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Assessing the Sustainability of an Aluminum Roofing Sheet Corrugating Machine by Reliability Centered Maintenance and Cost Reduction Technique

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Abstract:
In any organized manufacturing firm, maintenance of the operational machines or equipment is prominent since adequate maintenance prevents the system from unnecessary breakdown, hence promotes productivity. This study thereforeassessed the capability and sustainability of an aluminum roofing sheets corrugating machine by reliability centered maintenance cost approach ina manufacturing firm in Port Harcourt. For data acquisition, breakdown and maintenance records of selected components of the machine was collected from the company. Exponential distribution was used for analysis of failure trend, reliability, and mean time between failures of the components. Maintenance cost was also analyzed. Results shows that the minimum rate of failure of roll bearingswas 0.00050403yr-1 in 2014, while the maximum was 0.00996678 yr-1in 2020. The maximum reliability of the system due to cutting device for the period investigated was 0.367. The maximum reliability of the corrugating machine from the perspective of electric motor was 0.3678. Similarly, the minimum mean time between failures of the machine components were: rolls 100 hours; cutting device 151 hours; de-coiler121hours; electric motor 151hours. The maintenance cost of the system for the period investigated follows: 5,749,421.21 Naira, 3,795,238.92Naira, and 4, 783,796.05 Naira for 2016, 2017 and 2018, respectively; 3,844,911.48 Naira, 4,637,049.52 Naira and 6,582,397.53 Naira for 2019,2020 and 2021, respectively. The proposed technique enhances a reduction of maintenance cost by 3.6%.

Keywords: Maintenance cost, Reliability centered maintenance, Corrugating machine,Sustainability, Roofing sheet

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I. INTRODUCTION

Aluminum sheets of different designs are currently available for different purposes, like residential and factory buildings. So, corrugating machines of complex patterns to meet the demand are being design and manufacture. Despite the ever-increasing design for accuracy and reliability, frequent failure of equipment and hence poor quality of products still exists. It is therefore essential to maintain the equipment for sustainability in good operating condition. However, this noble condition depends on the maintenance strategy and cost approach adopted.
Based on this perspective, the concept of reliability centered maintenance become paramount. The concept of reliability can be matched with systems concept, since equipment may have many series or parallel components which may function with series or parallel relationship. So, the individual component's reliability and maintenance cost adversely affects the reliability of the products. Hence, enough attention needs to be given to reliability of corrugating machine right from design for sustainable mass production of aluminum roofing sheets with minimum cost.

Reliability and maintainability of equipment in any manufacturing outfit plays a crucial role in ensuring the smooth running of the production process, because it ensures production continuity and product quality [1]. In an attempt to solve this critical issue related to maintenance of aluminum sheet corrugating machine, reliability centered maintenancewith cost reduction inclusive was usedto established an acceptable conclusion.This enhancedachievement of thedesiredoperation in the economical manner [2].[3] used best fitted distribution of failure and repair rates to investigate reliability, availability, and maintainability of strudel production line. In that study, reliability and maintainability models of strudel production line was developed, from which the reliability and hazard rate for the individual workstations,including the entire production line were determined. Results showed that both models were adequate for assessing the current maintenance conditions, and the prediction of reliability of the production line. [4] also carried out research on reliability centered maintenance for schedule improvement in an automotive industry. The number of checklists in the body shop was reduced and this resulted in a significant reduction in the operator's workload and prevented fraud. Results confirmed that the implementation of reliability centered maintenance provided a high level of success and the same methodology could be applied to equipment in other shops. [5] conducted a study on reliability centered maintenance for rotating equipment through predictive maintenance. Thestudy evaluated the effectiveness of the existing maintenance strategy with optimization proposals for paint booth fans process. The author concluded that successful reliability centered maintenance implementation in any given industry can ensure improved performance to gain an edge over competitors in the global market.

