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Application of Reliability Analysis for Predicting Failures in Cement Industry

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ABSTRACT
This research entails the use of reliability analysis for predicting failures of machines used in the cement industries and was done by evaluating machine down times data. This research work was necessitated by the need to accurately predict failures of the machines used in the cement industries and come up with an effective planning, for preventive maintenance schedule and reducing down times through developed mathematical model for the machines. The failure frequency variation with time was determined and a regression analysis using least squares methods. Correlation was done to ascertain the suitability of linear regression of the data and also to determine that, the independent variable is a good predictor of the dependent variable. The reliability model of the machines was achieved by applying the down times and the regression analysis result of the machines studied for a period of six years to the Weibull model. Two critical components of the machines were identified; contributing a total of 55 % of the down time. It was concluded that the critical components indicate the trend of failure of the machines. Therefore, reducing the failure rate of these components will increase the useful life of the machines and the obtained failure ratemodel, could be used as an important tool for predicting future failures and hence, effectively planning against such failures.
Keywords: *Reliability, Failure rate model, Prediction, Weibull, Critical components, Down-time.*

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I. INTRODUCTION

Reliability engineering is a tool used to define the probability that a unit component or system will perform its intended function uninterruptedly, under a specified operational working condition over a given period of time. According to Shakuntla et al reliability analysis helps us toobtain the necessary information about the control of various parameters. According to (Barringer and Barringer, 1997), reliability plays an important role in the selection of equipment for lowest long term cost of ownership.The study ofthe reliability of various units in production industry will yield a high level of machine performance with consistency, andit is important to study the variation of reliability with respect to time,(Deepika and Kuldeep, 2009).With a growing competitive market, there is the need to cut down cost of production, (Khan and Darrab, 2010), improve productivity and delivery performance of manufacturing systems which are important to the industries, (Hani, 2012). (Okpala and Kotingo, 2007)as well describe the reliability evaluation of a product or processto include a number of different analysis, depending on the phase of the product life cycle. (Damilare and Olasunkanmi, 2010) described the failure of an item entering a given age and time interval as the conditional probability, while the failure increases with time. Building a reputation on reliability takes a longtime, and only a short while for unreliability (Okpala and Kotingo, 2007). According to (Igor, 2004), the price for unreliability is very high, and reliability is the cure. According to(O’Connor and Kleyner, 2012), unreliability is so high a prize to be paid by any industry, and the survival of any industry is reliability.

The reliability of mechanical components is usually estimation from test or experience by mean time to failure (MTTF) for each machine. Several works exist showing the relationship between machine reliability and production level, and that productivity is tied to machine system reliability. Machine reliability is assessed by three phases of failure, the early life phase, useful life phase and the wear out phase. The application of reliability engineering analysis is a viable tool to machine satisfactionand the constant practice of machine reliability will always sustain a company with its products. Hence, there is need for machine reliability, which is the live wire for the sustenance of every business. This research dwells on identifyingthe three stages of failure and development of model for predicting the likely failure times of the various machine components under study.

II. METHODOLOGY

Data Collection

Reliability data was collected from the maintenance report books of work done procedures in a cement production industry in south-south zone of Nigeria. The data covers a period of six years from 2008 to 2014, which consist of themachine down-time and the number of failures for two identical machines code named BE machine 01 and BE machine 02. The BE machine 01 and 02 hasfourteen components namely;segment wheel drive (SWD), chain, shackle, shaft, twin chute, bearing, heavy duty gear box (HDGB), electric motor, wheel, flange set, counter weight, turbo and hub.Thesecomponents are arranged in series, thatis, the failure of one means the failure of the entire machine as production would stop.

Procedure

The data obtained from the maintenance report books of work done procedures of the cement production industrywere used for evaluating the total down time and the failure rates of the machines over six years. Also, through the Weibull model the data were subjected to life testing with aresultant modelling of the failure rate for the machines.

Total Down-Time

The total down-time for the machines over the study period of six yearswas evaluated. This was determined by summing up the monthly downtimes of all eighteen components of both machines over the study period of six years(2008 – 2014)and presented in tables 1 and 2.

