cost is a universal parameter that can be easily related to severity by engineers and others.

Fuzzy logic is a form of many-valued logic or probabilistic logic. It deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

1.1 STATEMENT OF PROBLEM.

Many production or manufacturing equipment (machines) failed to operate or breakdown intermittently while production is in process, thereby causing loss of man-hour, low production, poor revenue, failed business target etc.

Lokoja Pump Station established in 1979 is one among the seven (7) Pump Stations on System 2C Pipeline Pumping/Boosting crude oil to Kaduna Refinery & Petrochemicals (KRPC) of Nigeria Pipeline and Storage Company, NPSC a subsidiary of Nigerian National Petroleum

1.2 AIM AND OBJECTIVES OF THE STUDY.

The aim of this study is to carry out analysis of conventional, life cost-based and fuzzy FMEA (failure mode and effects analysis), on 365KVA Caterpillar generator in NNPC Lokoja Pump Station. The objectives are provide relevant information on conventional failure mode and effect analysis sheet containing occurrence evaluation and detection evaluation of FMEA. The failure mode and effect analysis task force analyzes each potentials failure mode to determine the possibility of its occurrence and evaluate whether the existing operating regulations can effectively identify and control each failure mode. The failure mode and effect analysis, FMEA task force discuss each failure mode and allocates a score between 1(lowest) and 10(highest).Once failure mode identification, failure effect analysis and failure risk evaluations are completed, the failure modes and effects analysis task force can set a threshold value for the failure risk priority number, RPN. Risk priority number determines whether preventive and improvement measures should be prioritized to resolve failure risks and the order which this should be conducted

II. LITERATURE REVIEW

FMEA was begun in 1940s by the U.S. military during World War II, FMEA was further developed by aerospace and automobile industries. Several Industries maintain formal FMEA standards. The process was also adopted early on by the Society for Automotive Engineers (SAE) in 1967. The use of FMEA spread rapidly to other industries during the 1970s and subsequent years and is now utilized in a variety of industries including military, semiconductors, and the foodservice industry. More recently FMEA has been adopted within the healthcare industry to assess the high risk process of care (Franklin, Shebl, & Barber, 2012). FMEA is useful in understanding the failure modes of systems or products, qualifying the effects of failure, and aiding in the development of mitigation strategies. It is a useful tool in improving quality, reliability, and the maintainability of designs, and is a critical analysis component in risk management. FMEA can be applied to almost any system or process and thus universally valuable. It became widely known within the quality community as a total quality management tool in the 1980s and as a Six Sigma tool in the 1990s. A team should apply FMEA to perform risk assessment to see what the customer will experience if a key process input (X) were to fail. The team should then take action to minimize risk and document processes and improvement activities. FMEA is living document that should be reviewed and updated whenever the process is changed (Jogger, 2002).

The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat-vulnerabilities.

In the age of ever-growing global competition, production efficiency is one of the most

In this study the FMEA was implemented and accompanied by quality control of apparel production lines, to decrease the defective products and enhance the productivity. As a consequence, using Arena simulation software, enhancement programs and defensive actions can be taken prior to starting the project, through utilizing FMEA to avoid wasting resources and decreasing cost.

2.4 Review of FMEA Scales both In Industry and Academia

FMEA is a methodology designed to identify potential failure modes for the product, to assess the risk associated with those failure modes, to rank the issues in terms of importance, and to carry out corrective action to address the most serious failure modes. Failure modes may be introduced in design, manufacture, and/ or usage, and can be potential or actual. Effects analysis refers to studying the consequences of those failures.

Danny, Shariman, Fanny and Theresia (2013), of University Malaysia Pahang published a research paper on Failure Mode and Effect Analysis of Diesel Engine for Ship Navigation System. According to him the FMEA played a crucial role in preventing future failure in diesel engine of ships which reduce the number of accidents of ships in the sea.

In June 1996, Kim (1996), published a research paper on Failure Mode, Effect and Critical Analysis on Mechanical subsystem of Diesel Generator at Nuclear Power Plant. According to him this is first phase for implementation of RCM approach on diesel generator. It also included that it was the trail application of

FMECA to diesel generator, there will be a more systematic failure analysis and logic tree analysis will be performed in future.

In April 2016, Manish Behera published paper on Design Failure Mode and Effect Analysis of a Human Powered Recumbent Vehicle in International Journal of Engineering Research & Technology, JERT. According to him when he calculated Risk Priority Number of each component due to which it revealed the critical spot which are more likely to prone for failure which will help in modifying the design of Human Powered Recumbent Vehicle.

Rishav and Mondloi, (2018) posited that a full-fledged FMEA was carried out on the petrol engine of Maruti Suzuki Swift Car. Various aspect such as severity, likelihood of occurrence and detection were clearly described which help in calculating the RPN of each component of engine. From above analysis Ignition System, Fuel Injection System and Cooling System are the critical component with high RPN which require more attention and top notch maintenance so that preventive maintenance can be successful.

Various researchers have used FMEA in the analysis of industrial systems with many interacting components either in process, design applications or else.

Pantazopoulos and Tsinopoulos, 2005, found that FMEA is one potential tool with extended use in reliability engineering for the electrical and electronic components production field as well as in complicated assemblies (aerospace and automotive industries). The main purpose for their study was to reveal system weaknesses and thereby minimize the risk of failure occurrence.

Hoseynabadi et al., 2010, used the Failure Modes and Effects Analysis (FMEA) method to study the reliability of a wind turbine (WT) system, using a proprietary software reliability analysis tool. They compared the quantitative results of an FMEA and reliability field data from real wind turbine systems and their assemblies.

Segismundo and Miguel, 2008, proposed a systematization of technical risk management through the use of FMEA to optimize the decision making process in New Product Development (NPD) as case study in an automotive industry in Brazil.

Josiah, Keraita , Muchiri, (2018), posited that proper early failure detection methods and potential failure prediction or detection is fundamental for effective maintenance management. This reduces the probability of failure which leads to plant shut down and thus improving OEE. To reduce the adverse effects of breakdown and to increase the equipment availability at a low cost, FMEA is a key reliability analysis tool that needs to be instituted in industrial set-ups. From the failure modes Pareto analyses performed on milling plant critical sub-systems, the results identified the most critical failure modes for milling plant sub-systems.

Research on the maintenance and reliability of the equipment in semiconductor factories is increasing (Degbotse and Nachlas, 2003; Kuo and Sheu, 2006). As the precision and the size of the equipment in such factories are increasing, the maintenance and reliability of this equipment is of critical importance. By using empirical research, this study aimed to provide foundries with the data needed to know when to best maintain its key equipment. This study proposed using FMEA and a Monte Carlo Simulation to predict the time-points for preventive maintenance. With FMEA, a systematic record clearly highlighted the key or bottleneck equipment in the semiconductor foundry for the reference of the equipment engineering department.

III. METHODOLOGY

FMEA consists of two stages. Potential failure modes are identified in the first stage, and the values of severity, occurrence, and detection are assigned. The manager makes recommendations for corrective action in the second stage, and RPN must be recalculated after undertaking such corrective action (Su & Chou 2008; Gajdzik & Sitko 2016). The Risk Priority Number (RPN) can take the maximum value of 1000. In practice, established boundaries of this index are used, which can be defined as the level of acceptability of the risk. It is often assumed that the value of the RPN below 120 for the failure is an acceptable level of risk. In such a case it will not be necessary to make changes in the system. If the value of the RPN is in the range of 120-160, then corrective action should be taken which decreases the RPN value (Molenda et al. 2016). Chen (2007) pointed out that FMEA provides a structured systematic identification of the potential failure modes in design, manufacturing, or management.

