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Evaluation of Generator Components Functional Parameters using Reliability Analysis

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Abstract Investigation was carried out to demonstrate the reliability analysis of generator components functional parameters of various companies' products used in servicing or repairing of failed generator components in Nigeria. The generator components influenced by rotational motion was considered during the studies, which include bearing, shaft, shaft pulley and fan belt. In this research work the Monte Carlo model of reliability tools and techniques was applied for evaluating reliability, unreliability, availability as well as in the determine number of failure (NF), corrective time per failure (CTPE), mean time between failure (MTBF), failure rate (FR), loss time per year (LTPY), gross margin, scrap disposal cost and breakdown maintenance cost. Key results of this research work show that reliability of components decreases with increase in utilization time. In comparison, the minimum bearing reliability values were obtained as: 51.4% for company A, 60.7% for company B, 71.7% for company C, D and 84.6% for company E respectively. From the comparison, these results revealed that the generator components from company E have the highest reliability for bearings compared to other companies. The investigation revealed the mechanism of evaluating the functional parameters of generator components in terms failures and the financial implication.

Keywords Evaluation, functional parameters, reliability, analysis, generator, components

Introduction

The analysis of different generator components using reliability tools and techniques is the focus of this study. The research work reviews literatures published on recent modifications made in the field of reliability tools and techniques using different approaches in measuring failures. Performance measurement is a fundamental principle of management. The measurement of performance is important because it identifies gaps between current and desired performance and provides indication of progress towards closing the gaps. Carefully selected key performance indicators identify precisely where to take action to improve performance in terms of component failure [1].

Research conducted by Paul and Barringer on practical reliability tools for refineries and chemical plants revealed that reliability is the probability of equipment or processes to function without failure when operated correctly, for a given interval of time, under stated conditions. They further stated that reliability numbers, by themselves lack meaning for making improvements and for business, the financial issue of reliability is controlling the cost of unreliability from equipment and process failures which waste money. Reliability issues are understandable when converted into monetary values by using actual plant data. Several reliability engineering tools are discussed in this research work [2].

Reliability Tools: Reliability tools showed their real value in the 1930s, 40s and 50s when used on exotic military programs [3]. Fortunately many reliability tools do not need a rocket scientist to use them cost effectively. Some simple reliability tools provide big gains quickly and defer the use of higher powered tools for squeezing out the remaining improvements. In all cases, score cards for reliability improvements in business need measurements in dollars [4].

Research conducted by various groups revealed that the use of reliability tools is evolutionary, that is, by starting reliability improvement programmes with simple arithmetic and spreadsheets and quantify important cost and failure numbers [5-9]. This can be achieved by gaining momentum with good maintenance practices, improve team work using total productive maintenance progrmmes as well as using root cause analysis to efficiently solve problems identified [10]. Furthermore, learning and using the concept of a host of straight forward reliability engineering tools to solve problems identified is necessary [11].

The aim of this project is to carry out reliability analysis of some components of various generator make. Such components are bearing, shaft, shaft pulley and fan belt. The objectives of this study are as follows: to evaluate availability, reliability and unreliability of the selected generator components, to determine failure rate, mean time between failures, corrective time per failure, loss of time per failure and failure per year of the selected generator components and to determine the gross margin, scrap disposal cost and breakdown maintenance cost of some selected generator components.

Various problems have been identified to be associated with the failure of generator components within Nigerian environment. These problems are responsible for the total failure of most generators such as poor installation approach, inability to detect all failed components once, replacing the failed components with substandard materials and the application of manual methods of fault detection. This research work shall provide relevant information necessary for a very vivid analysis of different generator components using reliability tools and techniques. The best approach for correcting failure of the generator sets is to enhance good planning by eliminating the associated problems that leads to frequent generator components failure.

The approaches used will enhance efficiency of the generator components and reduce failure, useful in predicting the reliability, unreliability and availability of the components. The success of this research work will address most of the inadequacies in solving problems in engineering management as well as the generator components solution for maintenance of faulty generator set. Frequent failure of generator components experienced in Nigeria has resulted to high generation of scraps, increase in generator maintenance, effect on individual, companies and governmental organization with low production output and low profit margins.

The research work will address this issue with the best approaches to achieve low cost of maintenance with high efficiency that will lead to high output.

This research work covers the use of reliability tools and techniques in solving problem in the field of engineering management. The analysis of different generator components using reliability tools and techniques can be established by using the following approaches: selection of sampled components, data collection, analysis of data collection translating data into mathematical language, analysis of some functional parameters, formulation of the model from the mathematical language, application of the real values into the formulated mathematical expressions, computational approaches and analysis of the results

Generator components failure is a major problem in Nigeria, because the accurate failure prediction cannot be ascertained or the required availability of information on the service time is unknown. It is only when fault is detected that maintenance can be carried out. In carrying out the research work, one of the major limitations can be attributed to finance as well as the difficulty to get all required information that could have helped in detailed reporting of the research work.

