# Optimization of Maintenance Strategies in an Oil and Gas Production Facility to Minimize Maintenance Cost

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**Abstract:** In this study, maintenance strategies in an oil and gas production facility were optimized to minimize maintenance costs. The centrifugal pump system in Port Harcourt Refinery was selected for this study because it significantly impacts on the productivity of the refining plant. The pump system's failure mode effects and criticality analysis (FMECA) were examined, and an optimized maintenance task was developed for the system. The exponential reliability method was employed to analyse the pump's failure data to determine the pump systems' failure rate and reliability while reliability centred maintenance (RCM) and linear programming (LP) model were employed to optimize the pump's maintenance strategies and the pump's maintenance labour force respectively. Broad-based results of the optimized maintenance strategies consisted of on-condition-directed (CD) maintenance, preventive maintenance (PreM), and Proactive maintenance (ProM) strategies to be carried out monthly. The optimized maintenance labour force result revealed that approximately three engineers and two technicians should be employed for the pump's maintenance task with a minimum of ₦2, 585, 700 as cost of salaries for the labour force monthly as against the current maintenance labour force requiring fourteen engineers and thirteen technicians monthly. The results showed that the labour cost decreased from ₦180,000,000 per year to ₦31,028,400 per year (approximately 82.76% reduction) using the proposed optimized maintenance task compared to the current maintenance plan. Conclusion and recommendation were made that the maintenance optimization technique presented in this work should be adopted by the oil and gas processing and production companies in order to minimize maintenance cost.

**Keywords:** Equipment, Pumps, Maintenance, Oil and Gas Industry, Optimization, Processing, Production, Reliability, Refinery, RCM

## I. Introduction

Maintenance is the act of holding, keeping, sustaining, or preserving assets (Murtjhy et al., 2002). Maintenance, a process of production system management, is considered an activity or restoration process where a system or equipment has its failure arrested, reduced, or eliminated (Ethevenin, 2010). Maintenance aims to extend the system or equipment lifetime or at least extend the mean time to the next equipment failure, whose repair may be costly, thereby improving its availability and reliability (Khathutshelo & Brian, 2018). Maintenance is the stamina of any manufacturing organization. Without having the proper maintenance strategy and practice, an organization's assets or equipment cannot sustain its performance. It may depreciate quickly, impacting the organization's productivity and profitability. Oil and gas processing facilities rely on equipment and machinery for efficient processing and robust production, such as pump systems, heat exchangers, valves, compressors, etc. (Ilogamhc & Emmanuel, 2014).Inefficient and effective maintenance strategies for this equipment can result in a huge negative impact on production quality, productivity, and profitability (Alsyouf, 2007).

Maintenance strategy depends on several factors: maintenance goals, the nature of the facility or equipment to be maintained, workflow patterns, and the work environment (Al-Najjar, 2000). According to Misikir (2004), maintenance practices and systems must be incorporated with a set of maintenance strategies and maintenance performance indicators for production improvement. Due to equipment failures, poor equipment effectiveness in production industries poses economic problems and losses, especially in cost (Zineb et al., 2017). Maintenance costs over 70% of the total production expenditures, and to reduce maintenance costs, the various types of losses in the manufacturing industry must be identified, classified, and eliminated (Samuel et al., 2018). Effective utilization of man, machines, materials, and methods will result in higher productivity (Goodfellow, 2000; Itthipol et al., 2017). Maintenance and asset-management functions can increase profits in two main ways: by decreasing running costs and increasing capability. The total maintenance cost depends on the quality of the equipment, the way it is used, the maintenance policy, and the business strategy (Brah & Chong, 2004). The Port Harcourt Refining Company (PHRC) Limited is in business to optimally process hydrocarbon into petroleum products for the benefit of all stakeholders (PHRC, 2021). PHRC Limited is made up of two refineries-the old and new refinery. The old refinery was constructed in 1965 at Alesa Eleme in Port Harcourt (PH1) with a capacity of 35,000 bpsd. In the 1970s, the capacity was increased to 60,000 bpsd to accommodate the rapidly expanding Nigerian economy (PHRC, 2021). The new refinery, known as PHII, since it is connected to the old refinery in Alesa Eleme, was

