Journal of Newviews in Engineering and Technology (JNET)
Vol 2, Issue 3, September, 2020
Available online at http://www.rsujnet.org/index.php/publications/2020-edition

Application of Reliability Techniques to Evaluate Maintainability of Centrifugal Pump used for Petroleum Product Delivery

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ABSTRACT:

Proper Maintenance can be the major factor in distinguishing between a reliable pump and one which breaks down often. In this study, data concerning component life and occurrence of problems in centrifugal pumps was collected from a downstream petroleum product depot. This study analysed 40 occurrences of failures on 5 pumps used for 3 different products: PMS, AGO and DPK. Of these failures, mechanical seal occurred 13 times, suction strainer and coupling rubber occurred 6 times each, and other components accounted for the remaining. Mean Time Between Failures were computed as 1600hr, 1600hr, 4800hr, 738hr, 9600hr, 4800hr, 9600hr, 2400hr and 1920hr for Coupling Rubber, Suction Strainer, Pump Bearing, Mechanical Seal, Electrical Motor, Pump Casing, Oil Seal, Motor Coupling and Impeller respectively. Failure rates (λ) were computed as 0.0625%, 0.0625%, 0.0208333%, 0.1354167%, 0.0104167%, 0.0208333%, 0.0104167%, 0.0416667%, 0.000520833% and 0.0416667% in the same order. Ishikawa diagrams were used to present Root Cause Analysis of failures. Failure Modes Effects and Criticality Analysis was employed to analyse data. Cost analysis was done on current maintenance plan and a cost-effective and optimal Maintenance Plan was recommended for every Centrifugal Pump user. The idea behind this plan is to replace the maintenance work on mechanical seal and suction strainer from time-based to condition based. The new plan was shown to reduce total costs by 40% without compromising availability of equipment. With adherence to this plan, users can easily be rest assured of a pump with high reliability, available for use 97 percent of the time.

KEYWORDS: Availability, Centrifugal Pump, Failure Rate, Maintenance, Reliability.

Cite This Article: Olabisi, S. A., Ukpaka, C. P., & Nkoi, B. (2020). Application of Reliability Techniques to Evaluate Maintainability of Centrifugal Pump used for Petroleum Product Delivery. Journal of Newviews in Engineering and Technology (JNET), 2 (3), 11-21

1. INTRODUCTION:

The importance of pumps in petroleum product distribution and delivery plants cannot be over emphasized. From receipt operations to transfer operations and subsequent discharge, pumps have become very critical in ensuring success or failure of most processes. Various kinds of pumps are employed in petroleum product delivery processes but centrifugal pumps, due to their fair cost and adaptability for purpose are the most common pumps found. It thus becomes extremely expedient that a pump is available at all time to serve the purpose for which it was procured in the first place.

Mukesh (2015) opined that a centrifugal pump will serve the purpose for which it was procured always as long as it is ensured that operation is done with care and maintenance is adhered to strictly. When problems occur with a pump, we say it has failed. Some of the common problems encountered with operation of centrifugal pumps include suction clog or no flow, vibrations and excessive noise, spill and leakage of product or working fluid and production of excessive temperature. Major reasons for failure of pumps are excessive stress, reduction in strength of its component, variation in applied load, and poor design. Continuous working of the centrifugal pumps is essential in refineries and petroleum product depots, for non-stop operation of the plants. To this end, it is entirely necessary that the pumps function reliably as at when needed (Selvakumar & Natarajan, 2015).

This research assessed the maintainability of centrifugal pumps for petroleum product delivery. The products considered are PMS (Premium Motor Spirit), AGO (Automotive Gas Oil) and DPK (Dual Purpose Kerosene). The PMS fuel is used to power Petrol Engines that work on Otto Cycle, the AGO powers Diesel Engines while the DPK is Dual Purpose Kerosene used for either household kerosene or for powering Aviation Turbines. This research assessed the application of the Reliability Centred Maintenance practices to a centrifugal pump and the effect on its availability and workability with respect to breakdown times, cost of maintenance and delivery efficiency.

The aim of this research is to evaluate and systematically analyze the maintainability of a centrifugal pump used for petroleum product delivery utilizing reliability techniques. The objectives are to identify critical parts of a centrifugal pump that are susceptible to failures or breakdown, perform root cause analysis of the failure of selected critical components, calculate failure rates and reliability for selected components of the pump, design a reliability-centered maintenance plan for a generic centrifugal pump based on field data obtained, and calculate and present maintenance cost savings based on proposed plan.