FMEA provides a qualitative evaluation of the necessary corrective actions by studying the impact of failure on the system and by focusing on the problems affecting systematic reliability (Zasadzień 2014; Midor 2014). Failure modes and effects analysis also documents current knowledge and actions about the risks of failures, for use in continuous improvement. The results of the FMEA analysis serve as a basis for the introduction of changes in the product design or production processes, aimed at reducing the risk of occurrence of defects identified as critical. If it is not possible to completely eliminate the causes of defects, action should be taken in order to enhance their capability to detect or reduce the negative effects of their occurrence. Implementation of the recommended corrective action should be continuously monitored and their effects subjected to verification (Wyrębek 2012; Skotnicka-Zasadzień 2012; Wojtaszak & Biały 2015).

2.6 Review of Maintenance Strategies

Maintenance strategy is defined as a coherent, unifying and integrative pattern of maintenance decision elements in congruence with manufacturing, business and corporate level strategies and defines the nature of economic and non-economic contributions it intends to make to the organisation as a whole. There are five (5) maintenance strategies that can be adopted.

2.6.1 Passive maintenance strategy

Is followed when maintenance action on a machine is carried out when there are stoppages in the production process for some reasons other than breakdown. The fact that production has been stopped for any reason provides an opportunity for the maintenance department to undertake maintenance activities on the machine. Passive maintenance is thus an opportunistic type of maintenance.

2.6.2 Reactive Maintenance (Corrective Maintenance) Strategy/Breakdown or Run to Failure Maintenance Strategy

Turner (2002), Reactive maintenance is defined as those maintenance actions taken to fix a component when it reaches functional failure. It is also known as corrective maintenance, since it is performed purely to 'correct' failed or deficient equipment. Rather than performing maintenance actions to ensure design life is reached, reactive maintenance employs the "run it till it breaks" mentality.

Pride (2008) Reactive maintenance is particularly effective for non-critical, low-cost system components and equipment. As such, reactive maintenance should be used whenever the cost of maintaining an asset exceeds the asset's replacement value, unless the risk associated with failure is too severe. Sullivan et al., (2004) Reactive maintenance also provides benefits for small maintenance operations when the staff is not large or qualified enough to adequately perform routine maintenance activities. Despite these advantages there are numerous disadvantages to reactive maintenance.

Sullivan et al., (2004) the primary disadvantage of reactive maintenance is the high risk of unscheduled failures. Unscheduled failures often require more money to correct, especially if overtime labour is required to correct the problem. In addition, the opportunity cost of lost productivity from unplanned equipment downtime must also be included. A further risk of reactive maintenance is the potential for secondary system damages that may result from equipment failure. While reactive maintenance may seem to save maintenance and capital costs, it is an inefficient use of staff resources and has been shown to have higher long-term costs than other maintenance approaches.

Turner (2002), as with deferred maintenance, the compounding effects of reactive maintenance can have negative effects on the overall maintenance operation; this situation is known as the reactive maintenance strategy the premise of the reactive maintenance strategy is that successive preventable failures consume resources to the extent that the maintenance operation can only afford less- expensive, temporary repairs. In turn, these repairs have a higher probability of preventable failure which eventually consume even more resources, and the cycle continues. This potential pitfall poses a serious threat to maintenance managers; however, it can be avoided by ensuring reactive maintenance is only applied in the appropriate context.

Turner (2002) in addition to only using reactive maintenance when appropriate, the risks associated with reactive maintenance can he reduced by speeding the repair service, easing the task of repair, and providing alternate output during repair time. There are a number of ways to accomplish these effects, to include: increasing maintenance crew size, creating spare parts and redundant equipment inventories, designing equipment and system to facilitate maintenance and improving craftsman framing. Faster repairs correlate with lower labor costs, and less equipment downtime helps minimize the opportunity cost of halted production.

2.6.3 Preventive Maintenance Strategy/ (Time-Based Maintenance Strategy)

Preventive maintenance is defined as regularly scheduled maintenance actions performed on equipment and infrastructure systems to prevent wear and degradation, extend useful life, and mitigate the risk of catastrophic failure (Sullivan et al., 2004; Alaska Department of Education & Early Development (ADEED), 1999; Lewis, 1991; Kay, 1976). Unlike reactive maintenance which takes place when a failure occurs, PM actions are performed at an established frequency. These frequencies are based on average failure rates of equipment using either equipment run time or calendar time, and maintenance actions are accomplished prior to expected failure. (Quan, Greenwood, Liu, & Hu, 2007; Industrial Accident Prevention Association (IAPA), 2007). PM is particularly effective when the risk of system failure is unacceptable or when reliable data for maintenance versus equipment failure is available (Pride, 2008).

There are numerous advantages of PM; the two most cited ones are an increase in average equipment life span and a decrease in the risk of catastrophic equipment failure (Sullivan et al., 2004; IAPA; 2007; Lewis, 1991). By helping equipment run more efficiently, preventive maintenance can also lead energy savings, higher equipment output and safety, lower environmental impacts, and increased facility operability or avai1abiliy (Lewis, 1991; Sullivan et al., 2004).

Although PM offers a wealth of advantages for maintenance operations, it is not without its disadvantages. The primary disadvantage is that catastrophic failures are still likely to occur, regardless of the decrease in the risk of equipment failure from preventive maintenance (Sullivan et al., 2004). As such, a maintenance operation must still be able to respond to emergencies and cannot rely solely on PM. In fact, Nowland and Heap reached the conclusion that, "a maintenance policy based exclusively on some maximum operating age would no matter what the age limit, have little or no effect on failure rate. Extensive PM programs require a large amount of labour resources, and there is often a probability of performing excessive maintenance that has no positive impact on the equipment (Sullivan et al., 2004).

Furthermore, it is extremely difficult to determine the optimal level of preventive maintenance, and it may require years of maintenance actions and data collection before payback is realized (Idhammer, 2008; Chen, 1997). Since its impacts are often less visible than other types of work, PM is often the first work to be skipped in the light of emergencies or other requirements that may seem more important (Brown, 1996). While the impacts of such a decision may not be immediate, it can drastically impact the overall effectiveness of a PM program.

Preventive maintenance programmes can vary greatly depending on the context in which they are implemented; however, there are a number of characteristics that can be used to describe the differences between programmes. PM actions can be either simple or replacement while replacement actions improve the reliability of a maintained asset to that of a brand new system, simple actions only improve the reliability to some small degree. Whether simple or replacement, PM actions can be assigned one of three levels of priority: critical actions are those that will lead to immediate loss of facility function if not completed on time, required actions are those that can be postponed for a short period with no major impact on a facility, and discretionary actions are those that can be deferred indefinitely with no major impacts on a facility (Magee, 1988). There are five primary reasons for implementing a preventive maintenance program: sustain operations, lengthen equipment service life, identify equipment degradation, prevent equipment loss, and comply with standards (Magee, 1988). These reasons are directly related to the numerous potential advantages of preventive maintenance, and most programmes will be established to meet combination of these objectives.

When implementing a PM program, the first step is to identify the equipment that will be maintained (ADEED, 1999). Equipment assets and system with high downtime, high maintenance, or repetitive repairs are ideal candidates for preventive maintenance (Brown, 2003). Subsequently the equipment must be evaluated to determine its current condition and then ranked for maintenance priority among all candidate equipment (ADEED, 1999; Westerkamp. 1997). Criteria for defining maintenance priorities include the equipment's impact on organizational mission, safety risks, maintenance costs, and operational costs (Turner, 2002). Once the equipment and priorities for the PM program have been established, work actions for each activity must be defined (Westerkamp, 1997). Traditionally, each identified preventive maintenance action should consist of an established frequency, a description of the maintenance task, a list of necessary tools and equipment, and safety considerations (Quan et al., 1999). Establishing preventive maintenance actions can be a daunting task for the untrained maintenance manager; however, there are a number of available sources of information to assist with this process. The most common source of preventive maintenance information is manufacturer or vendor recommendations (ADEED, 1999). In many cases, a manufacturer's warranty is dependent upon implementation of the recommended maintenance plan (Magee, l988). Nevertheless, managers should not blindly use the manufacturer's recommendations in their original form because they may not align with the organization's goals or be optimized for certain environments (Brown, 2003). Another source of information is the tacit knowledge of maintenance personnel which is based on craftsman experience working with the equipment and infrastructure (Brown, 1999). A third source of preventive maintenance information comes from industry guidance (ADEED, 1999; Brown, 2003). Although detailed guidance may not be available for a specific piece of equipment. Information regarding general classes of equipment or similar equipment items can be modified to fit a specific facility requirement (Brown, 2003). A fourth source of preventive maintenance information is test results from impact analysis and/or failure analysis (ADEED, 1999). While failure analysis focuses on necessary actions to delay equipment failure, impact analysis focuses on mitigating the potential effects of equipment failure on an organization' s mission or resources (Magee, 1988).