Materials and Methods

Reliability Tools and Techniques Methodology

There are many reliability tools and techniques methodologies available for failure of plant components. For the one case study described herein, we have the Monte Carlo Reliability models which can realistically assess plant conditions when combined with cost, repair time and statistical events. Monte Carlo simulation model is very helpful for considering approximate operating conditions in a plant including cost effectiveness and sizing to provide protection for short duration failures.

Reliability model stimulate creative ideas for solving costly problems and prevents replication of old problems. Reliability models offer a scientific method for studying actions, responses and costs in the virtual laboratory of the computer using actual failure data from existing plants. It is noted that the Monte Carlo Model is never better than the data supplied or obtained as a result of failures that occurs.
The Monte Carlo provide a way to search for lowest cost operating alternatives and conditions by predicting the outcome of events and equipment. Monte Carlo model aids in finding the lowest long term cost of ownership.

Mathematical Language of Reliability
The following approaches were used in resolving the analysis of generator components using reliability tools and techniques

- Start reliability improvement program with simple arithmetic and spreadsheets to quantify important cost and failure numbers.
- Gaining momentum with good maintenance practices will improve team work using total productive maintenance program such as root cause analysis to efficiently solve problems.
- The application on improvement of program by using statistics to quantify the results.
- Application of Monte Carlo model to simulate generator components availability, reliability, maintainability, capability and life cycle costing for deciding reliability strategies.

Model Formulation and Development
The mathematical model for this research was established by considering three years study interval (SI) as well as the number of failures (NF) and the corrective time per failure (CTPE).

Mean Time between Failures (MTBF)

$$(MTBF) = \frac{SI}{NF} \quad (1)$$

Total mean time between failures
Thus:
Total failures per year (TFPy) =

$$\left[\left(\frac{1}{MTBF}\right)_A + \left(\frac{1}{MTBF}\right)_B + \left(\frac{1}{MTDF}\right)_C + \left(\frac{1}{MTBF}\right)_D + \left(\frac{1}{MTBF}\right)_E\right] x \text{ Annual hours per year} \quad (2)$$

Therefore, the total mean time between failures (TMTBF) for generator components is expressed as:

$$TMTBF = \frac{\text{Annual hours per year}}{\text{Total failures per year}} = \frac{AHPy}{TFPy} \quad (3)$$

Failure Rate
Thus:

$$FR = \frac{1}{MTBF} = \frac{1}{SI/NF} = \frac{NF}{SI} \quad (4)$$

$$(FR)_A = \left(\frac{1}{MTBF}\right)_A = \left(\frac{NF}{SI}\right)_A \quad (5)$$

Total Failure Rate (TFR)

$$TFR = \left[(FR)_A + (FR)_B + (FR)_c + (FR)_D + (FR)_E\right] \quad (6)$$

Mathematical Model on Functional Parameters of Generator Components Failure
To determine the time lost from unreliability per year of the generator components for each company generator components is as follows:

Failures Per Year (FPy)

Thus:

FPy = [failure rate for each product] x [annual hours per year] (7)

FPY = (FR) (AHPy) (8)

$$FPy = \left(\frac{NF}{SI}\right)(AHPy) \quad (9)$$

$$FPY = \left(\frac{1}{MTBF}\right)|AHPy| \quad (10)$$

Total failure per year (TFPy)

Thus:

$$TFPy = \Sigma(FPy)_A + (FPy)_B + (FPy)_C + (FPy)_D + (FPy)_E \quad (11)$$

Total Corrective Time Per Failure (TCTPF)

Thus:

$$(TCTPF) = \frac{Corrective\,time\ per\ Failure\ of\ each\ product\ x\ failures\ per\ year\ of\ each\ product}{Total\ failure\ per\ year}$$

$$Thus\,(TCTPF) = \frac{(CTPF)_A(FPy)_A + (CTPF)_B(FPy)_B + (CTPF)_C(FPy)_C + (CTPF)_D(FPy)_D + (CTPF)_E(FPy)_E}{(TFPy)} \quad (12)$$

Lost Time Per Year (LTPy)

Thus:

$$LTPy = [failures\ of\ each\ product\ per\ year]\ x\ [Corrective\,time\ failure\ for\ each\ product] \quad (13)$$

Total Lost Time Per Year (TLTPy)

Thus:

$(TLTPy) = (LTPy)_A + (LTPy)_B + (LTPy)_C + (LTPy)_D + (LTPy)_E$ (14)

Time Lost From Unreliability

a. Gross Margin (GM)

GM = [lost time per year (LTPy)] x [lost gross margin $ x hour] (15)

Therefore.