TSL Logistics Limited was used as case study for this work. The company is located at 2, Reclamation Road, Port Harcourt, Rivers State. The company runs OANDO PLC's White Product Terminal in Rivers State. The company receives petroleum products from large vessels, into the shore tanks, measuring to about 55 million litres total capacity, via pipelines that run from the jetty to the depot. The products are then discharged after storage into loading tankers via loading pumps and loading arms. Centrifugal pumps are the pumps used for the major operation.

Failure analyses of various components of centrifugal pumps have been carried out in manufacturing, processing and service and oil industries, to identify causes of component failure. Various researches have analysed how various parts of the pump can impact its overall availability. Prakash and Pandey (1996) stressed that impellers can be further strengthened through proper heat treatment and fine surface finishing.

Das *et al.* (1999) revealed the principal cause of shaft breakages in centrifugal pumps as poor heat treatment of the pump's main shaft and bad alignment between Major faults in centrifugal pumps were diagnosed by Sakthivel *et al.* (2010), considering six conditions namely cavitation, normal running, seal deficiency, bearing misalignment, impeller deficiencies and ordinary running operation. Golbabaei *et al.* (2009) improved availability of pumps by optimizing the design components and other parameters of the pump. Bloch and Geitner (1997) reported that untimely breakdown of bearing in a centrifugal pump occurs as a result of misalignment issues in assembly, production inadequacies and issues with operating conditions. Packing failure on the other hand, occurs because of bad use of pump by operator, presence of impurities in the product and improper pump-motor or pump-engine coupling.

This study conducted failure analysis of centrifugal pumps considering the life expectancy of its major components and frequency of occurrences of the issues affecting them. Data were collected concerning operation and maintenance of centrifugal pumps used for petroleum product distribution. Data collected through the survey were subsequently analysed. This research paper provides direction for future research by identifying the vulnerable components and frequently occurring problems in the pump.

Over the course of the years, there have been various arguments in favour of one kind of maintenance practice over another. There are strong supporters of pure preventive maintenance practices. There are also strong critics who strongly opine that maintenance should be seen more from an economic angle than an operational hand. These ones believe that maintenance constitutes a major cost centre in business and will rather run equipment to failure before replacing. At the long run however, cost of managing breakdowns is sometimes more than that of prevention. Here arises the concept of reliability centred maintenance. An approach that considers and implements a cost-effective reliability centred maintenance programme becomes the solution (Farzaneh *et al.*, 2016).

Reliability-Centred Maintenance (RCM) is the process of determining the most effective maintenance approach. The RCM simply involves application of the various maintenance types and processes for specific equipment and equipment parts. The systems used include but are not limited to preventive maintenance, reactive maintenance or run to failure, condition monitoring and proactive maintenance (Williem & Rommert, 2011). The RCM philosophy ensures that equipment uptime is achieved at minimal cost. It applies logical and sound judgements with economic justifications as the major criteria for maintenance decisions (Marasini & Bralee , 2014).

2. MATERIALS AND METHODS:

This research took into consideration five centrifugal pumps that have been put into continuous operations over the past five years. A typical centrifugal pump and its various parts are shown in Figure 1 (Gulich, 2014).

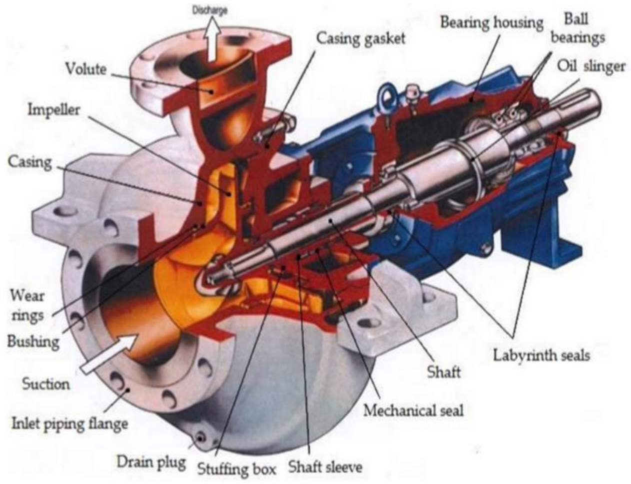

Fig 1: Centrifugal Pump Parts (Gulich, 2014)

These five pumps were used in moving various petroleum products. They have been put through the same maintenance schedule over these past five years and have experienced various forms of failure depending on the intensity of use, kind of use and petroleum product involved.