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completed and put into service in March 1989. It has an installed capacity of 150,000 bpsd. As a result, the Port Harcourt Refinery can now process 210,000 bpsd of crude oil (PHRC, 2021). It has five (5) process sections, numbered from 1 to 5. Areas 1-4 of the new refinery comprise the structure, while Area 5 is the old refinery (PHRC, 2021). It is also has a power plant and utilities section. The power plant consists of two (2) deaerators, five (5) centrifugal feed water pumps, four (4) boilers capable of generating 120 tons of steam per hour each, four (4) steam turbine units (4 x 14) MW at 100% load and four (4) condensers (PHRC, 2021),

Maintenance strategy may be inefficient; it may be too costly (in the long run) if it is done too often, and if it is done too little, it may result in an excessive number of failures, reducing the system's reliability (Goodfellow, 2000). The maintenance strategy must be optimized for a cost-effective scheme, and reliability centred maintenance (RCM) approach provides that solution (Afefy, 2010). Reliability-centred Maintenance is the optimum mix of reactive and run-to-failure, time- or interval-based, condition-based, and proactive maintenance practices. Rather than being applied independently, these principal maintenance strategies are integrated to take advantage of their strengths to maximize facility and equipment reliability while minimizing life-cycle costs. RCM philosophy employs preventive maintenance, predictive maintenance (PdM), real-time monitoring (RTM), run-to-failure (RTF), and proactive maintenance techniques in an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle with a minimum of maintenance (Afefy, 2010). RCM is a systematic approach to determining plant and equipment maintenance requirements for its operation. It is used to optimize preventive maintenance (PM) strategies. Sequel to the above, RCM is a process used to determine the maintenance requirements of any physical asset in its operating context. This is based on equipment condition, criticality, and risk (Afefy, 2010). Studies reveal that much attention is paid to the problem of optimizing maintenance strategies for production systems, such as Goodfellow (2000), Bhangu et al. (2011), Ahasan (2015) and Samuel et al. (2018). Zhu et al. (2019) focused on the reliability analysis of centrifugal pumps based on small-scale sample data, and Itthipol et al. (2017) conducted a reliability analysis for refinery plants.

## II. Methodology

This study optimized a comprehensive maintenance management strategy for production equipment in the Port-Harcourt refinery. Failure data of the oil and gas processing equipment obtained from the refinery was employed for reliability analysis and to improve its operations. The oil and gas production equipment were resolved into the smallest component of a system facilitating the formulation of FMECA and Root Cause Failure Analysis (RCFA).To analyze the collected failure data, the exponential reliability method was applied to analyse the oil and gas processing equipment's failure rate and other reliability parameters and generate the RCM task. The generated RCM plan uses a predictive and preventive maintenance strategy (not just the reactive and run-to-failure maintenance strategies currently used in the refinery).The method adopted for this research work is the RCM methodology with a linear programming technique for analysis.

### Reliability Model

The centrifugal pump system for the time between failures follows the Weibull distribution, where t is the continuous random variable representing the failure time. The Probability Density Function (PDF) of the Weibull distribution is given by (Igor, 2004):

$$f(t;\beta;\theta) = \frac{\beta}{\theta}.\left(\frac{t}{\theta}\right)^{\beta-1}.\exp\left[-\left(\frac{t}{\theta}\right)^{\beta}\right] \quad (1)$$

Where:

t = hours of operation or uptime

θ = scale parameter of the Weibull distribution

β = the shape parameter.

A value of $\beta > 1$ signifies an increasing failure rate (or hazard rate) function, whereas a value of $\beta < 1$ signifies a decreasing failure rate function. When $\beta = 1$, the failure rate function is constant. The scale parameter of the Weibull distribution, denoted by θ, influences both the distribution's mean and spread. As θ increases, the reliability at a given point in time increases, whereas the slope of the hazard rate decreases. When the failure rate **(λ)** of the system is determined, the reliability R (t) and the unreliability F (t) of the centrifugal pump system at the end of (t) hours of operation/ up time from exponential reliability model as given by(Igor, 2004):

$$R(t) = e^{-\lambda t} \quad (2)$$

$$F(t) = 1 - e^{-\lambda t} \quad (3)$$

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Where:

$\lambda$ = Failure rate of the centrifugal pump system.

t = time in operation of the centrifugal pump system.

**Determination of Parameters for Reliability Model**

The mean time between failures (MTBF), mean time to repair (MTTR), and failure rate parameters were computed to determine the availability, maintainability, and ultimately the reliability of the centrifugal pump system using the exponential reliability model as follows:

**Mean Time Between Failures (MTBF)**

The MTBF is a basic measure of reliability for reparable items. It is estimated by the total time in the operation of the centrifugal pump system and its subsystems divided by the total number of failures (breakdowns) recorded within a specific investigation period. Mathematically,

$$MTBF = \frac{\sum t_I}{n} \quad (4)$$

Where:

$\sum t_I$ = the total running time in the operation of the centrifugal pump system during an investigation period for both failed and non-failed items.

n = number of failures (breakdowns) of centrifugal pump system or its parts occurring during a certain investigation period.

