RESEARCH ARTICLE OPEN ACCESS

Optimization of Preventive Maintenance Practice in Maritime Academy Oron

Akpan, W. A[a], Ogunsola T. M[b]
[a]Mechanical Engineering Department, University of Uyo
[b]Boat and Shipbuilding Department, Maritime Academy, Oron

Abstract
This research study investigates preventive maintenance management of diesel engine generators at the Nigerian Maritime Academy, Oron. An optimization methodology taking cognisance of equipment age was applied on failure data of diesel engine generators obtained from the institution's maintenance data base to provide cost effective maintenance management / replacement programme for critical components of diesel engine generators. The analyzed results using Matlab provides a cost and reliability template which can be used to perform diesel generator maintenance management programme in the academy.
Keywords: Reliability, optimization, maintenance, modelling, maritime academy.

I. Introduction

The present Nigerian maritime academy Oron in Akwa Ibom State Nigeria started as a Nautical college of Nigeria in 1979 with a mandate to train shipboard officers, ratings and shore-based management personnel and in 1988 the college was upgraded to the present status and the mandate was expanded to training of all levels and categories of personnel for all facets of the Nigerian maritime industry (Wikipedia, 2014).

The epileptic power supply in Nigeria has prompted the academy to generate its electricity for the administrative activities of the institution using the diesel engine generators.

The diesel engine has become the overwhelming choice for marine industries both on board and off board.

This can be attributed to its, high performance. It has high reliability and a better fuel economy than gasoline engine and is more efficient at light and full loads. The diesel engine generator emits fewer harmful exhaust pollutants and is inherently safer because diesel fuel is less volatile than gasoline. However, diesel engines can be ineffective under certain conditions, thus affecting engine performance especially when poor diesel fuel quality is used and also when poor servicing and maintenance method is applied.

Maintenance is all actions which have the objective of returning a system back to another state. Thus, maintenance has the ability to bring back the system quickly to its normal functional state and reduces equipment down time (Moubray, 1995) and Tsang et al. (1999).

Maintenance can be categorized into two: corrective maintenance and preventive maintenance (Paz, 1994).
According to Koboa-Aduma (1991) Maintenance provides freedom from breakdown during operations. Maintenance of equipment is essential in order to:

(i) keep the equipment at their maximum operating efficiencies;
(ii) keep equipment in a satisfactory condition for safe operations; and
(iii) reduce to a minimum, maintenance cost consistent with efficiency and safety.

Maintenance can be perfect and imperfect Pharm and Wang (1996) and Nakagawa (1987).

The Nigerian Maritime Academy Oron has among others 500KVA, 600KV and 800KVA diesel engine generators to generate power for the administrative needs of the academy The maintenance costs of diesel engine generators in the academy is on the increase. This is mostly caused by lack of clear maintenance methodology by the institution to maintain these generators. The objective of this research is to conduct a maintenance methodology on 500KVA, 600KVA and 800KVA diesel engine generators own by the academy and to suggest ways maintenance and replacement actions should be performed on the generators with the objective of reducing the cost of maintenance at the required reliability of the diesel engine generators.

II. Methodology

The data were collected from both primary and secondary sources. The primary data were obtained from the log book for a period of three years. This data include the time of failure of the diesel engine generator, the components causing the failure and also when the failed components were repaired or replaced. The secondary information was obtained from maintainers, supervisors, engineers and managers. This information include: maintenance cost, failure cost and replacement cost of each part. Ten critical parts in the diesel engine were selected for the study. The data formed input into a maintenance and replacement model by Kamran (2008).The information was used to predict future maintenance planning for the three diesel generators in the next 60 months with the objective of reducing maintenance cost and increasing the reliability of the diesel generators used by the institution.

III. Optimization model

The model by Kamran (2008) provides a general framework that was applied on the study. In the total cost minimization equation, the constraints for the solution of the equation are as follows:

(i) Constraints that address the initial age of each component at the beginning of planning horizon.

