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Performance Evaluation of Waste Compactor Truck Age on Deliverability: The Concept of Reliability

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ABSTRACT

The aim of this study was to carry out the effect of age on waste compactor truck using reliability analysis: a case study of the Rivers State Environmental and Waste Management film located in Port Harcourt. The research work was carried out on 19 components of the waste compactor truck which are age-dependent for the period of four years, from January 2016 to December 2019 using the Reliability Block Diagram method. The reliability metrics such as mean time between failure (MTBF), failure rate (FR), failure probability F(t) and reliability R(t) were evaluated using the data obtained from Truck operation over the period of 4 years (January 2016 to December 2019) such as number of failures per year (N_f), operating time per year simply called uptime (UT). The research showed that the average MTBF for the 1st and 4th year were 5263.6842 and 1793.8972, the average failure rate was 0.00019 for the 1st year and 0.00062 at the end of the 4th year. The average failure probability was 0.36687 in the 1st year and 0.63060 at the end of the 4th year, while the reliability value of the Waste Compactor Truck was 52.79% in the 1st year and 36.94% at the end of the 4th year. It was observed that as the truck became older, its MTBF and reliability decreased while the failure rate and failure probability increased as the age increased. This research recommends that new Truck is preferable to old Truck, and failed components of trucks should be replaced with new ones in order to enhance better performability and reliability, while the use of older components to replace failed components should be avoided since age has significant effect on the reliability of the Tuck.

Keywords: Age, Failure Rate, Mean Time between Failure, Probability, Reliability Percentage.

1. INTRODUCTION

Throughout history, most human activities naturally result in the generation of waste. Waste generation is an unavoidable products of human activities and is one of the major environmental issues affecting the world today. A sustainable management of such waste is a challenge faced in many countries today.

The challenge that derives from the generation of waste is not just coping with the volume, but also its composition and having the ability to design and accomplish its management in an efficient and sustainable manner. Improper waste management affect the health of the population living nearby the polluted area or landfills. Waste disposal workers and other employees in the landfill facilities including the environment are at greater risk. Improper handling and disposal of waste causes skin irritations, blood infections, respiratory and growth problems. Waste should be disposed of in a safe way which take into cognizance the health of the environment and that of the public while ensuring non detrimentally effects on generations to come (Martin, 2020). In an attempt to manage waste, vehicles (Waste Compactor Truck)/ mechanisms were designed to collect, haul, compact and transport the waste to a designated dumpsite (Hoornweg & Giannelli, 2009).

The investigation in to the effect of road and routing on truck performance studied by Henry *et al.* (2006), Hazra and Geol (2009) show that poor road networks and poor route planning during the physical development of the cites lead to frequent breakdown of trucks and as well affect effective waste collection and transportation to the dumpsite. The study by Ebeling (2004) on causes of garbage truck failure, and Hasan (2017) on automotive components failure show that failure is common over time as a result of defective components, error in design, human error related to failure, lack of effective maintenance, mechanical stresses, wear mechanism, temperature degradation and oxidation mechanism resulting to undesirable performance of the truck.

Nakagawa and Chang (2014), Ruetschi et al. (2004), Xue et al. (2013) and Zachariadis et al. (2001) investigated into the aging effect of mechanical system components and the results show that age leads to loss of capacity, degradation of active material and failure due to erosion, wear and tears.

2. MATERIALS AND METHODS

2.1. Population

The Rivers State Environmental and Waste Management Firm which serves as data source has many varieties of trucks ranging from shovels, rope shovel, toll-truck, waste compactor trucks amongst others. The use of the full population of the waste compactor truck is for optimization. Although the population is inclusive of similar waste trucks models. The waste compactor truck is responsible for the loading, hauling, compaction and transportation of waste.

2.2. Sample

The collection of data is obtained for a chosen 19 major aging-dependent components of the waste compactor truck operating within Rivers State between 2016 and 2019 whose failure automatically affect the performance of the truck. The period selected allows for a comparison from one year to the other to be made. These 4-years period also provide an opportunity to evaluate failures and analyze reliability of the truck.

