

A Budget Based Optimization of Preventive Maintenance in Maritime Industry

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Abstract : This research work investigates preventive maintenance management of diesel engine generators at the Maritime Academy of Nigeria, Oron. A budget based optimization methodology taking cognisance of the age of the equipment was applied on failure data of diesel engine generators obtained from the institution maintenance data base to provide cost effective maintenance management / replacement programme for critical components of diesel engine generators. The results were analyzed using Matlab. The results provide effective cost and reliability template which can be used to perform a budget based maintenance planning programme in the Maritime Industry.

Keywords: Budget; optimization; maintenance; modeling;; reliability; diesel engines; maritime industry.

I. Introduction

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

The poor power supply in Nigeria country has prompted the academy to generate its electricity for the administrative activities of the institution using the diesel engine generators. The diesel engine is popular in maritime industries. 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 generator emits fewer harmful exhaust pollutants and is inherently safer because diesel fuel is less volatile than gasoline. However, diesel engines can be ineffective with poor maintenance method.

Maintenance is all actions which have the objective of returning a system back to another state. According to Moubray, (1995) and Tsang et al. (1999) maintenance has the ability to bring back the system quickly to its normal functional state and reduces equipment down time. Paz, (1994) categorized maintenance into two: corrective maintenance and preventive maintenance. Maintenance is very important in the life of any physical asset. The fundamental basis of any planned maintenance system is deciding in advance.

- The individual items of the plant and equipment to be maintained;
- The forms, method and details of how each item is to be maintenance;
- The tools, replacements, spares, tradesmen and time that will be required to carry out this Maintenance;
- The frequency at which these maintenance operation must be carried out;
- The method of administering the system and;
- The method of analyzing the results.

I

The introduction of planned maintenance scheme in an organization involve time, money and considerable amount of work. It has been shown that the benefits obtained from planned maintenance are numerous Kobo-Aduma (1991).

Maintenance provides freedom from breakdown during operations. Maintenance of equipment is essential in order to: keep the equipment at their maximum operating efficiencies; keep equipment in a satisfactory condition for safe operations; and reduce to a minimum, maintenance cost consistent with efficiency and safety (Kobo-Aduma (1991).

Studies on imperfect maintenance can be found in Pharm and Wang (1996) and Nakagawa (1987). The Maritime Academy of Nigeria Oron has 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 rising daily. This is caused by lack of clear maintenance methodology by the institution to maintain these generators. The objective of this research is to conduct a budget based 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 with the required reliability of the generators given any stipulated budget.

II. Methodology

Data for this research work were collected from both primary and secondary sources. The primary information was obtained from maintainers, supervisors, engineers and managers. This information include: maintenance cost, failure cost and replacement cost of each part. The main data were obtained from the log book for a period of five 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. Ten critical parts were selected for the study. This data formed input into a maintenance and replacement model developed by Kamran (2008). The information was used to predict future maintenance planning for the three diesel generators in the next five years with a given budget and the objective of reducing maintenance cost and increasing the reliability of the diesel generators used by the institution. The methods used in solving the problem are generalized reduced gradient (GRG) and simulating annealing (SA).

III. Optimization model

The model by Kamran (2008) provides a general framework that was applied on the study. In the reliability maximization 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.

$$\begin{aligned} &\text{Thus;} \\ &X_{ij} = 0; \quad i = 1 \dots N \end{aligned} \quad (1)$$

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

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

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

$$i = 1 \dots N \text{ and } j = 2 \dots T$$

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

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

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.

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

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

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

λi : 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:

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

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 $\alpha = 0$, the effect of maintenance is to return the system to a state of “good-as-new”. When $\alpha = 1$, maintenance has no 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 $v_i(X'_{i,j})$. At the start of period $j + 1$ the ROCOF drops to $v_i(0)$

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

$$X'_{i,j+1} = 0 \text{ for } i = 1, \dots, N; j=1, \dots, T \quad (8)$$

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 :

$$X'_{i,j} = X_{i,j} + \frac{T}{J} \text{ for } i = 1, \dots, N; j=1, \dots, T \quad (9)$$

$$X'_{i,j+1} = X_{i,j} \text{ for } i = 1, \dots, N; j=1, \dots, T \quad (10)$$

$$v_i(X_{i,j+1}) = v_i(X_{i,j}) \text{ for } i = 1, \dots, N; j=1, \dots, T \quad (11)$$

$T =$ 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

$$E[N_{i,j}] = \int_{X_{i,j}}^{X'_{i,j}} v_i(t) dt \text{ for } i = 1, \dots, N; j = 1, \dots, T \quad (12)$$

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

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

If the cost of each failure is F_i (in units of #/failure event), which in turn allows the computation of, F_{ij} , the cost of failures attributable to component i in period j is:

$$F_{ij} = F_i E[N_{i,j}] \text{ for } i = 1, \dots, N; j = 1, \dots, T \quad (14)$$