Thus;

$X_{ij} = 0;\ i = 1\dots N$ 1

where i *= component, j = period& N=No of components*

(ii) Effective age of the components based on preventive maintenance activities recursively.

$$X_{i,j} = (1-m_{i,j-1})(1-r_{i,j-1})X_{i,j+1} + m_{j+1}(\alpha i X'_{j,j+1}) \quad 2$$

$i = 1\dots$ N and j = 2. . . T

$$X'_{i,j} = X_{i,j} + \frac{T}{J} \quad i = 1, \text{N and j} = 1...\text{T} \quad 3$$

$$m_{i,j} + r_{i,j} \leq 1;\ i = 1...\text{N and j} = 1...\text{T}$$

Where: $X_{i,j}$ *Effective age of component i at the start of period j,* $X'_{i,j}$: *Effective age of component i at the end of period j.*

T = No. of periods, J = No. of intervals, $m_{i,j}:\begin{cases}1\\0\end{cases}$ *if component i at period j is maintained,* otherwise.

$r_{i,j}:\begin{cases}1\\0\end{cases}$ *if component i at period j is replaced, otherwise,* αi: *Improvement factor of component i*

(iii) Condition/constraint preventing occurrence of simultaneous maintenance and replacement actions on the components.

$$\prod_{i=1}^{N}\prod_{j}^{T} e^{-(\lambda_i(X'_{i,j})\beta_i-(X_{i,j})\beta_i} >> RR_{series} \quad 4$$

$$m_{i,j},\ r_{i,j} = 0 \text{ or } 1;\ i = 1...\text{N and j} = 1...\text{T} \quad 5$$

$$X_{i,j}\ \ X'_{i,j} \geq 0;\ i = 1, \text{N and j} = 1...\text{T} \quad 6$$

Whereλi: *Characteristic life (scale) parameter of component i*

βi: *Shape parameter of component, i,* RR_{series}: *Required reliability of the series system of components.*

Consider the case where component *i* is maintained in period *j*. For simplicity, it is assumed that the maintenance activity occurs at the end of the period. The maintenance action effectively reduces the age of component *i* at the beginning of the next period. That is:

$X_{i,j+1} = \alpha i X'_{i,j}$ *for* i *= 1,…, N; j=1,…,T* and $(0 \leq \alpha \leq 1)$ 7

The term α is an "improvement factor", similar to that proposed by Malik (1979), Jayabalan (1992). This factor allows for a variable effect of maintenance on the aging of a system. When α = 0, the effect of maintenance is to return the system to a state of "good-as new". When α = 1, maintenance has no good effect, and the system remains in a state of "bad-as-old".

The maintenance action at the end of period *j* results in an instantaneous drop in the ROCOF of component *i*,. Thus at the end of period *j*, the ROCOF for component *i* is $v_i(X'_j)$. At the start of period *j* + 1 ROCOF drops to $v_i(0)$

If component *i* is replaced at the end of period *j*, the following applies:

$X_{i,j+1=0}$ *=0 for* i *= 1,…,N; j=1,…,T* *8* i.e., the system is returned to a state of "good-as-new". The ROCOF of component *i* instantaneously drops from $v_i(X'_{i,j})$ to $v_i(X'_{i,j})$

If no action is performed in period *j*, there is no effect on the ROCOF of component i and thus :

$X'_{i,j} = X_{i,j} + \frac{T}{J}$ *for* i *= 1,..., N; j=1,...,T* 9

$X'_{i,j+1} = X_{i,j}$ *for* i *= 1,..., N; j=1,...,T* 10

$v_i(X_{i,j+1}) = v_i(X_{i,j})$ *for* i *= 1,..., N; j=1,...,T* 11

T = No. of periods, j = No. of intervals, ROCOF = Rate of Occurrence of Failure

For a new system, the cost associated with all component levels of maintenance and replacement actions in period *j*, remains as a function of all the actions taken during that period.

The expected number of failures of component *i* in period *j*, i

$E[N_{i,j}] = \int_{X_{i,j}}^{X.i.j} v_i(t)dt$ *for* i *= 1,..., N; j= 1,..., T* 12

Under the Non- homogenous piosson process assumption (NHPP) the expected number of component *i* failures in period *j* is

$E[N_{i,j}] = \lambda_i(X'_{i,j})^{\beta_i} - \lambda_i(X_{i,j})^{\beta}$ *for* i *= 1,..., N; j= 1,..., T* 13

If the cost of each failure is F_i , which in turn allows the computation of, F_{ij}, the cost of failures attributable to component *i* in period *j* is:

$F_{ij} = F_i E[N_{i,j}]$ *for* i *= 1,..., N; j= 1,..., T* 14

Hence regardless of any maintenance or replacement actions (which are assumed to occur at the end of the period) in period *j*, there is still a cost associated with the possible failures that can occur during the period.