Table 1: Total Down-Time of machine BE 01

Component	DT2009	DT2010	DT2011	DT2012	DT2013	DT2014	TDT
	(min)	(min)	(min)	(min)	(min)	(min)	(min)
SWD	0	0	0	0	0	0	0
Chain	134	0	107	133	80	290	744
Shackle	164	385	291	398	175	96	1509
Shaft	0	0	0	0	0	0	0
Twin Chute	0	0	0	0	0	0	0
Bearing	47	102	0	105	0	230	484
HDGB	0	0	0	0	0	0	0
Electric Motor	296	311	205	368	188	0	1368
Wheel	0	0	145	188	0	79	412
Flange Set	345	509	502	403	198	255	2212
Counter Weight	0	0	0	0	0	0	0
Turbo	163	0	0	0	0	268	431
Bucket	611	648	696	647	351	659	3612
Hub	0	0	0	0	0	0	0
						TOTAL	**10772**

Table 2: Total Down-Time of machine BE 02

Component	DT2009	DT2010	DT2011	DT2012	DT2013	DT2014	TDT
	(min)	(min)	(min)	(min)	(min)	(min)	(min)
SWD	0	0	0	201	0	0	201
Chain	217	177	136	160	179	345	1214
Shackle	205	140	168	317	262	234	1326
Shaft	73	0	0	0	186	0	259
Twin Chute	0	0	0	0	0	0	0
Bearing	47	0	212	209	83	257	808
HDGB	0	0	0	0	0	0	0
Electric Motor	53	174	247	234	140	0	848
Wheel	0	28	0	124	16	0	168
Flange Set	444	420	269	321	406	297	2157
Counter Weight	0	0	0	0	0	0	0
Turbo	85	231	0	205	199	17	737
Bucket	488	563	510	520	434	1079	3594
Hub	0	0	0	0	0	0	0
						TOTAL	**11312**

III. FAILURE FREQUENCY OVER TIME

The data obtained from the maintenance report books of work done procedures in a cement production industrywere used to determine the failure frequency variation with time. This was done by dividing the machine cumulative number of failures by the cumulative time of use of machine in hours to obtain tables 3 and 4 which were used in plotting the failure rate graphs for the machines in figures 1 and 2.

Table 3: Failure frequency over time for BE 01

Year	2009	2010	2011	2012	2013	2014
Cumulative time of use (hours)	8760	17520	26280	35064	43824	52584
BE 01 Cum. failure freq.	88	179	274	399	466	559
Failure Rate ($X10^{-3}$)	10.05	10.22	10.43	11.38	10.63	10.63
Rubber Coupling Cum. failure freq.	16	32	48	68	79	94
Failure Rate ($X10^{-3}$)	1.83	1.83	1.83	1.94	1.80	1.79
Bag Cleaner Cum. failure freq.	9	19	29	42	55	64
Failure Rate ($X10^{-3}$)	1.03	1.08	1.10	1.20	1.26	1.22

Table 4: Failure frequency over time for BE 02

Year	2009	2010	2011	2012	2013	2014
Cumulative time of use (hours)	8760	17520	26280	35064	43824	52584
BE 02 Cum. failure freq.	133	251	379	598	793	923
Failure Rate ($X10^{-3}$)	15.83	14.32	14.42	17.05	18.10	17.55
Bucket Cum. failure freq.	20	42	62	94	124	144
Failure Rate ($X10^{-3}$)	2.28	2.40	2.36	2.68	2.82	2.74
Flange Set Cum. failure freq.	13	25	38	60	82	94
Failure Rate ($X10^{-3}$)	1.48	1.43	1.46	1.71	1.87	1.79

