International Journal of Production Engineering
Vol. 4: Issue 2
www.journalspub.com

Reliability Analysis of an Automobile Brake System to Enhance Performance

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ABSTRACT

Reliability analysis of the brake system of a forklift automobile inspired by the forklift of Bouygues Construction Company was conducted in this study. The operations of a braking system in the automobile process and the reasons for failure in the brake's system operation were investigated; the various causes of failure in a brake system such as oil in the friction plate, failure of the caliper piston to home, lack of braking action and failure of the oil valve were examined for failure that can lead to its maintenance and improvement in its performance. The reliability results of a brake system to improve the performance of the forklift automobile were articulated and a flowchart of brake system replacement model was constructed. The descriptive statistics of the reliability indices was employed in the analysis and the mean mile to failures and availability indices were determined. Reliability analysis of the brake system of the forklift was conducted using exponential reliability model and broad-based results revealed that the brake system was established according to the structure and failure reason of brake system of the forklift automobile. Weibull distribution parameters of failure reasons of brake system were estimated using the maximum-likelihood estimation method. Reliability analysis of brake system which was carried out based on real-time value, parameter estimation such as failure rate, reliability, unreliability, availability and maintainability. The reliability of brake system is progressive between 2014 and 2017. Conclusions and recommendations were made to improve the performance of the forklift automobile as the failure causes probability of brake system was different under different reliability.

Keywords: analysis, automobile, brake system, enhance performance, reliability

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INTRODUCTION

Automobile systems are either used for business transportation lifting or for project execution. A complex system like an automobile is composed of numerous components and the probability that the system survives depends directly on each of the constituent components. The reliability analysis of a vehicle system can provide an understanding about the likelihood of failures occurring in the system and an increased insight to manufacturers about inherent breakdown. According to Tashtoush et al. [1], vehicles comprise the steering, injection, cooling, clutch and brake system. This research work will be more concerned with the brake system.

According to Gavaskar et al. [2], brake systems are crucial component of the automobile system, whose failure due to poor maintenance had claimed life through fatal accidents. For transportation efficiency and operational safety of a car, there is a great need for brake system [3]. He further stated that early detection of failure and expedient action to mitigate this anticipated mechanical failure which will

lead to accident was necessary. According to Kopp et al. [4], by carrying out routine check on the brake fluid and brake, road condition, frequent failures and accident resulting from brake failure may not occur. Meanwhile National Transport Safety Board in Gavaskar et al. [2], according to their study, show that poor maintenance practice in the part of user or operators contributes largely to the failure in brake systems.

It is not new that organizations use automobile systems to facilitate their businesses in the view to make huge profits, satisfy customers and maintain their stay in the ever-competitive business market. It, however, follows that the automobile systems (vehicles) which are means of transportation, lifting or project execution, according to Tashtoush et al. [1], must always be reliable to satisfactorily perform their functions, such as the frequently failed brake system of the vehicle must be efficient.

Hence, the poor vehicle performance and unreliability of the brake system are a major concern of this research, since it adversely affects business in terms of cost and time. Therefore, improving the vehicle performance through a reliability analysis of the brake system is the motivation for this research. The current brake system of the forklift automobile running in the facility of Bouygues Construction Company in Rivers State, Nigeria, has the complaint of frequent brake failures and the corresponding adjustment which leads to higher vehicle down time. Brake system is one of the most important subsystems in an automobile. The safe operation of a vehicle is very much determined by brakes. Disc brake and drum brake are the two different types of brakes used in automobiles. Drum brakes are one of the very commonly used rear brakes in today's automobiles. There are varieties of drum brakes available and each has its own advantages and disadvantages. The current system brakes running in the field have the complaint of frequent brake adjustment which leads to higher vehicle down time. Further, the other problems in using this manual adjuster hydraulic brakes are wheel cylinder kit leak, wheel cylinder jam, etc.

