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DEVELOPING MAINTENANCE OPTIMIZATION MODEL TO MANAGE OIL AND GAS EQUIPMENT: A CASE STUDY

KENNETH CHIBUEZE IKWUNZE
Technical /Design Engineer,
Schlumberger Technology Corporation,
Sugarland, Texas, USA.
mujunpen@yahoo.co.uk

CHIMAOBI KINGSLEY IHUNWO
Rivers State University,
Port Harcourt, Rivers State, Nigeria.
chimaobi.ihunwo@ust.edu.ng

Abstracts
Maintenance optimization models are mathematical models whose aim is to find the optimal balance between the costs and benefits of maintenance, while taking all kinds of constraints into account. Oil and gas equipment will be managed efficiently if models for predicting maintenance intervals existed. This 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 aim of the research was to develop maintenance model that will be used to effectively manage oil and gas equipment. The following equipment were considered for this paper: High pressure compressor, Electric generator (1000kva), and Pressure relief valve. The research relied mainly on data sourced from maintenance log book of oil and gas companies operating offshore, Offshore Reliability Data Handbook (OREDA), textbooks, journals, the internet and interviews of maintenance professionals. Markov models were applied to obtain the 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.

Keywords: *Maintenance, Maintenance management, Maintenance optimization models.*

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1.0 Introduction

The need for maintenance management is becoming more important than ever before because of the alarming high operation and repair costs of equipment and systems. Maintenance management is a combination of all technical, administrative, and managerial actions during the life cycle of an asset (or equipment) with the intent to keep the asset or restore it to a state in which it can perform the required function (Komonen, 2002). Nowadays, maintenance management is acknowledged as a major contributor to the performance and profitability of business organizations (Tsang and Others, 1999). Maintenance managers therefore explore every opportunity to improve on profitability and performance as well as achieve cost savings for the organization (Al-Najjar and Alsyouf, 2004). Industrial maintenance has two essential objectives – high availability of production equipment and low maintenance costs (Komonen, 2002).

Oil and gas equipment is designed to last for a period of time called the design life span. If the equipment does not last that long, major faults are attributed to the maintenance culture of the operator or equipment manager (Inge, 2011). In the past, models were developed to help engineers select maintenance intervals but these models 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 economic and safe maintenance intervals (Ahuja and Khamba 2008). Economic 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. In recent times, research is geared towards developing models that would help select equipment maintenance intervals that are economical and have low risk on losing the equipment.

1.1 Objective of Study

The key objective of the research is to develop maintenance models that will be used to effectively manage the selected oil and gas equipment.

2.0 Research Methodology

The oil and gas equipment under study include:

1. High pressure compressor
2. Electric generator(1000kva)
3. Pressure relief valve

This research aimed at getting the optimum maintenance interval of the selected oil and gas equipment under study, and the effect of cost of maintenance when the equipment is maintained at different maintenance intervals.

Markov models were applied to the selected oil and gas equipment under study to obtain their different state probabilities at various maintenance intervals. The graph of maintenance intervals (in days) against the operational unavailability for each equipment were plotted. The optimum maintenance interval for the 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).

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

where,

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

$$a_0, a_1 \; and \; a_2 \; = \; Constants$$

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

2.1 Markov Model

The research used Markov approach toevaluate the effects of maintenance on unavailability and risk. The Markov model is a preventive maintenance model whichutilizes transition rates for calculating the states probability of the component. The model is also known as a four state Markov maintenance model because it considers 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 equations below:

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

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

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

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

Where:

P_o = the probability that the component is in the operational state at a given time.

P_d = the probability that the component is in the degraded stateat a given time.

P_m = the probability that the component is in the maintenance state at a given time.

P_f = the probability that the component is in the failed state 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.

2.2 Data Collection Methods

The research relied mainly on data sourced from maintenance log book of the Well Services Department of the case study company operating offshore, Offshore Reliability Data Handbook (OREDA), textbooks, journals, the internet and interviews of maintenance professionals.