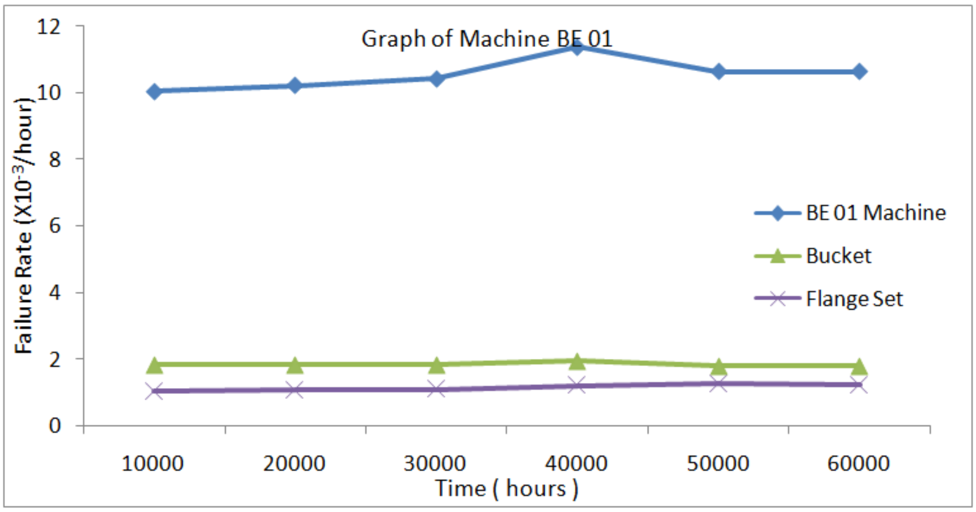

Figure 1: Graph of Failure Rate over Time of machine BE 01 and Critical Components

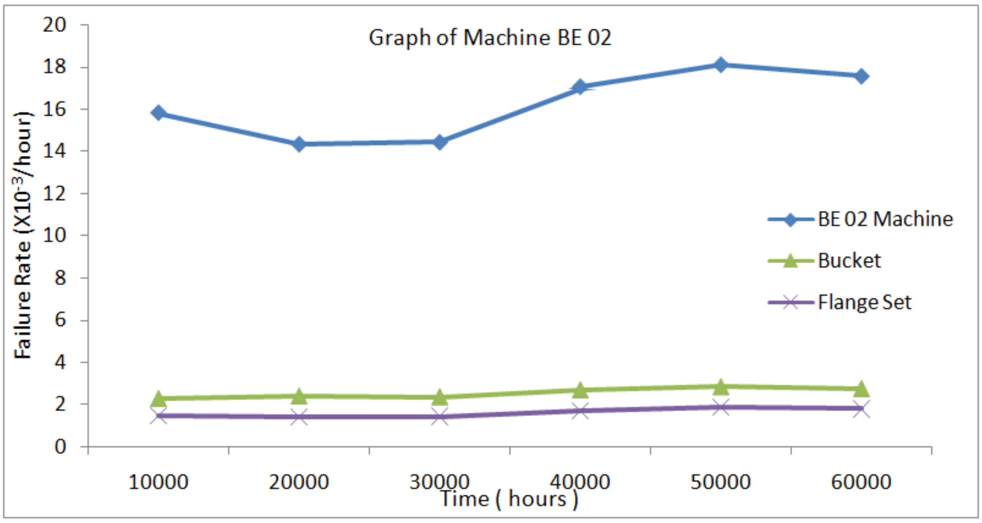

Figure 2: Graph of Failure Rate over Time of machine BE 01 and Critical Components

IV. MODELLING OF THE FAILURE RATE

According to (O'Connor and kleyner, 2012), it is useful in engineering to determine which distribution that best fits a set of data and to derive estimates of the distribution parameters.The Weibull model was used as the basisfor the modelling of the failure rate. (Lyonnet, 1991) stated that the Weibull model is the most suitable when carrying out reliability analysis for mechanical components and (O'Connor and kleyner, 2012) also stated that the Weibull probability data analysis is the most utilized technique for processing and interpretation of life data.

According to (O'Connor, 1991), the Weibull failure rate function is given by

$$Z(t) = \alpha\beta t^{\beta-1} \qquad (1)$$

Where:
α = scale parameter,
β = the shape parameter, also known as the Weibull slope.
t = variable time.
The failure density function according to (Lyonnet, 1991), is given as

$$F(t) = 1 - R(t), \qquad (2)$$

and the reliability function is given as

$$R(t) = 1 - F(t), \qquad (3)$$

the Weibull distribution is:

$$\ln\ln\frac{1}{R(t)} = \ln\alpha \qquad (4)$$

According to (O'Connor and Kleyner, 2012) the Weibull distribution is given by

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad (5)$$

which transforms to

$$\ln\ln\left[\frac{1}{1-F(t)}\right] = \beta(\ln t) - (\beta\ln\alpha) \quad (6)$$