Due to lining wear of the brakes during usage, often the pedal bottoms up while driving. The driver has to adjust all the wheel cylinders and make the pedal to come up. The boots may get damaged during adjustment, and it leads to dust and other impurities entering into the system and consequently leads to leak in system. Also, as the brakes are operating at higher temperature (especially in hilly regions), there is a possibility for the seals and boot to be damaged and may result in leak. Due to these leaks, the system failure can occur and it may lead to major fatal accidents. Safety critical systems are those systems whose failure could result in loss of life, significant property damage, or damage to the environment, and automobile brake system is an example of such. Even though these brakes are well established, there is continuous research by brake manufacturers to improve the performance and effectiveness of drum brakes.

According to research, most fatal auto accidents result from failures of vehicle braking system [2]. It was further stated that these failures occur very frequently due to poor maintenance of vehicle by users (drivers). It was discovered that the specific cause of this frequent failures is leakage in the brake wheel cylinder and tandem master cylinder [5]. The economic consequences of the aforementioned failures are such that it results in poor-quality product delivery, customer dissatisfaction, and little or no profit maximization. However, it follows that poor performance of vehicle depended upon transportation and material handling, resulting from failure in their braking system will consequently defeat the purpose of customer satisfaction, profit maximization safety and the goodwill of the company.

Having considered these drawbacks in the operational success of automobile engineering systems, this research seeks to solve the problem of reliability of the forklift automobile brake system with the Weibull models, to produce results which may help to rectify problems associated with failure of the brake system of forklift automobile and to improve the productivity of the automobile system with minimizing the cycle time which will lead to enhance customer confidence. And I am being inspired to use the forklift automobile of the facility of Bouygues Construction Company in Rivers State, Nigeria, with the ultimate goal of optimizing their forklift operations, availability and maintainability.

The aim of this project is to conduct reliability analysis on the brake system of a forklift automobile to improve its performance.

MATERIALS AND METHODS

Area of the Study

The approach and tools used in the study to achieving the stated objectives were presented in this chapter. These include area of the study, research design, methods of data collection, data selection/population, analytical model, etc. This study was carried out in Bouygues Construction Nigeria Limited (BCNL), which is a subsidiary of Bouygues Construction. Amongst all the building equipment employed by the company for the construction work is the forklift automobile braking system, and Bouygues Construction Company operates six forklift automobiles in NLNG project site, NLNG Road of Eastern by-pass, Port Harcourt. This research work seeks to conduct reliability analysis on four different forklift brake systems to enhance performance.

Research Design

Research design for reliability is a collection of techniques that are used to modify the initial design of a system to improve its reliability. An emerging approach uses design for reliability methods. This approach is based on the identification of potential failure modes, failure mechanisms, and failures sites for the system as a functional life circle condition.

Research Technique

Failure data are the backbone of reliability analysis because they provide invaluable information to concerned professionals such as reliability engineers, design engineers and managers. It indicates the appropriate course of action to take to correct subsequent occurrences. Reliability analysis is a process of collecting and analyzing failure data to determine the cause of failure with a goal of determining corrective actions or liability.

Failure data will be collected from Bouygues Construction Company for reliability analysis on the brake system of their forklift automobile. First, secondary data which will be gotten from the operational logs, maintenance records and historical data and archives of the brake system of their forklift automobile, will be analyzed and rearranged according to the subsystems of the forklift brake system, and according to the common troubleshooting method followed. After collection, sorting and classification of the 'data', the validation of the assumption for independent and identically distributed (IID) nature of the failure rates data of the brake system of their forklift automobile and the entire line must be checked. Thus, the statistical analysis to describe the basic features of the failure data for failure rates for the brake system and the entire automobile line will be analyzed with respect to theoretical distributions. The maximum likelihood and goodness-of-fit test will be used to determine the best theoretical distribution to represent the brake system and forklift failure data.

A quantitative analysis (i.e. descriptive statistics) of the failure data for the forklift

brake system will be obtained. The descriptive statistics will be done using the software package Microsoft Excel. Thus, it is possible to extract the minimum and maximum values of the sample, mean, coefficient of variation (Coef Var), skewness and kurtosis of the failure data at brake system and forklift level. After collection, sorting and classification of the 'data', the validation of the assumption for IID nature of the time between failure data of the brake system and the entire automobile will be checked. Data will be collected from Bouygues Construction Company for reliability analysis of their forklift brake system performance. First, the data will be analyzed, and rearranged according to the brake system subsystems and according to the common troubleshooting method followed. Second, the traditional standard maintenance technique that is suitably used in the maintenance of the forklift brake system will be applied to choose the best statistical analysis approach.