3.0 Data Presentation and Analysis

3.1 Equipment 1: High Pressure Compressor

Information obtained from OREDA handbook
Failure rate of high pressure compressor (ʎ) – 313.94×10^{-6} hr^{-1}
Degradation ratio (r_{od}) –2
Catastrophic failure fraction (f_{of}) – 0.152
Average repair time (r) –70 hrs

Table 3.1: Summary of results for probability states

T_m (days)	P_o	P_d	P_m	P_f	1-P_o
9	0.6149	0.127416	0.229191784	0.028459	0.3851
14	0.6278	0.148918	0.166266162	0.056993	0.3722
21	0.6349	0.18398	0.111312604	0.069797	0.3651
28	0.629	0.215226	0.082286384	0.073481	0.371
35	0.6026	0.237484	0.062812861	0.097076	0.3974

Where:
T_m= maintenance interval
P_o = the probability that the component is in the operational state at a given time.
P_d = the probability that the component is in the degraded state at a given time.
P_m = the probability that the component is in the maintenance state at a given time.
P_f = the probability that the component is in the failed state at a given time.

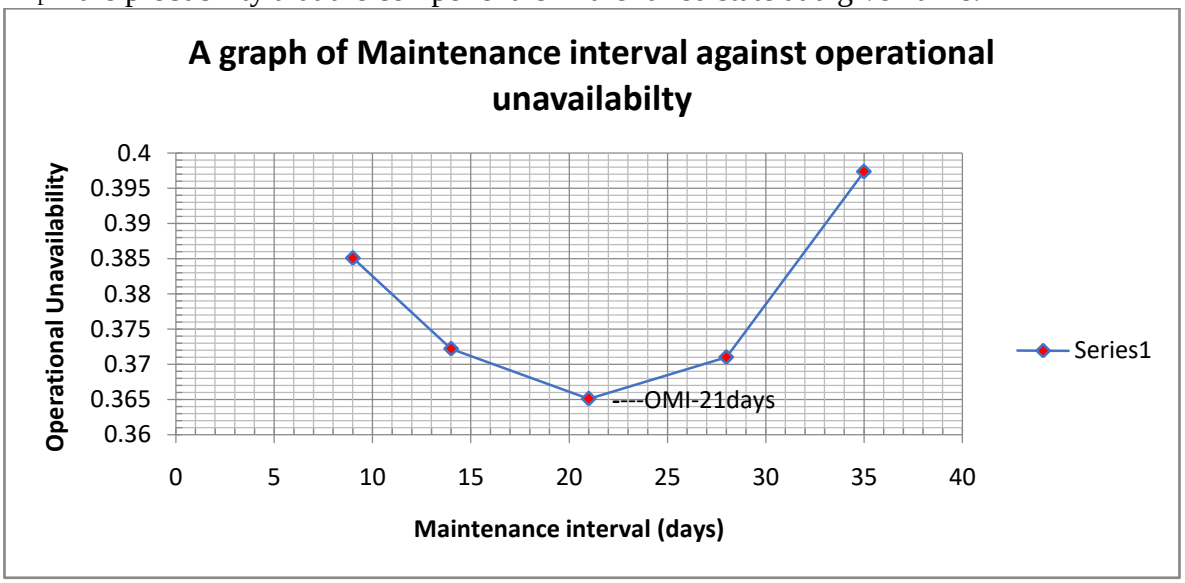


Figure 3.1: A graph of maintenance interval (days) against operational unavailability for high pressure compressor

From Figure 3.1, the optimum maintenance interval for a high pressure compressor should be 21days

Cost of Maintenance

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

Table 3.2: Cost of maintenance for the various maintenance intervals of high pressure compressor

Maintenance interval	Cost of maintenance (for a year)
9	$2,386,127
14	$3,750,252
21	**$7,039,559**
28	$11,938,320
35	$18,446,535