2.6.4 Predictive Maintenance Strategy/(Condition-Based Maintenance) Strategy

Sullivan et al., (2004) Predictive maintenance is defined as a process of determining maintenance action requirements according to regular inspections of an equipment or asset's physical parameters, degradation mechanisms, and stressors in order to correct problems before failure occur. Also known as conditions-based maintenance, this strategy differs from preventive maintenance in the fact that maintenance actions are performed according to the physical condition of the equipment, rather than an established frequency

(Kwak, Takakusagi, Sohn, Fujii& Park, 2004; Lin et al., 2002). Predictive maintenance works particularly well for systems that are easy to monitor and have easily identifiable characteristics that can be statistically analyzed to determine remaining system life (Lin et al., 2002).

The advantages of predictive maintenance are numerous (Sullivan et al., 2004). Predictive maintenance actions primarily consist of simple inspection which are rarely labour intensive and seldom require equipment downtime (Lin, et al., 2002; Westerkamp, 1997). These benefits correlate to conserving maintenance resources and minimizing impacts on facility operations. Since physical maintenance is only performed when conditions warrant, unnecessary maintenance is only actions are also prevented. This, in turn, allows maintenance operation to shrink material inventories, optimize work order scheduling, labour cost, and improve the quality of equipment maintenance (Sullivan et al., 2004Westerkamp, 1997).

2.6.5 Reliability Centered Maintenance (RCM) Strategy / (Proactive or Preventive Maintenance Strategy)

With a few exceptions, preventive maintenance has been considered the most advanced and effective maintenance technique available for use by industrial and facility maintenance organizations. A Preventive Maintenance (PM) program is based on the assumption of 'fundamental cause-and-effect relationship between scheduled maintenance and operating reliability.

This assumption was based on the intuitive belief that because mechanical parts wear out, the reliability of any equipment directly related to operating age. It therefore followed that the more frequently equipment was overhauled, the better protected it was against the likelihood of failure. The only problem was in determining what age limit was necessary to assure reliable operation." (Pride, 2010).

2.5.6 Review of Research Works on Maintenance Strategy Selection

In last few decades there were lots of research work that been done all over the world on maintenance strategy selections. Few of them are introduced in this research work M. Bevelacque et al. (March 2000); the research work is all about the selection of maintenance strategy in a plant which is still in construction phase. Possible alternatives are considered preventive, condition based, corrective and opportunistic maintenance. There are approximate 200 facilities for which best maintenance policy have to select the machines are clustered in three homogenous groups after a criticality analysis based on internal procedures of the oil refinery. With AHP (Analytic Hierarchy Process Technique, several aspects which characterize each of the above mentioned maintenance strategies, are arranged in hierarchic structure and evaluated using only a series of pair wise judgements

According to Massinio Bertolin et al. (2005) presents a lexicographic goal programming (LGP) approach to define the best strategies for the maintenance of critical centrifugal pumps in an oil refinery for each pump failure mode, the model allows to take into account the maintenance policy burden in terms of inspection or repair and in terms of the manpower involved, linking them to efficiency risk aspects quantified as in FMECA, Failure Mode and Effects Analysis Methodology through the use of the classic parameter occurrence, severity and detestability, evaluated through an adequate application of AHP technique.

According to Ling Wang et al. (2007) analysed deal with uncertain judgement of decision makers, a fuzzy modification of the AHP method is applied as an evaluation tool where uncertain and imprecise judgements of decision makers are translated into fuzzy numbers. In order to avoid fuzzy priority calculation and fuzzy ranking procedures in the traditional fuzzy AHP methods, a new fuzzy prioritization method is proposed. This fuzzy prioritization method can derive crisp priorities from a consistent or inconsistent fuzzy judgement matrix by solving an optimization problem with non-linear constraints.

2.7 Review of Public Facility Maintenance Culture in Nigeria Including NNPC Lokoja Pump station.

Adenuga, Iyagba, Odusami and Ogunsanmi (2007) study focuses on the evaluation of maintenance management strategies used in public hospital buildings in Lagos State. It also assesses the labour composition of maintenance operations. In achieving these objectives, opinions of maintenance officers of ten (10) hospitals in different local government areas of the state were sampled through well-structured questionnaires. The data collected were analysed using descriptive and inferential statistics. From the analysis, the study reveals that majority of public hospitals do not have specific budget for maintenance programmes, maintenance policies, maintenance manual to guide the operatives. About 98% if the sample does not understand the type of maintenance strategy being used for their maintenance operations. 78% of the maintenance works are only executed when there is a breakdown or in response to user's request. For labour composition, the cleaning of the interior and exterior of the building, inspection of building elements, repairs and replacements of building elements are mainly carried out by in-house staff, while the repair and replacement of equipment is by outsourcing. The study also reveals that executing maintenance programmes using outsourcing gives latest innovations in technologies to work done and better access to special skills than in-source. In-source method, gives reduction in cost of operation, higher security, more flexibility in staffing, better adjustment to workload fluctuation and reduction in equipment downtime than out-source. Both methods claim to produce special expertise in labour, better control of services and higher quality of work. The study recommends proactive measures such as providing necessary training and support for maintenance staff and users of these facilities and the provision of sufficient funds for maintenance programmes.

T.C. Madueme (2002) viewed that constant use of any production facility especially machines, equipment and tools increases its depreciation rate. Hence from time to time, repairs are needed, but repairs alone do not constitute good maintenance. Good maintenance policies prevent production interruption and losses in addition to the fact that it lengthens the service life of machines and equipment. This entails planned inspection, testing, cleaning, drying, monitoring, adjusting, corrective modification and repair of electrical equipment. This paper investigates the maintenance culture at Afam Power Station for selected years and the impact of such policies on installed machines and operational efficiency of the station results show that there are extensive deviations between maintenance policies guiding the station and actual practice. The resultant effect is that by 1997 only two generating units were working and the percentage performance of the station fell to 45.3%. The recommendations include the establishment of good maintenance work documentation system, increased training programme for local power workforce, privatization of electric power industry among others.

The historical evidence showed public road transport businesses managed by corporations in Nigeria have always been finding it difficult to recover the investment costs inspite of the increased number of passengers favouring this mode of transportation business. Operations performed by other public organisations such as River Basin Authorities, Nigeria Railway Corporation, Nigeria Telecommunications Limited (MTEL) are facing the same hindrance mentioned in the foregoing. For instance, MTEL paid heavily for its cost of operational inefficiency when MTN, a multinational foreign communication firm swept communication market with the introduction of mobile phone and the firm was able to recover its investment cost within a shortest period apart from the huge profit earned. Even though the objective of public sector organisation in the past was not to make profit, yet, they were still expected to provide services in an efficient manner in the right place and to be timely the increasing withdrawing of government support to the Public Corporation is clear indication that public organisations that are yet to be privatised should improve operational efficiency. Because of these vital reasons, privatisation of public organisations has of recent become popular in Nigeria. At present, most public corporations are expected not only to break even, but also to stand-alone by making sufficient surpluses. The Unfortunate aspect is the fact that the high remuneration payable to the workers in the government commercialized industries such as the Nigeria National Petroleum Corporation, (NNPC), the National Electric Power Authority, NEPA and the Nigeria Telecommunication Limited, (NITEL) fail to improve productivity(H.T. Iwarere and K.O. Lawal, 2011)

Public sector organisations must properly utilise their facilities in order to be judged efficient. Even though low capacity utilization has been one of the major global problems affecting many public sectors, yet, the basic fact is that, some public sector organisations performed better than others in their facility utilisation. Those organisations that possess better managerial and technical skills were able to perform better than those organisations that possess incompetent staff. More so, a corrupt practice of top management team in many public sectors in Nigeria is a major obstacle for achieving poor performance.