[6] investigated the properties of corrugated roofing sheet material from sugarcane bagasse fibers. The physical, mechanical, and thermal properties were tested. The parameters tested were TSI 876-2547and TIS 535-2556 concrete roofing tiles. The moisture content, thickness swelling, and water leakage were also tested, according to JIS A 5908-2003 (8 type). Similarly, modulus of rupture and modulus of elasticity were the mechanical properties tested based on TIS Standard test procedure (JIS A 5908-2003). The impact strength test was conducted based on ASTM D 256-2006a standard, while thermal conductivity and thermal resistivity were tested according to ASTMC177-2010 standard. Results of the experiments showed that sugarcane bagasse fiber had the best thermal conductivity and thermal resistance and as such, the achieved roofing sheet material was suitable for material asbestos roofing tiles making. Cost associated with maintenance was described as: down time cost due to equipment breakdown, cost of spares or other materials used for repairs, cost of maintenance labour and overheads of maintenance department, losses due to inefficient operations of machines, and capital requirements for the placement of machines [7].

From the reviewed works, reasonable number of researchers havestudied reliability centered maintenance on plant maintenance. However, only limited works has been established. Also, to the best of our knowledge, no researcher has conducted research on sustainability of aluminum roofing sheet corrugating machine byreliability centered maintenance, let alone consider the case study company selected for this study. Besides the proposed reliability centered maintenance of roofing sheet corrugating machine, this study also considered the cost associated with maintenance and possible reduction strategy

II. METHODS

Roofing sheet corrugating machine or equipment can be sustainedif appropriate maintenance policy is applied.For data acquisition, failure and cost of maintenance records of the componentswas collected. Reliability and cost reduction techniques were used for data analysis.

Determination of Failure Rate

The failure rate of the components of roofing sheet corrugating machine can be computed using Equation (2.1)[7].

$$\lambda = \frac{R}{t} \qquad (2.1)$$

where, λ is the failure rate, R is the number of failures and t is the time.

Determination of Mean Time betweenFailures

One of the indices of reliability adopted in this research is mean time between failures. It is regarded as maintenance metric for measurement of performance and safety of equipment.This approach assists maintenance department to elongate the time between failures of mechanical components. The mean time between failures can be computed with Equation (2.2)[7].

$$MTBF = \frac{1}{\lambda} \quad (2.2)$$

where, λ is the failure rate, and MTBF is the mean time between failures.

Determination of Reliability of Components

Exponential distribution is a reliability predictive model and is used in this study as in Equation (2.3)[7, 8].

$$\mathbf{R\ (t)} = e^{-\lambda t} \quad (2.3)$$

where, λ is the failure rateand t represent the time the machine was investigated.

Determination of Maintenance Cost

To improve the performance and sustainability of roofing sheet corrugatingmachine and other production equipment, it is essential to evaluate themaintenance cost. Some of the cost components utilized in this study were cost of labour, material cost, and cost of energy consumption. The corrective time can be obtained as given in Equation (2.4).

$$\mathbf{CLT = R \times F(t)} \quad (2.4)$$

where, CLT is the corrective lost time, R is the number of failures and F(t) stands for unreliability. In a similar way, the cost of materials can be computedby Equation (2.5).

$$MC = Pn \times Ci \quad (2.5)$$

where, M_C is the cost of materials, $P_n$stands for the number of part(s), and C_i represent the cost per part. Similarly, the labour maintenance cost can be determined from Equation (2.6).

$$LMC = N_T \times W \times CLT \quad (2.6)$$

where, N_T is the number of technicians, W stands for wage and CLT is the corrective lost time. Hence, the maintenance cost can be obtained according to Equation (2.7).

$$MC_R = LMC + MC \quad (2.7)$$

where, MC_R stands for reliability centered maintenance cost.

III. RESULTS AND DISCUSSION

The results of the data analyzed in this study are presented in the following subsections.

Analysisof Failure/Downtime of Roll

The failure of roll of sheet corrugating machine for the period investigated is presented in Figure 1.

