# DEVELOPING MAINTENANCE MODEL FOR EFFECTIVE OIL AND GAS EQUIPMENT MANAGEMENT: A CASE STUDY

**K. C. IKWUNZE**
Department of Mechanical Engineering,
Faculty of Engineering,
University of Port Harcourt,
Rivers State, Nigeria.
(Email: mujunpen@yahoo.co.uk , Phone: *+2348083132621)*

**H. U. NWOSU**
Department of Mechanical Engineering,
Faculty of Engineering,
University of Port Harcourt,
Rivers State, Nigeria.

**ABSTRACT**
*Equipment maintenance is essential in all industrial sectors, but should be considered more in the oil and gas sector because of the high cost of purchasing oil and gas equipment. The research work was aimed at developing maintenance models for effective oil and gas equipment management. Data were obtained from the maintenance log book of oil and gas companies operating offshore, Offshore Reliability Data Handbook (OREDA), textbooks, journals and the internet. Information extracted from the logbook includes the maintenance interval(s), maintenance duration(s), average maintenance duration(s), average repair time and so on. Markov models were applied to ten (10) different oil and gas equipment selected to obtain their different state probabilities at various maintenance intervals and the graph of maintenance intervals against the operational unavailability for the selected oil and gas equipment were plotted to obtain the optimum maintenance interval for each equipment. Quadratic models were developed to predict the cost of maintaining the selected oil and gas equipment for one year and it was observed that the cost of maintaining the selected oil and gas equipment at the various optimum maintenance intervals were not always the cheapest costs in monetary terms. However, research and experience have shown that in trying to economise costs for oil and gas equipment by prolonging maintenance intervals; huge capital is lost due to unforeseen failures of equipment leading to very expensive emergency shutdown maintenance. Finally, recommendations were made as regards to oil and gas equipment management.*

**Keywords:** Maintenance, Maintenance Management, Maintenance Optimization Models

## 1.0 Background

Petroleum, which is a natural liquid found in rock formation, consists of a complex mixture of hydrocarbons. The petroleum industry is responsible for the global processes of exploration, extraction, refining, transportation and marketing of petroleum products. Petroleum is vital to many industries and is of importance to the maintenance of industrial civilization. The industry is divided into three major components upstream, midstream and downstream. The upstream sector includes the searching for potential underground or underwater crude oil and natural gas fields, drilling of exploration wells and subsequently drilling and operating the well that recover and bring the crude oil and natural gas to the surface.

Oil exploration can be either done offshore or onshore. Drilling of natural gases offshore requires the drilling platform to be hundreds of miles away from the nearest landmass but this has be found to be of an advantage as a great number of large natural gas deposit is found there. Due to the harsher and remote environment associated with offshore, the installation of the facilities and equipment used for drilling are more challenging than the land based installation, therefore these equipment should have an effective management system.

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.

In the past models have been developed to help engineers select maintenance intervals but these models have had limitations in aspects of differentiating the equipment operational, maintenance and degradable states. The Probability Risk Assessment (PRA) has however corrected these limitations and has helped engineers/managers to obtain economical and safe maintenance intervals. Economical analysis of total cost of maintenance as compared to salvage value of the equipment is also used in combination with these stated models to certify its effectiveness.

### 1.1 Statement of Problem

The need for maintainability is becoming more important than ever before because of the alarming high operation and repair costs of equipment and systems. The need for proper maintenance is essential as it not only reduces the cost of operation but also ensures optimal component availability and plant performance.

Management of oil and gas equipment will be carried out easily if models for predicting maintenance intervals existed. The research presents a solution to this problem, where, with information such as cost and life span of oil and gas equipment, the maintenance interval can be predicted. The prediction of maintenance interval for oil and gas equipment will certainly lead to an effective and efficient way of managing them.
Thus, the research work is aimed at developing maintenance model that will be used to effectively manage oil and gas equipment.