Three of the pumps were used in pumping PMS popularly called Petrol, one was used for the pumping of AGO also known as diesel fuel while the last was employed for the pumping of DPK popularly known as Kerosene. The striking difference between these fuels comes from their viscosity and specific gravity. Specific gravity of petrol is between 0.70 - 0.74, that of kerosene is 0.81 - 0.83 while that of diesel is between 0.82 - 0.88. Data were collected on pump performance and associated failures over the period of use, taking full cognisance of product used for pumping (PMS, AGO or DPK) and the frequency of use.

2.1. Analytical Tools

The collected data was analysed using various Root Cause Failure Reliability Centered Maintenance methods as:

i. Ishikawa or Fishbone Diagram which is a visualization tool for categorizing the potential causes of a problem in order to identify its root causes. A fishbone diagram is useful in troubleshooting sessions to focus conversation. The method permits the researcher to reach conclusion based on all possible root causes of an issue. The design of the diagram looks much like a skeleton of a fish. Fishbone diagrams are typically worked right to left, with each large "bone" of the fish branching out to include smaller bones containing more detail. For the purpose of this research, the Fishbone was used to examine various causes or factors that together led to pump failure.

ii. Failure Modes and Effects Analysis which is is a step-by-step approach for identifying all possible failures and their modes or symptoms in a design, a manufacturing or assembly process, or a product or service. Failure modes means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. FMECA involves creating a series of linkages between potential failures (Failure Modes), the impact on the mission (Effects) and the causes of the failure

(Causes and Mechanisms). Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. Failure modes and effects analysis also documents current knowledge and actions about the risks of failures, for use in continuous improvement.

iii. Criticality Analysis which is a process by which assets are assigned a criticality rating based on their potential risk. It ranks equipment and parts of equipment according to their criticality and the severity of their impact if failure occurs. It helps to think about criticality analysis as part of a larger Failure Modes, Effects (and Criticality) Analysis (FMEA/FMECA). Criticality Analysis is important because using a predetermined system to evaluate risk allows you to remove emotion from the equation. This ensures that reliability is truly approached from a risk-based point of view, rather than individual perception.

2.2. Analytical Models

Various analytical models were employed to analyze data collected. These models were employed to compare reliability parameters of the various parts of a centrifugal pump based on field data obtained.

2.2.1 Mean Time Between Failures

MTBF is the average elapsed time between breakdowns of equipment. A high MTBF signifies a high efficiency of maintenance work being done on such equipment. The formula for calculating MTBF is stated in Equation (1).

$$MTBF = \frac{Total\ Time\ (t)}{Number\ of\ failures\ observed} \quad (1)$$

2.2.2 Failure Rate

Failure Rate, represented by the symbol λ, is the frequency with which equipment or component of an equipment fails. It is given as,

$$Failure\ Rate\ (\lambda) = \frac{1}{MTBF} \quad (2)$$

2.2.3 Reliability

The reliability of equipment is a function of its failure rate. It is the measure of the probability of equipment remaining in service to serve the purpose for which it was procured. Reliability is calculated thus:

$$Reliability\ [R(t)] = e^{-\lambda t} \quad (3)$$

2.2.4 Unreliability

The unreliability of equipment, measures how much an equipment is likely to fail. It is simply computed by subtracting the reliability from 1, as shown in Equation (4).

$$Unreliability\ (Ur) = 1 - R(t) \quad (4)$$

2.2.5 Probability of Failure

This parameter measures the probability of failure of a particular part of an equipment as compared to the total number of failures observed. It is computed with Equation (5).

$$Probability\ of\ Failure = \frac{Pp}{T} \quad (5)$$

where, Pp = Frequency of occurrence of failure of a particular part

T = Total number of failures observed

2.2.6 Maintenance Costing

Calculations for maintenance costing were obtained using Equations (6), (7) and (8):

$$Labour\ Cost = n \times N \times t \times r \quad (6)$$

where, n = Frequency of Maintenance job in a Year

t = Duration of Work

r = Man Hour Rate

$$T_1 = C_1 + L_1 \qquad (7)$$

where, T_1 = Total Cost of Maintenance of a part

C_1 = Cost of Consumables
L_1 = Labour Cost

$$T = T_1 + T_2 + T_3 + \ldots\ldots + T_n \qquad (8)$$

T = Total cost of maintenance of equipment

3. RESULTS AND DISCUSSION:

As described in the Materials and Methods section, five different pumps were analysed in terms of their operation and maintenance.

3.1 Parts Responsible for Failure

From field data obtained, many different parts have been responsible for putting centrifugal pumps out of service due to failure. Table 1 shows the various parts of the pump whose failures were captured from the field data obtained. The data in Table 1 were obtained from various reports and performance records as from the place of case study: TSL Logistics Ltd.

