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Cost Effectiveness in Preventive Maintenance and Replacement Policy

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Abstract

Deciding whether to replace an item now or later, still remains a dilemma to owners and manufacturers of equipment. A lot of researchers have made efforts to determine the optimum time of replacement through various models. Replacement theory is confronted with the problem of replacement of men, equipment and machines due to deterioration, decreased efficiency, failure or breakdown. This paper uses the statistical package for social sciences (SPSS) for its data analysis. The data generated for this study were presented in tables and this helped simplified the arrangement of the data in sequential order for easier analysis and interpretation. The table shows the running cost per year and resale prices of the automobile (Toyota). The result clearly shows that the average total cost (ATC) is minimum at the 6th year-hence the need for replacement and suggests the need to look at mathematical approaches in tackling problems of preventive maintenance.

Keywords: *Automobile, Preventive maintenance, Replacement policy, Average total cost*

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Background to the Study

Deciding whether to replace an item now or later is always a dilemma to owners and manufacturers of deteriorating items. Decisions as to whether to replace or not should not only be made, but also decision as to how often to replace these items is necessary. The replacement theory is a decision-making process of replacing a used equipment with alternative substitute; mostly by a new item of superior quality. The replacement might be urgent due to the deteriorating item or malfunction or the breakdown of a particular item. Replacement theory is used in some cases such as when an item has outlived its usefulness, or it may not be economical any longer or the equipment might have been ruined or destroyed by accident. This paper seeks to ascertain whether the replaceable period of items can be determined.

Ajibola, (2012), opined that asset replacement theory is a management tool to analyses and plan the optimum replacement strategy to be adopted. According to Prem Kumar Gupta and Hira (2010), equipment needs replacement not because it no longer performs to the designed standards, but because more modern equipment performing at higher standards are discovered.

For an optimal replacement decision to be taken on an item, the following need to be considered:

a. The cost of the new item
b. The cost of the old item
c. Maintenance cost of the new item to be replace
d. Cost already incurred on the item to be replace
e. Tax and investment incurred on the item to be replace
f. Opportunity cost (Ajibade, Odusina, Rafiu, Ayaunde , Adeleke, and Babarinde, 2014)

Murthy, (2007), said when organizations or individuals decides to replace items, they may come across various alternatives where they have to compare the various cost elements such as running cost and maintenance cost. To be able to make an optimal choice, there are various strategies to decide the time to replace deteriorating items, these includes:

i. Replacement of equipment whose maintenance cost increase with time and value of money remains same during the period.
ii. Comparing alternative choices or the concept of present value.
iii. Replacement of items whose maintenance cost increase with time and value of money also changes with time.

Economic decision analysis is a useful tool, offering individuals and companies, the strategies to model economic decision- making problems, such as maintenance and replacement decisions, and determining an optimal decision. However, the accuracy of the model determines the validity of the conclusion. In many situations, the assumption of certainty in many models is made not so much for validity, but the need to obtain simpler and more readily solvable formulations. Importantly, the tradeoff is between an inaccurate, but solvable model and more accurate but potentially unsolvable one.

A decision maker can explicitly model the uncertainty using specific paradigms such as internal analysis, possibility theory, probability theory, or evidence theory (Behrens and Choobineh, 1989). A new economically sound methodology for assisting with equipment replacement at Texas DOT is presented. This new method takes full advantage of Texas DOT'S comprehensive equipment operating system database, can priorities the units on the basis of comparison among all units within any desired class of equipment and uses life-cycle cost trends as a replacement criterion. This methodology was implemented through the Texas equipment replacement model; a menu Driven software that allows the fleet manager to efficiently apply the methodology (Weisman and Gomas, 2006)

Kapoor (1999), identified the items to be replaced and also their Failure mechanisms. There are two types of failure; Gradual failure and sudden failure. Item such as machines equipment follow the gradual failure mechanism and they deteriorate with time. Such type of failure accounts for increased expenditure in the form of operating costs, decrease of productivity of the equipment and decrease in the values of the equipment; i.e. salvage value. The items which follow the sudden failure mechanism may fail anytime, thus precipitating the cost of failure. The cost of the failure of an item may be quite high as compared to the value of item itself. Sudden failure may cause loss of production and may also cause faulty product. This type of failure may cause safety risk to workers and road users. The item should be replaced before it actually fails.