### 1.2 Definition of terms

**Maintenance:** Maintenance is a combination of all technical, administrative, and managerial actions during the life cycle of an item intended to keep it in or restore it to a state in which it can perform the required function (Komonen, 2002)

**Maintenance Management:** Standards Norway (SN) - NS-EN13306 have defined Maintenance Management as:
*"All activities of the management that determine the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance*

*control and supervision, improvement of methods in the organization including economical aspects."*

**Maintenance Optimization Models:** maintenance optimization models are those mathematical models whose aim is to find the optimum balance between the costs and benefits of maintenance, while taking all kinds of constraints into account. In almost all cases, maintenance benefits consist of savings on costs which would be incurred otherwise (for example, less failure costs).

## 1.3 Objective of Study

The primary objective of the research work is to develop maintenance models that will effectively manage oil and gas equipment.

## 2.0 Research Methodology

The research was aimed at getting the optimum maintenance intervals of the various oil and gas equipment selected, and the effect of cost of maintenance when the various equipment are maintained at different maintenance intervals. Markov models were applied to the different oil and gas equipment to obtain their different state probabilities at various maintenance intervals. The graph of maintenance intervals (in days) against the operational unavailability for the selected oil and gas equipment were plotted. The optimum maintenance interval for each equipment was obtained when the curve is at its lowest point.

Quadratic models were developed to predict the cost of maintaining the oil and gas equipment for one year. The quadratic models took the general form as in Equation (1)

$$Y = a_0 + a_1 x + a_2 x^2 \qquad (1)$$

where,

Y = Cost of maintaining the specified oil and gas equipment for one year.

$a_0, a_1 \text{ and } a_2 = \text{Constants}$

$x$ = Optimum maintenance interval (in days) got from the Markov maintenance model.

## 2.1 Markov Model

The Markov approach is actually used for quantifying the effects of maintenance on unavailability and risk. The model is a preventive model, which makes use of transition rates for calculating the states probability of the component. The model is considered as a four state Markov maintenance model because it consider four states of the component which are the operational state, a degraded state, a maintenance state and a failed state. The four state Markov model can be determined from the equation below:

$$P_o = \frac{1}{1 + r_d + r_m + r_f} \qquad (2)$$

$$P_d = \frac{r_d}{1 + r_d + r_m + r_f} \quad (3)$$

$$P_m = \frac{r_m}{1 + r_d + r_m + r_f} \quad (4)$$

$$P_f = \frac{r_f}{1 + r_d + r_m + r_f} \quad (5)$$

Where:

$P_o$ = the probability that the component is in the operational state (o) at a given time.

$P_d$ = the probability that the component is in the degraded state (o) at a given time.

$P_m$ = the probability that the component is in the maintenance state (o) at a given time.

$P_f$ = the probability that the component is in the failed state (o) at a given time.

$r_d$ = the probability of the ratio for degraded state.

$r_m$ = the probability of the ratio for maintenance state.

$r_f$ = the probability of the ratio for failed state.

Markov model is better than other maintenance model because it is a preventive model rather than a corrective model which helps to reduce the effect of maintenance downtime and possible maintenance related error. Markov model also considers various states of the component as oppose to other model which just consider the operational and failed state of the component, because of the other states such as the degradation state and the maintenance state which Markov approach consider, it helps to evaluate maintenance explicitly and allows optimal maintenance intervals to be determined.

## 2.2 Samples Chosen

Ten carefully selected oil and gas equipment were chosen for this work, the list of the equipment are shown in Table 1. The equipment that were used for this project work are some of the major equipment used for offshore exploration, and absent of one of these equipment can cause major disturbance in production.

Table 1: List of oil and gas equipment.

| S/N | NAMES OF EQUIPMENT |
|---|---|
| 1 | Low pressure compressor |
| 2 | High pressure compressor |
| 3 | Centrifugal pump |
| 4 | Emergence shutdown valve |
| 5 | Pressure relief valve |
| 6 | Surge tank |
| 7 | Heat exchanger |
| 8 | Combustion engine |
| 9 | Electric generator(1000kva) |
| 10 | Electric motor |

**N/B:**
For the purpose of this paper, three (3) equipment will be considered. For more details, contact the corresponding author.