Since public organisations in Nigeria operate at the cost of inefficiency, it is suggested that they should adopt four key perspectives of balance scorecard that focus on four separate but related perspectives of organisational performance and management such as financial performance, internal processes, customer satisfaction or customer value and workforce support.

Tijani Saheed Abiodun, Adeyemi, Akinwale, Olayemi and Omotehinshe Olusegun Joseph (2016) opined that maintenance culture in this study suggests the habit of regularly and consistently keeping a building, machine, facilities, equipment, infrastructures etc. in good and working condition. In support of this assertion, Suwaibatui-Islamiah, Abdul-Hakim, Syazwina, and Eizzatul (2012) posited that maintenance culture is the values, way of thinking , behaviour, perception and the underlying assumptions of any person or group or society that considers maintenance as a matter that is important and practices it in their life. If a nation must develop, it is imperative that installation as well as maintenance of its existing facilities be given priority. This is more so for developing nations like Nigeria where there is a huge gap between the supply and demand for such facilities due to high rate of population growth and other factors (Dabara, Ankeli, Guyimu, Oladimeji and Oyediran, 2015). Attaining sustainable infrastructural development by successive governments and cultivation and practicing maintenance culture are essential in achieving this vision. Infrastructure facilities generally referred to as economic and social overhead capital which includes education, water supply, sewage systems and energy. Others are postal and telecommunication services, transport system, hospitals and roads (World Bank, 1994, Oluwasegun, Okorie, Dabara, and abdulazeez, 2013; DabaraLawal, Adebowale, Ankeli and Gambo (2016).

Governments (Federal, State and Local), private organisations and individuals need to have a strategy on how to maintain their infrastructural facilities to ensure sustainability of same. This can be achieved through maintenance culture which is said to have a correlation with national development.

2.8 Evolution of Maintenance

The first generation of maintenance started about 1940 till 1950. It is characterized by reactive mode which is mostly fixing equipment any time it fails (breakdown/corrective maintenance). The asset availability and reliability is not guaranteed and production losses and deferment are always encountered. Within this period, industry was not fully mechanized, so downtime did not matter much. This implies that prevention of equipment failure was not a priority. At the same time, most equipment was simple in design and can be easily repaired. Maintenance operations were simply cleaning, servicing and lubrication routines.

Second generation of maintenance (1950 - 1977) improved on the first generation, where the focus is on preventive maintenance rather than corrective. The Second World War changed so many things. The wartime pressures increased the demand for goods of all kinds while the supply of industrial manpower dropped sharply. This gave rise to increase in mechanization. Machines ranging from simple to complex ones were produced. Industries now depend on them to meet up targets in volume and quality. As this dependence grew, downtime came into sharper focus. The danger of not meeting production deadlines due to machine failure/downtime became a source of worry. This situation gave rise to the concept of preventive maintenance. The objective is to forestall any situation that can generate machine/equipment downtime in a production system. The cost of maintenance started to rise relative to the other operating costs. This led to the growth of maintenance planning and control systems. These have helped to bring maintenance under control, and are now an established part of the practice of maintenance. The expectations of maintenance in the second generation of maintenance include higher equipment availability, longer equipment life and lower maintenance cost.

The third generation of maintenance commenced from 1978 - 2000. Since the mid-seventies, the process of change in the industry has gathered greater momentum. Equipment/machine failures and their inherent consequence of downtime are not tolerable. Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service.

2.9 Reliability

According to Kumar (2000) ever since the very beginning of the industrial era, customers have demanded better and faster deliveries of products and services, all these at lower costs. In other words, they want to get value for their money spent. This problem is due to the fact that one produces, what someone else-consumers' needs and demands, this is important due to the competitive market. "Operators want infinite performance of assets, at Zero life- cycle costs, with 100% availability from the day they take delivery to the day they dispose it.

This is of course the ideal request, but of course impossible to achieve. The operators demand is to get as close as possible to this extreme, or at least closer than their competitors. One step to reach a high level of availability is to increase the reliability of the products, although this is on its own, one can't fulfill all those demands, but it is a link in the chain consisting of reliability, maintenance and logistic support, where maintenance comes as a natural part of reliability

2.9 Literature review on life cost-based FMEA

Steven Kmenta & Kosuke Ishii, 2000. Stated that risk contains two basic elements: chance and consequences. Probability is a universal measure of chance, and cost is an accepted measure of consequences (Gilchrist, 1993). For a given failure scenario, risk calculated as expected cost: the product of probability and failure cost (Rasmussen, 1981: Modarres, 1992). Expected cost is used extensively in the fields of Risk Analysis, Economics, Insurance, Decision Theory, etc.

2.9.1 Probability Theory

Probability theory is applicable in various situations where the outcome is uncertain, such as in experiments, trials and repeated processes etc. Where predictions have to be made. This is a topic that plays a leading role in modern science. In fact it was previously developed as a tool to guess the outcome of some game chance; however this thesis does not intend to describe the topic in detail with theorems and proofs, but just to give some brief overview of the concept; in probability that may be applied to problems during this study considering reliability, maintenance and logistic support.

2.9 Literature review on life cost-based FMEA

Steven Kmenta & Kosuke Ishii, 2000. Stated that risk contains two basic elements: chance and consequences. Probability is a universal measure of chance, and cost is an accepted measure of consequences

(Gilchrist, 1993). For a given failure scenario, risk calculated as expected cost: the product of probability and failure cost (Rasmussen, 1981: Modarres, 1992). Expected cost is used extensively in the fields of Risk Analysis, Economics, Insurance, Decision Theory, etc.

2.9.2 The Reliability Function

The most frequently used function in life data analysis and reliability engineering is the reliability function. This function gives the probability of an item operating for a certain amount of time without failure. As such, the reliability function is a function of time, in that every reliability value has an associated time value. In other words, one must specify a time value with the desired reliability value i.e 95% reliability at 100 hours. This degree of flexibility makes the reliability function a much better reliability specification than the MTTF, which represents only one point along the entire reliability function.

2.9.3 Lifetime Distributions

A statistical distribution is fully described by its PDF (or probability density function). The functions most commonly used in reliability engineering and life data analysis, namely the reliability function, failure rate function, mean time function and median life function, can be determined directly from the pdf definition, or f(t). Different distributions exist, such as the normal, exponential etc., and each one of them has a predefined f(t). These distributions were formulated by statisticians, mathematicians and/or engineers to mathematically model or represent certain behaviour. For example, the 'Weibull distribution was formulated by Weibull and thus it bears his name. Some distributions tend to better represent life data and are most commonly referred to as lifetime distributions. The pdf of the well-known normal, or Gaussian, distribution is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

In this definition, note that t is our random variable which represents time and the Greek letters (mu) and (sigma) represent what are commonly referred to as the parameters of the distribution. Depending on the values of and, f(t) will take on , different shapes. The normal distribution is a two-parameter distribution, with two parameters μ and σ.

For any distribution, the parameter or parameters of the distribution are estimated from the data. For example, in the case of the normal distribution, μ, the mean, and, the standard deviation, are its parameters. Both of these parameters are estimated from the data, i.e. the mean and standard deviation of the data. Once these parameters are estimated, the pdf function f(t),is fully defined and we can obtain any value for f(t) given any value of t. Given the mathematical representation of a distribution, we can also derive all of the functions needed for life data analysis, such as the reliability function. Once again, this will only depend on the value of t after the value of the distribution parameter or parameters are estimated from data.