The maintenance schedule of a Toyota automobile record, is found that the cost per year of running a car whose purchase price is N6,000,000 and the resale values are as follows:

Table 1: Shows the running cost and resale value of a Toyota automobile.

Year	Running Cost (₦)	Resale Value (₦)
1	500,000	4,000,000
2	650,000	2,500,000
3	800,000	1,500,000
4	900,000	1,000,000
5	1,200,000	750,000
6	1,400,000	500,000
7	1,800,000	300,000
8	2,250,000	180,000

Source: Kaura Motors, Kaduna 2022.

Model Specification

The mathematical approach to this problem is given by

$$TC = C - S + \int_0^n R(t)\,dt$$

When time 't' is a continuous variable and

$$TC = C - S + \sum_0^n R(t)$$

When time 't' is discrete variable

Methodology
Replacement of items whose efficiency deteriorate with time: When operational efficiency of an item deteriorates with time (gradual failure), it is economical to replace the same with a new one. For instance, the maintenance cost of a machine increases with time and a stage is reached when it may not be economical to allow the machine to continue in the system. Besides, there could be a number of alternatives on the basis of the running costs (average maintenance and operating cost) involved. In this section, we shall discuss various strategies for making such comparisons under different conditions. While making such comparisons, it is assumed that suitable expressions for running cost are available. (Darius, Bala, and Lambawan, 2018)

Model 1: Replacement policy for items whose running cost increases with time and value of money remains constant during a period.

Theorem 1: The cost of maintenance of a machine is giving as a function increasing with time and it scrap value is constant. If time is measured continuously, the average annual cost will be managed by replacing the machine when the average cost to date becomes equal to the current maintenance cost: If time is measured in discrete units, then the average annual cost will be minimized by replacing the machine when the next period's maintenance cost becomes greater than the current cost.

Symbols and Variables
C = Capital or purchase cost of new equipment
S = Scrap (or salvage) value of the equipment at end of t years.
R(t) = running cost of equipment for the year t
n = replacement age of the equipment.

When time 't" is a continuous variable: if the equipment is used for t years, then the total cost incurred over the periods is given by

TC = capital (or purchase) cost-scrap value at end of t years + running cost for t years.

$$TC = C - S + \int_0^n R(t)dt$$

Therefore, the average cost per unit time incurred over the period of years is:

$$ATC_n = \frac{1}{n}\left\{C - S + \int_0^n R(t)dt\right\}$$

Policy: Replace the equipment when the average annual cost for n years becomes equal to the current annual running cost. That is,

$$R(n) = \frac{1}{n}\left\{C - S + \int_0^n R(t)dt\right\}$$

When time t is a discrete variable: the average cost incurred over the period n is given by

$$ATC_n = \frac{1}{n}\left\{C - S + \sum_{t=0}^{n} R(t)dt\right\}$$

If $C - S$ and $\sum_{t=0}^{n} R(t)$ are assumed monotonically decreasing and increasing respectively, then the will exist a value of n for which ATCn is minimum. Thus, we shall have inequalities:

$$ATC_{n-1} \succ ATC_n \prec ATC_{n+1} \text{ or } ATC_{n-1} - ATC_n \succ 0 \text{ and } ATC_{n+1} - ATC_n \succ 0$$

Policy 1: IF the next year running cost R(n+1) is more than average cost of nth year, ATCn is economical to replace at the end of the nth years, that is

$$R(n+1) \succ \frac{1}{n}\left\{C - S + \sum_{t=0}^{n} R(t)\right\}$$

Policy 2: IF the present year running cost is less than the previous year`s average cost, ATCn-1 do not replace, that is,

$$R(n) \prec \frac{1}{n-1}\left\{C - S + \sum_{t=0}^{n-1} R(t)\right\}$$

Results and Discussions

All computations and analysis were done using software package and the statistical package for social sciences (SPSS).