### 2.3 Data Collection Methods

The primary data were obtained from the maintenance log book of the Well Services Department of the case study company operating offshore. Information that was extracted from the logbook is the maintenance interval, maintenance duration, average maintenance duration, average repair time and so on. The research also relied on offshore reliability data handbook (OREDA), Oil and Gas Journals, and so on.

## 3.0 Data Presentation and Analysis

### 3.1 Equipment: Low Pressure Compressor

Table 2: Summary of Results for Probability States

| Tm | Po | Pd | Pm | Pf | 1-Po |
|---|---|---|---|---|---|
| 6 | 0.5304 | 0.114219 | 0.32837586 | 0.027004 | 0.4696 |
| 9 | 0.570711 | 0.146874 | 0.234340199 | 0.048075 | 0.429289 |
| 12 | 0.588251 | 0.176281 | 0.180765843 | 0.054702 | 0.411749 |
| 15 | 0.5934 | 0.203031 | 0.145913731 | 0.057655 | 0.4066 |
| 18 | 0.579594 | 0.222943 | 0.119014373 | 0.078449 | 0.420406 |
| 21 | 0.575743 | 0.245876 | 0.101685125 | 0.076695 | 0.424257 |
| 24 | 0.568993 | 0.267002 | 0.088318595 | 0.075686 | 0.431007 |

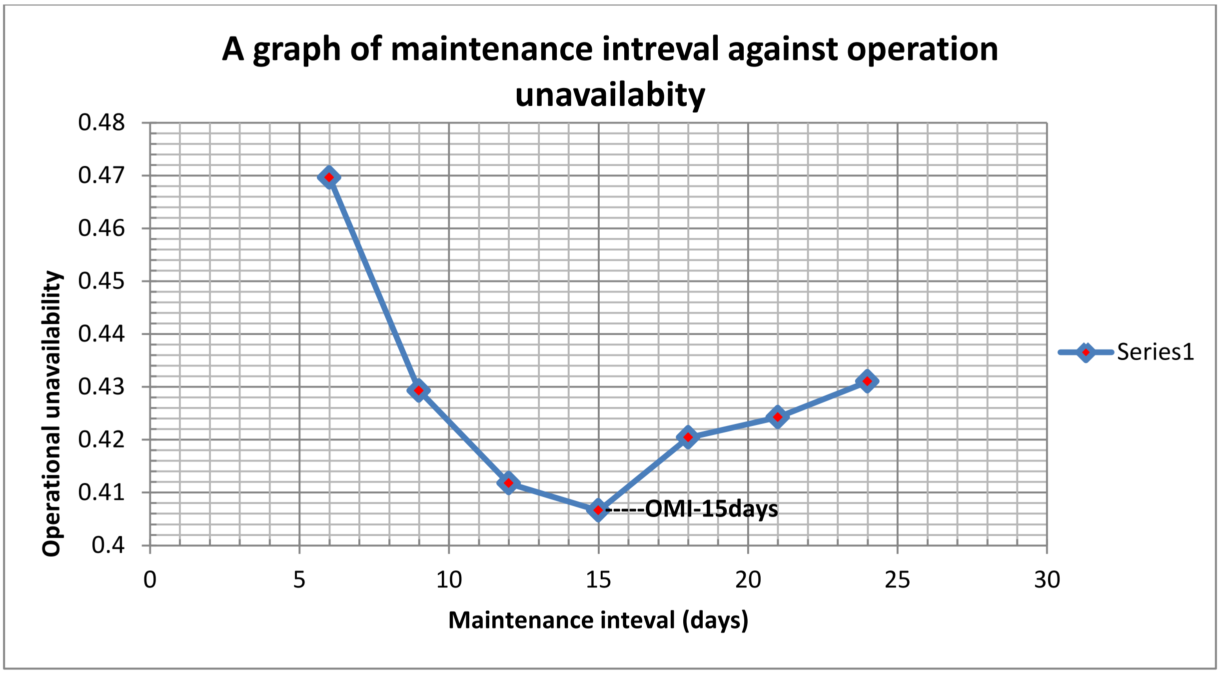


*Figure 1: A graph of maintenance intervals (days) against operational unavailability for a low pressure compressor.*

From the figure above, the optimum maintenance interval should be 15 days.