If maintenance is performed on component *i* in period *j*, a maintenance cost constant M_i is incurred at the end of the period**.** Similarly If component *i* is replaced, in period *j*, the replacement cost is the initial purchase price of the component *i*, be denoted by R_i.

For a multi-component system, the cost structure is defined as stated above the problem can be reduced to a simple problem of finding the optimal sequence of maintenance, replacement, or do-nothing for each component, independent of all other components. That is, one could simply find the best sequence of actions for component one regardless of the actions taken on component two and so on. This would result in *N* independent optimization problems. Such a model seems unrealistic, as there should be some overall system cost penalty when an action is taken on any component in the system. It would seem that there should be some logical advantage to combine maintenance and replacement actions, e.g., while the system is shutdown to replace one component, it may make sense to go ahead and perform maintenance/replacement of some other components, even if it is not at its individual optimum point where maintenance or replacement would ordinarily be performed. Under this scenario, the optimal time to perform maintenance/replacement actions on individual components is dependent upon the decision made for other components. As such, a fixed cost of "downtime", *Z* , is charged in period *j* if any component (one or more) is maintained or replaced in that period. Consideration of this fixed cost makes the problem much more interesting, and more difficult to solve, as the optimal sequence of actions must be determined simultaneously for all components.

From the vantage point, at the start of period *j* = 0, it is right to determine the set of activities, i.e., maintenance, replacement, or do nothing, for each component in each period such that total cost is minimized. In order to have X_{ij} age of component *i* at the end of period *j* by using equation 2. First, define m_{ij}, and r_{ij}, as binary variables of maintenance and replacement actions for component *i* in period *j* as:

$m_{i,j} \begin{cases} 1 \\ 0 \end{cases}$ if component *i* at period j is maintained, otherwise. 15

$r_{i,j} \begin{cases} 1 \\ 0 \end{cases}$ if component *i* at period j is replaced, otherwise. 16

The following recursive function of X_{ij}, X'_{ij}, m_{ij}, r_{ij}, α, with a constraint are constructed:

$$\begin{cases} X_{i,j} = (1-m_{i,j-1})(1-r_{i,j-1})X'_{i.j-1} + m_{i,j=1} + (\alpha X_{i,j-1}) & 17 \\ X'_{i,j} = X'_{i,j} + \frac{T}{J} & 18 \end{cases}$$

$m_{i,j} + r_{i,j} \leq 1$ 19

In addition, the initial age for each component is equal to zero:

$X_{i,j} = 0 \text{ for } i = 1, \ldots, N$ 20

If component replacement occurs in the previous period then,

$r_{i,j-1} = m_{i,j-1} = 0,$ 21

$X_{i,j}$. If a component is maintained in the previous period then

$r_{i,j-1} = m_{i,j=1} = 1$ *22*

$X_{i,j} = \alpha i X'_{i,j-1}$ *23*

and finally if nothing is done,

$r_{i,j-1} = o,\ m_{i.j-1} = 0$ and $X_{i,j} = X'_{i,j+1}$ *24*

which corresponds to our basic assumptions given in equation one. From the definitions of each type of cost, the total cost function is:

$$Total_{\min imum} Cost = \sum_{i=1}^{N} \sum_{j-1}^{N} [(F_i \lambda_i (X'_{I,J})^{\beta_i} - (X_{i,j})^{\beta_i}) + M_{i,j} m_{i,j} + R_{i,j} r_{i,j}) + \sum_{j=1}^{T} [Z(1 - \prod_{i=1}^{N} (1 - m_{i,j} + r_{i.j}))]$$

Subject to: 25

$X_{i,j} = 0$. i=1….N 26

$X_{i,j} = (1 - m_{i,j-1})(1 - r_{i,j-1}) X'_{i.j-1} + m_{i,j=1} + (\alpha X_{i,j-1})$ *i=1…N, j=2…T* *27*

$X'_{i,j} = X'_{i,j} + \frac{T}{J}$ i=1….N, j=1….T 28

$m_{i,j} + r_{i,j} \leq 1$ i=1….N, J=1….T 29

$\prod_{i=1}^{N} \prod_{j}^{T} e^{-(\lambda_i (X'_{i,j})\beta_i - (X_{i,j})\beta_i} >> RR_{series}$

$m_{i,j}$, $r_{i,j}$ = 0 or 1; i = 1. . . N and j = 1. . . T 30

$X_{i,j}$ $X'_{i,j} \geq 0$ i = 1, N and j = 1. . . T 31

This objective function computes the total minimum cost subject to the above stated constraints with input parameters from tables 1, 2 and 3.