Maintenance Model

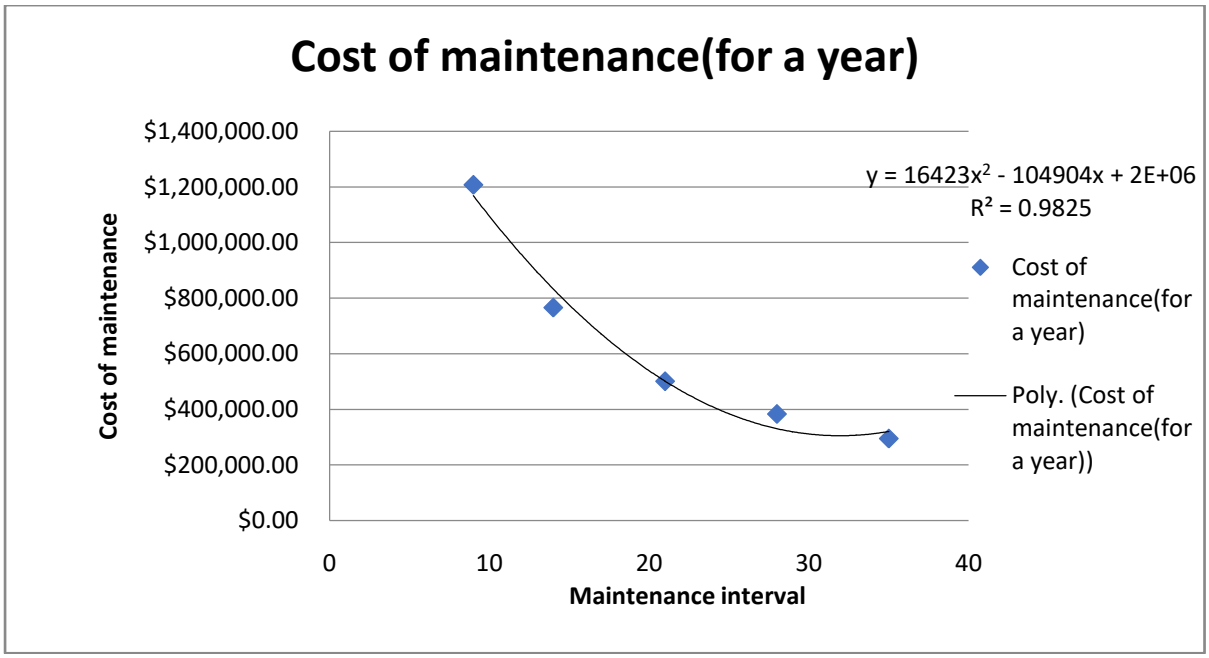


Figure 3.2: Quadratic model for cost of maintenance of high pressure compressor

The quadratic model obtained is
$Y=2E+06 – 104904x + 16423x^2$
Coefficient of correlation $R^2 =0.983$

3.2 Equipment 2: Electric generator (1000kva)
Information obtained from OREDA handbook
Failure rate of high pressure compressor (λ) $–77.29\times10^{-6}$ hr^{-1}
Degradation ratio (r_{od}) –2
Catastrophic failure fraction (f_{of}) – 0.46
Average repair time (r) –5 hrs

Table 3.3: Summary of results for probability states

T_m (days)	P_o	P_d	P_m	P_f	1-P_o
21	0.742905	0.126924	0.0881178	0.042053	0.257095
35	0.747327	0.146962	0.0527979	0.052913	0.252673
42	0.751649	0.157613	0.0441346	0.046604	0.248351
50	0.752451	0.169073	0.0370276	0.041449	0.247549
77	0.740221	0.204362	0.0236001	0.031816	0.259779

