USING DIAGNOSIS AND LIFE CYCLE COST TO IMPROVE RELIABILITY OF AN EXCAVATOR

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Abstract—Diagnosing of equipment before actual failure and reduced total ownership cost of excavator (TOC) is a significant issue for the mining and civil construction industries to unavoidably consider. Consequences of prolonged project execution time and extra cost due to sudden breakdowns are better minimized by studying the reliability of the equipment and having knowledge of life cycle cost model which was used in this research to ascertain the economic replacement time and cost of an excavator. Results from life cycle cost analysis carried out on an excavator show that the replacement time and total ownership cost of excavator 320C from 2010 to 2017 is 8 years and ₦10, 214 respectively.

Index Terms—Maintenance, Reliability, Diagnosis, Excavator and Life Cycle Cost.

I. INTRODUCTION

For every mining and construction company that owns or hires equipment for business purposes, it is very crucial to regularly monitor and analyze the reliability of their equipment to enable them increase productivity, favorably feature in the ever increasing competition and improve on their profit margins biannually or annually.

An important equipment commonly used for various projects in the mining and construction industries is the excavator. The excavator is an important heavy duty equipment in the mining and civil construction industry, which is primarily used for digging, loading and dumping Xiangyu *et al.* [1]. It moves on wheel or track and consists of boom, stick and bucket that are driven by their corresponding hydraulic actuators. Necessary steps which includes good operating practice and proper preventive maintenance (PM) actions for impending failure, proper corrective maintenance (CM) actions for failed excavator must be taken in other for it to be profitable Sharma, [2]. According to Qing and Hongqin [3], maintenance is primarily provided for the purpose of reducing failure by replacement, repair or servicing in order to achieve the economic utilization of the construction equipment during its work life. Reliability analysis is important in order to identify the equipment weakness and quantify the impact

of component failure Qing & Hongqin, [3]. Therefore, reliability study of equipment and early prediction of failure (unreliability) with a reasonable degree of accuracy will mitigate losses associated with time and cost Qing & Hongqin, [3].

An important aspect of reliability study which considers saving cost as well as answers the question of the most economic decision to replace an old equipment with a new one, is Life cycle cost analysis, Hamodi, [4]. According to Douglas *et al.* [5], for proper replacement analysis of construction equipment the data from its history card is collected, bearing in mind that the older an equipment gets the higher the repair and maintenance cost – which constitutes the largest amount of the operating cost.

It is basically estimating the procurement and ownership costs of an acquired equipment, which may include acquisition cost, operation cost, maintenance cost, installation cost, transportation cost, taxes, scrap value and equipment useful life. Life cycle cost analysis comprises of life cycle costs, equipment decision procedures, and replacement analysis models, Gransberg and Edward [6]. They further stated that life cycle costs for equipment has two component which are ownership and operating cost that determines the decision to repair, overhaul or replace equipment. According to Okoye [7], equipment replacement decision is hinged on the knowledge or outcome of a comparative cost analysis of how much cost is saved when old equipment is replaced with a new one as well as the consequences of non-replacement. It is worthy to know that equipment is not only replaced for the reason of its deterioration, but also for a reason of its failure to meet the advanced developmental standard, irrespective that it is in a good working condition, Mahajan, [8]. However this research work emphasizes on the need to replace and old equipment with a new one on the basis of its deterioration, after carrying out a life cycle cost on excavator 320C through a period of 10 years, using the excavator's history details which includes procurement cost, operating and maintenance cost and yearly interest rate.

As an effective approach to improving the reliability of equipment (excavator), studies show that early diagnosis of equipment fault is of great benefit as it brings about increase in plant and personnel safety, decrease in maintenance cost, reduction in spare parts provision, lowered insurance rates, minimized downtime and increased availability, Rosaler *et al.* [9]. Fredriksson & Larsson [10] in their research, guaranteed that failure will recur if the root cause of failure is not identified, as such the problem is not solved and losses as per cost of maintenance and delay will be incurred. They further stated that documenting this root causes in the work order history will prevent futuristic recurrence of failure. Tung and Yang [11] explained fault detecting as the task of indicating whether something is going wrong with equipment; fault isolating as locating the faulty component while fault identification as determining the nature of the fault when it is detected. Literatures review of Xu *et al.* [12], Tung & Yang [11] show that there is basically the data-driven and model-based methods of diagnosing equipment faults. Xiangyu *et al.* [1] proposed the principal component analysis (PCA) as fault diagnosis method.

This research considers the PCA and adopts the use of expert system which is a type of the data driven method to diagnose faults in excavator due to its convenience.

II. MATERIALS AND METHODS

A. Excavator Fault Diagnosis

For efficient diagnosis of equipment fault using expert system (shown in Figure 1), the equipment information data must be effectively communicated via a data link situated in the equipment as shown in Appendix A. The diagnostic expert system chosen for this research work is the Caterpillar Electronic Technician device (Cat ET). The procedure for diagnosing excavator faults is outlined as follows:

- (i) Put on the Cat ET
- (ii) Plug the communication adapter to the Cat ET.
- (iii) Ensure a firm connection of the other end of the communication adapter to the excavator's data link connector situated at the engine harness.
- (iv) Automatically the ECMs controlling the hydraulic system (shown in Appendix B) and engine displays (shown in Appendix C) as ECM₁ ECM₂ on the interface (computer monitor).
- (v) Click on ECM₁ for data and a fault code, say **72** displays.