**Cost of Maintenance**

The effect of cost of maintenance for the various maintenance intervals is shown in Table 3.

Table 3: Cost of maintenance for the various maintenance intervals of low pressure compressor

| Maintenance interval | Cost of maintenance(for a year) |
|---|---|
| 6 | $1,354,460 |
| 9 | $1,109,855 |
| 12 | $917360 |
| **15** | **$776,975** |
| 18 | $688,700 |
| 21 | $652,535 |
| 24 | $668,480 |

**Maintenance Model**

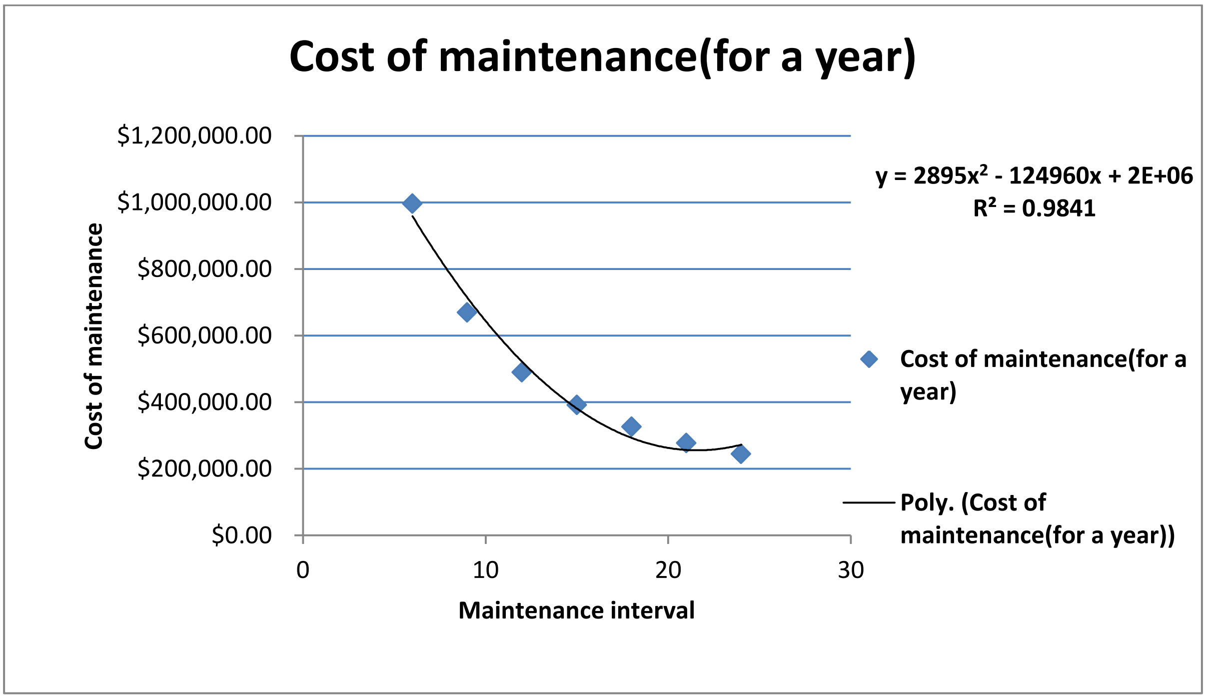


*Figure 2: quadratic model for cost of maintenance of low pressure compressor*

The quadratic model obtained is:

$Y=2E+06-124960x+2895x^2$

Coefficient of correlation $R^2=0.984$

### 3.2 Equipment: Centrifugal Pump

Information obtained from OREDA handbook
Failure rate of centrifugal pump ($\lambda$) – $112.64\times10^{-6}$ $hr^{-1}$
Degradation ratio ($r_{od}$) –2
Catastrophic failure fraction ($f_{of}$) – 0.2
Average repair time (r) – 22hrs