The generalized reduced gradient and the simulated annealing algorithms were used to solve the cost minimization using Matlab software and the results presented in tables 4, 5 and 6. Tables 1, 2 and 3 were generated based on data obtained from maintenance log book and information from maintenance engineers.

IV. Results and discussion

The characteristic life λ, shape factor β , maintenance factor α , failure cost, maintenance cost, and replacement cost are presented in tables 1, 2 and 3 for 500KVA, 600KVA and 800KVA diesel generators respectively for the selected components shown in tables 1.2 and 3.

Table 1 Parameters for 500KV a diesel generator

Month	Component	λ(Days)	β	∝	Failure Cost (₦)	Maintenance Cost (₦)	Replacement Cost (₦)
1.	Injector Pump	950	0.0005	0.00025	128,000.00	68,000.00	91,000.00
2.	Calibration of Valve	1080	0.0007	0.00025	340,000.00	32,000.00	180,000.00
3.	Cutting of Ring	1090	0.0004	0.00025	210,000.00	80,000.00	170,000.00
4.	Top Gasket Cylinder Replacement	1170	0.0004	0.00025	260,000.00	80,000.00	183,000.00
5.	Radiator	1050	0.0004	0.00025	96,000.00	16,000.00	36,000.00
6.	Oil Pump	1005	0.0004	0.00025	80,000.00	16,000.00	80,000.00

7.	Injector Nuzzle	900	0.0005	0.00025	270,000.00	80,000.00	270,000.00
8	Air Filter	1160	0.0004	0.00025	120,000.00	40,000.00	80,000.00
9	Alternator	250	0.0006	0.00025	154,000.00	46,000.00	85,000.00
10	Water Pump	1050	0.0005	0.00025	87,000.00	40,000.00	70,000.00

The characteristics life and shape factors were calculated from failure data while the failure costs, maintenance costs and replacement costs data were obtained from maintenance engineers. The maintenance factors were assumed based on the frequency of failure of components.

Table 2 Parameters for 600KV a diesel generator

Month	**Component**	**λ(Days)**	**β**	**∝**	**Failure Cost (₦)**	**Maintenance Cost (₦)**	**Replacement Cost (₦)**
1.	Injector Pump	1100	0.0007	0.00010	128,000.00	68,000.00	91,000.00
2.	Calibration of Valve	800	0.0006	0.00010	340,000.00	32,000.00	180,000.00
3.	Cutting of Ring	470	0.0003	0.00010	240,000.00	80,000.00	190,000.00
4.	Top Gasket Cylinder Replacement	1020	0.0005	0.00010	310,000.00	80,000.00	189,000.00
5.	Radiator	1020	0.0004	0.00010	96,000.00	16,000.00	36,000.00
6.	Oil Pump	800	0.0005	0.00050	80,000.00	16,000.00	80,000.00
7.	Injector Nuzzle	900	0.0005	0.00050	270,000.00	80,000.00	270,000.00
8	Air Filter	1200	0.0006	0.00050	160,000.00	40,000.00	110,000.00
9	Alternator	990	0.0006	0.00050	210,000.00	76,000.00	115,000.00
10	Water Pump	780	0.0007	0.00050	87,000.00	40,000.00	70,000.00

The failure cost is higher than replacement cost which in the same vain higher than the maintenance cost. The costs of components in 600KVA, 700KVA and 800KV generators are different in some cases or similar in others.