2.9.4 Failure Rate

Failure rate is the frequency with which an engineered system or component fails and is expressed for example as failure per hour. It is often denoted by the Greek letter; λ (lambda) and is important in reliability engineering. The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system. For example, an automobile's failure rate in its fifth year of service may be many times greater than its failure rate during its first year of service. One does not expect to replace an exhaust pipe, overhaul the brakes or have major transmission problems in a new vehicle.

In practice, the mean time between failures (MTBF) is often used instead of the failure rate. This is valid if the failure rate is constant (general agreement in some reliability standards (Military and Aerospace) - part of the flat region of the Reliability bathtub curve, also called the "useful life period". The MTBF is an important system parameter in systems where failure rate needs to be managed, in particular for safety systems. The MTBF appears frequently in the engineering design requirements, and governs frequency of required system maintenance and inspections. In special processes called renewal processes, where the time to recover from failure can be neglected and the likelihood of failure remains constant with respect to time, the failure rate is simply the multiplicative inverse of the MTBF (1/λ). A similar ratio used in the transport industries, especially in railways and trucking is mean distance between failures', a variation which attempts to correlate actual loaded distances to similar reliability needs and practices.

According to Howland (2004) the main objective of a reliability study should always be to provide information as a basis for decision. The results provided by a reliability study will not tell us exactly what to do, but in what direction to look.

For example, a reliability study can be useful in areas of risk analysis, optimization of operations and maintenance. The risk analysis is a way of identifying causes and consequences of failure events, and the optimization is a way of telling how failures can be prevented and how to improve the availability of a system. One can see reliability theory as a tool for analyzing and improving the availability of the system.

2.9.5 The Bathtub curve

Davies (1998) stated that normal mechanical failure modes degrade at a speed directly proportional to their severity. Thus, the problem is detected early, major repairs can be prevented in most instances.

According to Davies one needs to find the right time for the failure to prevent major repairs, but before trying to find the time for a failure, one needs to examine and learn more about the lifetime of the component. The failure rate of a component is often high in the initial phase of its lifetime. This can be explained by the fact that there may be undiscovered defects in the components, when the component has survived the initial period; the failure rate stabilizes at a level where it remains for a certain time until it starts to increase again as the component begin to wear out. The shape of the curve depicting the failure rate of the component, is similar to that of a bathtub, hence the expression bathtub-curve. Figure 1 and 2 shows the bathtub curve with the three typical phases. The initial phase is called burn in period, the stable phase is called useful life period and the end phase is called wear out period. Other example of names for these three periods are break in, operations and breakdown.

Describing the bathtub curve, NIST (National Institute of Standards and Technology, USA) states that the initial region that begins at time zero when a customer first begins to use the product is characterized by, a high but rapidly decreasing failure rate. This region is known as the Early Failure Period (also' referred to as Infant Mortality Period, from the actuarial origins of the first bathtub curve plots). This decreasing failure rate typically lasts several weeks to a few months. Next, the failure rate levels goes off and remain roughly constant for (hopefully) the majority of the useful life of the product. This long period of low level failure rate is known as the Intrinsic Failure Period (also called the Stable Failure Period) and the constant failure rate level is called the Intrinsic Failure Rate. Note that most systems spent a lot of their lifetimes operating in this flat portion of the bathtub curve. Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the Wear out Failure Period.

Figures 1 and 2 shows the reliability "bathtub curve" which models the cradle to grave failure rates vs. time.

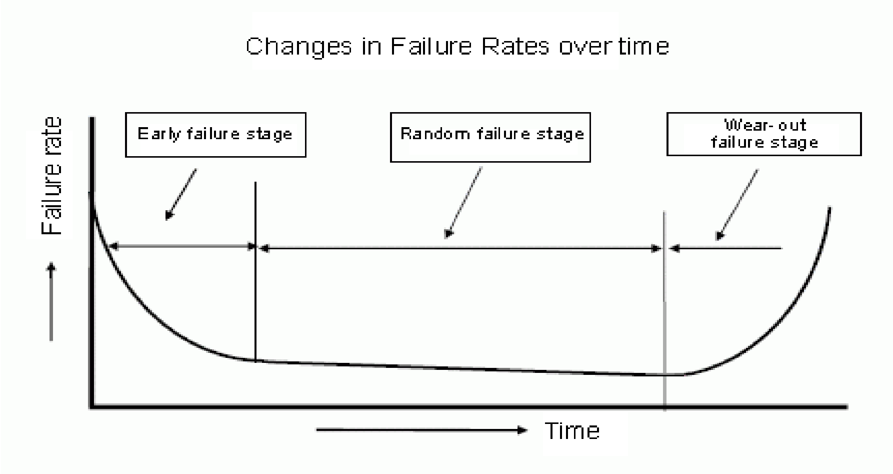

Figure 1. Bathtub Curve

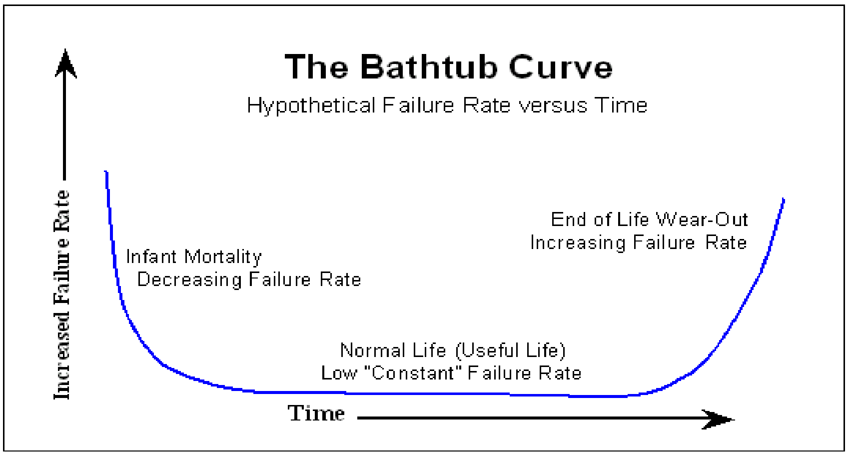

Figure 2. Reliability Bathtub Curve

2.8.6 Maintenance Management

Dunn (2007) defined maintenance as any activity carried out on an asset or system in order to ensure that it will continue to perform its intended functions. Smith (2000) Maintenance activities can be technical or administrative in nature, and they include any effort to protect, preserve, or prevent a system from decline. Regardless of construction and durability, all buildings, equipment, and infrastructure require responsible operation and some amount of periodic maintenance; failure to perform intended maintenance will shorten the operating life of these assets (Whole Building Design Group Sustainable Committee).

In many maintenance organizations, daily activities are often dominated by unplanned events. However, organizations rarely have adequate resources to address all unplanned events and perform all scheduled maintenance actions on infrastructure and equipment assets. Scheduled maintenance that goes uncompleted is known as deferred maintenance. In addition to the sum of all maintenance deficits, deferred maintenance also includes the compounding negative effect on the assets (Sullivan et al., 2004).

Accumulation of deferred maintenance can eventually destroy a maintenance operation when the resources required to meet the maintenance deficit become greater than the resources available for the entire maintenance operation (Vanier, 2001).

Vanier (2001) Furthermore, opined that deferred maintenance accumulates unplanned maintenance requirements increase and further expand the overall maintenance deficit and risk of premature system failures .In order to avoid the serious threats of deferred maintenance, organizations rely on the study and application of maintenance management.

Rajamani (2002) reported that the primary conflict facing managers of maintenance operations is the struggle of maximizing equipment availability while minimizing resource expenditures. Additionally, maintenance operations are often constrained by external factors and increasing maintenance resources is rarely an option (Turner, 2002). Since maintenance consists of many different activities, management gets increasingly difficult as the scope of maintenance operations grows. In an attempt to combat these challenges, organizations have turned to the study of maintenance management, which focuses on reducing the adverse effects of breakdown and maximizing facility availability at minimum cost while operating within environmental constraints.