To improve the performance of forklift exponential reliability model, maintainability, reliability, availability and failure rate are used in this research work.

Method of Data Collection

Data for the replacement and reliability analysis of the brake system will be obtained from failure history of the brake system of a forklift in Bouygues Construction Company utilizing the reliability models established.

Failure data will be collected from Bouygues Construction Company for reliability analysis in the brake system of their forklift automobile. First, secondary data are collected from the operational logs, maintenance records and historical data.

Data Sampling/Population

Data will be collected from BCNL on the machine maintenance spreadsheet on the occurrence of failure.

This failure will be translated in mathematical language such as the exponential reliability model, mathematical tools as well as the mathematical application.

Data Selection

It is necessary to select the parts (materials) that have sufficient quality and are capable of delivering the expected performance and reliability in the application of both random and systematic selections.

Analytical Model

To improve the performance of the forklift, the following models are discussed as follows: exponential reliability model, mean time between failures (MTBF), mean time to repair (MTTR), failure rate, availability, reliability and maintainability.

Exponential Reliability Model

The forklift brake system for time between failures follows the Weibull distribution and it is fair to indicate T as the continuous random variable representing the failure time. The PDF of the Weibull distribution is as follows:

$$f(t;\beta;\theta) = \frac{\beta}{\theta}.\left(\frac{t}{\theta}\right)^{\beta-1}.\exp\left[-\left(\frac{t}{\theta}\right)^{\beta}\right] \quad (1)$$

where the parameter β is the shape parameter. A value of $\beta > 1$ signifies an increasing *failure rate* (or *hazard rate*) function, whereas a value of $\beta < 1$ signifies a decreasing *failure rate* function. When $\beta = 1$, the failure rate function is constant and the Weibull distribution is identical to the exponential distribution. The scale parameter of the Weibull distribution, denoted by θ, influences both the mean and the spread of the distribution. As θ increases, the reliability at a given point in time increases, whereas the slope of the hazard rate decreases.

When failure rate (λ) of the brake system is determined, the reliability $R(t)$ and the unreliability $F(t)$ of the brake system of the

forklift automobile at the end of (*t*) hours of operation/up time from our exponential reliability model are as follows:

$$R(t) = e^{-\lambda t} \quad (2)$$

$$F(t) = 1 - e^{-\lambda t} \quad (3)$$

Mean Time Between Failures (MTBF)

The MTBF is a basic measure of reliability for reparable items, and is estimated by the total time in operation of the forklift automobile brake system and its subsystems used by the Pabod Brewery Company divided by the total number of failures (breakdowns) recorded within a specific investigation period:

$$\text{MTBF} = \frac{\sum t_I}{n} \quad (5)$$

where $\sum t_I$ is the total running time in operation of the forklift automobile brake system during an investigation period for both failed and non-failed items, *n* is the number of failures (breakdowns) of forklift automobile brake system or its parts occurring during a certain investigation period, and MTBF is used for non-reparable parts or subsystems in the automobile brake.

Mean Time to Repair (MTTR)

MTTR is the average time required to troubleshoot and repair failed equipment and return it to normal operating conditions. It is a basic technical measure of the maintainability of equipment and repairable parts. Maintenance time is defined as the time between the start of the incident and the moment the system is returned to operation (i.e. how long the equipment is out of production). This includes notification time, diagnostic time, fix time, wait time (cool down), reassembly, alignment, calibration, test time, back to operation, etc. It generally does not take into account lead time for subsystems. MTTR ultimately reflects how well the brewery can respond to a problem and repair it.

The MTTR is the ratio of the total accumulative time of forklift automobile brake system or parts to repair or maintain in statistical time to the number of repair or maintenance actions in the forklift automobile brake system during the specified investigation time period. It is suitable for all kinds of automobile brake system or subsystems and it is given by

$$MTTR = \frac{total\ maintenance\ time}{number\ of\ repairs}$$

$$\text{MTTR} = \frac{\sum t_i}{N} \quad (6)$$

where t_1 is the total accumulative time of forklift automobile brake system or its parts to repair or maintain in statistical time, *N* is the number of repair actions in the population of forklift automobile brake system during the specified investigation time period.

