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Improving the Reliability of an Excavator Using Maintenance Management and 2-Parameter Weibull Distribution Model

EnyindahNdamzia Clement; B., Nkoi and O.E. ISAAC
Department of Mechanical EngineeringRivers State UniversityP.M.B.5080Port Harcourt Nigeria
Corresponding Author: E.O. ISAAC

ABSTRACT: *Reliability of excavator which will enhance increased profit margins, is a significant issue for the mining and civil construction industries. Consequences of prolonged project execution time and extra cost due to sudden breakdowns are better mitigated by studying the reliability of the equipment and predict the failures before occurrence. This research adopted the 2-parameter Weibull distribution model for reliability analysis and failure prediction of excavator. Results from reliability analysis of excavator showed that reliability decreased from 54.70% to 46.83% between 2014 and 2017, while it was predicted that 8 failures are expected 12 months after 2017.*

KEYWORDS*: Maintenance, Reliability, Weibull distribution, Excavator, Diagnosis.*

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I. INTRODUCTION

It has become increasingly crucial for every organization that owns or hires equipment for business purposes, to regularly monitor and analyze the reliability of their equipment to enable them increase productivity, blend well in the ever increasing competition and improve on their profit margins.

In the mining and construction industries, an important equipment commonly used for various projects 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 Xiangyuet al. [1]. It moves on wheel or track and consists of boom, stick and bucket that are driven by their corresponding hydraulic actuators. It is believed that based on excavator failure history, the hydraulic components are known as critical component due to their susceptibility to regular failure Sumar&Bayuseno, [1]. Xiangyuet al. [1] affirmed by further stating that, failures resulting from pump fault, valve fault and actuator faults are the most frequent failures experienced with excavator. 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, [3]. According to Qing and Hongqin [4], 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. Furthermore, predicting failures and repairing equipment before breakdown is essential for effective cost management of construction equipment. Therefore, managers should adopt the preventive maintenance approach to mitigate this breakdowns bearing in mind that it is cost effective and lessens work disruptions and its frequency.

Mahajan [5] held the view that it is only when maintenance management, which entails properly directing and organizing resources sets in, that the equipment which are reliable can be available to perform certain tasks. In the same vein, Murthy and Eccleston [6] emphasizes that it is only when maintenance strategies that are formulated are implemented, that we can say that there is maintenance management. Maintenance management is a combination of all technical, administrative and management actions during which the life cycle of an equipment intend to retain it in, or restore it to, a state in which it can perform a required function, Fredriksson and Larsson [7].In order to execute steps involved in maintenance management which includes understanding the equipment being maintained, planning optimal maintenance actions and implementing them, concepts and techniques from reliability analysis plays an important role according to Murthy and Eccleston [6].

Reliability analysis is important in order to identify the equipment weakness and quantify the impact of component failure Qing &Hongqin, [4]. 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, [4]. However this research adopts the Weibull distribution model for reliability analysis of case study (excavator) construction equipment, collecting working records of downtime, uptime, failures, and repair to make predictions of failure occurrences in the future.

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, Rosaleret al. [9]. Fredriksson& Larsson [7] 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 [10] 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. [11], Tung &Yang [10] show that there is basically the data-driven and model-based methods of diagnosing equipment faults. Xiangyu et al. (16] 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

Excavator Fault Diagnosis

For efficient diagnosis of equipment fault using expert system, the equipment information data must be effectively communicated via a data link situated in the equipment. 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 and engine displays as ECM_1 ECM_2 on the interface (computer monitor).

(v) Click on ECM_1 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.

The block diagram of excavator fault diagnosis is shown in Figure 1.

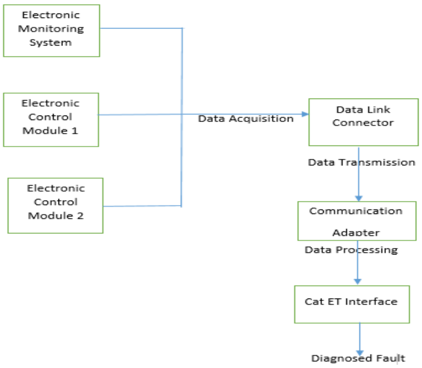


Figure 1: Block diagram of Excavator diagnosis

Equipment Reliability Model

The reliability tools to be used in this research work for failure prediction are, meantime before failure, availability, maintainability and a 2-parameters Weibull distribution model.

$$\text{MTBF} = \Upsilon + \eta \times \left({}^{1}/_{\beta} + 1\right) \qquad (2.1)$$

Ebeling [12]

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2.2}$$

Ebeling [12]