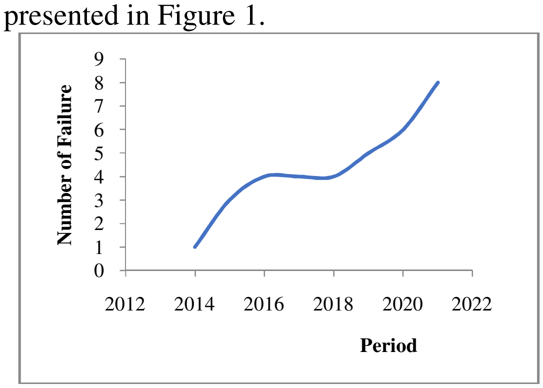

Figure 1: Failure of Rollers of SheetCorrugating Machine versus Year

From Figure 3.1, it was found that failures of roll bearings increased from the value of 1 in 2014 to 4 in 2016. The failure of roll bearings was also found to remain approximately constant at 4 within 2016 to 2018, but later increased steadily to a maximum value of 8 in 2021. The trend indicate that roll experienced the least failure in 2014 and maximum failure in the year 2021. The results revealed that with age of service, reliability of system components decreased as the failure increased. This trend is principally due to depreciation.

Analysis ofFailure/Downtime of Cutting-Device

Figure 2 is a plot of failures of cutting-device in relation to years of usage.

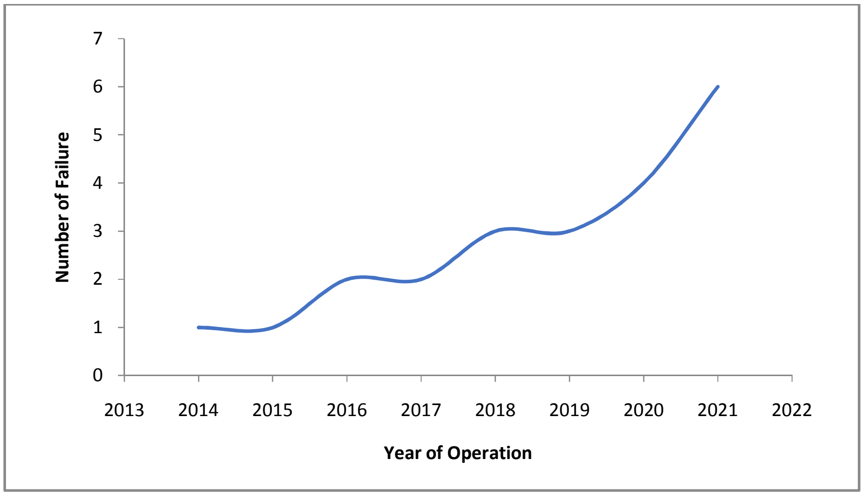

Figure 2: Failure of Cutting-Device of Corrugating Machine versus Year

From Figure 2, failure of cutting device occurred once in the year 2014 and 2015 as observed. It was, however, found that failure frequency of cutting device increased gradually to seven (7) in 2021. In 2016 to 2017, failures of cutting device were 2. Also, the results revealed that the failure frequency of cutting device was constant in 2017 and 2018, then increased to 4 in 2020, and 6 in 2021.

Analysis of Failure/Downtime of De-Coiler of Machine

The result of failure frequency of de-coiler also obtained from the company record, is depicted in Figure 3.