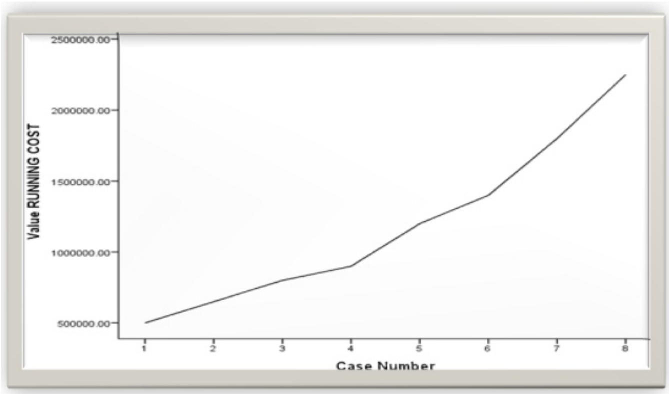

Figure 1: Represent the Running cost of maintenance from the first year to the eight year

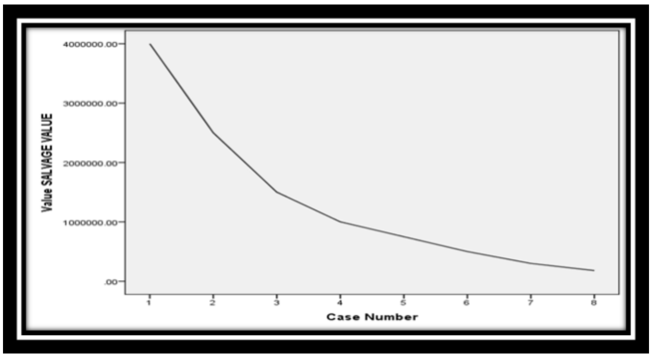

Figure 2: Represent the scrap value as the value deteriorate with time

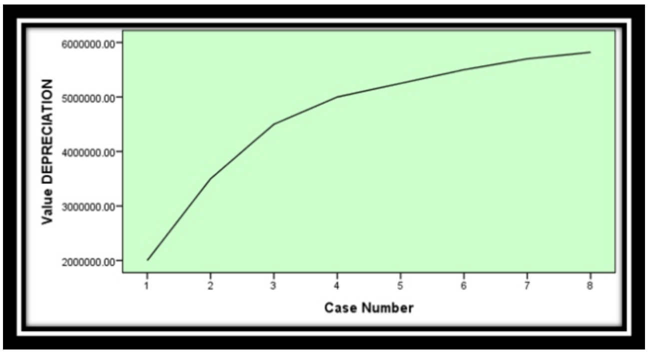

Figure 3: Shows the value of depreciation, indicating that the salvage value is less than 6000000

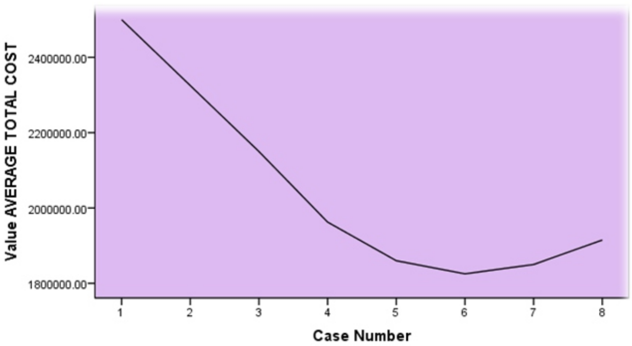

Figure 4: Represent the average total cost and the turning point is minimum in the sixth year

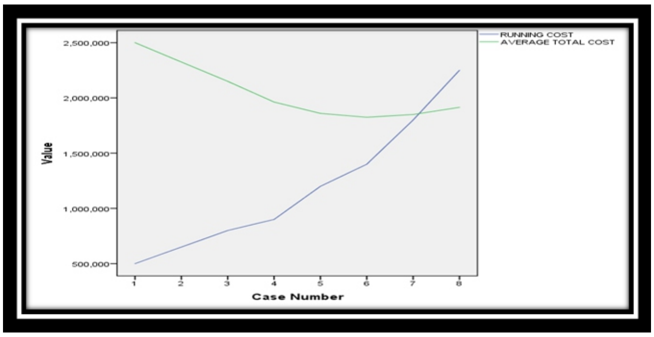

Figure 5: Shows the interception of the running cost and the average total cost at 1825000

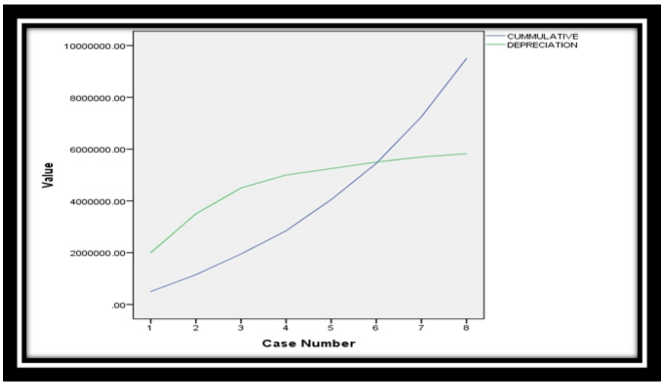

Figure 6: Represent the cumulative and depreciation intercepting in the sixth year