According to Krajewski (1994) Competent and effective maintenance management will have a direct, positive impact on the profitability and reputation of any organization. According to Greenwood (2000) there are four primary objectives of maintenance management is to counter for: system function, system life, safety, and what is known as 'human- well-being.

2.9.6 Optimization of maintenance

The objective of maintenance optimization models is to determine the optimum maintenance tasks that minimize the downtime while providing the most effective use of systems in order to secure the desired result at the lowest possible costs, taking all possible constraints into account. The models can be either quantitative or procedure based such as reliability centered maintenance, age related or total productive maintenance (Kumar et al., 2000)

2.10 Types of FMEA, failure modes and effect analysis

2.10.1 Introduction to Design Failure Mode and Effects Analysis (DFMEA)

When first envisioned, Design Failure Mode and Effects Analysis (DFMEA) considered potential failures modes and their causes. It was first used in rocket science. Initially, the rocket development process in the 1950's did not go well. The complexity and difficulty of the task resulted in many catastrophic failures. Root Cause Analysis (RCA) was used to investigate these failures but had inconclusive results. Rocket failures are often explosive with no evidence of the root cause remaining. Design FMEA provided the rocket scientists with a platform to prevent failure. A similar platform is used today in many industries to identify risks, take counter measures and prevent failures. DFMEA has had a profound impact, improving safety and performance on products we use every day.

2.10.2 What is Design Failure Mode and Effects Analysis (DFMEA)

DFMEA is a methodical approach used for identifying potential risks introduced in a new or changed design of a product/service. The Design FMEA initially identifies design functions, failure modes and their effects on the customer with corresponding severity ranking / danger of the effect. Then, causes and their mechanisms of the failure mode are identified. High probability causes, indicated by the occurrence ranking, may drive action to prevent or reduce the cause's impact on the failure mode. The detection ranking highlights the ability of specific tests to confirm the failure mode / causes are eliminated. The DFMEA also tracks improvements through Risk Priority Number (RPN) reductions. By comparing the before and after RPN, a history of improvement and risk mitigation can be chronicled.

2.10.3 Why Perform Design Failure Mode and Effects Analysis (DFMEA)

Risk is the substitute for failure on new / changed designs. It is a good practice to identify risks on a program as early as possible. Early risk identification provides the greatest opportunity for verified mitigation prior to program launch.

2.10.4 How to Perform Design Failure Mode and Effects Analysis (DFMEA)

There are five primary sections of the Design FMEA. Each section has a distinct purpose and a different focus. The DFMEA is completed in sections at different times within the design timeline of the project, not all at once. The Design FMEA form is completed in the following sequence:

2.10.5 DFMEA Section 1 (Quality-One Path 1)

Item / Function

The Item / Function column permits the Design Engineer (DE) to describe the item that is being analyzed. The item can be a complete system, subsystem or component. The function is the "Verb – Noun" that describes what the item does. There may be many functions for any one item.

Requirement

The requirements, or measurements, of the function are described in the second column. The requirements are either provided by a document or are converted from a process known as Quality Function Deployment (QFD). The requirement must be measurable and should have test methods defined. If requirements are poorly written or nonexistent, design work may be wasted. The first opportunity for recommended action may be to investigate and clarify the requirements to prevent wasted design activity.

Effects of Failure

The effects of a failure on multiple customers are listed in this column. Many effects could be possible for any one failure mode. All effects should appear in the same cell or grouped next to the corresponding failure mode

Severity

The highest severity is chosen from the many potential effects and placed in the Severity Column. Actions may be identified to change the design direction on any failure mode with an effect of failure ranked 9 or 10. If a recommended action is identified, it is placed in the Recommended Actions column of the DFMEA.

Classification

Classification refers to the type of characteristics indicated by the risk. Many types of special characteristics exist in different industries. These special characteristics typically require additional work, either design error proofing, process error proofing, process variation reduction (optimized Cpk) or mistake proofing. The Classification column designates where the characteristics may be identified for Process FMEA Collaboration

2.10.6 DFMEA Section 2 (Quality-One Path 2)

Potential Causes / Mechanisms of Failure

Causes are defined for the Failure Mode. The causes should be determined at the physics-level. The causes at a component level can be related to the material properties, geometry, dimensions, interfaces with other components and other energies which could inhibit the function. These can be derived from pre-work documents such as Boundary (or Block) Diagrams, Parameter (P) Diagrams and Interface Analysis. Causes at the system level are cascaded as failure modes in more detailed analysis. Geometry and dimensions are cascaded (waterfall) into special characteristics, which can be transferred to the Process FMEA. Use of words like bad, poor, defective and failed should be avoided as they do not define the cause with enough detail to make risk calculations for mitigation.

Current Design Controls Prevention
The prevention strategy used by an engineering team when planning / completing a design has the benefit of lowering occurrence or probability. The stronger the prevention, the more evidence the potential cause can be eliminated by design. The use of verified design standards, proven technology (with similar stresses applied) and computer-aided engineering (CAE) are typical Prevention Controls

2.10.7 DFMEA Section 3 (Quality-One Path 3)
Current Design Controls Detection
The activities conducted to verify design safety and performance are placed in the Current Design Controls Detection column. The tests and evaluations intended to prove the design is capable are aligned to the causes and failure modes identified with the highest risks. Specific tests must be identified when risks are in the highest severity range (9-10) or the high criticality, non-safety combinations.

Detection Rankings
Detection Rankings are assigned to each test based on the type of test / evaluation technique with respect to the time it is performed. It is ideal to perform tests (on high risk items) as early in the design process as is possible. Testing after tools are completed is called Product Validation (PV) and is used to supplement Design Verification (DV) tests. PV tests may be used to save test time and resources on low risk items. There is often more than one test / evaluation technique per Cause-Failure Mode combination. Listing all in one cell and applying a detection ranking for each is the best practice. The lowest of the detection rankings is then placed in the detection column.

2.10.9 DFMEA
Risk Priority Number (RPN)
The Risk Priority Number (RPN) is the product of the three previously selected rankings,
- Severity
- Occurrence
- Detection.
- RPN thresholds must not be used to determine the need for action. RPN thresholds are not permitted mainly due to two factors:
- Poor behavior by design engineers trying to get below the specified threshold
- This behavior does not improve or address risk. There is no RPN value above which an action should be taken or below which a team is excused of one.
- “Relative Risk” is not always represented by RPN

Recommended Actions
The Recommended Actions column is the location within the Design FMEA that all potential improvements are placed. Completed actions are the purpose of the DFMEA. Actions must be detailed enough that it makes sense if it stood alone in a risk register or actions list. Actions are directed against one of the rankings previously assigned.

2.10.10 DFMEA
Actions Taken and Completion Date
List the Actions Taken or reference the test report which indicates the results. The Design FMEA should result in actions which bring higher risks items to an acceptable level of risk. It is important to note that acceptable risk is desirable and mitigation of high risk to lower risk is the primary goal.
Re-Rank RPN
The new (re-ranked) RPN should be compared with the original RPN. A reduction in this value is desirable. Residual risk may still be too high after actions have been taken. If this is the case, a new action line would be developed. This is repeated until an acceptable residual risk has been obtained.

2.11 Machinery Failure Mode and Effect Analysis (MFMEA)

Machinery FMEA – is used to analyze low-volume specialty machinery (equipment and tools), that allows for customized selection of component parts, machine structure, tooling, bearings, coolants, etc.

- Focuses on designs that improve the reliability and maintainability of the machinery for long-term plant usage.
- Considers preventive maintenance as a control to ensure reliability.
- Considers limited volume, customized machinery where large scale testing of a number of machines is impractical prior to production and manufacture of the machine.
- Considers parts that can be selected for use in the machine, where reliability data is available or can be obtained before production use.

2.13 When did Machinery FMEA Started?

A Machinery FMEA must be started early in the design phase when the equipment and tooling being specified is able to take advantage of revisions in order to derive the desired benefits.