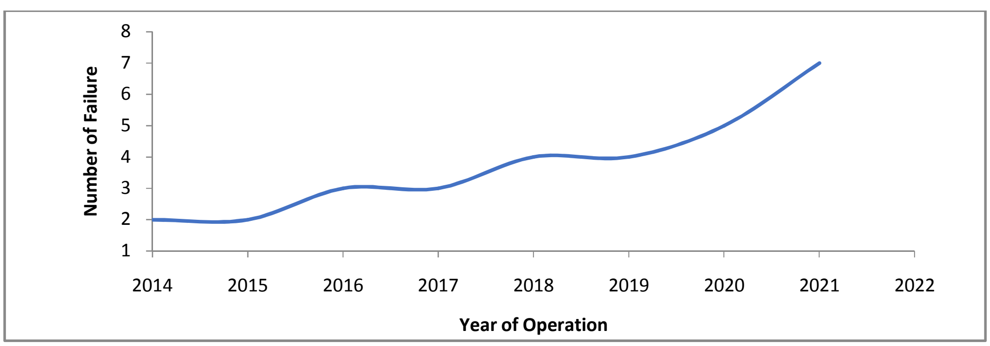

Figure 3: Failure of De-Coiler of SheetCorrugating Machine against Year

The number of failures of de-coiler of corrugating machine presented in Figure 3 indicated that 2 failures occurred in 2014 and 2015, 3 in 2016 and 2017, 4 in 2018 and 2019. The highest number of de-coiler failure was observed in 2021. This observation followed that the reliability of component or system decreases with year of service.

Analyzes of Failure/Downtime of Electric Motor

The failure of electric motor component of corrugating machine is shown in Figure 4.

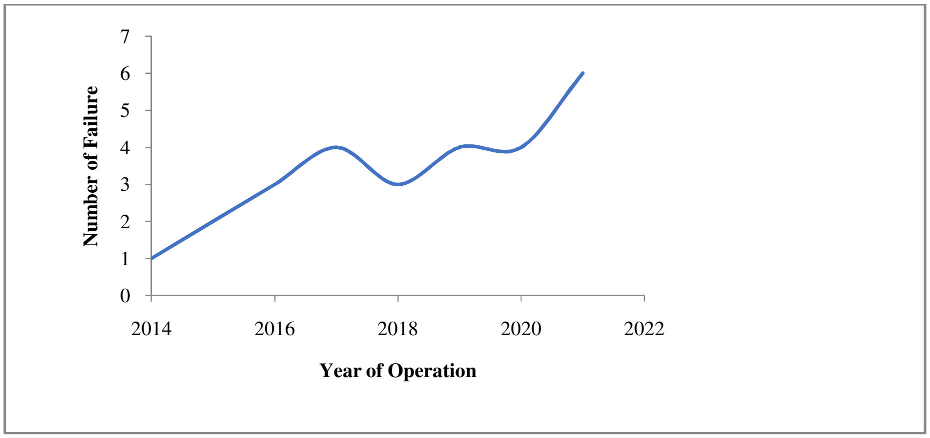

Figure 4: Failure of Electric Motor of Sheet Corrugating Machine against Year

According to results presented in Figure 4, number of failures of electric motor was found to occurred once in 2014, but later increased to a maximum value of 6 in 2021. This also, demonstrates the continuous depreciation of the component with the understanding of unreliability.

Analysis of Failure Rate of Corrugating Machine for Eight Years Period

To determine the failure rate of aluminum sheet corrugating machine, the operating time for the system was obtained from the company'smaintenance record. The operating time remained the same except forfailure interruption. The average failure rate of roofing sheet corrugating machine for the period studied due to failure of roller bearings is 3.13542× $10^{-3}yr^{-1}$. It was observed that the least failure rate (5.0403× $10^{-4}yr^{-1}$) occurred in 2014. However, failure rate was found to increase from 5.0403× $10^{-4}yr^{-1}$ to its maximum value of 9.96678× $10^{-3}yr^{-1}$ in the year 2020. The results indicatethat failure rate of roller bearings increased with age. Also, the failure rate of sheet corrugating machine due to failure of cutting device for the year 2014 to 2021 was obtained based on numerical application of failure rate model. The average failure rate of sheet corrugating machine due to failure cutting device is 2.00083× $10^{-3}yr^{-1}$. It was also, found that the minimum failure rate(5.0403× $10^{-4}yr^{-1}$) occurred in 2014. Similarly, failure rate was found to increase from5.50403× $10^{-4}yr^{-1}$ to its maximum value of 6.6252× $10^{-3}yr^{-1}$ in the year 2020. From the failure rate of De-coiler evaluated, it was found that the least failure rate (1.56250× $10^{-3}yr^{-1}$) occurred in 2014. Similarly, failure rate was found to increase from 1.56250× $10^{-3}yr^{-1}$) to its maximum value of 8.27814× $10^{-3}yr^{-1}$ in 2020. In addition, from the failure rate of electric motor evaluated, it was found that the least failure rate (1.54959× $10^{-3}yr^{-1}$) occurred in 2014. Failure rate was found to increase from 1.54959× $10^{-3}yr^{-1}$) to its maximum value of 6.62252× $10^{-3}yr^{-1}$ in 2020.