Table 4: Summary of results for probability states

| Tm | Po | Pd | Pm | Pf | 1-Po |
|---|---|---|---|---|---|
| 15 | 0.676093 | 0.11676 | 0.169136429 | 0.03801 | 0.323907 |
| 25 | 0.708967 | 0.14144 | 0.10577215 | 0.043821 | 0.291033 |
| 27 | 0.712356 | 0.145951 | 0.098301681 | 0.043392 | 0.287644 |
| 30 | 0.716133 | 0.152514 | 0.088808356 | 0.042544 | 0.283867 |
| 35 | 0.709021 | 0.160573 | 0.075196623 | 0.05521 | 0.290979 |

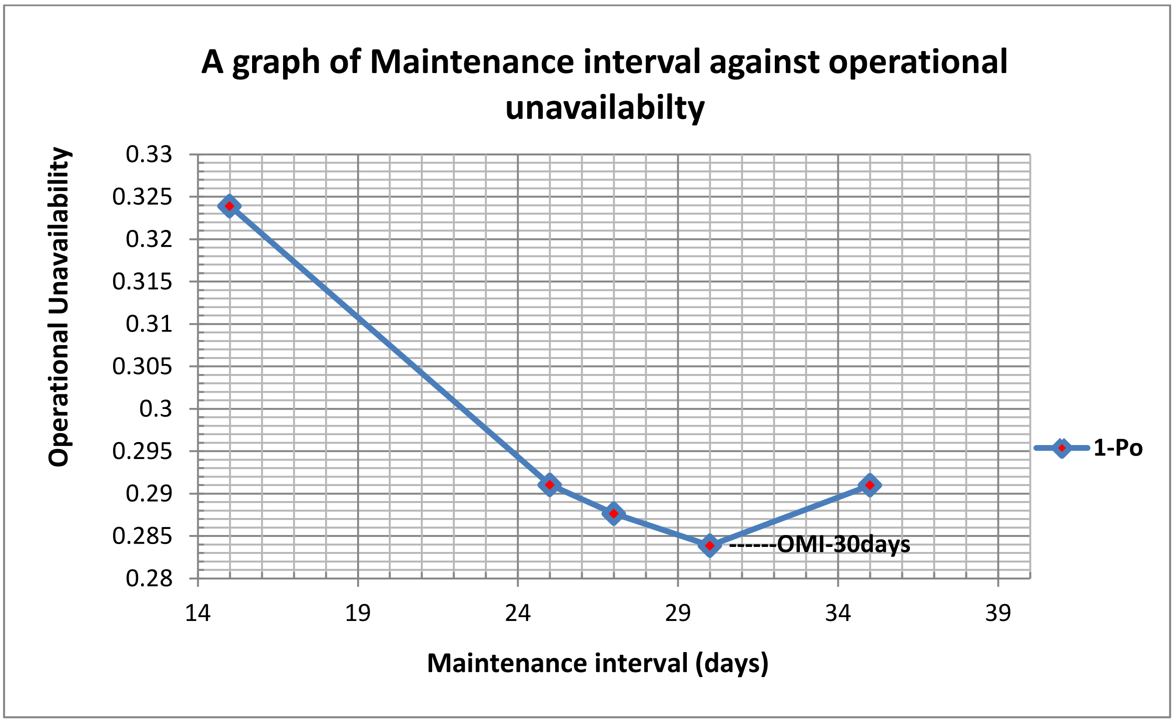


*Figure 3: A graph of maintenance interval (days) against operational unavailability for centrifugal pump*

From the figure, the optimum maintenance interval for the centrifugal pump should be 30days

**Cost of Maintenance**

The effect of cost of maintenance for the various maintenance intervals is show in the table below