2.3. Methods of Data Collection

In order to find answers to the research questions, data was obtained through primary and secondary sources; for primary data collection, field observation and interviews of some truck mechanics and waste compactor truck management personnel at the Rivers State Environmental and waste Management firm was done. The secondary data was retrieved through an extensive desk research of relevant literatures.

2.4. Research Approach

The quantitative approach which gives a mathematical analysis of the Truck and Component reliability is adopted in this work based on the complexity of the waste compactor truck. Some of the quantitative reliability approaches are presented using the Reliability Block Diagram method. It is possible to choose one or combination of these methods based on components failure behavior distribution model. However, due to the fact that the truck is a mechanical system involving complex components, the most appropriate and common method for analytical calculation of a mechanical system reliability based on component reliabilities is the block diagram method (Niknafs, *et al.*, 2018). This approach considers every system as a set of components so that the superposition of their interactions results to the overall function of the system.

2.5. Material Components

The 19 chosen material components that are analyzed include cylinder Head, Steering Pump, Hydraulic shaft, Radiator, Compressor, Turbo-charger, Gearbox, Oil filter, Alternator, Shock Absorber, Electrical converting unit, Rotor, Crankshaft, clutch, Axle, Pinion, Bearing, Compacting Pump and Brake system.

2.6. Model Analysis

The mathematical model for the Truck reliability indices such as mean time between failure (MTBF), failure rate (λ), failure probability (PROB), reliability and reliability percentage for the four (4) years study interval (S.I) was analysed.

2.6.1 Mean Time Between Failures (MTBF)

This is the predicted elapsed time between inherent failures of a system. It is mathematically expressed as (cadwallader, 2012):

$$MTBF = \frac{study\ interval}{No.of\ failures} = \frac{S.I}{N_f} \qquad 1$$

where S.I= study interval (the time period measured in hours within which the study is conducted), N_f=the number of failures recorded within the study interval.

Thus, S.I = number of hours per year=24hours×7 days×4 week×12 months=8760 hours.

However, the total mean time between failures for each components of the waste compactor truck for 4 years' study interval is mathematically expressed as (Beke *et al*.2020):

2.6.2. Total Mean Time Between Failure

According to Beke *et al., (*2020), the mathematical expression for the determination of total mean time between failure for a component is

$$(TMTBFPY)_c = \frac{annual\ hour\ per\ year}{total\ failure\ per\ year} = \frac{8760}{N_f} \qquad 2$$

where $(TMTBF)_c$ = total mean time between failures of components. Hence, the mean time between failures (MBTF) of the waste compactor truck as a system per year can be expressed as the average $(MTBF)_{av}$ of the components $(MTBF)_c$ within the study years interval using Monte Carlo Model equation (3)

$$(MTBF)_s = \frac{\sum_{c=1}^{c=19} (MTBF)_C}{N_c} \qquad 3$$

where $(MTBF)_C$ = MTBF of the components under investigation, N_c= number of components under investigation for the study period, and $(MTBF)_T$ = mean time between failure of the waste compactor truck (system).

2.6.3. Annual Mean Time Between Failure

The annual mean time between failures (AMTBF) of the waste compactor truck could be evaluated using the equation

$$(AMTBF)_{Spy} = \frac{(MTBF)_{c1} + (MTBF)_{c2} + \cdots + (MTBF)_{c19}}{N_c} \qquad 3$$

2.6.4. Failure Rate (FR)

The failure rate of the waste compactor truck can be determined using the expression below

$$\lambda = \frac{Number\ of\ failures\ in\ a\ given\ period\ of\ time}{Total\ operating\ time}$$

$$= \frac{N_f}{S.I} = \frac{1}{MTBF} \qquad 4$$

The components failure rate is denoted as λ_c is evaluated using the equation

$$\lambda_c = \frac{1}{(MTBF)_c} \qquad 5$$

And the Annual failure rate (AFR) of the waste compactor truck (system) is the average number of components mean time between failures per year represented by the equation:

$$\lambda_{Sy^n} = \frac{(\lambda)_{c1y^n} + \lambda_{c2y^n} + \cdots + \lambda_{c19y^n}}{N_c} \qquad 6$$

