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Enhancing the Reliability of Urea Pumps in Fertilizer Production Lines through Exponential Reliability Analysis

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Abstract: This research aimed at improving the reliability of the urea pump of a fertilizer production line at Urea Plant of Notore Chemical Industry Limited, Onne, Rivers State, Nigeria, using reliability exponential analysis.The investigation of the constraints associated with the performance of the fertilizer production line by analysis of maintenance log revealed that the pump was the most frequently failed critical component. Failure data of the urea pump, evaporator, scrubber and condenser were obtained from logged maintenance activities, which were used to carry out reliability analysis using exponential failure distribution model for a period of five years (2014 to 2018). Thereafter, triple redundancy was introduced to have enhance a balanced pressure and act as backup when failure occurs and consequently prevent breakdown. Also, a pressure monitors with an alarm system had been installed for immediate switchover to avoid sudden breakdown and equally reduce change over time prior to corrective maintenance. Results of reliability analysis carried out showed that reliability decreased from 64% to 30% from 2014 to 2018. However, after improvement strategies with redundant pumps, reliability for each year improved thus, 2014, 22%, 2015 35%, 2016, 36%, 2017, 35%, 2018, 34% respectively. This gives an average of 32.4% increase across the years. Conclusively, Preemptive maintenance strategy was adopted by planning maintenance schedule to coincide with idling time or shut down period to minimize losses from breakdown or corrective maintenance.

Keywords: Reliability, Improvement, Urea Pump, Fertilizer, Exponential Analysis.

1. INTRODUCTION

Production of fertilizer is critical to food security and sufficiency. Fertilizers are either natural or chemically synthesized components used to supplement depleted nutrients in the soil to aid plant growth and crop yield. The recentrequest for fertilizer in the international market is to intensificationharvest, increase area of cultivation by extension of cropland which are all channeled towards increased production. According to Vanleer (2014), every performance is measured by various kinds of performance indicators (PIs). Hatice (2012) opined that bottleneck are the best estimator for the production quantity which includes: Inherent equipment capacity limitations, mechanical or electrical reliability problems, yield losses, long change over and inappropriate scheduling or lack of synchronizations. Peter, (2011) described bottleneck as any resource whose capacity is equal or less than the demand placed on it or any process with

Original Article

utilization of 100% or greater. According to Siram and Tang,(2017), detecting bottleneck in a production system is not a trivial task. Current bottleneck detection methods can be separated into two categories: analytical and simulation-based. Various improvement strategies have been proposed by scholars for detection, analysis and elimination of bottleneck in process plants in order to increase throughput. A machine is inactive if it is blocked or starved; otherwise it is active. Consecutive active states are considered as one active state.

Kolinsky (2017) stated that according to the theory of constraints (TOC), the central task of effective production management is to find and eliminate the impact of a bottleneck in a company. Also, Hadas*et al.* (2015) opined that each system has a goal, a system is expected to improve its achievements (related to the goal), and achievements of every system are limited with constraints. According to Kolinska (2017) TOC defines a set of tools which may be used to control and manage constraints and, consequently, increase profit. One of the basic tools is the five focusing steps; Identify, Exploit, Subordinate, Elevate andGo back to Step 1. The total productive maintenance is a methodology to continuously manage, optimize and improve a supply chain by eliminating all losses, and involving all employees of the organization (Ahuja, 2011). Total productive maintenance (TPM), is mostly known from Japanese car manufacturers like Toyota, and was introduced in the early 1970s (Vanleer, 2014). The philosophy of TPM is aimed at continuously improving production efficiency. TPM is applied through the entire organization and involves directors, management, support and operators. By training employees, a working culture can be created in which losses are not accepted and processes are structurally improved.

This research work investigates the constraint (bottlenecks) associated with theurea pump of the fertilizer production line at Notore Chemical Industries Limited, Onne, Rivers State. The plant is characterized with constant failure and resultant reliability challenges in spite of its designed capacity.Improving the production line is necessary to meet the growing demand of chemical fertilizer and reduce production losses arising from idling, machine breakdown and bottleneck processes on the production line. Improving an already designed line with obsolete parts dated to the past four decades is an uphill task. However, a modification has to be made to improve performance using appropriate tools that will enhance line efficiency and elimination of losses.The redundancy and improvementdatawere generated. The reliability exponential analysis was determined on the system.The improved reliability of the known constraint by the application of redundancy was determined.theredundancy and improvementgenerated data was compared and appropriate maintenance program was recommended to enhance effectiveness of the plant.