Table 3 Parameters for 800KV a diesel generator engine

Month	**Component**	**λ(Days)**	**B**	**∝**	**Failure Cost (₦)**	**Maintenance Cost (₦)**	**Replacement Cost (₦)**
1.	Injector Pump	900	0.0005	0.00022	128,000.00	68,000.00	91,000.00
2.	Calibration of Valve	1050	0.0004	0.00035	340,000.00	32,000.00	180,000.00
3.	Cutting of Ring	1050	0.0005	0.00038	210,000.00	80,000.00	170,000.00
4.	Top Gasket Cylinder Replacement	980	0.0007	0.00034	33,600.00	6,720.00	28,800.00
5.	Radiator	1010	0.0003	0.00032	310,000.00	80,000.00	189,000.00
6.	Oil Pump	1015	0.0003	0.00028	96,000.00	16,000.00	36,000.00
7.	Injector Nuzzle	1020	0.0003	0.00015	80,000.00	16,000.00	80,000.00
8	Air Filter	1030	0.0005	0.00012	270,000.00	80,000.00	170,000.00
9.	Alternator	1010	0.0003	0.00025	270,000.00	80,000.00	170,000.00
10.	Water Pump	1110	0.0006	0.00020	120,000.00	40,000.00	80,000.00

In tables 4, 5 and 6 the minimum required reliability is presented in the third column by the decision maker, while a search algorithm of generalized reduced gradient and simulated annealing calculate the total optimized cost function for each component and the optimum reliability in the sixth column using Matlab software. A gap analysis shows the effectiveness of each algorithm. At 98% reliability and a total optimized cost of 7,082,250.51 naira, six number periods at ten months per period for the 60 months prediction has the highest cost. This is expected because of the high expected reliability of 98% and long period of maintenance. However this option is less preferable to 36 number of periods and about 1.7 months per period and a cost of 960,421,43 naira by generalized gradient method at a reliability of 50% for the 500KVA diesel generator as shown in table 4.

Table 4 Required reliability and total cost optimized function for 500KV diesel generator

No. of components	Number of periods	Required Reliability	Algorithm	Total cost optimized function value (OFV)	Reliability (%)	OFV Gap
10	6	98	Generalized reduced Gradient (GRG)	7,082,250.51	98.00	-
			Simulated Annealing (SA)	7,499,248.68	97.95	5.89%
	12	90	GRG	1,840,017.981	97.00	-
			SA	1,942,845.804	97.02	5.59%
	18	80	GRG	4,767,597.09	90.00	-
			SA	5,014,618.05	90.01	5.17%
	24	70	GRG	2,813,854.26	70.00	-
			SA	2,950,837.53	69.50	4.87%
	30	60	GRG	3,732,178.10	60.00	-
			SA	3,913,284.73	60.54	4.85%
	36	50	GRG	960,421,43	50.00	-
			SA	1,006,157.79	49.47	4.76%
	42	97	GRG	1,467,308.49	97.00	-
			SA	1,549,307.76	97.02	5.59%
	48	90	GRG	2,127,321.16	90.00	-
			SA	2,260,309.31	90.02	6.25%
	54	80	GRG	1,156,146.96	80.00	-
			SA	1,226,803.17	79.80	6.11%
	60	70	GRG	2,965,264.07	70.00	-
			SA	3,154,952.01	69.64	6.40%

However for the 600KVA and 800KVA diesel engine generators, 48 periods , representing an interval of 1.25 months, has the lowest cost of 950,421,43 naira at 50% reliability. This formulation presents different options for the decision maker and is effective in making maintenance management decisions for the assets.

Table 5 Required reliability and total cost optimized function for 600KVA diesel generator

No. of components	Number of periods	Required Reliability	Algorithm	Total cost optimized function value (OFV)	Reliability (%)	OFV Gap
10	6	97	Generalized reduced Gradient (GRG)	2,965,264.07	70.00	-
			Simulated Annealing (SA)	3,154,952.01	69.64	6.40%
	12	90	GRG	5,693,688.96	90.00	-
			SA	6,049,626.347	90.02	6.25%
	18	80	GRG	2,675,884.570	80.00	-
			SA	2,839,417,283	79.80	6.11%
	24	70	GRG	1,143.506.918	70.00	-
			SA	1,216,657.052	69.64	6.40%
	30	60	GRG	3.576,008.178	60.00	-
			SA	3,812,394.917	59.93	6.61%
	36	50	GRG	2,264,196.091	50.00	-
			SA	2,416,235.994	49.00	6.71%
	42	97	GRG	3,732,178.10	60.00	-
			SA	3,913,284.73	60.54	4.85%
	48	90	GRG	960,421,43	50.00	-
			SA	1,006,157.79	49.47	4.76%
	54	80	GRG	1,467,308.49	97.00	-
			SA	1,549,307.76	97.02	5.59%
	60	70	GRG	2,127,321.16	90.00	-
			SA	2,260,309.31	90.02	6.25%