2.6.5. Probability Model

The probability of the system components to function can be expressed according to Zharkenov *et al.* (2017) using an exponential distribution equation as:

$$P(t)_c = e^{-\lambda_c t} \qquad 7$$

where λ_c= components failure rate, $P(t)_c$=probability of the component to function in time t and t= the operation time of the components in hours. Thus, the probability that the components fail is also considered as unavailability expressed by an exponential distribution equation according to Zharkenov *et al*. (2017) as:

$$F(t)_c = 1\text{-}\exp(-\lambda_c t) \qquad 8$$

where $F(t)_c$ is the probability that the components failed (unavailability). Hence the system probability failure for the four years' study can be expressed as:

$$F(t)_{Syn} = \frac{\sum[F(t)_{c1} + F(t)_{c2} + \cdots + F(t)_{c19}]}{n_c} \qquad 9$$

where n_c=19 (number of components under study), $F(t)_{Syn}$=failure probability of the system(waste compactor truck), s= system, y=year and n=1,2.3 and 4 (number of years of study). thus equation 9 is used repeatedly to calculate probability failure of the system for four years.

2.7. Reliability Model

The easiest method to represent failure probability of the components of the waste compactor truck is its reliability expressed as an exponential (Poisson) distribution equation (Patarasuk, *et al*., 2016) as:

$$R(t)_c = \exp\left(-\frac{t}{\text{MTBF}}\right) = \mathrm{e}^{-\lambda t} \qquad 10$$

$$\text{where } (\text{MTBF}) = \frac{1}{\lambda} \qquad 11$$

where λ = failure rate of each component, $R(t)_c$= reliability each components of the waste compactor truck.
t= the operating hours of each component. Component reliability of the 1st, 2nd, 3rd and 4th year for the first component based on equation 10 is sampled as:

$$R(t)_{c1} = \exp\left(-\frac{t}{\text{MTBF}}\right) = \mathrm{e}^{-\lambda t}$$
$$R(t)_{c1} = \mathrm{e}^{-0.00011\times 2688} = 0.73576,$$
$$R(t)_{c1} = \mathrm{e}^{-0.00023\times 2352} = 0.58451,$$
$$R(t)_{c1} = \mathrm{e}^{-0.00046\times 2016} = 0.39830,$$
$$R(t)_{c1} = \mathrm{e}^{-0.00057\times 1680} = 0.38331$$

Thus, the reliability of the waste compactor truck (system reliability) for the four-year study interval is obtained based on its individual component reliabilities which could be defined as average sum of the reliabilities of all the components per year expressed as:

$$R(t)_{Sy^n} = \frac{\sum_{n=1}^{c=19} R(t)_c}{N_c} =$$

$$\frac{(e^{-\lambda t})_{c1} + (e^{-\lambda t})_{c2} + \cdots + (e^{-\lambda t})_{c19}}{19} \qquad 12$$

Equation 12 is used to evaluate the truck reliability for the 4 years by substituting n=1,2,3 & 4 and the corresponding component reliabilities $(e^{-\lambda t})_c$ in to it from 1st year to the 4th year.

2.7.1. Reliability percentage

The reliability percentage of the truck accounts for the percentage contribution of age to the reliability of the truck. The percentage dependability (reliability) of the truck per year is evaluated using a mathematical relation given as:

$$\%R(t)_{Sy^n} = (e^{-\lambda t})_{cavy^n} \times 100/1 \qquad 13$$

where y^n= number of study years for n= 1,2 ,3 & 4, $(e^{-\lambda t})_{cavy^n}$=average reliability of the components for nth year.
The reliability percentage of the truck for the first year is calculated using equation 13 as

$$\%R(t)_{Sy^1} = 0.52786 \times 100/1 = 52.79\%.$$

The reliability percentage of the truck for the second, third and fourth year can as well be calculated using the same equation 13
Thus, the 4th year reliability percentage of the waste compactor truck is

$$\%R(t)_{Sy^4} = 0.36940 \times 100/1 = 36.94\%$$

3. RESULTS AND DISCUSSION

The computational procedure of Table 1 is implemented in an excel computing environment using an excel sheet based on modelled equations.