**Mean Time to Repair (MTTR)**

Mean time to repair (MTTR) is the average time required to troubleshoot and repair failed equipment and return it to normal operating conditions. It reflects how well the system can respond to and repair a problem. It is suitable for all kinds of systems, and it is given by (Igor, 2004):

$$MTTR = \frac{Total\ Ma\text{int}enance\ time}{Total\ number\ of\ repairs}$$

$$MTTR = \frac{\sum t_i}{n} \quad (5)$$

Where:

$t_1$ = total accumulative time of the centrifugal pump system to repair or maintain in statistical time.

n = number of repair actions in the population of the centrifugal pump system during the specified investigation period.

**Failure Rate (λ)**

Failure rate is the probability of failure per time unit. It is the rate of occurrence of failures. It is the reciprocal of the MTBF /MTTF function and is given by (Igor, 2004):

$$\lambda = \frac{1}{MTBF} = \frac{n}{\sum t_1} \quad (6)$$

Where:

$\sum t_I$ = the total running time in the operation of the centrifugal pump system during an investigation period for both failed and non-failed items.

n = number of failures (breakdowns) of centrifugal pump system or its parts occurring during a certain investigation period.

**Repair Rate**

The repair rate is the probability of repair per time unit. It is the rate of occurrence of repairs. A repair rate is used for systems with repairable parts. It is the reciprocal of the MTTR function and is given by (Igor, 2004):

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$$\mu = \frac{1}{MTTR} \quad (7)$$

Where,

MTTR = Mean time to repair

**Availability**

The "availability" of a system is, mathematically, MTBF / (MTBF + MTTR) for scheduled working time. It is given by (Igor, 2004):

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (8$$

Or $$A = \frac{T_O}{T_O + T_1} \quad (9)$$

Where:

$T_0$ = uptime of the centrifugal pump system.

$T_1$ = downtime of the centrifugal pump system, including repair and maintenance time.

## III. Results

Failure data of the pump system was used to analyse the reliability metrics of the pump equipment for maintenance.

**Table 1:Failure Data of the Centrifugal Pump System in the Refinery**

| Centrifugal Pump System | Number of Failure | Operating Time (hrs) | Downtime (hrs) | Total Available Time (hrs) |
|---|---|---|---|---|
| P01 | 13 | 7827.02 | 452.98 | 8280.00 |
| P02 | 7 | 8101.60 | 178.40 | 8280.00 |
| P03 | 9 | 8044.84 | 235.16 | 8280.00 |
| P04 | 5 | 8167.65 | 112.35 | 8280.00 |
| P05 | 11 | 7973.28 | 306.72 | 8280.00 |

**Table 2:Current Equipment Labour Cost.**

| Item | Labour type | Number of labours Per day (Current Maintenance) |
|---|---|---|
| Engineers (₦ 700 000.00/month) | Mechanical | 4 |
| | Electrical | 6 |
| | Control | 4 |
| Technician (₦ 400, 000.00/month) | Mechanical | 6 |
| | Electrical<br>Control | 6<br>1 |
| **Total cost (Naira/year)** | | **180,000, 000** |

**Reliability Analysis of the Centrifugal Pump System in the Oil and Gas Production Facility**

Table 3 presents the reliability parameters for the centrifugal pump system in the refinery.

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**Table 3:Reliability Indices of the Centrifugal Pump System in the Refinery**

| Centrifugal Pump System | Operating Time (hrs) | Downtime (hrs) | MTBF (hrs/failure) | MTTR (hrs/repair) | Failure rate (failure/hr) | Repair rate (repair/hr) | Availability | Reliability (%) |
|---|---|---|---|---|---|---|---|---|
| P01 | 7927.02 | 352.98 | 602.07 | 34.85 | 0.001660 | 0.0287 | 0.945 | 47.2 |
| P02 | 8101.60 | 178.40 | 1157.37 | 25.49 | 0.000864 | 0.0392 | 0.979 | 85.7 |
| P03 | 8088.84 | 191.16 | 893.87 | 26.12 | 0.001120 | 0.0383 | 0.972 | 76.9 |
| P04 | 8177.65 | 102.35 | 1633.53 | 22.47 | 0.000612 | 0.0445 | 0.985 | 93.4 |
| P05 | 8033.28 | 246.72 | 724.84 | 27.88 | 0.001380 | 0.0359 | 0.963 | 65.5 |

Figure 1 represents the mean time between failures (MTBF) of the centrifugal pump system in the refinery. The results show that, out of the five (5) centrifugal pumps that make up the centrifugal pump system in the power plant, pump P04 has the highest MTBF with 1633.53 hours, and pump P01 has the lowest MTBF with 602.07 hours within the study period.