Data presented firstly reflects that not all parts responsible for putting out a centrifugal pump out of service can be attributed to the type of product that the pump pushes. However, the mechanical seal and suction strainer showed a little bias for breakdown when they are employed for AGO pumping over when used for PMS or DPK. Out of thirteen total mechanical seal failures recorded, four failures were recorded for the three PMS pumps, seven were recorded for one AGO pump while two were recorded for the only 1 DPK pump. Table 1 shows information discussed above.

Table 1: Parts Responsible for Failure

Pump Part	Number of Occurrences	PMS	AGO	DPK
Coupling Rubber	6	4	1	1
Suction Strainer	6	3	2	1
Pump Bearing	2	2	0	0
Mechanical Seal	13	4	7	2
Electric Motor	1	1	0	0
Pump Casing	2	2	0	0
Oil Seal	1	1	0	0
Pump-Motor Coupling	4	2	1	1
Impeller	5	2	1	2
Total	40	21	12	7

3.2 Root Cause Analysis

In Maintenance Management, every break down or failure results from one or a series of direct or indirect causes. Some of the major issues reported as faults from the centrifugal pumps are:

i. no/ inhibited flow from Pump
ii. fuel leakage from pump
iii. pump failed to work
iv. too much noise/ vibration from pump

Root Cause Analysis of each of these failure modes are depicted in Figures 2, 3, 4 and 5 using the Ishikawa/Fishbone diagram.