The Input parameters: Waste compactor truck components and the number of failures per year at different operational time for the four years' study interval necessary for the computation and simulation of the various mathematical equations is presented in the Table 1 (Rivers State Environmental and Waste Management Office, 2021).

Table 1: Components and Failures Per Year for four operational years

S/No.	Components	No. of failures in 2688 hours	No. of failures in 2352 hours	No. of failures in 2016 hours	No. of failures in 1680 hours
1	Cylinder Head	1	2	4	5
2	Steering Pump	2	4	5	6
3	Hydraulic shaft	3	4	4	6
4	Radiator	0	1	2	3
5	Compressor	2	3	4	7
6	Turbo-charger	1	2	3	5
7	Gearbox	1	2	3	4
8	Oil filter	4	4	4	7
9	Alternator	1	2	3	5
10	Shock Absorber	2	3	4	6
11	Electric converting unit	3	4	6	8

12	Rotor	1	1	2	3
13	Crankshaft	0	1	2	3
14	Clutch	2	3	4	5
15	Axle	1	1	2	3
16	Pinion	1	2	3	5
17	Bearing	2	2	4	7
18	compacting pump	2	3	5	7
19	Brake system	2	4	5	9

3.1. Result for Average MTBF, FR, PROB., and Reliability of the Truck

Table 2 shows the average of all the reliability indices of the truck from the first year up to the fourth year based on equations 1 to 12. It shows the numerical values of the reliability indices which include: mean time between failures, failure rate, failure probability and reliability in respect to aging for the four study years.

Table 2. Average MTBF, FR, PROB., and Reliability of the Truck for four years

Year	MTBF	FR (λ)	Reliability	Probability
year 1	5263.68421	0.00019	0.52786	0.36687
year 2	4418.42105	0.00029	0.52952	0.47048
year 3	2697.15789	0.00041	0.44835	0.55165
year 4	1793.89724	0.00062	0.36940	0.63060

3.2. Result for Mean Time Between Failures

The result for the Mean Time Between Failures of the Truck for the study years is presented in Table 2 as calculated using normal distribution equation 3 in an excel sheet. It is evident as presented in the Table 2 that in the first year of operation (about 8760 hours), the truck operates a longer time before failure occurs. But, by the end of the second year, within the same study hours, the truck operates lesser time before failure occurs compared to the first year, and as the year increases, the truck keeps reducing in its hours of operation before failures set in. Figure 1 shows the relationship between age and MTBF of the truck.

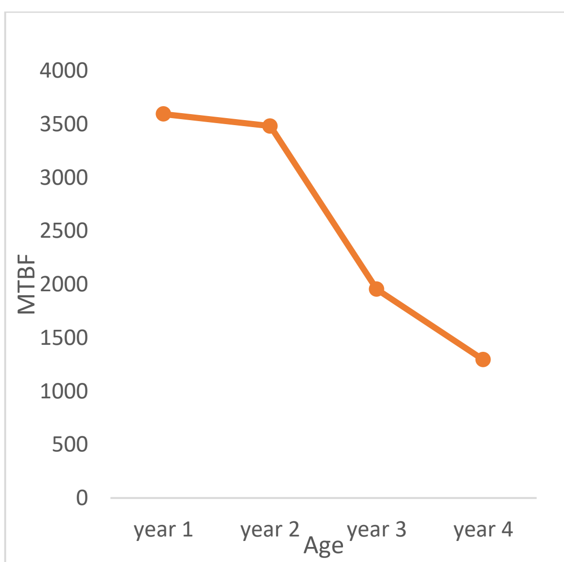

Figure 1: Mean Time Between Failure vs. Age

The Mean Time between Failure against age (year) is shown in Figure 1 for four years of operation of the waste compactor truck. It shows that as the truck gets older, its MTBF drops. This result is similar to that of Beke *et al.* (2020). Meaning that the number of hours the truck operates before failure occurs decreases as year increases.