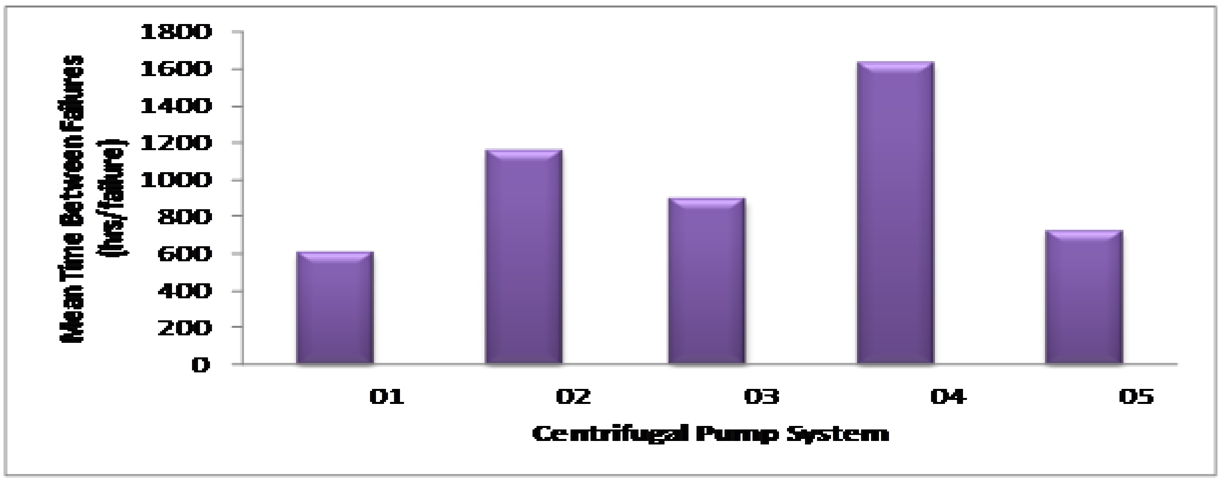


**Figure 1: Centrifugal Pump System's Mean Time Between Failures (MTBF)**

Figure 2 represents the mean time to repair (MTTR) of the centrifugal pump system in the refinery. The results show that, out of the five (5) centrifugal pumps that make up the centrifugal pump system in the refinery, pump P01 has the highest MTTR with 34.85 hours, and pump P04 has the lowest MTTR with 22.47 hours within the study period.