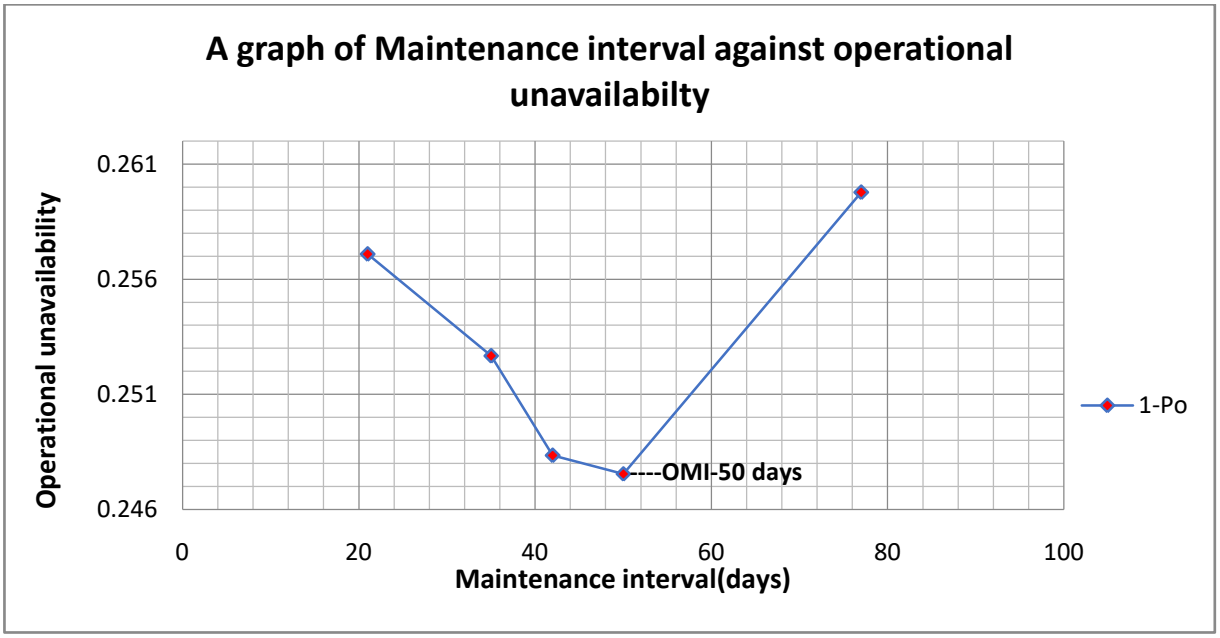


Figure 3.3: A graph of maintenance interval (days) against operational unavailability for electric generator

The optimum maintenance interval for Electric generator (Emergence power 1000kva) is 50 days.

Cost of Maintenance

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

Table 3.4: Cost of maintenance for the various maintenance intervals of electric generator

Maintenance interval	Cost of maintenance(for a year)
21	$119,447
35	$77,041
42	$61,130
50	**$47,266**
77	$34,495

Maintenance Model

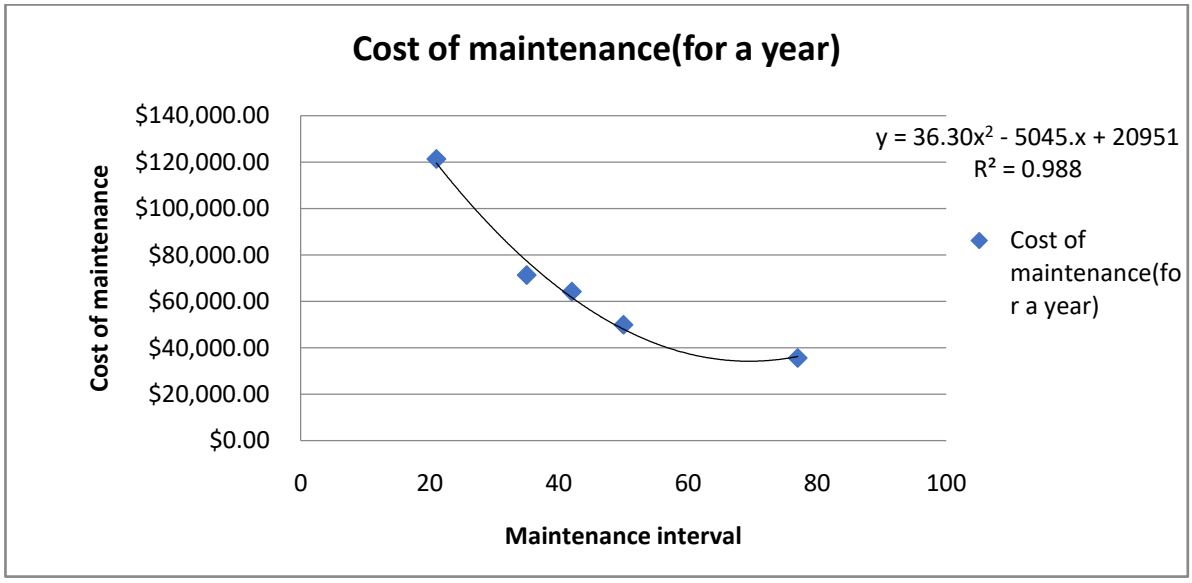


Figure 3.4: Quadratic regression model for cost of maintenance of electric generator

The quadratic regression model obtained is

$Y=209516 -5045x+36x^2$

Coefficient of correlation $R^2=0.988$

3.3 Equipment 3: Pressure relief valve

Information obtained from OREDA handbook
Failure rate of high pressure compressor (λ) – 23.29×10^{-6} hr^{-1}
Degradation ratio (r_{od}) –2
Catastrophic failure fraction (f_{of}) – 0.17
Average repair time (r) – 7hrs

Table 3.5: Summary of results for probability states

T_m (days)	P_o	P_d	P_m	P_f	$1-P_o$
30	0.782064	0.116771	0.065659823	0.035505	0.217936
60	0.804505	0.133387	0.033617905	0.02849	0.195495
90	0.809724	0.147666	0.022465825	0.020144	0.190276
120	0.806811	0.160551	0.016728404	0.01591	0.193189
130	0.805011	0.164665	0.015390157	0.014934	0.194989