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2.3}$$

Ebeling [12]

$$\lambda(t) = \left({}^{\beta}/_{\eta}\right) \times \left({}^{t}/_{\eta}\right)^{\beta-1} \tag{2.4}$$

Ebeling [2]

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \tag{2.5}$$

Nwachukwu[13]

$$\text{MTTR} = \frac{\text{total failure hour}}{\text{number of failure}} \tag{2.6}$$

Nwachukwu, [13]

$$F.F = \frac{F(t+u) - F(t)}{1 - F(t)} \tag{2.7}$$

Abernethy [14]

For a sound reliability analysis of a system it is important to know the reliabilities of components that constitute the system.

$$R(t) = R_c(t) + R_n(t) \tag{2.8}$$

Lilly et al. (15),

where

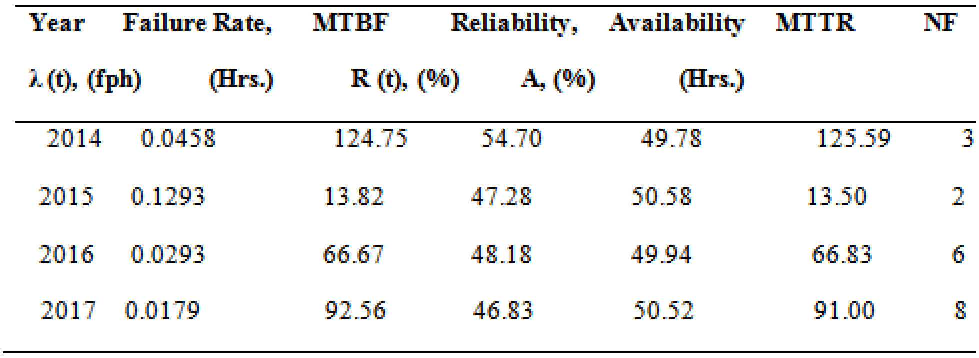
n = Equipment Life (years)
F (t) = Probability of Failure or fraction failing
t = Failure Time
R (t) = Reliability Function
A = Availability, (%)
MTBF= Mean Time before Failure
MTTR = Mean Time to Repair
λ (t) = Failure rate, (failure/hour)
N = No of Machines or components
F.R= Future Failure Risk
β = Shape parameter or slope
η= Scale parameter or characteristics life
Γ= Gamma function
$R_c(t)$ = reliability of collective critical component
$R_n(t)$ = reliability of collective noncritical components

The software to be used for analysis is PTC Windchill Quality Solution 11.0

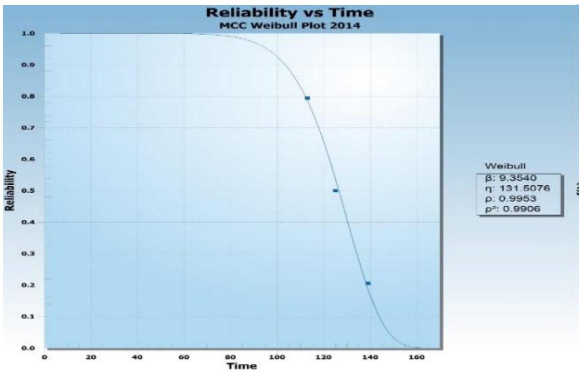
III. RESULTS

Table 1 shows the result of reliability analysis carried out from 2014 to 2017, while the Weibull plots for 2014, 2015, 2016 and 2017 based on the reliability models are shown in Figures 1, 2, 3, 4,5,6,7 and 8.

Table 1: Result of Reliability Analysis of Excavator 320C from 2014 to 2017



Year	Failure Rate, λ (t), (fph)	MTBF (Hrs.)	Reliability, R (t), (%)	Availability A, (%)	MTTR (Hrs.)	NF
2014	0.0458	124.75	54.70	49.78	125.59	3
2015	0.1293	13.82	47.28	50.58	13.50	2
2016	0.0293	66.67	48.18	49.94	66.83	6
2017	0.0179	92.56	46.83	50.52	91.00	8