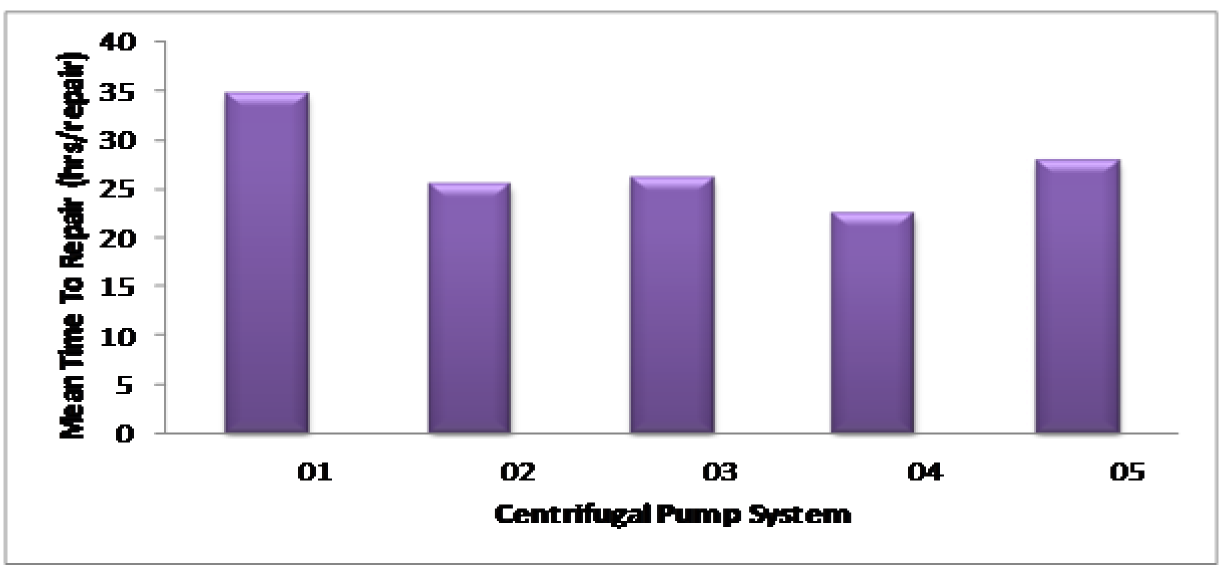


**Figure 2: Centrifugal Pump System's Mean Time to Repair (MTTR)**

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The failure rate of the centrifugal pump system in the refinery is represented in Figure 3. The results show that out of the five (5) pumps that make the centrifugal pump system in the refinery, pump P01 has the highest failure rate at 0.001660failure/hr, and pump P04 has the lowest failure rate with 0.000612failure/hr within the study period.

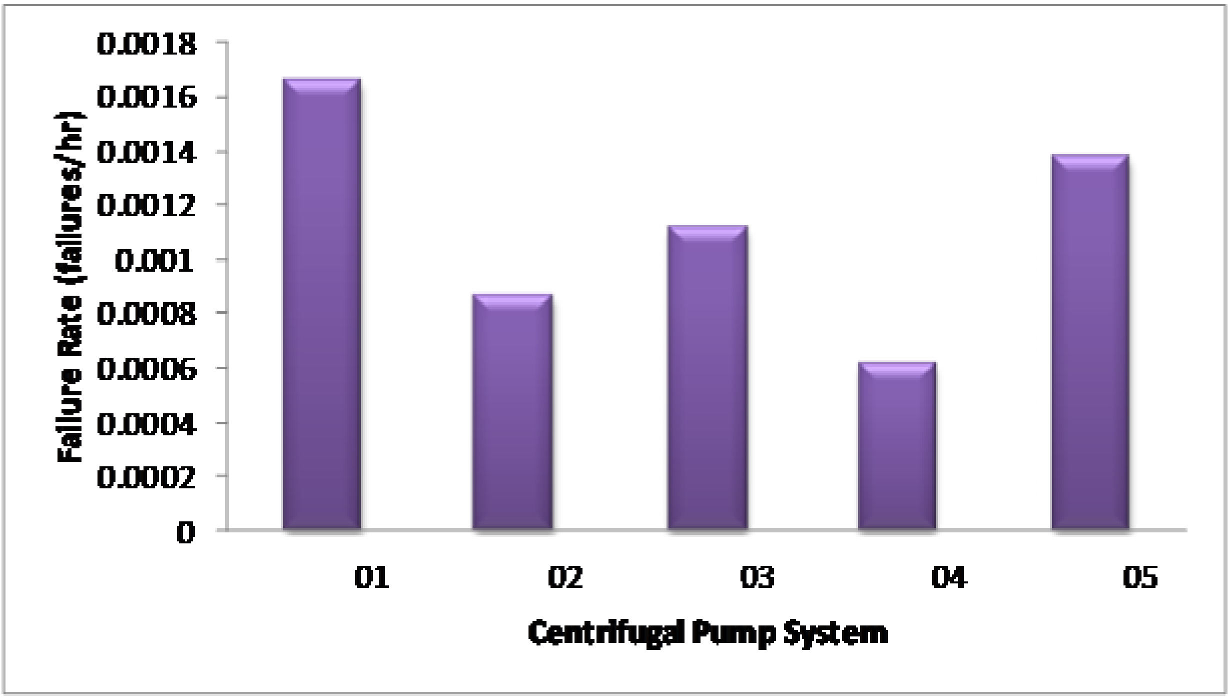


**Figure 3: Centrifugal Pump System's Boiler's Failure Rate**

Figure 4 represents the repair rate of the centrifugal pump system in the refinery. The results show that out of the five (5) pumps that make the centrifugal pump system in the refinery, pump P04 has the highest repair rate at 0.0445repairs/hr, and pump P01 has the lowest repair rate at 0.0287repairs/hr within the study period.