Table 2: Represent the total running cost

Year (n)	Running Cost R(n)(₦)	Cumulative $\sum R(n)$ (₦)	Purchase Cost Cost(C)(₦)	Salvage Value Value(s)(₦)	Depreciation C-S(₦)	Total Cost (₦)
(1)	(2)	(3)	(4)	(5)	(6)=(4)-(5)	(7)=(3)+(6)
1	500,000	500,000	6,000,000	4,000,000	2,000,000	2,500,000
2	650,000	1,150,000	6,000,000	2,500,000	3,500,000	4,650,000
3	800,000	1,950,000	6,000,000	1,500,000	4,500,000	6,450,000
4	900,000	2,850,000	6,000,000	1000,000	5000,000	7,850,000
5	1,200,00	40,50,000	6,000,000	750,000	5,250,000	9,300,000
6	1,400,000	5,450,000	6,000,000	5,000,000	5,500,000	10,950,000
7	1,800,000	7,250,000	6000,000	3000,000	5,700,000	12,950,000
8	2,250,000	9,500,000	6000,000	180,000	5,820,000	15,320,000

Table 3: Table 3 indicates that the average total cost ATC_n is minimum during the 6th year. The red color representing 1,825,000. Hence, the automobile should be replaced every 6th year.

Year (n)	Running Cost R(n)(₦)	Cumulative $\sum R(n)$ (₦)	Purchase Cost Cost(C)(₦)	Salvage Value Value(s)(₦)	Depreciation C-S(₦)	Total Cost (₦)	Average Total Cost (₦)
(1)	(2)	(3)	(4)	(5)	(6)=(4)-(5)	(7)=(3)+(6)	(8)=(7)÷(1)
1	500,000	500,000	6,000,000	4,000,000	2,000,000	2,500,000	2,500,000
2	650,000	1,150,000	6,000,000	2,500,000	3,500,000	4,650,000	2,325,000
3	800,000	1,950,000	6,000,000	1,500,000	4,500,000	6,450,000	2,150,000
4	900,000	2,850,000	6,000,000	1000,000	5000,000	7,850,000	1,962,000
5	1,200,00	40,50,000	6,000,000	750,000	5,250,000	9,300,000	1,860,000
6	1,400,000	5,450,000	6,000,000	5,000,000	5,500,000	10,950,000	1,825,000
7	1,800,000	7,250,000	6000,000	3000,000	5,700,000	12,950,000	1,850,000
8	2,250,000	9,500,000	6000,000	180,000	5,820,000	15,320,000	1,915,000

Conclusion and Recommendation

Average Total Cost (ATC) is minimum at the 6th year; hence it is important to replace the Vehicle after every 6th year. When the operational efficiency of an item deteriorates with time, it is normally economical to replace the item with a new one. Most at times, there are a number of alternatives and one may like to compare available choices on the basis of cost (average maintenance and operating cost). To arrive in this model, an assumption is made, that is, the value of money is constant. If the next year running say, R(n+1) is more than the average cost of the nth year ATC, then it is economical to replace at end of nth years, that is:

$$R(n+1) \succ \frac{1}{n}\left\{C - S + \sum_{t=0}^{n} R(t)\right\}$$

If the present year running cost is less than the previous year's average total cost ATCn-1 then do not replace, that is:

$$R(n) \prec \frac{1}{n-1}\left\{C - S + \sum_{t=0}^{n-1} R(t)\right\}$$

This paper therefore, recommends that: Management responsible for economic decisions, most especially in the area of maintenance and replacement decisions should as a matter of fact, enbibed economic-decision models to attain optimal decisions in solving their problems. However, the accuracy of the model determines the validity of the conclusion. Kaura Motors Kaduna, should continue to apply mathematical theories into their operations as a modern tool in decision making. This is not only to be applied in in one aspect of their operations like logistics but it should cover all areas of concern. Managers of assets are advice to always study the life cycle and the life cycle cost of their assets to enable them make optimal decisions.

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