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 , 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 1 regardless of the actions taken on component 2 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 good 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 $X_{i,j}$ age of component i at the end of period j by using equation 2. First, define $m_{i,j}$, and $r_{i,j}$, as binary variables of maintenance and replacement actions for component i in period j as:

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

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

The following recursive function of $X_{i,j}, X'_{i,j}, m_{i,j}, r_{i,j}, \alpha$, with a constraint are constructed:

$$\begin{cases} X_{i,j} = (1 - m_{i,j-1})(1 - r_{i,j-1})X'_{i,j-1} + m_{i,j-1} + (\alpha X_{i,j-1}) \end{cases} \quad (17)$$

$$\begin{cases} X'_{i,j} = X'_{i,j} + \frac{T}{J} \end{cases} \quad (18)$$

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

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

$$X_{i,j} = 0 \text{ for } i = 1, \dots, N \quad (20)$$

If component replacement occurs in the previous period then,

$$r_{i,j-1} = m_{i,j-1} = 0, \quad (21)$$

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

$$r_{i,j-1} = m_{i,j-1} = 1 \quad (22)$$

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

and finally if nothing is done,

$$r_{i,j-1} = 0, m_{i,j-1} = 0 \text{ and } X_{i,j} = X'_{i,j+1} \quad (24)$$

The formulation of a budget constraint, GB is introduced. The objective of this model is to maximize the system reliability, through our choice of maintenance and replacement decisions, such that we do not exceed the budgeted total cost. This model is formulated as:

$$\text{Max Reliability} = \prod_{i=1}^N \prod_{j=1}^T e^{-[h(x'_{i,j}) \beta_i - h(x_{i,j}) \beta_i]} \quad (25)$$

Subject to

$$X_{ij} = 0; \quad i = 1 \dots N \quad (26)$$

$$X_{ij} = (1 - m_{i,j-1})(1 - r_{i,j-1})X'_{i,j-1} + m_{i,j-1}(\alpha X'_{i,j-1}) \quad (27)$$

$$i = 1 \dots N \text{ and } j = 2 \dots T \quad (28)$$

$$X'_{i,j} = X_{i,j} + \frac{T}{j}; \quad i = 1 \dots N; \text{ and } j = 1 \dots T \tag{29}$$

$$m_{i,j} + r_{i,j} \leq 1; \quad i = 1 \dots N; \text{ and } j = 1 \dots T \tag{30}$$

$$\sum_{i=1}^N \sum_{j=1}^T [F_i \alpha_i ((X'_{i,j})^{\beta_i}) - (X_{i,j})^{\beta_i}) + M_{i,j} \cdot m_{i,j} + R_{i,j} \cdot r_{i,j}] + \sum_{j=1}^T [Z(1 - \prod_{i=1}^N (1 - (m_{i,j} + r_{i,j})))] \leq GB \tag{31}$$

$$m_{i,j}, r_{i,j} = 0 \text{ or } 1 \quad i = 1 \dots N \text{ and } j = 1 \dots T \tag{31}$$

$$X_{i,j}, X'_{i,j} \geq 0 \quad i = 1 \dots N \text{ and } j = 1 \dots T \tag{32}$$

$$M_{i,j}, r_{i,j} = 0 \text{ or } 1; \quad i = 1 \dots N \text{ and } j = 1 \dots T \tag{33}$$

$$X'_{i,j} = X_{i,j} \geq 0; \quad i = 1, N \text{ and } j = 1 \dots T \tag{36}$$

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

λ_i : Characteristic life (scale) parameter of component i β_i : Shape parameter of component, i

RR_{series} : Required reliability of the series system of components. α_i : Improvement factor of component i

\sum : Summation, Π : Multiplication, F_i : Unexpected failure cost of component i in period j

N : No. of components, M_i : maintenance cost of component i , R_i : Replacement cost of component i , Z : Fixed cost of the system

Decision variables

$M_{i,j}$: $\begin{cases} 1 \\ 0 \end{cases}$ 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.

This objective function computes the maximum reliability subject to a given budget cost with stated constraints and 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	α	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 Nozzle	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	α	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 Nozzle	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 500KVA, 600KVA 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	α	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 Nozzle	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 given budget with maximum reliability is presented in the third and sixth columns 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 98.21% reliability and a given cost of 800,000.00 naira, six number periods at ten months per period for the 60 months prediction has a total cost of 800,000.00 naira and 792,027.2 naira as shown in table 4. From periods of 36 and above , the calculated total cost is less than the given budget. The optimized reliability lies between 46.96% and 84.71% for simulated annealing algorithm and 55.42% and 95.06% for generalized reduced gradient method.