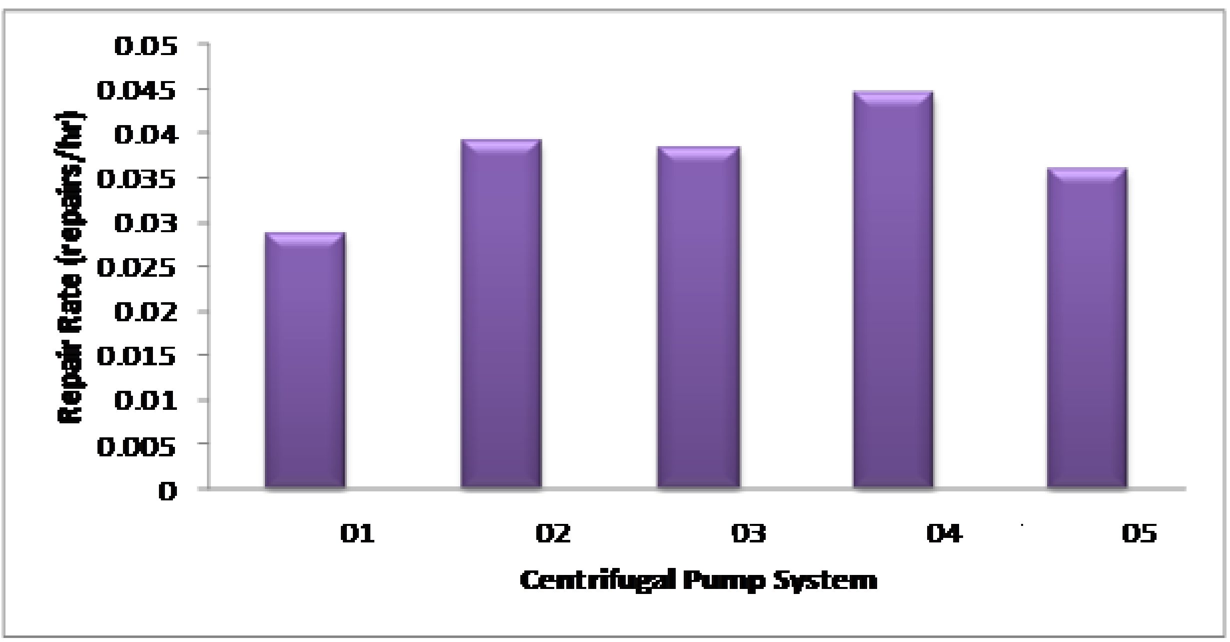


**Figure 4: Centrifugal Pump System's Repair Rate.**

Figure 5 represents the availability of the centrifugal pump system in the refinery. The results show that, out of the five (5) pumps that make up the centrifugal pump system in the refinery, pump P04 has the highest availability with 0.985, and pump P01 has the lowest availability with 0.945 within the study period.

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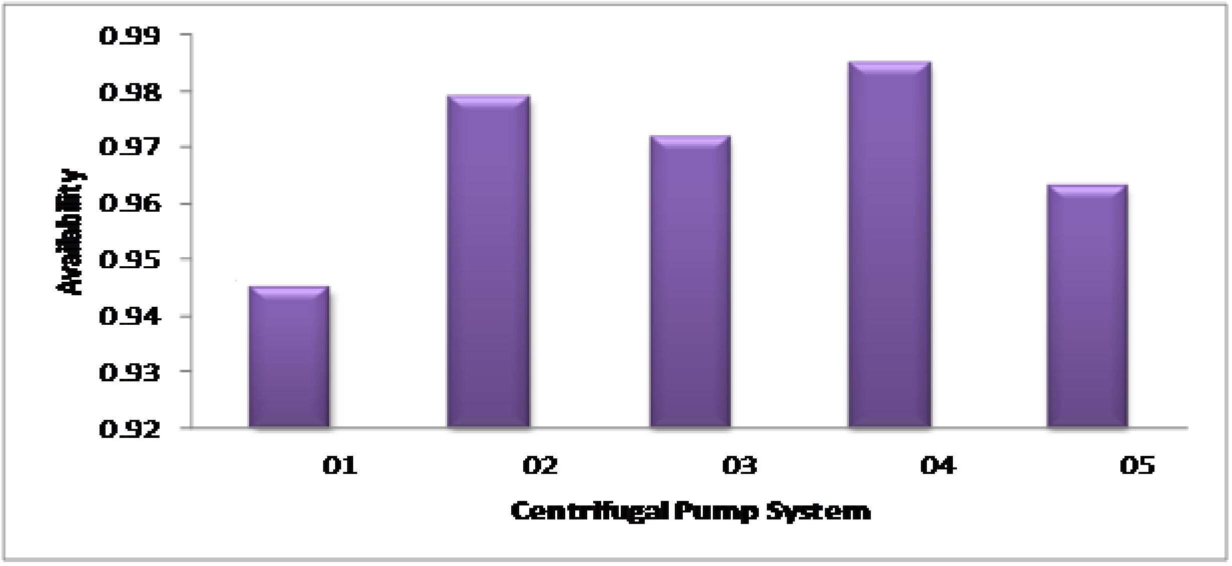