2. MATERIALS AND METHODS:

The sources of data for this research include the plant logbook on maintenance failure, personal interview with operators, textbooks and journals. The reliability analysis of the various components data was carried out using exponential function model equations. While MATLAB software was used in writing a programme for the analysis

The analytical models for the reliability of a production line due to frequent pump failures are discussed using the exponential function as follows:

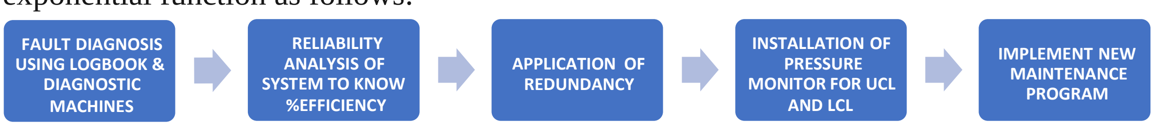

Figure 1: Modeled Block Diagram of Improvement Process

Original Article

The relevance of various equations stated was considered for their applications to this analysis, each model is to analyze the failures based on logged maintenance data in order to reach a conclusion and make recommendations.

Reliability Model

The reliability equation as stated in Equation (1) is used basically to determine the reliability of the system. It can be stated in various forms, such as.

$R(t) = e^{-\lambda}$ (1)

(Ebeling, 2003) where

$R =$ Reliability

$e =$ Exponential function $\lambda =$ Failure rate

Equation (2) is the exponential reliability model. It is used primarily for its brevity in solving reliability problems. It is used for resolving total reliability of a system while taking into cognizance the individual components in a given time as expressed by Lilly *et al*, (2015)

$R(t) = R\ (t) + R\ \ t_c$ (., 2) (2)

(Lilly *et al*, 2015)

where

R_c = Reliability component

R_N= Sum of reliability

$R\ t\ = R\ \ t\ \times R\ \ t\ \times R\ \ t\ ..\times..R\ \ t)\ {}_1() {}_2\ {}_3\ {}_n(\ )()\ ()$ (3)

(Lilly *et al*, 2015)

When the total reliability of a system is to be taken, the various reliability of each component is put into consideration. The total reliability of the system therefore, is gotten based on Equation (3) where:

$R_1 =$ Reliability of the first component

$R_2 =$ Reliability of the second component

R_3 = Reliability of the third component

$R_n =$ Reliability of the number of components by the time in focus

Unreliability Equation

The unreliability equation is used to know the unreliability rate of the system; it is clearly stated in equation

$F_{(t)} = 1 - e^{-\lambda t}$ (4)

(Ebeling, 2003)

Unreliability is the direct opposite of reliability. It shows the degree of failure per time of a particular system

Failure rate

The failure rate equation is typically depicted by Equation (5). It is stated as follows:

$\lambda = \frac{1}{MTBF}$ (5)

(Ebeling, 2003) where

MTBF = Mean Time between Failure

Original Article

It is inversely proportional to mean time before failure. It is the time it takes to operate before failure occurs. It is the average time the system operates before failure is registered. It was expressed by (Ebeling, 2003)

$$\lambda_{(t)} = (^{\beta}/_{\delta}) \times (^{t}/_{\delta})^{\beta-1} \quad (6)$$

where β = Shape parameter. δ = Characteristic life.

Maintenance Rate

The maintenance rate is given as stated in Equation (7) is applied for the purpose of tracking how often maintenance is carried out on the system. It is inversely proportional to mean time to repair (MTTR).

1

□□ (7)

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MTTR

(Nwachukwu, 2013) where:

μ= Maintainability

MTTR = Mean Time to Repair

The maintenance rate tells how effective the system functions. A constantly maintained system occasioned by breakdown may affect the operating hours thereby reducing productivity. Hence a strategic approach to maintenance has to be adopted in order to forestall incessant breakdown and increase mean time before failure. When this is carried out, reliability (R) will increase and failure rate (λ) will decrease.

Mean time Between Failures

The mean time before failure as calculated by (Predrag*et al*, 2015)

$$MTBF = \frac{OperatingHour}{NumberofFailure} \quad (8)$$

The mean time before failure gives an insight into how often the failure occurs after operating for a given time. The operating hours is how long the system operates and it is measured in hours. It can be called machine hours. It gives an idea of how often failure occurs in a system which helps to make failure predictions in the future based on previous records.