Analysis of Mean Time between Failures of Roll Bearing

Based on the data of mean time between failures evaluated statistically, the graph of MTBF of machine rollerbearings was plotted and presented in Figure 5.

From Figure 5, mean time between failures was found to decrease from 1984 hours in the year 2014 to 651 hours in 2015, but later remained approximately steady from 2016 to 2019.

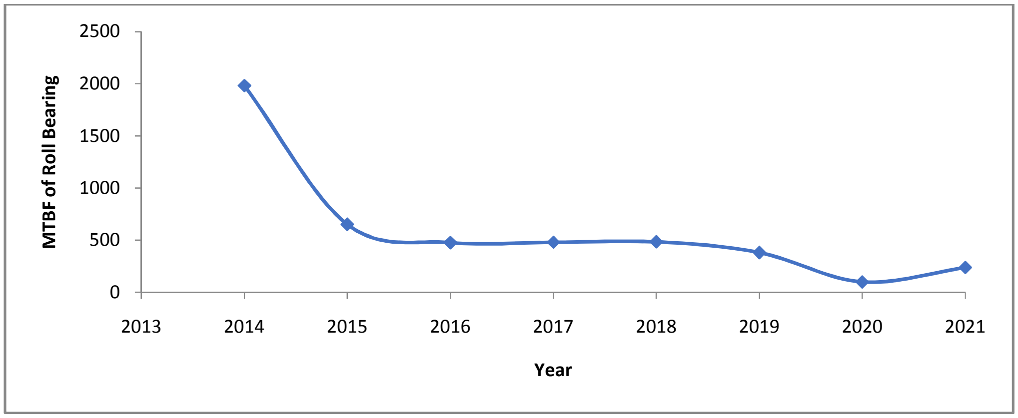

Figure 5: Mean Time betweenFailures of Roll Bearing

Similarly, the mean time between failures of roll bearings was found to decrease sharply to a value of 100 hours in 2020, however, later rises to a value of 238 hours in 2021. In practice, high mean time between failures indicates high reliability, while low mean time between failures signifies low reliability. Figure 5 illustrates that the machine roll has high reliability within 2014 and 2015, after which its reliability depreciated to the condition of repair every 100 hours of services, to avoid total breakdown.

Analysis of Mean Time betweenFailures of Cutting Device

The mean time between failures of cutting device for a period of eight years (2014 - 2021) investigated during the current study was evaluated, and the results were plotted as depicted in Figure 6.