**Figure 5: Centrifugal Pump System's Availability (A)**

The reliability of the centrifugal pump system in the refinery is represented in Figure 6. The results show that, out of the five (5) pumps that make the centrifugal pump system in the refinery, pump P04 has the highest reliability with 93.4%, and pump P01 has the lowest reliability with 47.2% within the study period.

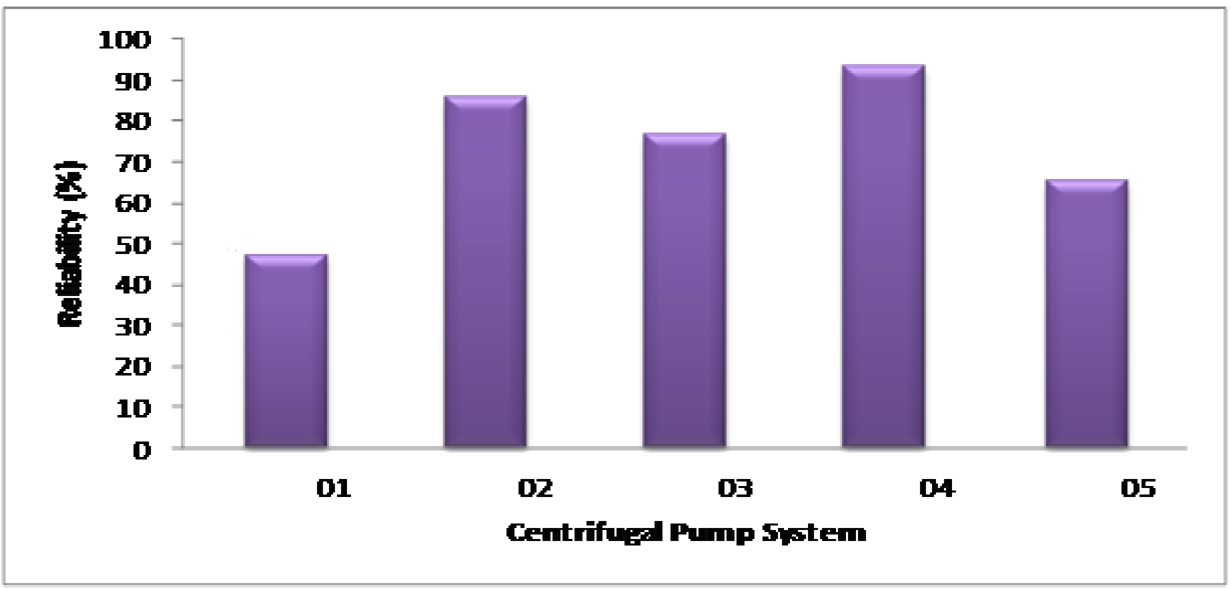


**Figure 6: Centrifugal Pump System's Reliability (R)**

The maintenance strategy is directed towards the item, a major contributor to system failures (Afefy, 2010). In the present case, pump P01as has the least reliability at 47.2% and the highest failure rate at 0.00166 failures/hr. Table 4 revealed that the centrifugal pump failure mode effect analysis and the criticality analysis for the centrifugal pump were used to generate the maintenance plan for the pump, as presented in Table 5.