Mean Time to Repair

Mean time to repair as calculated by (Nwachukwu, 2013)

$$MTTR = \frac{TotalfailureHour}{NumberofFailure} \quad (9)$$

Mean time to repair is the average time it takes the system to operate without failure. When MTTR is known, a proper prediction of the next possible failure time can be properly done based on logged record and a preventive maintenance can be planned outside production schedule. **Availability**

Availability of equipment is measured in percentage (%); It is the fraction of the working hours that a system is available to work. This was calculated by (Nwachukwu, 2013).

$$A = \frac{MTBF}{MTBF + MTTR} \quad (10)$$

Adequate knowledge of the mean time before failure by the summation of mean time before failure and meantime to repair gives an idea of how available a system is. The availability of a system which is a function of MTBR/MTBF+MTTR shows the ultimate reliability of the system. A greater % (percentage) of availability means reliability. And the total reliability of the system is gotten based on Equation 3.7.

Original Article

R_1 = Reliability of the first component
R_2 = Reliability of the second component
R_2 = Reliability of the number of components by the time in focus

3. RESULTS AND DISCUSSION:

Reliability of the Pumps is observed to have decreased from 100% to 64% within a period of 12 months.The reliability plot by use of MATLAB shows a decrease in reliability due to increase in failure rate with a total failure time of 222 hours in 2014 distributed across 8 failures. This is because reliability is decreasing with time as indicated in figure 2. Improved reliability results of 86% shows 22% increased after application of triple modular redundancy.

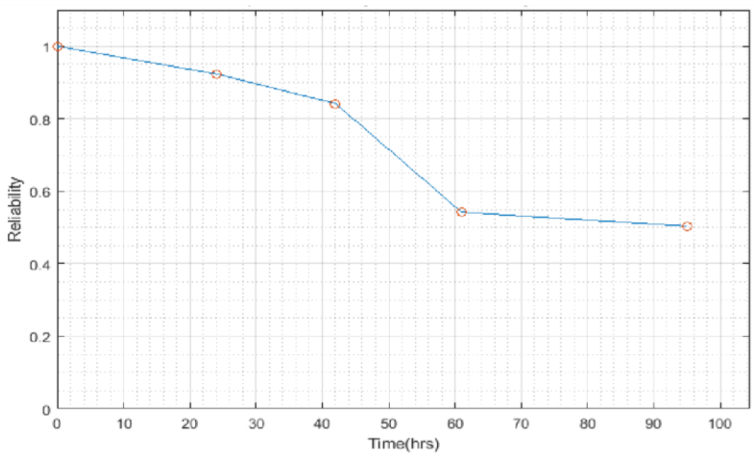

Figure 2: Reliability VS Failure Time of Pump in 2014

From the graph it shows that reliability decreased to 49% within a period of 12 months. However, failure rate is constantly increasing consequent to decreasing reliability. Figure 3, indicates that reliability has decreased with a 15% increase in unreliability bringing total reliability to 49% in 2015 and five additional failures with a total failure time of 547 hours. After application of triple modular redundancy, reliability improved to 84% which is an increment of 35%.

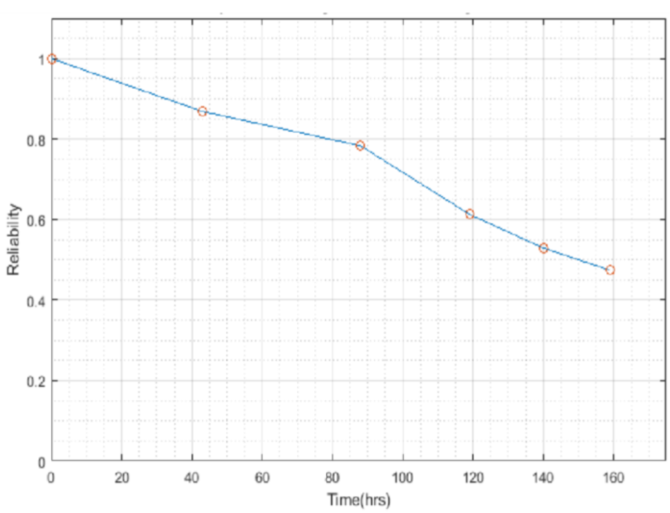

Figure 3: Reliability VS Failure Time of Pump in 2015

Reliability decreased 39% within this period of 12 months. Thus, it consequently implies that failure rate is on the increase. The Matlab plot indicates in figure 4, additional decrease in reliability by 10% over a period of 12 months, with 8 failure covering a total time of 451 hours for 2016. This is because failure rate is increasing with a corresponding decrease in reliability. Application of triple modular redundancy for the year 2016 generated a total reliability 75% which is an increase of 36%.