3.3. Result for Failure rate of the truck

Table 2 shows the failure rates of the Waste Compactor Truck for the four years as calculated using equation (6). The results show that as the Truck becomes aging, the rate at which the truck failed becomes frequent. The relationship between failure rate and age of the truck is shown in Figure 2. The upward slope of the graph from left to right indicates that failure rate increases as the truck becomes older. This observation agrees with that of Nakagawa and Chang (2014). The more the truck gets older, the higher the failure rate and the lesser its performance in service delivery.

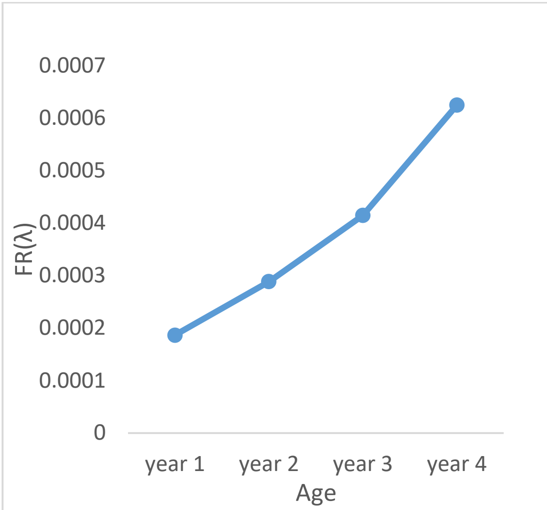

Figure 2: Failure rate vs. age

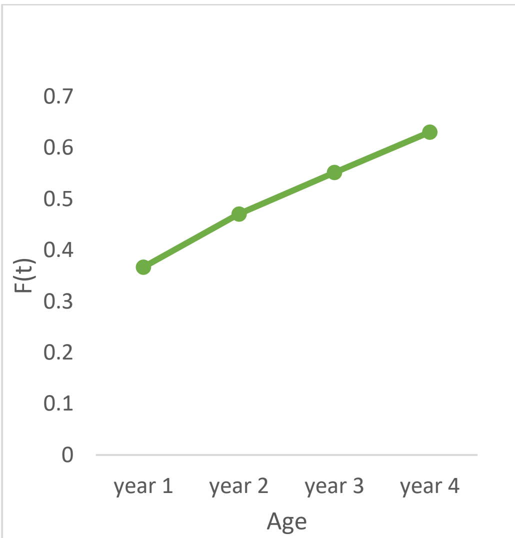

Figure 3: Probability to fail vs. Age

3.4. Result for Probability of the Truck

The result presented in Table 2 shows that the truck has a lesser probability to fail within the first year of operation and lesser probability to fail within the second year of operation. But from the third year up to the fourth year, the probability of failure becomes high due to age. Figure 3 shows graph of probability of failure of the truck vs. age. The graph slopes upward from left to right indicating that the failure probability values of the waste compactor truck increases as the truck gets older or becomes older. Thus, the truck probability to fail becomes real and certain as a result of age.

3.5. Result for Reliability of the Truck

Table 2 shows how the reliability of the truck decreases as years go by. In the first year of operation, the reliability value of the truck was as high as 0.52786 but by end of the fourth year, we observed a decrease in the reliability values of 0.36940. Graph of reliability vs. age is shown in Figure 4. The graph slopes downward from left to right indicating a decrease in reliability as a result of age increment.