**Table 4:Criticality Analysis for the Centrifugal Pump**

| Equipment | Failure Mode | Failure Cause | Criticality Analysis | | | Criticality Index | Group/Level |
|---|---|---|---|---|---|---|---|
| | | | Safety | Production | Cost | | |
| | Low discharge pressure | Water excessively hot | 2 | 3 | 1 | 2.2 | B (Medium-High) |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pump | High bearing temperature | Bent shaft | 3 | 3 | 3 | 3.0 | A (High) |
| | | Worn bearing | 3 | 3 | 2 | 2.8 | A (High) |
| | | Lack of lubrication | 3 | 3 | 2 | 2.8 | A (High) |
| | | Improper installation of bearing | 3 | 3 | 2 | 2.8 | A (High) |
| | Pump casing overheats | Misalignment of pump drive motor | 3 | 3 | 3 | 3.0 | A (High) |
| | | Shaft sleeve worn | 3 | 3 | 3 | 3.0 | A (High) |
| | Low flow | Impeller damaged on loose shaft | 3 | 3 | 3 | 3.0 | A (High) |

**Table 5:Centrifugal Pump Maintenance Task.**

| Equipment | Failure Mode | Failure cause | Group | Task | Description | Frequency |
|---|---|---|---|---|---|---|
| Pump | Low discharge pressure | Water excessively hot | B (Medium-High) | CD | Check the temperature of water | Monthly |
| | High bearing temperature | Bent shaft | A (High) | CD | Check and replace the bent shaft | Monthly |
| | | Worn bearing | A (High) | ProM | Check and replace worn bearing | Monthly |
| | | Lack of lubrication | A (High) | PreM | Lubricate adequately | Monthly |
| | | Improper installation of bearing | A (High) | CD | Check bearing for improper installation | Monthly |
| | Pump casing overheats | Misalignment of pump drive motor | A (High) | CD | Check pump drive motor for misalignment | Monthly |
| | | Shaft sleeve worn | A (High) | CD | Check and replace worn shaft sleeve | Monthly |
| | Low flow | Impeller damaged on loose shaft | A (High) | CD | Check for loose shaft and replace damaged impeller | Monthly |

**Optimization of Maintenance Labour Cost**

Table 2 shows the facility's current maintenance force: four mechanical engineers, four electrical engineers, four control engineers, six mechanical technicians, six electrical technicians, and one control technician. The facility's current maintenance task costs the industry N180, 000, 000 annually. The maintenance cost was optimized using a linear programming method.

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**Table 6:Model Formulation**

| | | | | Labour type | | Cost of Salaries |
|---|---|---|---|---|---|---|
| | | M | El | C | | (x $10^3$Naira |
| Labour Rank | E | 4 | 6 | 4 | | 699 |
| | T | 6 | 6 | 1 | | 399 |
| Quantity available | | 20 | 14 | 13 | | |

Let the number of engineers needed for maintenance (E) = $x_1$

Let the number of technicians needed for maintenance (T) = $x_2$

Let F denote the cost to be minimized

The linear programming model for the above production data is given by:

$$Min \quad F = 699000\, x_1 + 399000\, x_2$$

$$S.t.$$

$$4x_1 + 6x_{2\ 5} \geq 20$$

$$6x_1 + 6x_{2\ 5} \geq 14$$

$$4x_1 + x_{2\ 5} \geq 13$$

$$x_1 , \quad x_2 \leq 0$$

Converting the model into its corresponding standard forms;

$$Min \quad F = 699000\ x_1 + 39000\ x_2 + 0s_1 + 0s_2$$

$$S.t.$$

$$4x_1 + 6x_2 + s_1 \geq 20$$

$$6x_1 + 6x_2 + s_2 \geq 14$$

$$4x_1 + x_2 + s_3 \geq 13$$

$$x_1 , \quad x_2 , \quad s_1 , \quad s_2 \leq 0$$

The formulated linear programming model was solved, and the fourth iteration gave an optimal solution of$x_1$ =2.9, $x_2$ = 1.4, and F =2585700 naira.

## IV. Conclusion

The results of the optimized maintenance strategies using reliability-centred maintenance and linear programming model applied for the centrifugal pump system in the oil and gas production facility generated the reliability centred maintenance tasks and plan. Results of the optimized maintenance strategies consisted of on-condition-directed (CD) maintenance, preventive maintenance (PreM), and Proactive maintenance (ProM) strategies to be carried out monthly. The optimized maintenance labour force results showed that approximately three engineers and two technicians should be employed for the maintenance task to spend a minimum of ₦2, 585, 700 naira as the cost of salaries for the labour force monthly and ₦31, 028, 400 annually. The results showed that the labour cost decreased from ₦180,000,000/year to ₦31,028,400/year (approximately 82.76% reduction) using the proposed optimized maintenance plan compared to the current maintenance plan. The study recommends that the maintenance optimization technique presented in this work should be adopted by the oil and gas processing and production companies in order to minimize maintenance cost.

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