- (vi) Click on the icon "SIS", which is service information system situated in the Cat ET and diagnostic code like this **CID/FMI 1-11** displays
- (vii) Read the description code that display **injector cylinder # 1, mechanical failure**. Where component identifier (CID) states that the injector cylinder 1 as faulty and failure mode identifier (FMI) shows that it failed due to mechanical failure.
- (viii) Print result page to commence with maintenance and repair.

Figure1: A pictorial view of an electronic technician expert system.

The block diagram of excavator fault diagnosis is shown in Figure 2.

Figure 2: Block diagram of Excavator diagnosis

B. Equipment Replacement Models

The decision to replace equipment is hinged on knowing the appropriate time to replace equipment as well as the most cost effective maintenance strategy to adopt. Therefore equipment replacement model for this research is discussed as follows:

C. Life Cycle Cost Model

Life cycle cost = Acquisition cost + Ownership cost

$$TOC_n = P + \Phi_C \quad (1)$$

Hamodi [4]

$$\Phi_C = \sum_{i=1}^n R_n - RV \quad (2)$$

Verma [13]

$$R_n = MC_n + OC_n \quad (3)$$

Verma [13]

$$OC_n = F_C + W \quad (4)$$

$$d = (1 + r)^{-n} \quad (5)$$

Verma [13]

$$RV = Pd^{n-1} \quad (6)$$

Therefore, by substituting equations (2) and (6) into (1), we have

$$TOC_n = P + [\sum_{i=1}^{RT} R_n - Pd^{n-1}] \quad (7)$$

$$W(n) = \frac{P + \sum_{i=1}^n R_n d^{n-1}}{\sum_{i=1}^n d^{n-1}} \quad (8) \text{ Verma [13]}$$

The economic time to replace equipment RT, is known when

$$R_n < W(n) < R_{n+1} \quad (9)$$

where

n = Number of years

P = Initial or purchase cost of equipment

TOC_n = Total ownership cost in n years

R_n = Running cost at n years

d = Depreciation value

r = Annual interest rate

RV = Resale or Scrap value

RT = Replacement Time

$W(n)$ = Weighted average of all cost

III. RESULTS

The running cost history of excavator 320C for 9 years, according to the plant admin department of MCC is shown in Table: 3.1. Procurement cost show that the initial cost of excavator 320C is ₦ 5,000,000 and the yearly interest rate of 10%. The result of life cycle cost (LCC) analysis performed is shown in Table I.

Table I: a life cycle analysis of Excavator 320C for 8 years

n	R_n	d^{n-1}	$R_n d^{n-1}$	$P + \sum_{i=1}^n R_n d^{n-1}$	$\sum_{i=1}^n d^{n-1}$	$W(n)$	$P + \sum_{i=1}^{RT} R_n$	Pd^{n-1}	TOC_n
1	538	1.000	538	5,538	1.000	5,538	5,38	5,000	538
2	786	0.910	715	6,253	1.910	3274	1324	4550	1774
3	895	0.828	738	6,991	2,738	2,553	2,219	4,140	3,079
4	1,087	0.753	818	7,809	3,491	2,237	3,306	3,768	4,538
5	1,178	0.656	773	8,582	4,147	2,069	4,484	3,429	6,055
6	1,585	0.590	935	9,517	4,737	2,009	6,069	3,120	7,949
7	1,800	0.531	956	10,473	5,268	1,988	7,869	2,655	10,214
8	3,410	0.517	1,763	12,236	5,785	2,115	11,279	2,585	13,694
9	3,786	0.428	1,620	15,539	6,683	2,325	18,645	2,140	21,505

Table II: running cost of excavator for 9years in MCC

Year of service	Operating Cost (× ₦ 1000)	Maintenance Cost(× ₦ 1000)
2010	201,000	337,000
2011	201,000	585,000
2012	203,845	691,155
2013	208,008	879,092
2014	208,151	969,849
2015	192,103	1,392,897
2016	152,089	1,649,011
2017	167,000	3,243,000
2018	193,189	3,592,811

IV. DISCUSSION OF RESULT

Looking at the life cycle cost analysis performed on excavator 320C from 2010 through 2017, results show that the most economical replacement time for the equipment is 7 years, since the value of the weighted average, $W(n)$ is minimum (1988) on the seventh year, with a total ownership value of ₦ 10,214. And this is justified by the condition that $R_n < W(n) < R_{n+1}$. The trend line in 2016 Microsoft Excel plot of total ownership cost (TOC) against time (n) and weight average, $W(n)$ against time (n) in figure 4.5 and figure 4.6 shows that the minimum values of TOC and $W(n)$ are ₦ 10,214 and ₦1988 respectively as pointed by the arrow heads.

V. CONCLUSION

Judging from the increase in running cost of the equipment during life cycle cost analysis, from ₦538, 000 to ₦3, 786,000 between 2010 and 2017 respectively; which has consequently increased total ownership cost from ₦538, 000 to ₦21, 505,000 is attributed to the constantly increasing maintenance cost of the equipment hinged on frequent contracting of maintenance of equipment to third party, owing to their use of expert system for diagnosis and better procurement management.

Based on the prevailing issues of poor equipment fault diagnosis and inadequate knowledge of equipment replacement time for effective decision and maintenance policies, it is recommended that:

- Expert diagnosing system be used as a preventive and corrective measure for diagnosis of equipment faults, in other to save time and cost.
- Life cycle cost analysis be carried out to help the management of any organization plan, make replacement decision and set maintenance policies that will save cost and time.

Figure 3: Total expected ownership cost for Excavator 320C.

Figure 4: Economic replacement time for excavator 320C

APPENDIX

A: Excavator Data Link Connector

B: Electronic Control Module for Hydraulic System

C: Electronic Control Module for Engine Unit

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