Failure Rate (λ)

Failure rate is the probability of failure per time unit. It is the rate of occurrence of failures. A degraded failure rate is used for systems with repairable parts; a critical failure rate is used for non-reparable parts (Meeker & Escobar, 2008). It is the reciprocal of the MTTF/MTBF function and is given by

$$\lambda = \frac{1}{\text{MTBF}} = \frac{n}{\sum t_1} \quad (7)$$

where $\sum t_I$ is the total running time in operation of the forklift automobile brake system during an investigation period for both failed and non-failed items, *n* is the number of failures (breakdowns) of forklift automobile brake system or its parts occurring during a certain investigation period

Availability

The availability measure is used for forklift automobile brake system when failure consequences only lead to economic losses. The 'availability' of a device is, mathematically, MTBF/(MTBF + MTTR) for scheduled working time. It is given by

$$A=\frac{MTBF}{(MTBF+MTTR)}$$

$$\text{or } A = \frac{T_O}{T_O+T_1} \quad (8)$$

where T_0 is the time that forklift automobile brake system works, T_1 is the time that forklift automobile brake system does not work, including repair and maintenance time.

Reliability

Reliability is defined as the probability of an item to perform its intended function without failure under stated condition within a specified period of time. To determine the reliability (R_t) of a forklift brake system, the mathematical expression is given as

$$R(t) = e^{-\lambda t} \quad (9)$$

where λ is the failure rate and t is the expected time.

Reliability emphasizes dependability in the lifecycle management of a product. Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability is closely related to availability, which is typically described as the ability of a component or system to function at a specified moment or interval of time. Reliability plays a key role in the cost-effectiveness of systems.

Maintainability

Maintainability is a qualitative characteristic related to failure prevention, failure elimination and recovery of the normal working state. Maintenance is a set of procedures to ensure the serviceability of a product or system.

The maintainability model is given by

$$M(^0/_0) = 1 - e^{-\lambda t} \quad (10)$$

where λ is the failure rate and t is the total operating time.

Types of Maintenance

Basically, there are three types of maintenance which include:

i. Preventive (corrective) maintenance
ii. Prognostic (predictive) maintenance
iii. Breakdown maintenance

Preventive Maintenance

Preventive (corrective maintenance) is a maintenance that is regularly performed on a piece of equipment to lessen the probability or likelihood of it failing. It is performed while the equipment is still working so that it does not breakdown unexpectedly. It is planned maintenance that ensures any required resources are available. The maintenance is scheduled based on a time or usage trigger. It is less complex to coordinate than predictive maintenance because monitoring strategies do not have to be planned nor the results interpreted.

Prognostic or Predictive Maintenance

Predictive maintenance techniques are designed to help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted.

The main promise of predictive maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures.

Breakdown Maintenance

Breakdown maintenance is maintenance performed on equipment that has broken down and is unusable. It is based on a breakdown maintenance trigger. It may be either planned or unplanned. An example of planned maintenance is run-to-failure maintenance, while examples of unplanned maintenance include corrective maintenance and reactive maintenance. Breakdown maintenance can be more costly than preventative maintenance (fiixsoftware.com).

RESULTS AND DISCUSSION

The data collected is for a period of one year (2014) and is analyzed based on exponential reliability model. The following reliability parameters were evaluated: MTBF, MTTR, availability (*A*%), reliability *R*(*t*), maintainability (*M*%), etc.

The result and summary were presented in tables and graphs, after which interpretation and discussion of data were given.

Forklift Braking System Failure Data

Forklift Braking System Failure Data in BCNL in 2014

Table 1 shows the failure data of forklift braking system for the year 2014.

Figure 1 shows the equivalent failure rate of the research sample, and it can be seen that the failure rate of the sample increases as the operation time increases, as well as maintains a uniform failure rate as the operation period increases. The system demonstrates rapid increase in the failure rate as the operation time is extended. This is as a result of wear and tear of the components.