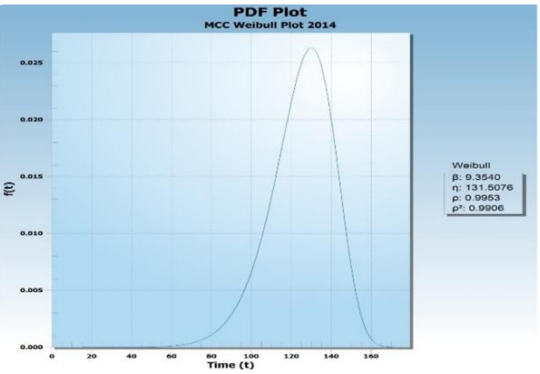
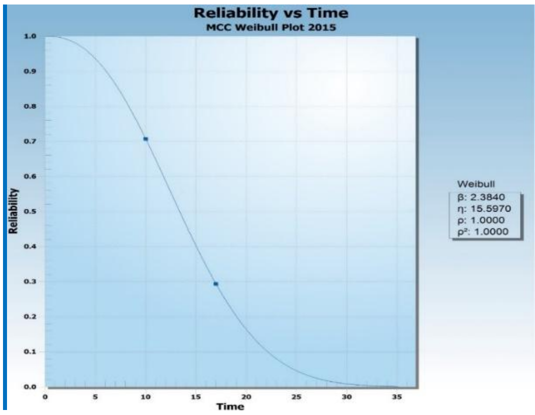


Figure 1: A Plot of Reliability for Excavator 320C in 2014Figure 2: A Plot of PDF for Excavator 320C in 2014



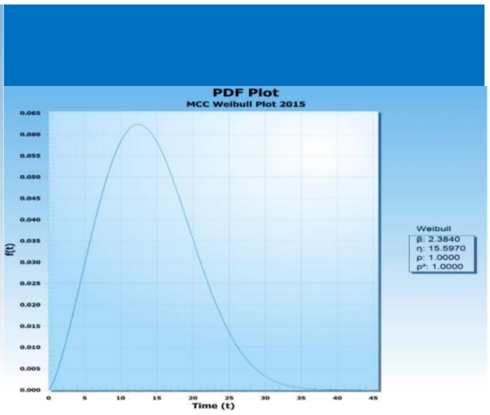
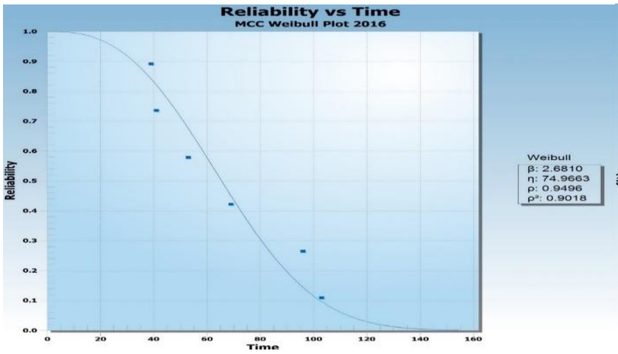


Figure 3: A Plot of Reliability for Excavator 320C in 2015 **Figure 4:** PDF for excavator 320C in 2015



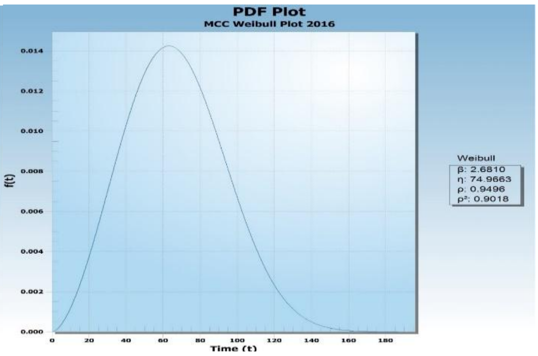
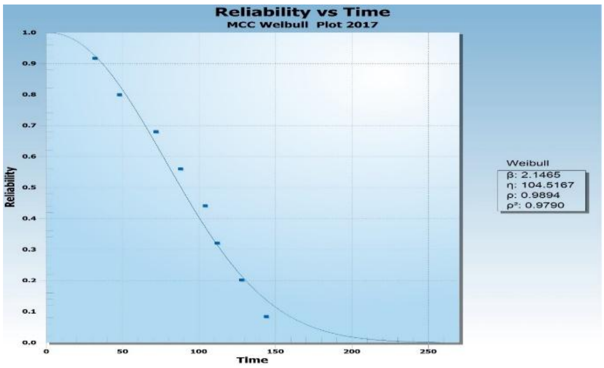


Figure 5: A Plot of Reliability for Excavator 320C in 2016 **Figure 6:** PDF for excavator 320C in 2015



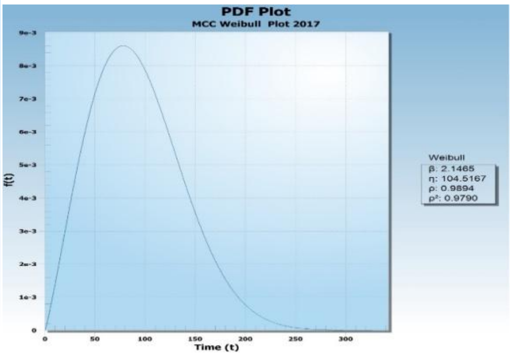


Figure 7: A Plot of Reliability for Excavator 320C in 2017 **Figure 8:** PDF for excavator 320C in 2017