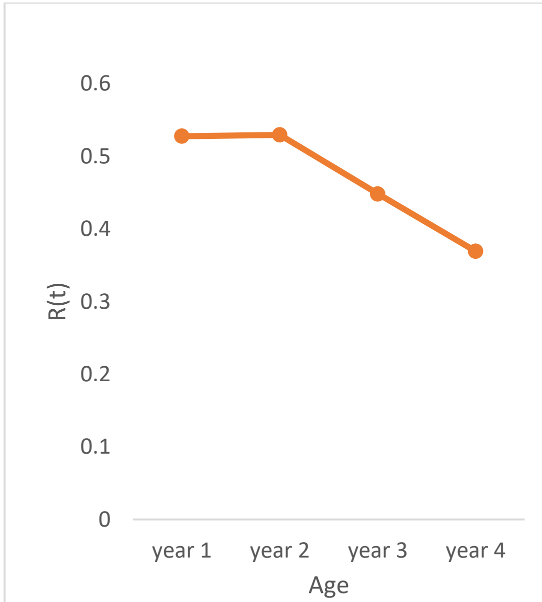

Figure 4: Reliability vs. Age

4. CONCLUSION

This research was carried out to analyze the effect of age on waste compactor truck using reliability analysis. The work was to assess how much effect age has on the truck in terms of service delivery as it becomes older. The first objective was to evaluate the reliability indices of the components of the truck. This was achieved using reliability metrics based on the data collected in table 1 and equations 1-12 implemented in an excel spread sheet environment. The results from the computation revealed that the reliability indices (MTBF) drops as the age of the truck increases, FR and PROB. of failure of the components increases as the truck is aging. At first when the truck was new, all the components function well with high reliability values but as the truck becomes older, wears and tears began, deterioration, erosion and breakdown increases and reliability decreases.

The second objective was to carry out failure analysis on the components of the truck. In order to achieve this, the applied research approach was adopted as field observation and interview of some truck mechanics who used the planet computer software to diagnosed (OBD) the truck, the truck driver and waste management personnel were carried out at the Rivers State Environmental and Waste Management firm in Port Harcourt. Through this, it was seen that some failures were catastrophic while others degradation and were caused either due to poor design, poor maintenance practices, system complexity, age and human reliability. Then the Reliability Block Diagram method (which include the Monte Carlo exponential model equation) and Excel tool were used due to the complexity of the system. In the Reliability Block Diagram method, every component was treated as a system so that the superposition of their individual characteristics mean time between failure (MTBF), failure rate (FR), failure probabilities F(t) and reliabilities R(t) gives an overall MTBF, FR, F(t) and R(t) of the waste compactor truck. An Excel tool was used to do the computation based on the data in table 1. Equations 5 and 6 were used according to *Wang et al.* (2014), *Xie et al*. (1996) and *Zeng et al. (2016)* to achieve the result shown in Table 2 which agree with the result of Beke *et al.* (2020). Generally, the failure rate increases as age increases.

The third objective was to determine the relationship between age and reliability of the waste compactor truck. The reliability of the waste compactor truck was determined for the four years' study interval using relevant equations in chapter 3 in an Excel spread sheet. Age was plotted against the reliability and it was observed that as year increases, reliability decreases suggesting an inverse relationship. Hence, it can be concluded that among other factors such as poor maintenance, poor design and assembly, poor routing that affects the reliability of the waste compactor truck, age also affect the reliability of the truck.

Therefore, the aim of this study titled Performance Evaluation of Waste Compactor Truck Age on Deliverability: The Concept of Reliability could be said to have been achieved.

NOMENCLATURE

Abbreviations	***Description***
AFR	Annual Failure Rate
FR	Failure Rate
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
MTBF	Mean Time between Failures
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair

Symbols	**Description**
A	Availability
n_c	Number of Component
P(t)	Probability of the Component
F(t)	Component Failure Probability
R(t)	Reliability at time t
λ	Failure rate
U	Unavailability
λ_c	Component failure rate
λ_s	System failure rate
$R(t)_s$	System reliability
$R(t)_c$	Component Reliability
n_f	Number of Failures

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This study has not received any external funding.

Conflict of Interest
The author declares that there are no conflicts of interests.

Data and materials availability
All data associated with this study are present in the paper.

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