Table: 4. Budget Algorithm and Optimized function value (OFV) for 500KVA

No. of components	Number of periods	Given Budget (₦)	Algorithm	Optimized Function Value (OFV) Reliability %	Total cost (₦)	OFV Gap (%)
10 For 500KVA	6	800,000.00	GRG	98.21	800,000.00	-
			SA	97.09	792,027.2	1.15%
	12	480,000.00	GRG	90.32	480,000.00	-
			SA	85.81	464,187.2	4.99%
	18	640,000.00	GRG	81.24	640,000.00	-
			SA	71.36	636,337.60	12.16%
	24	800,000.00	GRG	73.11	800,000.00	-
			SA	69.37	800,030.40	5.12%
	30	960,000.00	GRG	64.96	960,000.00	-
			SA	58.31	970,774.40	10.24%
	36	1,120,000.00	GRG	55.42	1,120,000.00	-
			SA	46.96	1,112,390.00	15.27%
	42	1,685,654.4	GRG	95.06	1,320,000.00	-
			SA	84.71	1,042,416.00	10.89%
	48	2,061,760.0	GRG	75.64	1,280,000.00	-
			SA	74.15	1,277,782.40	1.97%
	54	2,198,049.6	GRG	63.49	1,600,000.00	-
			SA	58.93	1,609,659.20	7.18%
60	2,918,223.78	GRG	52.15	1,920,000.00	-	
		SA	50.47	1951,516.80	3.22%	

For the 600KVA and 800KVA diesel engine generators, the same trend is followed. However, the allocated given budgets are much more higher than that of the 500KVA generator

Table :5. Budget Algorithm and Optimized function value (OFV) for 600KVA

No. components of	Number of periods	Given Budget (₹)	Algorithm	Optimized Function Value (OFV) Reliability %	Total cost (₹)	OFV Gap (%)
10 For 600KVA	6	1,600,000.00	GRG	97.53	1,600,000.00	-
			SA	97.43	1603,318.40	0.10%
	12	960,000.00	GRG	85.06	960,000.00	-
			SA	84.71	942,416.00	0.41%
	18	1,280,000.00	GRG	75.64	1,280,000.00	-
			SA	74.15	1,277,782.40	1.97%
	24	1,600,000.00	GRG	63.49	1,600,000.00	-
			SA	58.93	1,609,659.20	7.18%
	30	1,920,000.00	GRG	52.15	1,920,000.00	-
			SA	50.47	1951,516.80	3.22%
	36	2,400,000.00	GRG	49.91	2,400,000.00	-
			SA	46.93	2,425,304.00	5.97%
	42	2,355,771.2	GRG	98.21	800,000.00	-
			SA	97.09	792,027.2	1.15%
	48	3,432,178.10	GRG	90.32	480,000.00	-
			SA	85.81	464,187.2	4.99%
	54	2,207,536.00	GRG	64.96	960,000.00	-
			SA	58.31	970,774.40	10.24%
	60	3,732,178.10	GRG	55.42	1,120,000.00	-
			SA	46.96	1,112,390.00	15.27%

Table: 6. Budget Algorithm and Optimized function value (OFV) for 800KVA

No. components of	Number of periods	Given Budget (₹)	Algorithm	Optimized Function Value (OFV) Reliability %	Total cost (₹)	OFV Gap (%)
10 For 800KVA	6	480,000.00	GRG	90.32	480,000.00	-
			SA	85.81	464,187.2	4.99%
	12	960,000.00	GRG	85.06	960,000.00	-
			SA	84.71	942,416.00	0.41%
	18	640,000.00	GRG	81.24	640,000.00	-
			SA	71.36	636,337.6	12.16%
	24	1,600,000.00	GRG	63.49	1,600,000.00	-
			SA	58.93	1,609,659.2	7.18%
	30	1,920,000.00	GRG	52.15	1,920,000.00	-
			SA	50.47	1951,516.8	3.22%
	36	1,120,000.00	GRG	55.42	1,120,000.00	-
			SA	46.96	1,112,390.00	15.27%
	42	1,280,000.00	GRG	90.32	480,000.00	-
			SA	85.81	464,187.2	4.99%
	48	1,600,000.00	GRG	81.24	640,000.00	-
			SA	71.36	636,337.60	12.16%
	54	1,061,760.0	GRG	52.15	1,920,000.00	-
			SA	50.47	1951,516.80	3.22%
	60	2,198,049.6	GRG	49.91	2,400,000.00	-
			SA	46.93	2,425,304.00	5.97%

V. Conclusions

The results presented from the study show that the formulation is quite effective in maintenance decision making for diesel engine generators. The research shows that shorter maintenance interval is effective allowing budget surplus for the decision maker. The generalized reduced gradient gives a lower cost than the simulated annealing. This methodology is therefore recommended to the Maritime Academy Oron for effective budget based maintenance management programme for the diesel engine generators.

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