Table 5: Cost of maintenance for the various maintenance intervals of centrifugal pump

| Maintenance interval | Cost of maintenance(for a year) |
|---|---|
| 15 | $465,220 |
| 25 | $231,700 |
| 27 | $196,804 |
| **30** | **$151,840** |
| 35 | $96,580 |

**Maintenance Model**

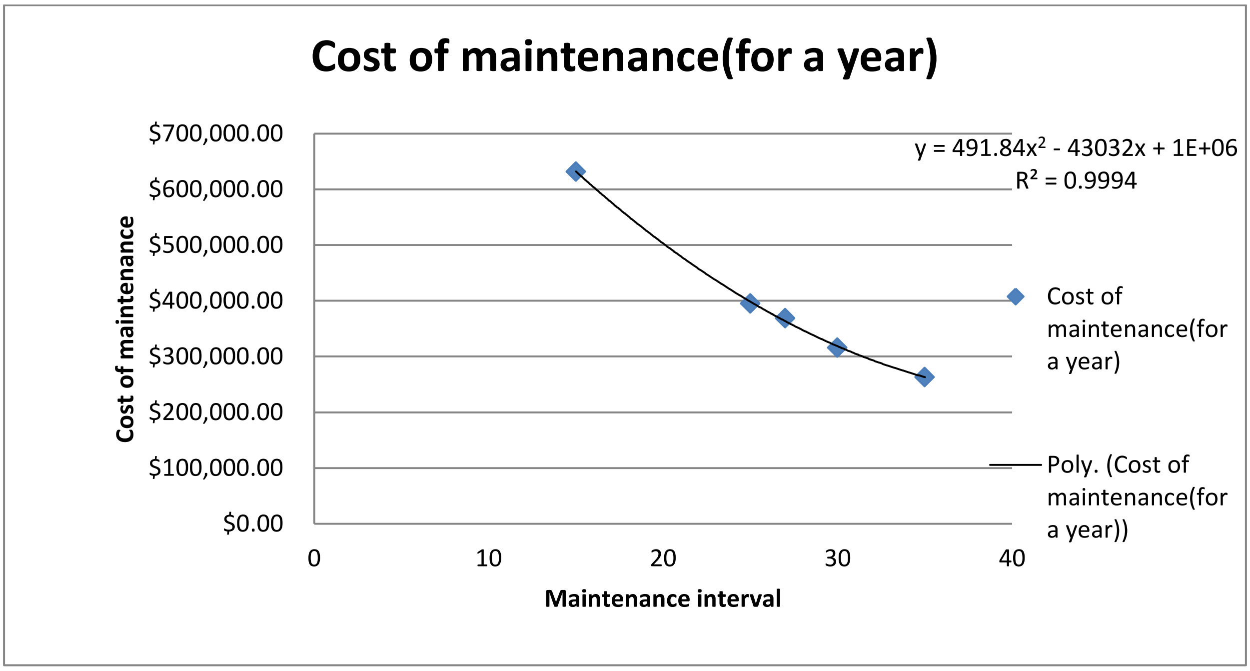


*Figure 4: linear regression model for cost of maintenance of Centrifugal Pump*

The quadratic model obtained is:

$Y=1E+06 - 43032x + 492x^2$

Coefficient of correlation $R^2 = 0.983$

### 3.3 Equipment: Surge Tank

Information obtained from OREDA handbook
Failure rate of surge tank ($\lambda$) –$102.15\times10^{-6}$ $hr^{-1}$
Degradation ratio ($r_{od}$) –2
Catastrophic failure fraction ($f_{of}$) – 0.183
Average repair time (r) –15 hrs

Table 6: Summary of results for probability states

| Tm | Po | Pd | Pm | Pf | 1-Po |
|---|---|---|---|---|---|
| 10 | 0.705884 | 0.11076 | 0.177380154 | 0.005975 | 0.294116 |
| 14 | 0.717096 | 0.119443 | 0.128374338 | 0.035087 | 0.282904 |
| 21 | 0.734292 | 0.134761 | 0.087270562 | 0.043677 | 0.265708 |
| 30 | 0.743827 | 0.152807 | 0.061598296 | 0.041768 | 0.256173 |
| 35 | 0.734037 | 0.159761 | 0.051987886 | 0.054214 | 0.265963 |