Table 2: Excavator's predicted number of failure 12 months after 2017

No of Units (N)	Current Time on Each units (t)	Time on Each Unit in 12months, (t+ u)	F(t)	F(t + u)	Each Unit risk	Total Unit risk	$\frac{F(t+u)-F(t)}{1-F(t)}$ $\frac{F(t+u)-F(t)}{1-F(t)} \times N$
1	144	444	0.8855	1.0000	1.0000	1.0000	
1	128	428	0.8096	1.0000	1.0000	1.0000	
1	112	412	0.7062	0.9999	0.9999	0.9996	
1	104	404	0.6649	0.9999	0.9999	0.9997	
1	88	388	0.5077	0.9998	0.9999	0.9998	
1	72	372	0.3619	0.9999	0.9999	0.9998	
1	48	348	0.1639	0.9999	0.9999	0.9998	
1	31	331	0.0681	0.9999	0.9999	0.9999	
7.9986							

The predicted number of failure in 2018 will be 8.

Table 3: Reliability parameters of critical components in 2014

t (Hrs.)	NF	$F_C(t)$	$R_c(t)$	$\lambda_c(t)$ (fph)	MTBF (Hrs.)	MTTR (Hrs.)
139	1	0.8135	0.1865	0.1134	8.8183	139.0000
125	1	0.4632	0.5368	0.0467	21.4132	125.0000
113	1	0.2149	0.7850	0.0201	49.7535	113.0000
		30.0808	**0.0786**	**0.1795**	**79.9850**	**377.0000**

Table 4: Reliability parameters of critical components in 2017

t (Hrs.)	No of Failure	$F_C(t)$	$R_c(t)$	$\lambda_c(t)$ (fph)	MTBF (Hrs.)	MTTR (Hrs.)
144	1	0.8855	0.1145	0.0344	29.0698	144.3333
128	1	0.8096	0.1904	0.0296	33.7952	128.0000
112	1	0.7062	0.2938	0.0249	40.0962	112.0000
104	1	0.6449	0.3551	0.0227	44.1112	104.0000
88	1	0.5077	0.4923	0.0183	54.5851	88.0000
72	1	0.3619	0.6381	0.0142	70.5219	72.0000
48	1	0.1639	0.8361	0.0084	118.4834	48.0000
32	1	0.0681	0.9319	0.0050	119.2032	32.0000
	8	**0.0007**	**0.0005**	**0.1576**	**489.8660**	**728.0000**

Discussion of Reliability Result

In 2014, there is decrease in reliability and the shape of the probability density function (PDF) which did not start from the origin was as a result of the value of Weibull shape parameter, β= 9.3540, (β>3) as shown in figures 1 and figure 2 respectively. This means failure rate is consequently increases. The reliability of excavator when considering just the critical components is 7.86%.

In 2017, reliability decreases which indicates that the failure rate is on the increase. Meanwhile the Weibull shape parameter which is β=2.1465 (i.e. β<3), accounts for the probability density function (PDF) starting from the origin. The reliability of excavator 320C when considering only the critical components is 0.05%.

IV. CONCLUSION

Judging from the Weibull reliability analysis carried out on the case study excavator 320C, it is worthy to state that for an asset whose probability of performing without failing during a specified time frame to be as low as 54.70% let alone 46.83%, shows that it has low reliability and requires effective maintenance measures to improve its reliability. It is on this premise that the Weibull risk analysis performed predicted 8 failures in the future (being 2018), if effective diagnosis of equipment fault and proper maintenance management is not ensured.

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.
- Efficient reliability analysis be performed using the Weibull distribution tools that will help the management of any organization know the condition of equipment through reliability results and predicts of likely future failure occurrence in other to take preventive measures.

Contribution to Knowledge

This research work has made contributions in the areas of proposing the use of electronic technician (ET) expert diagnostic device for equipment diagnosis. This encourages the use of modern equipment that has electronic monitoring system for quick and reliable fault diagnosis. Secondly, performing reliability analysis that considers the reliabilities of critical components and reliability of the entire system due to failure, brings to attention that the sum of the reliabilities of critical components is an integral part of the reliability of the entire system. Finally, using PTC Windchill Quality Solution 11.0 software tool to model real time data, makes this work original and worthy contribution to knowledge.

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