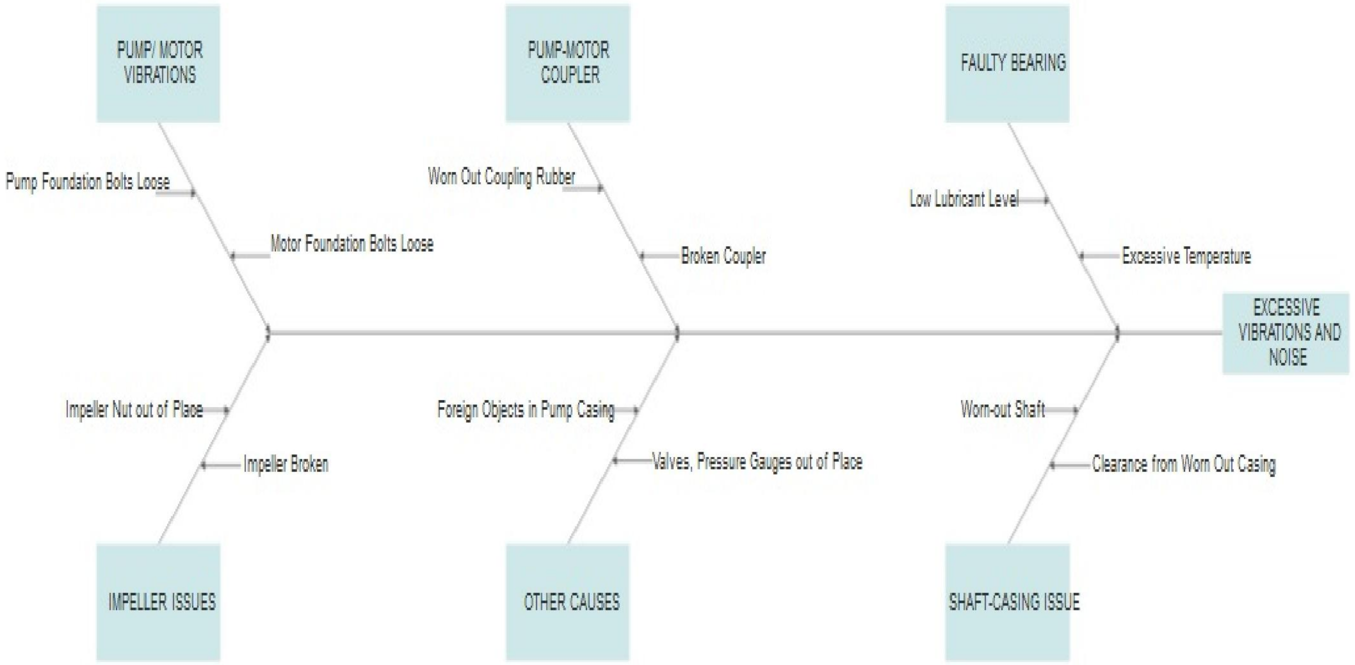

Figure 2: Ishikawa Diagram for Excessive Noise and Vibrations

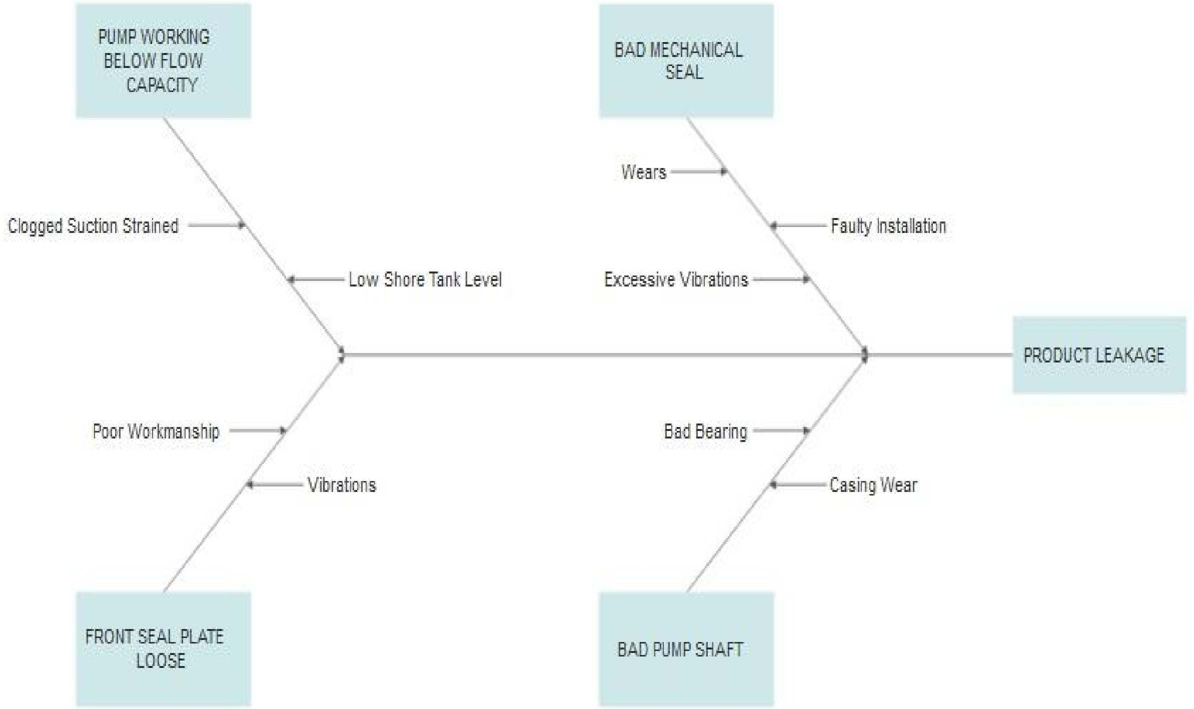

Figure 3: Ishikawa Diagram for Product Spill and Leaks

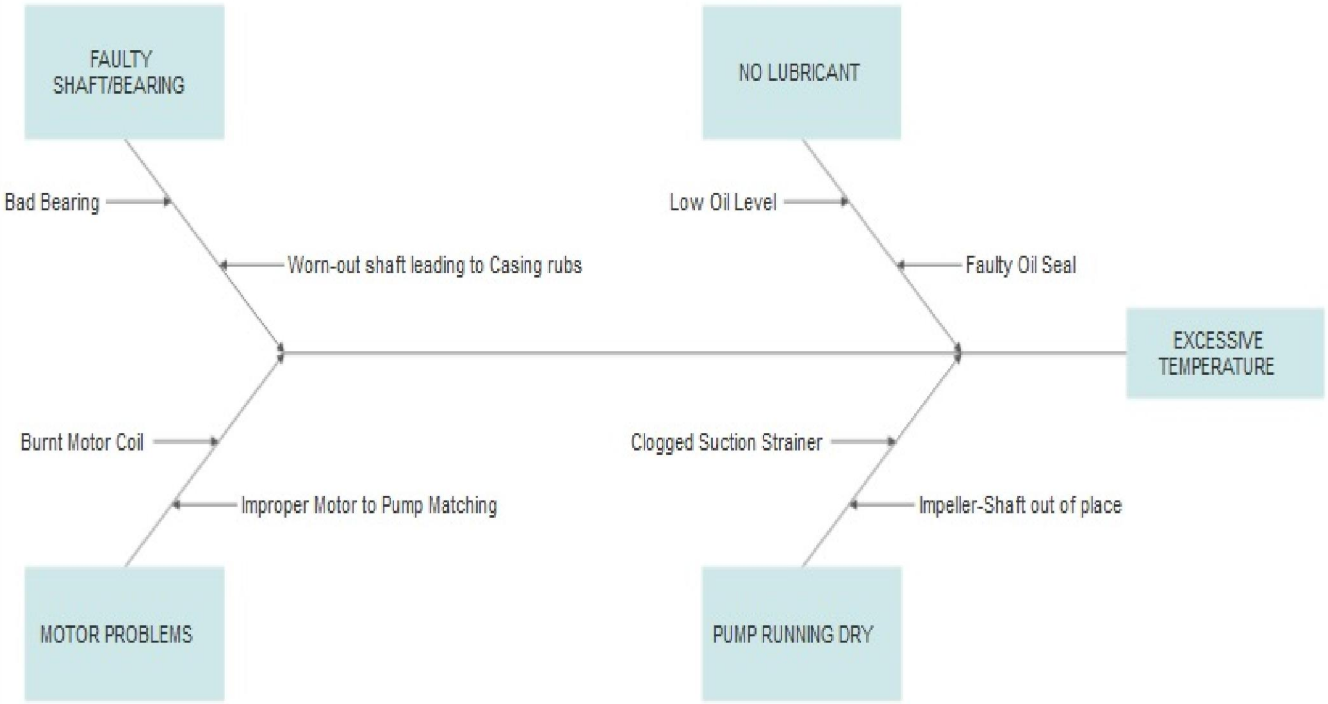

Figure 4: **Ishikawa Diagram for Excessive Heating**

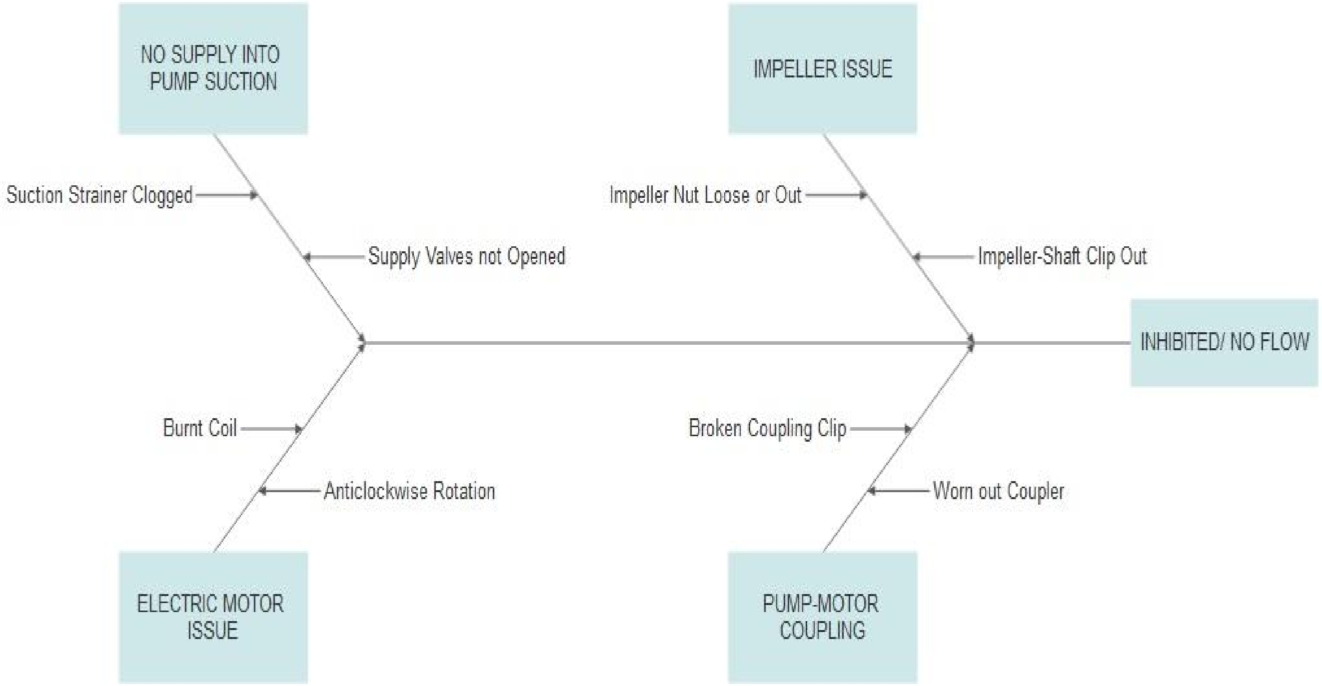

Figure 5: **Ishikawa Diagram for No Flow**

3.3 Reliability Analysis of Centrifugal Pump

Using Reliability formulas to Calculate Mean Time Between Failures, Failure Rates, Reliability of the System and Unreliability of the system as presented in Equations (1), (2), (3) and (4), calculations for each selected components of the pump are given thus:

For the Coupling Rubber:

The Mean Time Between Failures is given below

$$MTBF = \frac{9600}{6}$$

$$= 1,600 \text{ hrs}$$

Failure Rate is thereafter computed as given

$$\lambda = \frac{1}{1600}$$

$$= 0.000625 \text{ hr}^{-1}$$

The Reliability of the system after an interval of 1 hour is given below

$$R(t) = e^{-1*0.000625}$$

$$= 0.999375195$$

The Unreliability is finally given as

$$Ur = 1 - R(t)$$

$$= 1 - 0.999375195$$

$$= 0.000624805$$

Calculations for the other parts are also computed in the same vein and are presented in Table 2.

Table 2: Reliability Analysis of Centrifugal Pump Components

Pump Part	Number of Failures	MTBF	Failure Rate (λ)	Reliability	Unreliability
Coupling Rubber	6	1600	0.000625	0.999375195	0.000624805
Suction Strainer	6	1600	0.000625	0.999375195	0.000624805
Pump Bearing	2	4800	0.000208333	0.999791688	0.000208312
Mechanical Seal	13	738.4615385	0.001354167	0.99864675	0.00135325
Electric Motor	1	9600	0.000104167	0.999895839	0.000104161
Pump Casing	2	4800	0.000208333	0.999791688	0.000208312
Oil Seal	1	9600	0.000104167	0.999895839	0.000104161
Motor Coupling	4	2400	0.000416667	0.99958342	0.00041658
Impeller	5	1920	0.000520833	0.999479302	0.000520698
The Whole Pump	40	240	0.004166667	0.995842002	0.004157998

3.4 Proposed Maintenance Plan for Centrifugal Pump

From exclusive analyses of the preventive and corrective maintenance reports obtain during the study, there was a nagging trend of mechanical seal failure and suction strainer blockage at a common operational period. Despite the preventive maintenance activities in place, these occurrences occur just after a full process of Evacuation.

Evacuation involves taking out the dead stock (Quantity of product way below suction which may include a lot of dirt, debris and sludge) for the purpose of cleaning a tank or changing product.

This is usually done with the aid of a support equipment, usually a diaphragm or pneumatic pump powered by an air compressor. The content of the shore tank is thereafter discharged into the product receipt line into the centrifugal pump. This is what leads to the excessive amount of sludge and debris that passes through the pump's suction strainer and poses extra pressure on the centrifugal pump's mechanical seal. Data concerning maintenance cost were collected from place of case study and is presented in Table 3. The table shows the cost of the traditional preventive maintenance plan in use.

Table 3: Annual Maintenance Cost based on Traditional Preventive Maintenance Plan

S/N	Part	Cost of Consumables	Labour Cost	Total Cost
1	Lube Oil	₦ 120, 000	₦ 16, 000	₦ 136, 000
2	Mechanical Seal	₦ 800, 000	₦ 32, 000	₦ 832, 000
3	Suction Strainer	0	₦ 32, 000	₦ 32, 000
4	Other PM Parts	0	₦ 96, 000	₦ 96, 000
	Total	₦ 920, 000	₦ 176, 000	₦ 1, 096, 000

The main difference between the traditional preventive maintenance plan in use and the Reliability Centred Maintenance plan that is being proposed comes from the savings made on Mechanical seal and the attention given to the suction strainer after every evacuation procedure. The Mechanical Seal is to be assessed and probably replaced after every product evacuation procedure which is estimated to occur twice a year through each pump. To this end, mechanical seal is to be changed estimated at twice a year contrary to the four times it is replaced using the conventional preventive maintenance plan. The suction strainer is to be serviced twice also preferably after every product evacuation operation. Based on this new plan, annual maintenance costing is presented in Table 4.