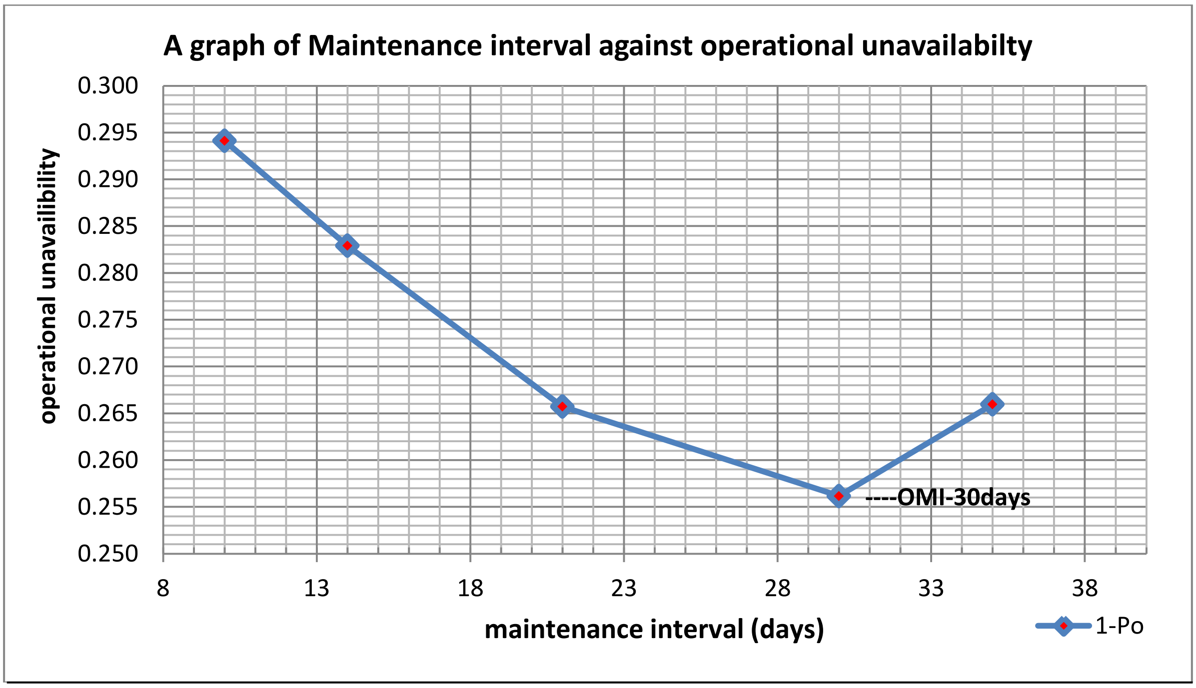


*Figure 5: A graph of maintenance interval (days) against operational unavailability for surge tank*

The figure above shows that the optimum maintenance interval for the surge tank should be 30days

**Cost of Maintenance**

The effect of cost of maintenance for the various maintenance intervals is show in the table below

Table 7: Cost of maintenance for the various maintenance intervals of surge tank

| Maintenance interval | Cost of maintenance(for a year) |
|---|---|
| 10 | $2,124,630 |
| 14 | $1,566,842 |
| 21 | $855,208 |
| **30** | **$434,890** |
| 35 | $441,830 |