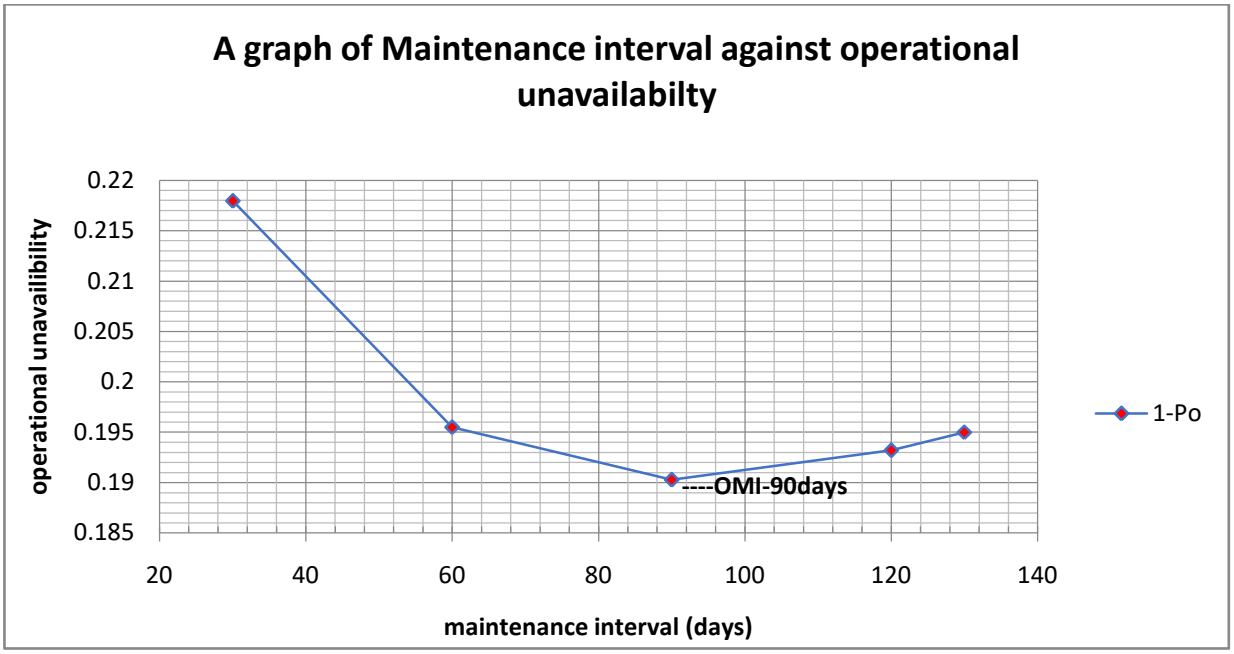


Figure 3.5: A graph of maintenance interval (days) against operational unavailability for Pressure Relief valve

From the figure, the optimum maintenance interval for a Pressure relief valve is 90days

Cost of Maintenance

The effect of cost of maintenance for the various maintenance intervals are shown in the table below

Table 3.6: Cost of maintenance for the various maintenance intervals of pressure relief valve

Maintenance interval	Cost of maintenance(for a year)
30	$53,362
60	$30,322
90	**$18,082**
120	$16,642
130	$18,562