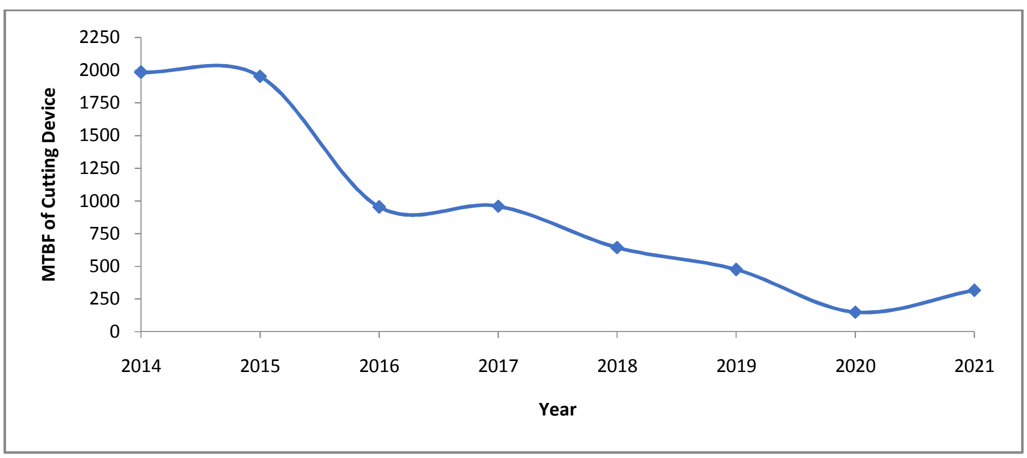

Figure 6: Mean Time between Failures of Cutting Device

As observed, the trend of the graph illustrates in Figure 6 revealed that mean timebetween failures decreased from its maximum value of 1984 hours in 2014, the start year of this study, to its minimum value of 151 hours in the year 2020. Since the correlation between reliability and mean time between failures is directly proportional, it is pertinent to state that the reliability of cutting device reduced to its least value in 2020. The mean time between failures was however, found to increase from 151 hours in 2020 to 317 hours in 2021. This observation was due to the maintenance conducted at the first quarter of 2021.

Analysis of Mean Time Between Failures of De-Coiler

In course of investigating the reliability of aluminum roofing sheet corrugating machine, the mean time between failures of de-coiler was evaluated and reported in Figure 7.

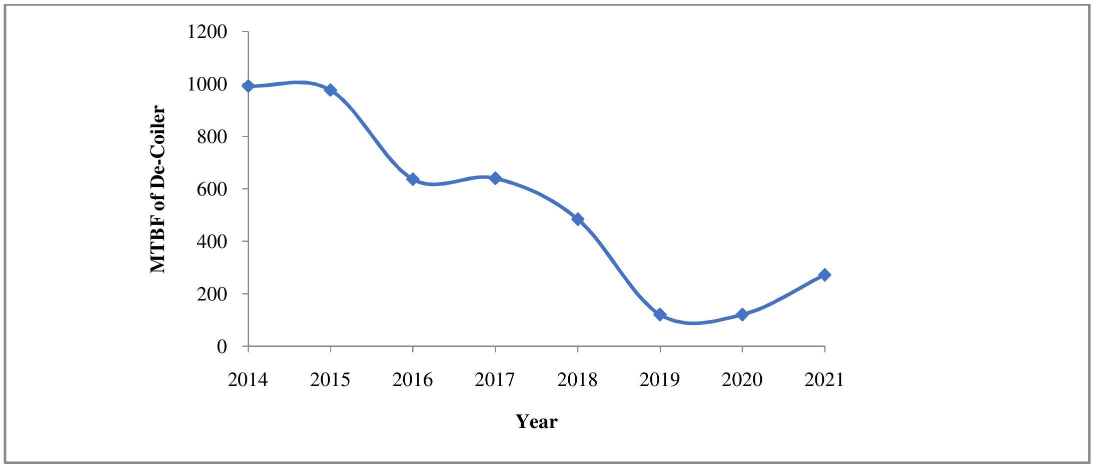

Figure 7: Mean Time between Failures of De-Coiler

From Figure 7, the maximum mean time between failures (992 hours) occurred in 2014. The maximum reliability of de-coiler was also observed in the year 2014. It was found that mean time between failures of de-coiler decreases from 976 hours in 2015 to 484 hours in 2018. Also, there was sharp decrease in mean time between failures of de-coiler from 484 hours in 2019 to 121 hours in 2020. As observed, the maintenance conducted in the first quarter of 2020 as reported by the company also improved the reliability of the de-coiler, hence the mean time between failures increased from 121 hours to 272 hours.

Analysis of Mean Time Between Failures of Electric Motor

In a similar development, the mean time between failures of Electric Motor was also evaluated and presented in Figure 8.