From Figure 2, it can be concluded that the availability of equipment depends on the MTTR. Therefore, it supports the mathematical expression of availability.

$$A(\%) = \frac{MTBF}{MTBF + MTTR}$$

From the result obtained, it can be concluded that the availability is inversely proportional to MTTR. The higher the MTTR, the lower the availability.

This result supports the previous study on availability of physical assets with bias to braking system of forklift.

Table 1. *Forklift braking system failure data in BCNL in 2014.*

Failed component	No. of failure (h)	Operating time (OH) (h)	Down time/failure time	Expected operating time (h)
Brake drum	1	184	–	184
	–	160	–	160
	–	162	–	162
	–	176	–	176
	–	102	82	184
	–	42	134	176
	–	102	82	184
Wheel cylinder	1	184	–	184
	–	176	–	176
	–	152	32	184
	–	176	–	176
Brake caliper	1	184	–	184
Total	**3**	**1916**	**330**	**2152**

Note: 8 working hours per day.

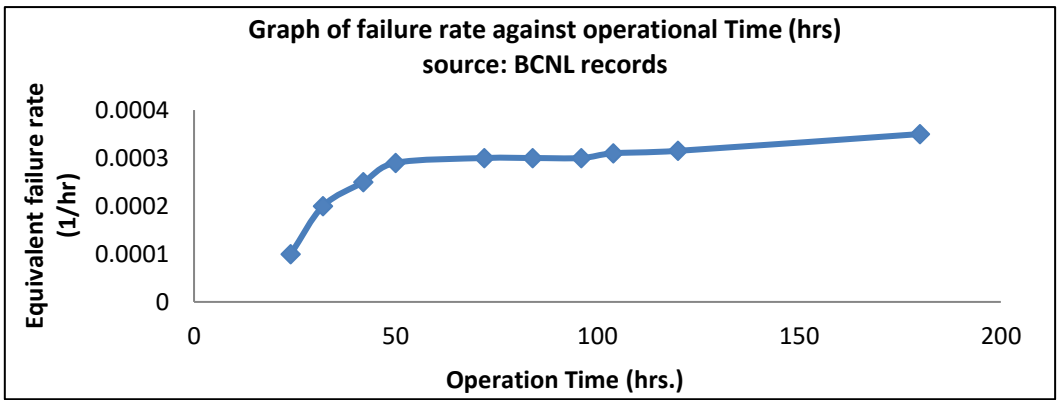

Fig. 1. *Graph of failure rate against operational time (h).*

Table 2. *MTTR (h) against availability (%).*

S/no.	MTTR (h)	Availability (%)
1	0	100
2	6	95
3	8	90
4	12	85
5	24	80
6	32	78
7	48	76
8	60	70
9	66	68
10	72	66
11	84	50

Graph of Availability (%) Against MTTR (h) Showing the Effect of MTTR on the Reliability of Forklift Break System

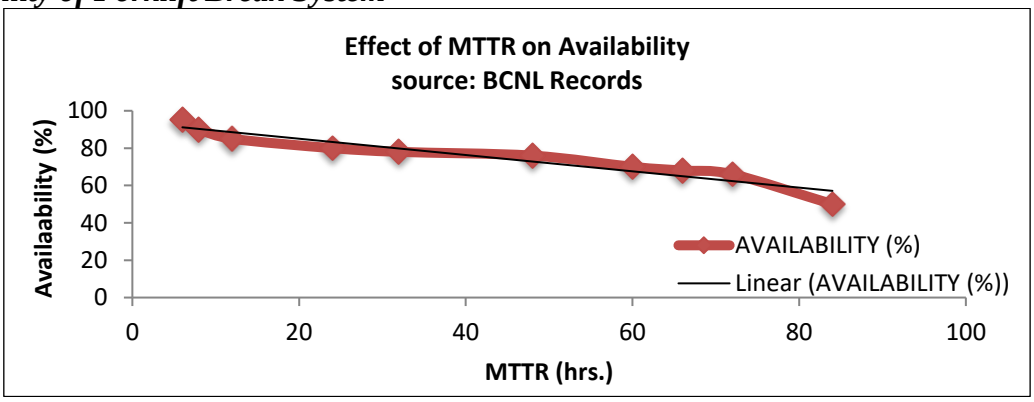

Fig. 2. *Graph of MTTR and availability.*

Table 3. *Reliability against operation time.*

S/no.	Operation time (h)	Reliability (%)
1	0	1
2	30	0.9
3	35	0.8
4	50	0.7
5	60	0.6
6	70	0.5
7	80	0.4
8	90	0.3
9	100	0.2
10	175	0.1