Table 6 Required reliability and total cost optimized function for 800KVA diesel generator

No. of components	Number of periods	Required Reliability	Algorithm	Total cost optimized function value (OFV)	Reliability (%)	OFV Gap
10	6	80	Generalized reduced Gradient (GRG)	1,885,488.0	80.00	-
			Simulated Annealing (SA)	2,000,716.8	79.80	6.11%
	12	70	GRG	1,968,848.0	70.00	-
			SA	2,094,795.2	69.64	6.40%
	18	60	GRG	2,061,760.0	60.00	-
			SA	2,198,049.6	59.93	6.61%
	24	97	GRG	1,182,446.4	97.00	-
			SA	1,248,526.4	97.02	5.59%
	30	90	GRG	1,586,476.8	90.00	-
			SA	1,685,654.4	90.02	6.25%
	36	50	GRG	2,207,536.0	50.00	-
			SA	2,355,771.2	49.00	6.71%
	42	97	GRG	3,732,178.10	60.00	-
			SA	3,913,284.73	60.54	4.85%
	48	90	GRG	960,421,43	50.00	-
			SA	1,006,157.79	49.47	4.76%
	54	80	GRG	4,767,597.09	90.00	-
			SA	5,014,618.05	90.01	5.17%
	60	70	GRG	2,786,005.66	80.00	-
			SA	2,918,223.78	80.00	4.75%

V. Conclusions

The results presented from the research show that Kamran (2008) formulation can be used in maintenance decision making for diesel engine generators. The research also shows that shorter maintenance interval is much preferable for multiple component equipment at an optimum reliability of 50%. From the results, the generalized gradient method algorithm provides a lower total optimized cost compared to simulated annealing method and therefore recommended in solving such problems. This methodology is therefore recommended to the Maritime Academy Oron for effective maintenance management programme for the diesel engine generators.

References

[1] Kamran, S. M(2008) Preventive Maintenance and Replacement Scheduling: Models and algorithms. Ph.D thesis, University of Louisville, Kentucky, USA.
[2] Koboa-Aduma, B. (1991) “Maintenance Management of Small scale Industries’’, in the Proceedings of the International Conference Workshop on Engineering for Accelerated Rural Development (Eds) Anazodo, U. G. N. Chukwuma. G. O. and Chukwueze, H. O.; Faculty of Engineering, University of Nigeria, Nsukka. 243
[3] Jabayalan, V.; Chaudhuri, D. (1992) Sequential Imperfect Preventive Maintenance Policies: a case study , microelectronics and reliability, V 32, n 3 September pp 223-229
[4] Malik, M. A.K.(1979) Reliable Preventive Maintenance Scheduling, AIIE Transaction, V11, N 3 September, pp 221-228
[5] Moubray, J. (1995) Maintenance Management – A New Paradigm. (Online serial) Available: www.thealadonnetwork.com/PDFs/PartUK.pdf [June 18, 2013].
[6] Nakagawa, T. and Yusui, K, (1987) “Optimum Policies for System with Imperfect Maintenance”, *IEEE Transaction on Reliability*. Vol. R-36, No. 5, pp. 631-633.
[7] Paz, N. M. (1994) “Maintenance Scheduling: Issues, Results and Research Needs”. *International Journal of Operations and Production Management*. Vol. 14, No. 8, pp. 47-69.
[8] Pharm, H. and Wang, H. (1996) “Imperfect Repair”, *European Journal of Operational Research* Vol. 94, pp 423-438.
[9] Tsang, A. H. C., Jardine, A. K. S., Kolodry, H. C. (1999) “Measuring Maintenance Performance: A Holistic Approach’’ International Journal of Operations and Production Management. Vol. 19. 1ssue 1, pp. 691-715.
[10] Wikipedia (2014) Maritime Academy of Nigeria : Available [Online] http//en.wikipedia.org