When GDT information on component parts are available and Critical/Special Characteristics are identified. Normally, Design FMEAs on the products that are being manufactured and Process FMEAs on the steps used during the manufacture will be available.

2.14 Key Differences between a Product Design FMEA and Machinery FMEA

- Product Design FMEAs are intended for high production systems/subsystems and components. Prototype or surrogate part testing is used to verify design intent.
- Machinery FMEAs are used for relatively low volume designs, where statistical failure data on prototypes is not practical to be obtained by the manufacturer.
- Machinery FMEAs are targeted for long-term, repetitive cycles, where wear out is a prime consideration. For example, machinery running at two 10-hour shifts per day, 50 weeks per year, will accumulate 120,000 hours of operation in twenty years. This would be equivalent to a vehicle being driven 600,000 miles at an average speed of 50 mph.
- The severity, occurrence, and detection tables used are tailored to meet the needs of the machinery design engineer in order to maintain a standard interpretation across a wide variety of machinery designs

2.15 Similarities between a Product Design FMEA and Machinery FMEA

- Both emphasize operator/passenger safety as the first consideration of the design. Both emphasize robustness in designs to prevent problems before they occur.
- Both use 1-10 ranking scales for calculating Risk Priority Numbers.
- Both emphasize taking corrective actions based first on severity and then on overall RPN
- Both use a standardized form to document the FMEA analysis.

IV. CONCLUSION

A Machinery FMEA must be started early in the design phase when the equipment and tooling being specified is able to take advantage of revisions in order to derive the desired benefits.

When GDT information on component parts are available and Critical/Special Characteristics are identified. Normally, Design FMEAs on the products that are being manufactured and Process FMEAs on the steps used during the manufacture will be available.

Many production or manufacturing equipment (machines) failed to operate or breakdown intermittently while production is in process, thereby causing loss of man-hour, low production, poor revenue, failed business target etc. Lokoja Pump Station was established in 1979 and it is among the seven (7) Pump Stations on System 2C Pipeline Pumping/Boosting crude oil to Kaduna Refinery and Petrochemicals (KRPC) of Nigeria Pipeline and Storage Company, NPSC a subsidiary of Nigerian National Petroleum. This paper examined and provided a baseline knowledge and overview of conventional, life cost-based and fuzzy FMEA (failure mode and effects analysis) on pump station generator using 365KVA Caterpillar generator in NNPC Lokoja Pump Station as case study**.**

REFERENCES

[1]. Rishav Kumar1 and R. K. Mondloi, 2018. Failure Mode and Effect Analysis of Petrol Engine of Car. International Journal of Science and Research (IJSR), Volume 7, Issue 6,p-2.

[2]. Maheshwaran .G.,and Anders. S., 2018. Machine criticality based maintenance prioritization Identifying productivity improvement potential, International Journal of Productivity and Performance Management Vol. 67 No. 4, p-2-3.

[3]. Marc .B, Kari Babski-R., Linkan .B. and Lesley, S., 2018. Subjectivity in Failure Mode Effects Analysis (FMEA) Severity Classification within a Reliability Centered Maintenance (RCM) Context. International Journal of Aviation, Aeronautics, and Aerospace, Vol. 5, Issue 1, Article 2-p.6

[4]. Sang-Bing .T. Jie .Z. , Yang .G. Jiangtao .W. Guodong, L. Yuxiang .Z. Peng R. , Wei .X.,2017. Combining FMEA with DEMATEL models to solve production process problems, /journal.pone.0183634

[5]. Nikola Banduka, 2018. Improvement of product reliability during the production process in the automotive industry using improved fmea analysis, University of Split faculty of electrical engineering, mechanical engineering and naval architecture, p-38

[6]. Josiah, A.K. J.N. Keraita2, P.N. Muchiri3, 2018. Failure Mode Identification And Prioritization Using FMEA- A Case Study Of Corn Milling Industry, Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 15, Issue 2 Ver. III (Mar. - Apr. 2018), PP 22- 27.

[7]. Parzireh, E., Sadeghi .A.H. and Shokohyar, S. 2017. Analyzing the enhancement of production efficiency using FMEA through simulation-based optimization technique: A case study in apparel manufacturing, Journal Cogent Engineering Volume 4,-issue1, P1

[8]. Ibrahim Z. Z., Ibrahim. A .and El-Nafaty U. A., 2016. Failure Analysis of Feedstock Preheater Unit of the Kaduna Refinery using Failure Modes Effects and Criticality Analysis (FMECA), The International Journal Of Engineering And Science (IJES) || Volume 5, Issue 4, p-7.

[9]. Arabian-Hoseynabadi, H. and Oraee, H. and Tavner, P. J. (2010) 'Failure Modes and Effects Analysis (FMEA) for wind turbines.' International journal of electrical power and energy systems.,p -14.

[10]. Tsu-Ming .Y. and Jia-Jeng .S, 2011 Preventive maintenance model with FMEA and Monte Carlo simulation for the key equipment in semiconductor foundries, Academic Journals, P-14.

[11]. Waghmare, S.N,.D.N.Raut, Dr.S.K.Mahajan and Dr.S.S.Bhamare, 2014. Failure Mode Effect Analysis and Total Productive Maintenance, International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Volume 1, Issue 6 , p-1

[12]. Wessiani, N. A and .F. Yoshio, (2017). Failure mode effect analysis and fault tree analysis as a combined methodology in risk management, International Conference on Industrial and System Engineering (IConISE) 2017, p-3.

[13]. Patrycja Hąbek and Michał Molenda, (2017). Using the FMEA Method as a Support for Improving the Social Responsibility of a Company, 6th International Conference on Operations Research and Enterprise Systems, p2-p3.

[14]. Pantazopoulos, George, and George Tsinopoulos. (2005). "Process Failure Modes and Effects Analysis (PFMEA): A Structured Approach for Quality Improvement in the Metal Forming Industry." Journal of Failure Analysis and Prevention 5(2): 5–10.

[15]. D. R. Prajapati, 2012, Implementation of Failure Mode and Effect Analysis: A Literature Review, International Journal of Management, IT and Engineering, ijmie volume 2, issue p279

[16]. Seung & Cherrill s., 2009. Life cost based fmea manual: a step by step guide to carrying out a costbased failure modes and effects analysis, (slac-tn-09-001)

[17]. Pinnarat N., Santirat N., and Adisak P., 2018. Modified Fuzzy FMEA Application in the Reduction of Defective Poultry Products: ENGINEERING JOURNAL Volume 23 Issue 1.

[18]. Mahfoud, et al, 2016. Preventive Maintenance Optimization in Healthcare; Journal of Quality and Reliability Engineering Volume 2016, Article ID 5314312, 10 pages.

[19]. Mohamed et al, 2018. Critical Success Factors of Risk-Based Inspection; Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/p.119.

[20]. Fazlollahtabar,et al. 2018. Fault Tree Analysis for Reliability Evaluation of an Advanced Complex Manufacturing System**:** Journal of Advanced Manufacturing Systems.

[21]. Jari H.,& Antti A., 2012. Fault tree analysis for maintenance needs: 25th InternationalCongressonConditionMonitoringandDiagnosticEngineering(Journal of Physics Conference Series).

[22]. Petra et al, 2013:The application of fuzzy fmea, metal, P15. - 17https://quality-one.com/dfmea/

[23]. Degu Y.M & Moorthy R.S,2014. Implementation of Machinery Failure Mode and Effect Analysis in Amhara Pipe Factory P.L.C., Bahir Dar, Ethiopia. American Journal of Engineering Research (AJER), Volume-03, Issue-01, pp-57-63.

[24]. http://www.volumetric.com.br/artigos/fordmachineryfmea.pdf

[25]. In Ippoliti & Fragassa (2016). Failure mode effects and criticality analysis (fmeca) as a quality tool to plan improvements in ultrasonic mould cleaning systems: International Journal for Quality Research 10(4) 847–870.