**Maintenance Model**

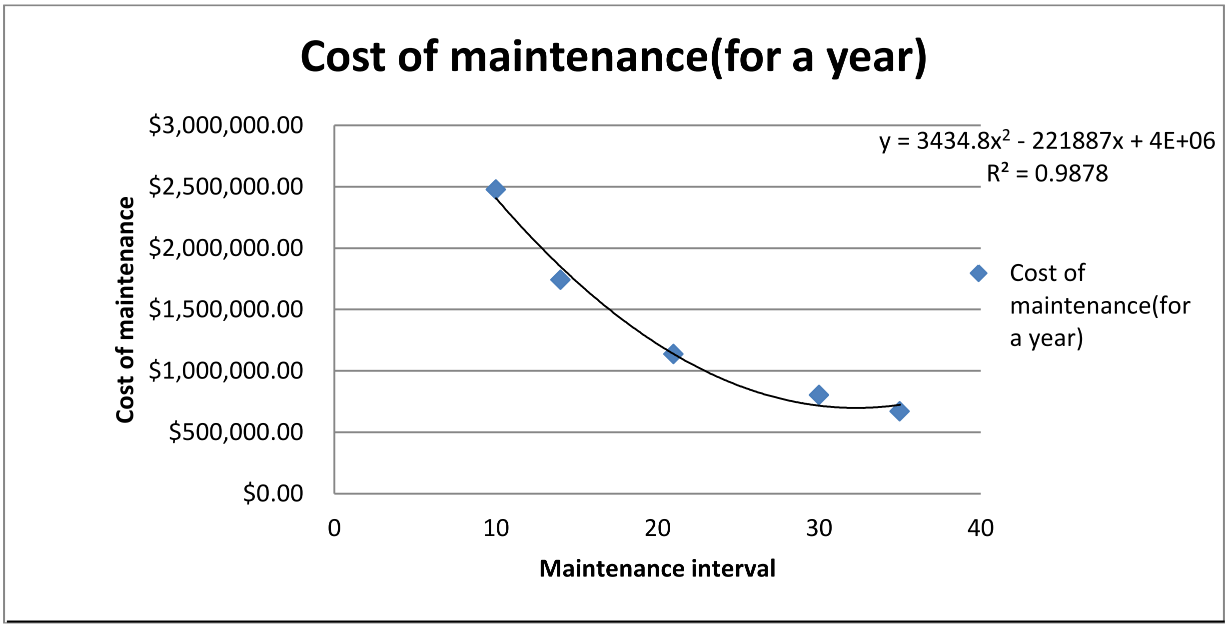


*Figure 6: Quadratic regression model for cost of maintenance of surge tank*

The quadratic regression model obtained is:

$Y=4E+06 -221887x+3435x^2$

Coefficient of correlation $R^2$=0.9878

The summary of the quadratic models developed, the optimum maintenance intervals and the cost associated with the optimum maintenance intervals as predicted by the model for each oil and gas equipment selected, is given in the table below:

Table 8: Summary of quadratic models, optimum maintenance intervals with the associated cost for each oil and gas equipment

| S/N | Equipment Name | Quadratic model developed | Optimum maintenance interval (days) | Cost of maintenance (for a year) |
|---|---|---|---|---|
| 1 | Low pressure compressor | $Y= 2 \times 10^6 - 124960x+2895x^2$ | 15 | $776,975 |
| 3 | Centrifugal pump | $Y= 1 \times 10^6 - 43032x + 492x^2$ | 30 | $151,840 |
| 6 | Surge tank | $Y=4 \times 10^6 - 221887x+3435x^2$ | 30 | $434,890 |

## 4.0 Conclusion:

From the research, it was observed that the cost of maintaining the selected oil and gas equipment at the various optimum maintenance intervals were not always the cheapest cost in monetary terms. However, research and experience have shown that for oil and gas equipment; trying to economise cost by prolonging maintenance intervals always lead to unforeseen equipment failure, thus, warranting emergency shutdown maintenance and repairs whose cost (both monetary, time and so on) are usually far exceeding the cost associated with the optimum maintenance intervals. The implication of this is that; in trying to economise cost, huge capital is lost due to unforeseen failures of equipment leading to very expensive emergency shutdown maintenance.

## 4.1 Recommendations

This study recommend as follows:

1. Maintenance managers of oil and gas industries should carry out reliability study before choosing maintenance interval for the various oil and gas equipment to be managed.

2. Optimum maintenance interval should be used as a determining factor instead of the cost of maintenance when managing oil and gas equipment.

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