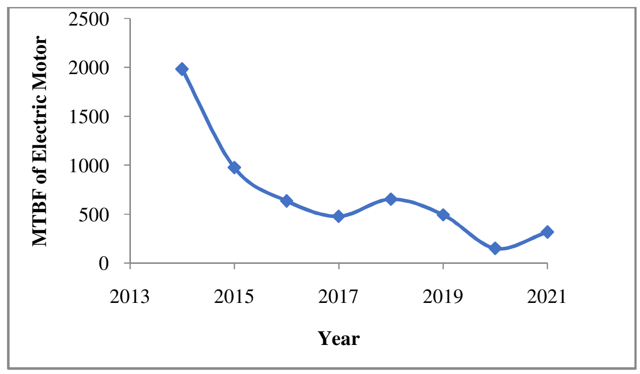

Figure 8: Mean Time Between Failures of Electric Motor

From Figure 8, mean time between failures was found to decrease from1984 hours to 480 hours in 2017. It was however, observed that from 2017, mean time between failures increased to a value of 655 hours in 2018, but later decreased to a minimum value of 151 hours in 2020. Also, due the general maintenance carried out in the first quarter of 2021, mean time between failures steps up to317 hours in 2021. The higher the mean time between failures is, the higher the reliability of the Electric Motor. The trend of the plotted graph indicated that reliability of the Electric Motor was relatively high in 2014, but decreased as the service year increased.

Analysis of Reliability of De-Coiler

The reliability of machine de-coiler is reported in Figures 9.

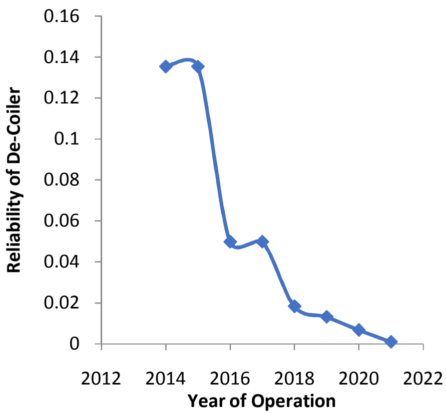

Figure 9: Reliability of De-Coiler and Year of Operation

From Figure 9, reliability of de-coiler remains constant for 2014 and 2015, then later decreases steadily until 2016. Between 2016 and 2017, reliability was found to remain approximately uniform. Reliability of de-coiler also decreased constantly between 2017 and 2018, and then decrease to zero in 2021. This result agreed with the result of Tarar (2014).

Analysis of Reliability of Machine Cutting Device

The evaluated results of reliability of machine cutting device for the period investigated was plotted and presented in Figure 10.

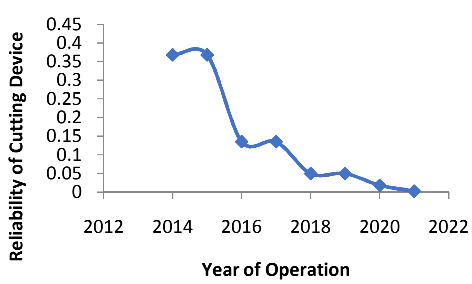

Figure 10: Reliability of Machine Cutting Device against Year of Operation

From Figure 10, reliability of cutting device remains constant for 2014 and 2015, then later decreases steadily until 2016. Between 2016 and 2017, reliability was found to remain approximately uniform. Reliability of cutting device was also viewed to decrease linearly between 2017 and 2018 and then decreased to zero in 2021.

Analysis of Reliability of Roller Bearings

The evaluated results of reliability for roll bearing for the period investigated was plotted and presented in Figures 11.

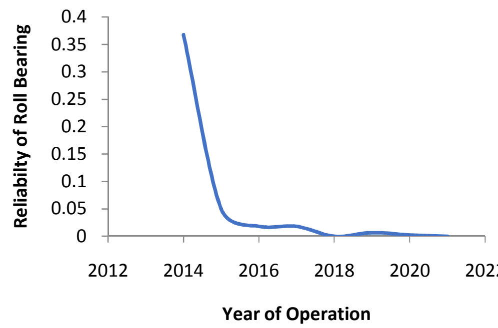

Figure 11: Reliability of Roll Bearing against Year of Operation

From Figure 11, it was found that reliability decreased gradually from the value of 0.36788 in the year 2014 to 0.04978 in the year 2015. Also, reliability of roll decreased sharply in the year 2016 to 2018. However, the reliability of roll bearing was found to decrease sharply from 2016 to 2018, and later decreased insignificantly with year of service between 2018 and 2022.