Graph Showing the Relationship Between Reliability and Operation Time

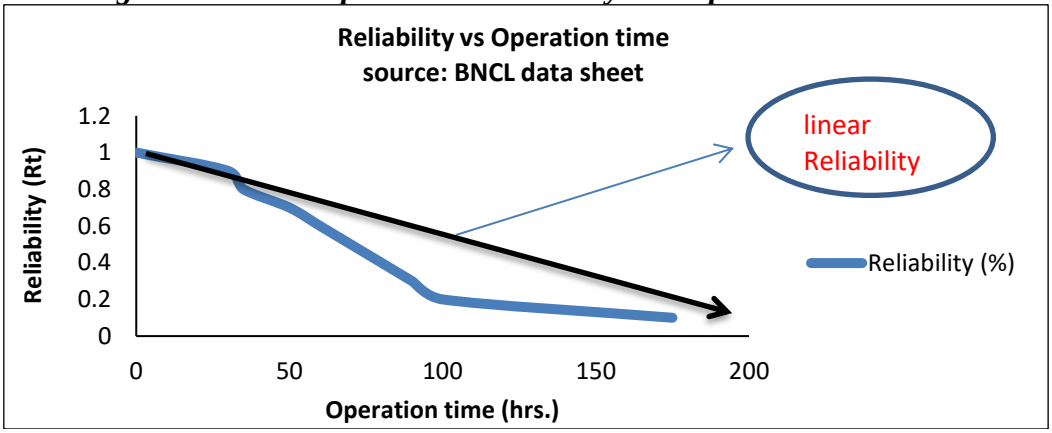

Fig. 3. *Graph of reliability against operation time.*

Figure 3 shows the reliability $R(t)$ against operation time for the period of four years. This indicates that, in 2014, reliability was low at 43% because of the low maintenance practice as time progresses. The company BCNL has improved in its maintenance practice from corrective maintenance to preventive and routine maintenance so that, in 2017, RELIABILITY increased to 64%.

CONCLUSION

The brake system is an important device that ensures safety of automobile. Automobile maneuverability is influenced by the performance of the brake system, and many accidents are caused by brake system failures. Disc brakes are applied in many brake systems; hence, several optimization plans for analyzing and studying the brake system have been proposed in recent years [6].

The aim of this research work has been to conduct reliability analysis on the brake system of a forklift automobile of Bouygues Construction Company. The objectives of this dissertation had been to understudy the operations of the braking system of an automobile; to carry out reliability analysis of the brake system of the forklift using exponential reliability model; to articulate the reliability results of a brake system to improve performance and to determine the critical failures components of the brake system of the forklift.

Reliability is an important index for measuring product safety, quality and fatigue. The research on this dissertation is shown from the figure 3, it can be seen that the availability dropped from almost 3% in 2017 because of the cost of corrective maintenance and increases unplanned downtime; therefore, preventive maintenance should be implemented for optimum performance.

NOMENCLATURE

Symbols	Description
$F(t)$	Failure or unreliability function
T	Time
$R(t)$	Reliability Function
$A(\%)$	Availability
$M(\%)$	Maintainability
MTBF	Mean time before failure
MTTR	Mean time to repair
λ	Failure rate
μ	Maintenance rate
$\sum t_I$	The total running time in operation of the forklift automobile brake system during an investigation period for both failed and non-failed items.
n	Number of failures (breakdowns) of forklift automobile brake system or its subsystems occurring during a certain investigation period
t_1	Total accumulative time of forklift automobile brake system or its parts to repair or maintain in statistical time
N	Number of repair actions in the population of forklift automobile brake system during the specified investigation time period
T_0	Time that forklift automobile brake system works
T_1	Time that forklift automobile brake system do not work, include repair and maintenance time
T_2	Expected operating time
w	Number of units
OT	Operating time
FH	Failure hour
NF	Number of failures
BCNL	Bouygues Construction Nigeria Limited

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