Maintenance Model

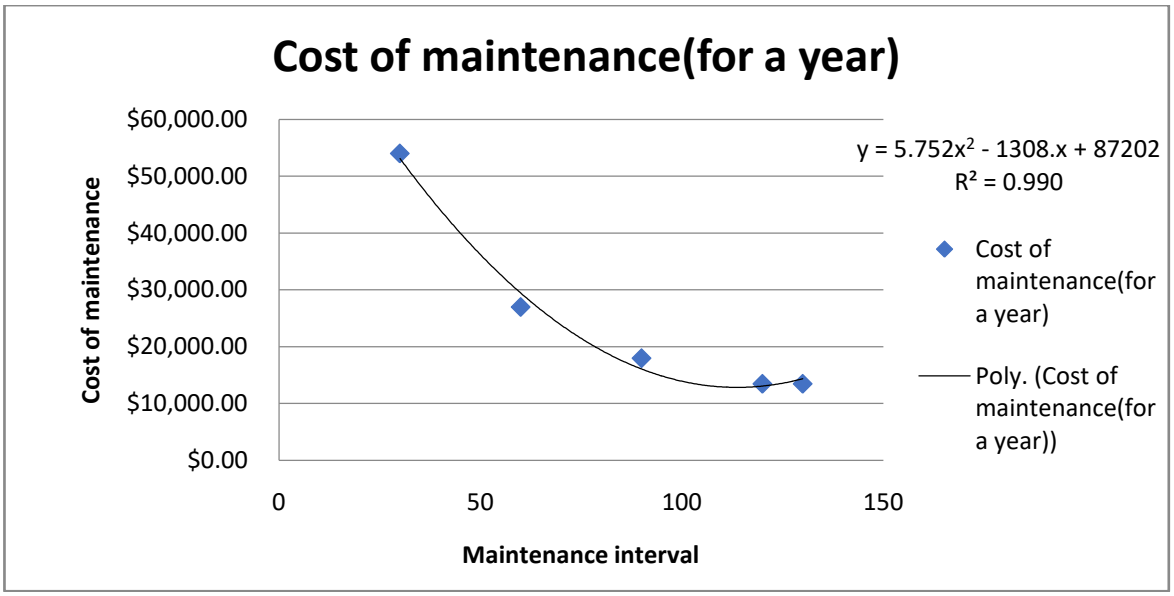


Figure 3.6: Quadratic model for cost of maintenance of pressure relief valve

The quadratic model obtained is
$Y=87202– 1308x + 6x^2$
Coefficient of correlation $R^2 =0.99$

4.0 Comparative Analysis

Table 4.1: Summary of maintenance intervals as proposed by this research and the maintenance intervals used by the case study company for the selected oil and gas equipment

S/N	Oil and Gas Equipment	Optimum maintenance interval proposed by the model (days)	Maintenance interval in practice by the case study company (days)
1	High pressure compressor	21	365
2	Pressure relief valve	90	180
3	Electric generator (1000kva)	50	180

Table 4.2: Summary of the annual cost of maintenance proposed by the model at the optimal maintenance intervals, and the annual cost of maintenance currently in use in the case study company for the selected oil and gas equipment

S/N	Oil and Gas Equipment	Annual Cost of maintenance proposed by the model	Annual Cost of maintenance currently in use
1	High pressure compressor	$739,559	$762,810
2	Pressure relief valve	$18,082	$29,580
3	Electric generator (1000kva)	$47,266	$186,152

Table 4.3: 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	High pressure compressor	$Y= 2 \times 10^6 – 104904x + 16423x^2$	21	$7,039,559
2	Pressure relief valve	$Y=87202– 1308x + 6x^2$	90	$18,082
3	Electric generator (1000 Kva)	$Y=209516 -5045x+36x^2$	50	$47,266

5.0 Conclusion

Markov model is just not a maintenance model; it tries to show both the positive and negative side of maintenance. Using Markov model, the progress of equipment can be monitored as it not only considered the operational and the failed state, it also takes into consideration the degraded and maintenance state. The beauty of Markov model is that some parameter gotten such as the component unavailability P_f due to failure and the component unavailability P_m due to maintenance can be used in other models such as the Probability Risk Assessment model to determine the reliability of system.

References

Ahuja, I.P.S. and Khamba, J. S. (2008): "Total Productive Maintenance: Literature Review and Directions," International Journal of Quality and Reliability Management, 25(7), pp.709-756.

Al-Najjar, B. and Alsyouf, I. (2004): "Enhancing a Company's Profitability and Competitiveness Using Integrated Vibration-Based Maintenance: A Case Study." European Journal of Operational Research", 157(3), pp. 643-657.

Inge L. B. (2011): Pre-work for Master Thesis, NTNU Department of Marine Systems. Rotvoll Trondheim, Norway.

Komonen, K. (2002): "A Cost Model of Industrial Maintenance for Profitability Analysis and Benchmarking." International Journal of Production Economy, 79(1), pp. 5-31.

Pintelon, L. and Van Puyvelde, F. (1997): "Maintenance Performance Reporting Systems; Some Experiences." Journal of Quality in Maintenance Engineering, 3(1), pp. 4-15.

Rankin, W., Hibit, R., Allen, J. and Sargent, R. (2000), "Development and evaluation of the Maintenance Error Decision Aid (MEDA) process", International Journal of Industrial Ergonomics, Vol. 26, pp. 261-276.

Tsang, A.H.C., Jardine, A.K.S. and Kolodny, H. (1999): "Measuring Maintenance Performance: A Holistic Approach." International Journal of Operation and Production Management, 19(7), pp. 691-715.

Vineyard, M., Amoako-Gyampah, K. and Meredith, J. R. (2000): "An Evaluation of Maintenance Policies for Flexible Manufacturing Systems." International Journal of Operation and Production Management, 20(4), pp. 409-426.