Maintenance Cost of Corrugating Machine Components

The maintenance costs of the corrugating machine obtained from the company record and the values evaluated based on reliability centered maintenance are illustrated under the following subheadings.

Maintenance Cost of System for 2014

The evaluated maintenance cost for the year 2014 is shown in Table 1.

Table 1: Maintenance Cost for 2014

Materials	Cost
Roll bearings material	N6,000
De-coiler material	N20,000
Cutting device	N5,400
Electric Motor	N19,500
Total Cost	**N50,900**

From the analysis, the corrective lost time is presented in Table 2.

Table 2: Corrective Lost Time (CLT Component)

Components	Failures	Unreliability	CLT
Roll Bearing	1	0.632119	0.632119
De-Coiler	2	0.8646635	1.69327
Cutting Device	1	0.632119	0.632119
Electric Motor	1	0.6321189	0.6321189
			3.5896268

$LMC = N_T \times W \times CLT = 5 \times 90{,}000 \times 3.5896268$ = 1,615,332.06

$MC_R = LMC + MC = 1{,}615{,}332.06 + 50900 =$ ₦1,666,232.06

The maintenance cost evaluated for the first data point (year 2014) was calculated as shown above. The cost of maintenance evaluated for other years (2015-2021) are presented in Table 3.

Table 3: Maintenance Cost of Corrugating Machine Evaluated

Year	PMC (N)	MC(N)	MC_R (N)
2014	1,929,164.95	19,500	1,666,232.06
2015	3,241,859.00	53,000	2,726,711
2016	5,986,141.30	70,750	5,749,421.25
2017	3,632,385.25	65,200	3,795,238.92
2018	4,964,837.40	97,666	4,783,796.05
2019	4,618,249.00	79,100	3,844,911.48
2020	3,773,864.50	63,000	4,637,049.52
2021	6,896,738.00	125,500	6,582,397.53
Total	**35,043,189.40**		**33,785,757.81**

In Table 3, PMC is the present maintenance cost, MCis the material cost and MC_Rstands for the reliability centered maintenance cost. The present maintenance cost of corrugating machine as obtained from the company's record amounted to the sum of N35,043,189.40. The maintenance cost, based on the proposed reliability centered maintenance evaluated amounted N33,785,757.81. The difference between the present maintenance cost and the proposed maintenance cost, based on the new maintenance policy expected to be implemented is N1,257,431.59. This represent a 3.6% cost to be saved for the period investigated.

IV. CONCLUSION

In course of this study, failure data was obtained from a manufacturing company in Port Harcourt. The data was analysed based on which the following are reached:

i. The least failure rate (5.0403×10^{-4}/hr) of the system occurred in 2014, while the maximum failure rate (9.96678×10^{-3}/hr) occurred in 2020.

ii. The highest mean time between failures (1984 hours) ofelectric motor component occurred in 2014, while the least value of 151 hours occurred in 2020. For continuous used of the machine, the Motor should be maintained less than 151 hours interval, regularly. Similarly, the maximum mean time between failures (992 hours) of de-coiler occurred in 2014, while the least value of 121 hours occurred in 2020. The maintenance of de-coiler is less than 121 hours interval. Also, the least mean time between failures of cutting device is 151 hours and the highest is 1984 hours. So that maintenance is less than 151 hours interval. In the case of machine roll, the least mean time between failures is 151 hours and the highest mean time between failures is 1984 hours. The expected maintenance time for roll is less than 151 hours.

iii. A 3.6% reduction in maintenance cost of the corrugating machine for the proposed maintenance policy was obtained.

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