The above equation is of a linear form $y = \beta x + c$

$$\text{Where}: y = \ln\ln\left[\frac{1}{1-F(t)}\right] = \ln F(t)\,, x = \ln t,$$

$$c = (-\beta\ln\alpha) = \ln\alpha, \text{ and } \beta = \text{slope}$$

Therefore, equation 6 can thus be written as

$$\ln\ln\left[\frac{1}{1-F(t)}\right] = \ln\alpha + \beta\ln t \qquad (7)$$

Therefore, using the recommended estimator by(Lyonnet, 1991) for the behavior of part failure, the values of the various parameters can be estimated. Thus, *F*(t) can be obtained by the given equation below.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \qquad (8)$$

Where n= sample times = 6, which corresponds to the number of years of study. i= the year from 1- 6
Therefore, the first year: i= 1, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_1) = \frac{1 - \frac{1}{2}}{6}$$

For the second year: i= 2, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_2) = \frac{2 - \frac{1}{2}}{6}$$

For the third year: i= 3, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_3) = \frac{3 - \frac{1}{2}}{6}$$

For the fourth year: i= 4, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_4) = \frac{4 - \frac{1}{2}}{6}$$

For the fifth year: i= 5, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_5) = \frac{5 - \frac{1}{2}}{6}$$

For the sixth year: i= 6, and n = 6.

$$F(t_i) = \frac{i - \frac{1}{2}}{n} \quad = \quad F(t_6) = \frac{6 - \frac{1}{2}}{6}$$

V. LEAST SQUARES AND LINEAR REGRESSION

To determine the values of β and α for machinesBE 01, the methods of least squares is used with the established linear relation Y = βx + lnα. The least square estimation applies to the *n* observation pairs of (x_iy_i), where *i*= 1, 2, 3,……, *n* which leads to the estimates.

A regression analysis is done and the formulation of tables 5 and 6 for the machines with the transformed linear function.

Where x_i = ln F(t), and y_i = ln t_i

With the corresponding values for*F(t)*, t_i and y_i regression analysis table was evaluated for BE 01 machine.

Table 5: Regression Analysis for machine BE 01

F(t)	t_i	x_i	y_i	x_iy_i	X^2	Y^2
0.08	8730	9.08	-2.53	-22.97	82.45	6.4
0.25	17439	9.77	-1.39	-13.58	95.45	1.93
0.42	26163	10.17	-0.87	-8.85	103.43	0.76
0.58	34914	10.46	-0.55	-5.75	109.41	0.3
0.75	43636	10.69	-0.29	-3.1	114.28	0.08
0.92	52355	10.87	-0.08	-0.87	118.16	0.0064
		Σx_i=61.04	Σy_i=-5.71	Σx_iy_i=-55.12	ΣX^2=623.18	ΣY^2=9.48

Table 6: Regression Analysis for machine BE 02

F(t)	t_i	x_i	y_i	x_iy_i	X^2	Y^2
0.08	8733	9.08	-2.53	-22.97	82.45	6.4
0.25	17464	9.77	-1.39	-13.58	95.45	1.93
0.42	26198	10.17	-0.87	-8.85	103.43	0.76
0.58	34944	10.46	-0.55	-5.75	109.41	0.3
0.75	43673	10.69	-0.29	-3.1	114.28	0.08
0.92	52395	10.87	-0.08	-0.87	118.16	0.0064
		Σx_i=61.04	Σy_i=-5.71	Σx_iy_i=-55.12	ΣX^2=623.18	ΣY^2=9.48

Correlation is determined to ascertain the suitability of linear regression for this data.

According to (Stevenson 1991).

$$r^2 = \left[\frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2) - (\Sigma x)^2}\sqrt{n(\Sigma y^2) - (\Sigma y)^2}}\right]^2$$

$$r = \left[\frac{6(-55.12) - (61.04)(-5.71)}{\sqrt{6(623.18) - (61.04)^2}\sqrt{6(9.48) - (-5.71)^2}}\right]$$

$$r = 0.996$$

From the above value, the independent variable is a good predictor of the dependent variable, therefore regression is very suitable.