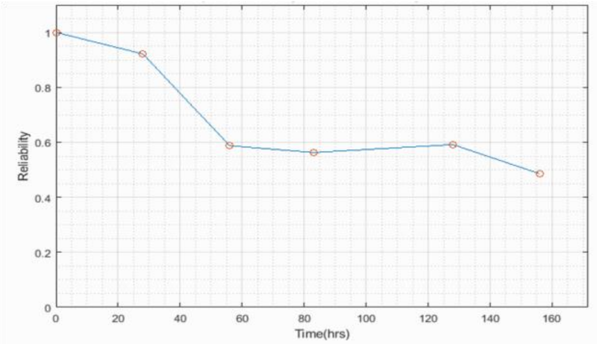

Figure 4: Reliability VS Failure Time of Pump in 2016

Reliability has decreased 33% within the period of 12 months. Therefore, it implies that failure rate is on the increase. The MATLAB plot in Figure 5, indicates that failure is taking greater dimension of increase by 33% with an increase failure rate of 604 hours for a total number of 7 failures. It follows a constant failure pattern of increase and decreasing reliability. Reliability improved after application of redundancy by 35% to a total of 68% reliability in 2017.

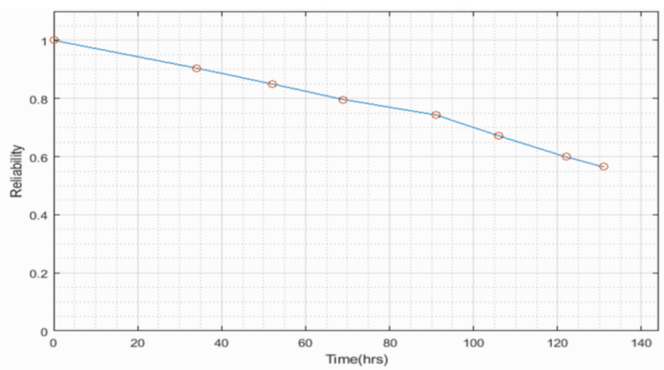

Figure 5: Reliability VS Failure Time of Pump in 2017

From the graph it shows that reliability decreased to 30% within a period of 12 months. However, it means that failure rate is constantly increasing consequent to decreasing reliability. The MATLAB plot of figure 6, indicates that reliability is at its lowest within the five years period with a value of 30%. This is because failure rate is on the increase and establishes a relationship between failure rate and reliability for a given time. Hence failure rate is inversely proportional to reliability. After application of triple modular redundancy total reliability increased to 64% with an increment of 34%

Original Article

$$\lambda = \frac{1}{r}$$

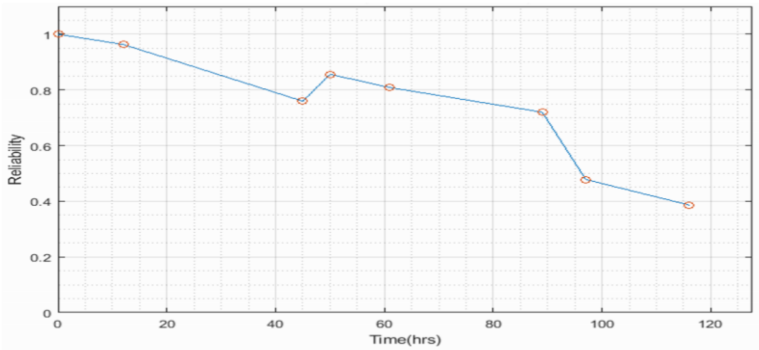

Figure 6: Reliability VS Failure Time of Pump in 2018

4. CONCLUSION:

In conclusion, improving the reliability of the urea pump of a fertilizer production line at Urea Plant of Notore Chemical Industry Limited, Onne, Rivers State, Nigeria,was achievedusing reliability exponential analysis, the constraints associated with the production line were obtained on investigation from the maintenance log data which showed that the pump was the most frequently failing component of the plant with resultant reduction in total reliability.

Also, reliability analysis of the various components data was carried out using exponential function model equations. While MATLAB software was used in writing a programme for the analysis. Results obtained showed that the pump had the lowest reliability value compared to other components spanning a period of five (5) years (2014-2018) with a progressive decline from 64% to 30%.

Furthermore, a comparison of original data with improved data by application of triple redundancy showed an increase in reliability across the five years (2014 - 2018) at an average of 75.4%, from 86% in 2014 to 64% in 2018. Preemptive maintenance strategy therefore, was adopted by planning maintenance schedule to coincide with idling time or shut down period to minimize losses from breakdown or corrective maintenance.Conclusively, the aim of this research to improve reliability of the urea pump of the case study fertilizer production line, through reliability exponential analysis has been achieved.

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Original Article

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