[26]. http://www.npd-solutions.com/fmea.html

[27]. Rakesh et al, 2013. FMEA Analysis for Reducing Breakdowns of a Sub System in the Life Care Product Manufacturing Industry: International Journal of Engineering Science and Innovative Technology (IJESIT), Volume 2, Issue 2,

[28]. S. Rebello and N.K. Goyal, 2010. Software system reliability and safety assessment: an extended FMEA approach: International Journal of Reliability and Safety, Vol. 4, No. 4,

[29]. Anette von Ahsen, 2008. Cost-oriented failure mode and effects analysis: International Journal of Quality & Reliability Management · May 2008.

[30]. Steven Kmenta & Kosuke Ishii, 2000. SCENARIO-BASED FMEA: A LIFE CYCLE COST PERSPECTIVE; (https://www.researchgate.net/publication/228692426) P5

[31]. Rhee S. & Spencer C. M., 2009. a step by step guide to carrying out a costbased failure modes and effects analysis, life cost based fmea manual(SLAC-TN-09-001)

[32]. Dnyandeo et al, 2018, Fishbone Diagram: Application to Identify the Root Causes of Student–Staff Problems in Technical Education, (https://www.researchgate.net/publication/322749017) p.654

[33]. Mario COCCIA, 2017, The Fishbone diagram to identify, systematize and analyze the sources of general purpose technologies; Journal of Social and Administrative Sciences , Volume4, Issue 4 (www.kspjournals.org) p.291-303

[34]. Rudolf Seising, 2013: On a History of Fuzzy Sets and Systems; centre for science, technology, medicine and society; University of California, Berkeley.

[35]. Dinmohammadi F.,& Shafiee M., 2013: A Fuzzy-FMEA Risk Assessment Approach for Offshore Wind Turbine; International Journal of Prognostics and Health Management, p1-p9 ISSN 2153-2648.

[36]. FengLi, et al, 2013: Fuzzy Sets Method of Reliability Prediction and Its Application to a Turbocharger of Diesel Engines; Hindawi Publishing Corporation, Advances in Mechanical Engineering; p1-p6

[37]. Haq et al, 2015, Fuzzy Logic Based Failure Mode and Effect Analysis of Automotive Powertrain Assembly Systems; Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan, p57

[38]. Nuchpho et al, 2019. Modified Fuzzy FMEA Application in the Reduction of Defective Poultry Products; Engineering Journal, Vol. 23 Issue 1 p177-178.

[39]. Singh et al, 2013. Real-Life Applications of Fuzzy Logic; Hindawi Publishing Corporation Advances in Fuzzy Systems Volume2013,ArticleID581879,3 pag1-2.

[40]. Husain et al, 2017, Comparative Analysis of Defuzzification Approaches from an Aspect of Real life problem; IOSR Journal of Computer Engineering (IOSR-JCE) e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 19, Issue 6, Ver. III PP 19-25.

[41]. Liu et al2017, risk evaluation in failure mode and effects analysis using fuzzy measure and fuzzy integral; p1-13
[42]. Mahmood et al, 2013. Fuzzy fault tree analysis: a review of concept and application; The Society for Reliability Engineering, Quality and Operations Management (SREQOM), International Journal System Assur Engineering Management 4(1):19–32
[43]. Jari H. and Antti A., 2012. Fault tree analysis for maintenance needs; Journal of Physics: Conference Series 364(25th International Congress on Condition Monitoring and Diagnostic Engineering IOP Publishing) p.10
[44]. Dnyandeo et al, 2018, Fishbone Diagram: Application to Identify the Root Causes of Student–Staff Problems in Technical Education, (https://www.researchgate.net/publication/322749017) p.654
[45]. Mario COCCIA, 2017, The Fishbone diagram to identify, systematize and analyze the sources of general purpose technologies; Journal of Social and Administrative Sciences , Volume4, Issue 4 (www.kspjournals.org) p.291-303
[46]. Gartlehner et al 2017, User testing of an adaptation of fishbone diagrams to depict results of systematic reviews; BMC Medical Research Methodology; p1-3
[47]. Slameto, 2016; The Application of Fishbone Diagram Analisis to Improve School Quality; DINAMIKA ILMU Vol. 16 No. 1 page 61-63
[48]. Ravi S. R.,& Yadavalli B. 2019. Quality Improvement of Capacitors through Fishbone and Pareto Techniques; International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-2, pp.2248-2249
[49]. Zhua, et al, 2019. Spare Parts Inventory Control based on Maintenance Planning; https://www.researchgate.net/publication/335130822 page 2-25
[50]. Huiskonen, J. 2001. Maintenance spare parts logistics: Special characteristics and strategic choices; International Journal of Production Economics, vol.71 pp. 125-133
[51]. Auweraera et al 2019, Forecasting Spare Part Demand with Installed Base Information: a Review; International Journal of Forecasting, page 1-2.
[52]. Qiwei et al 2018. OR in Spare Parts Management: A Review, European Journal of Operational Research, vol. 266 pp.395–414.
[53]. C. Teixeira et al 2018. Classification methodology for spare parts management combining maintenance and logistics perspectives; Journal of Management Analytics, pp. 2-17.
[54]. Xiao. L. and Xuanzi W.,2017. Extended VIKOR Method for Intuitionistic Fuzzy Multi-attribute Decision-Making Based on a New Distance Measure, Hindawi Mathematical Problems in Engineering Vol. 2017, 4072486, 16 p. 1, 2 (https://doi.org/10.1155/2017/4072486)
[55]. Prasenjit C. and Shankar C., 2016: A comparative analysis of VIKOR method and its variants, Decision Science Letters series, vol. 5 pp. 469–486
[56]. Ketut P. S.& Gede E. W. P., 2019; Comparison of VIKOR and TOPSIS Methods in Multiresponse Taguchi Optimization; Journal of Educational Research and Evaluation Volume 2, Number 3, pp. 106-107 (https://www.researchgate.net/publication/330992532)
[57]. Morteza .Y. & Felipe R. G. 2014; VIKOR and its Applications: A State-of-the-Art Survey; International Journal of Strategic Decision Sciences,vol. 5, series 2, pages 56- 63. (https://www.researchgate.net/publication/266731774)
[58]. Ahuja I.P.S and Khamba J.S., 2008: Total productive maintenance: literature review and directions; Journal of Quality & Reliability Management (IJQRM); Emerald Group Publishing Limited Vol. 25 No. 7, 2008 pp.709, 710, 715 709-756
[59]. Bakri, et al 2014. Maintenance Management: Rationale of TPM as the Research Focus; Applied Mechanics and Materials, Trans Tech, Vols. 670-671, pp1575,1578 (https://www.researchgate.net/publication/286901622)
[60]. Narinder. S. & Onkar .S. B; 2015. Review Paper on: Total Productive Maintenance; International Journal of Advanced Research Mechanical Engineering & Technology (IJARMET); Vol. 1, Issue 1, pp 21-26
[61]. Othman et al.,2019. The Total Quality Management (TQM) journey of Malaysian building contractors; Ain Shams Engineering Journal pp-2(https://doi.org/10.1016/j.asej.2019.11.002)
[62]. Abimbola O. A, & Esther T. A; 2013. Implementation of CMMS Software for a Maintenance Plan in a Manufacturing Industry; International Journal of Mechanical and Industrial Engineering Vol:7, No:11, pp-2207-2209.
[63]. Pannu N., & Aastha C. and Tewari, P. C.2019. Computerized Maintenance Management System for Thermal Power Plant, Hisar; Journal of Physics: Conf. Series 1240 pp-2-4.
[64]. Arsovski et al 2008. Improving the Quality of Maintenance Processes Using Information Technology; International Journal for Quality research, Vol.2, No. 2, pp-101-111
[65]. Jerzy Mikler , 2015 On Improvement Of Maintenance Function, A Doctoral thesis, School of Industrial Engineering and Management Department of Production Engineering Royal Institute of Technology pp-15-17

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