The slope

$$\beta = \left[\frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2}\right]$$

$$\beta = \left[\frac{6(-55.12) - (61.04)(-5.71)}{6(623.18) - (61.04)^2}\right]$$

$$\beta = 1.35$$

Y intercept, lnα is given by

$$\ln \alpha = \left[\frac{(\Sigma y) - \beta(\Sigma x)}{n}\right]$$

$$\ln \alpha = \left[\frac{(-5.71) - 1.35(61.04)}{6}\right]$$

$$\ln \alpha = -14.69$$

$\alpha = e^{-14.69}$

$\alpha = 4.1708 X 10^{-7}$

Then for BE 01

$Z(t) = \alpha\beta t^{\beta-1}$

$Z(t) = 5.63 X 10^{-7} t^{0.35}$

$MTTR = \mu = \alpha^{-1/\beta}\Gamma(1 + 1/\beta)$

$MTTR = \mu = 4.17 X 10^{-7^{(-1/1.35)}}\Gamma(1 + 1/1.35)$

$MTTR = \mu = 52,613.76\ \Gamma(1.7)$

Where $\Gamma(1.7)$ is gamma function obtained from standard tables to be = 0.9086

$MTTR = \mu = 47,804.86$ hours

For Machine BE 02,
Table 5 and Table 6 for BE 01 and BE 02 respectively are almost the same apart from the second column that differs. The other six remaining columns for both machines are the same. Hence, the failure rate model and the mean time to failure for machines BE 01 and BE 02 are the same.

Reliability Model for the Machine
The reliability model is attained by recalling the modelled reliability Weibull distribution equation and substituting for the values of α and $\beta$for BE 01 machine intoequation 2.Therefore, the needed reliability model for the BE machines is given as

$$\ln\ln\frac{1}{R(t)} = \ln 4.17 X 10^{-7} + 1.35 \ln t$$

VI. DISCUSSION OF RESULTS

Total Down-Time of Machine
Table 1 and Figure1 presented results of the total down-time of machine BE01 over the six years period of study, with a total down-time of 10,772minutes. The two components with the highest percentage of down-times are the bucket and flange set, with each contributing 34% (3,612 minutes) and electric drive drum 21% (2,212 minutes) respectively making a total contribution of 55% to the total down-time. Observation of Table 2 and Figure2 also show a similar trend but this time contributing 31% to the total down-time of machine BE 02 which has a total downtime of 11,312 minutes, with bucket contributing 32% (3,594 minutes) and flange set 19% (2,157 minutes) respectively to the machine total down-time. The two components bucket and flange set with greater inputs to the machine down-time are the critical components of the machine, and the reduction of the down-times of these critical components would equally reduce the down-times of the machine.

Failure Rate Graph for Machine
The Bath-tub curve which is the ideal failure rate graph can be used to tell the operational state of any system. The curve may be divided into three stages, the early life stage with a decreasing failure rate, the useful life stage with a constant failure rate and the wear out stage with an increasing failure rate. Comparing a systems failure rate curve with that of the Bath-tub will give the stage at which a particular system is operating. The graph in Figure 1 shows that the machine (BE 01) and its flange set are still within its useful life stage, the bucket appears to have erratic failure rate tending towards the wear out stage. Observation of the graph of Figure 2 shows a similar trend with the slope of the flange set being similarto that of the machine and indicating that the failure rate of the flange set is adversely affecting the machine with a constant failure rate. The slope of the machine shows that the machine is tending towards the wear out portion, reducing the failure rate of the flange set will put the machine back to its useful life stage.

Modelling
The model obtained for machines BE 01 and BE 02, could serve as a very important tool in extrapolating the likely failure rate with time of each of these machines and hence, institute planned maintenance to reduce the down-time of the machines, save cost and increase productivity. A failure rate model obtained for any system can be used to predict when failure

VII. CONCLUSION AND RECOMMENDATION

This study looked at reliability engineering and shows how to predict reliability and demonstrate it with test and field data. Model was also developed with which machine failure in the cement industry in Nigeria could be predicted. Two components were identified as been critical for the machine operation. Thesaddle set and impeller blade, bothdepicts the trend of the machines failure. Therefore, reducing the failure rate of the two critical components of the machines will increase the useful life of the machines. It is recommended for the manufacturer to have these components arranged in parallel rather than in series, as this will in turn appreciate the useful life of the machines since the failure of a component will kick-start the parallel pair to take over its function and reduce the overall down-time of the machine.

The failure rate model obtained could serve as a working tool intheforecast or prediction of further future failure rate in the machinesand hence instituting a planned maintenance.

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