Table 4: Annual Cost based on Proposed Plan

S/N	Part	Cost of Consumables	Labour Cost	Total Cost
1	Lube Oil	₦ 120, 000	₦ 16, 000	₦ 136, 000
2	Mechanical Seal	₦ 400, 000	₦ 16, 000	₦ 416, 000
3	Suction Strainer	0	₦ 16, 000	₦ 16, 000
4	Other PM Parts	0	₦ 96, 000	₦ 96, 000
	Total	₦ 520, 000	₦ 144, 000	₦ 664, 000

Figure 6 presents and justifies the reason why every pump user should opt for the reliability centred maintenance method over the traditional preventive maintenance plan. Total annual maintenance cost based on old preventive maintenance plan was calculated to be ₦ 1,096,000 while the cost from the proposed plan falls to ₦ 664, 000. The new plan thus promises a 39.4% decrease in annual maintenance cost. The cost decrease comes basically from the 50% decrease in frequency of maintenance work achievable from Reliability Centred Planning of the mechanical seal replacement and the suction strainer service. In other words, moving from the traditional preventive maintenance plan on centrifugal pump not only ensures better uptime on equipment by preventing unplanned shutdowns, it also promises almost 40% savings on annual maintenance cost.

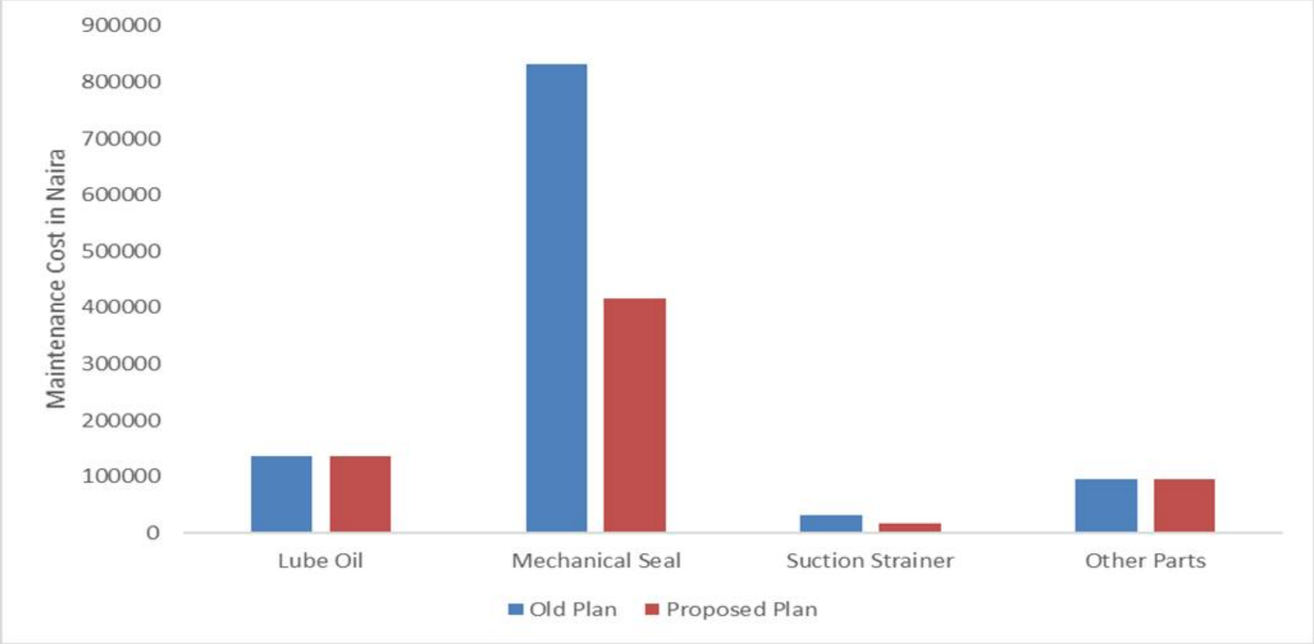

Figure 6: Cost Comparison between the Old and Proposed Plan

4. CONCLUSION:

This research set out to evaluate the maintainability of centrifugal pumps used for petroleum product delivery and results revealed that the centrifugal pump remains a highly dependable and maintainable equipment. Data obtained from place of case study were presented and analysed to show the various parts of the centrifugal pump responsible for putting a pump out of service.

Results showed that the mechanical seal caused the most failures on analysed pumps, putting the pump out of service thirteen times out of the total forty failures observed from obtained data. Root cause analysis was carried out on the failure modes observed and were presented using Ishikawa Diagrams and the FMEA.

Failure rates and reliability of parts were computed for the various parts highlighted previously and the reliability of the oil seal was highest at 99.99% and that of mechanical seal was lowest at 99.86%, a result which further buttresses the fact that centrifugal pumps are very reliable. With the knowledge of occurrence of failures and consequences, a new maintenance plan was designed and presented to be employed for the centrifugal pump. Cost analysis and comparison were done to prove that the proposed plan is not only more effective, but also far cheaper than the old plan.

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