GM = (LTPy) (lost gross margin of $ x per hour] (16)

b. Total Gross Margin (TGM)

(TGM) = [(LTPy) (LGM at $ x per hour)]$_A$ +[(LTPy) (LGM at $ x per hour)]$_B$ +
[(LTPy) (LGM at $ x per hour)]$_C$ + [(LTPy) (LGM at $ x per hour)]$_D$ +
[(LTPy) (LGM at $ x per hour)]$_E$ (17)

c. Scrap Disposal Cost Per Incident (SDCPI)

$$SDCPI = \begin{bmatrix} Filure\ per\ year\ (FPy) \\ for\ each\ product \end{bmatrix} \begin{bmatrix} Scrap\ disposal\ cost \\ of\ \$Z\ per\ incident \end{bmatrix} \quad (18)$$

d. Breakdown Maintenance Cost (TBdMC)

$$BdMC = \frac{Gross\ Margin\ x\ Scrap\ Disposal\ Cost}{Total\ Breakdown\ Maintenace\ Cost} \quad (19)$$

e. Total Breakdown Maintenance Cost (TBdMC)

$$TBdMC = (BdMC)_A + (BdMC)_B + (BdMC)_C + (BdMC)_D + (BdMC)_E \quad (20)$$

f. Total Lost Cost (TLC)

$$(TLC)A = (GMC)A + (SDC)A + (BdMC)A \quad (21)$$

Reliability, Unreliability and Availability Model

Reliability Model

To determine the generator components reliability (GCR) the equation used is expressed mathematically as:

$$GCR = \ell^{-}\left(\frac{1}{MTBF}\right) x t \quad (22)$$

Whereas for the various companies generator components investigated, the reliability is determined by the summation of each company generator component reliability, as stated below,

$$BR = \ell^{-}\left(\frac{1}{MTBF}\right)_A + \left(\frac{1}{MTBF}\right)_B + \left(\frac{1}{MTBF}\right)_C + \left(\frac{1}{MTBF}\right)_D + \left(\frac{1}{MTBF}\right)_E \; xt \quad (23)$$

Unreliability Model

To determine the generator components unreliability (GCUR) we use the expressed:

$$BU = 1 - \ell^{-}\left(\frac{1}{MTBF}\right)_T xt \quad (24)$$

Availability Model

To determine the generator components availability (GCA) we have:

$$GCAV = \frac{Mean\,Time\,between\,Failure - Lost\,Time\,Per\,year}{Mean\,Time\,between\,Failure} \quad (25)$$

Data Collection on Failures of Generator Components

This study was inspired by using some generator manufacturers' models as a case study. The number of failure was obtained from the various companies generator set plant maintenance checklist and spread sheet data covering the period of 1st January, 2014 to 31st December, 2016. The generator components of common interest were chosen such as bearing, shaft, shaft pulley and fan belt.

Samples for the investigation were collected from five different companies located in Port Harcourt in Rivers State of Nigeria. The data collected was evaluated using the necessary engineering tools and techniques in the determination of the time lost from unreliability, the cost of unreliability and annual availability, reliability and unreliability.

Root Cause Analysis (RCA) of Generator Components

There are many RCA methodologies available for failure events investigation. For the two case studies describe herein, we have the structured methodology originally developed by Apollo Associated Services [12] which is designed to minimize personal bias and maximize solution oriented thinking, stating an event problem definition statement based on a meticulous evidence data gathering and managing process – followed by a detailed cause effect tree analysis and finalizing with a complete investigation report which indicates the most effective solutions, including preventive and corrective actions to modify or prevent causes to avoid the event repetition. This methodology is associated with software for the graphic cause-effect analysis representation, evident capture and report facilitation. This methodology is based on the most accepted failure theory, which demonstrates that any failure event is based on multiple causes and each single event or effect is a consequence of a group of immediate causes occurring at the same time and place was reported by Henry and Zoighadri, [13]. These causes can be understood as a group of specific conditions set in motion by an action or behaviour. In addition to the operational and physical aspects involved in the failure event, a complete and structured RCA methodology shall take into consideration all types of possible causes [14], especially regarding behaviour based aspects [15], like psychological conditions, human errors [16] and operational discipline aspects [17].

Event Description

The investigation data inventory covers the period of 1st January, 2014 to 31st December 2016, by considering a normal generator set of 100KVA in operation, failures during operation produces unexpected sound, as well as stop the base load causing immediate generator set shutdown. The generator maintenance team with a troubleshooting device and technical support personnel examine the failed components.

During the abnormal shutdown, the control monitoring system demonstrates a discharge pressure decrease, followed by a decrease in suction pressure and combustion fuel system. It was also observed that the radiator water temperature increased which lead to the malfunctioning and automatic shutdown of the generator. All the generator components considered in this research work can cause such effect. It was also observed that vibration oscillation can cause failure since the generator components investigated in this research work undergoes rotational motion which is influenced by fractional force when installed for operation.

Results and Discussion

The results obtained from the investigation are presented in Figures 1 to 12 and Tables A1, B2 to B12, whereas results in Tables are shown in the appendix.

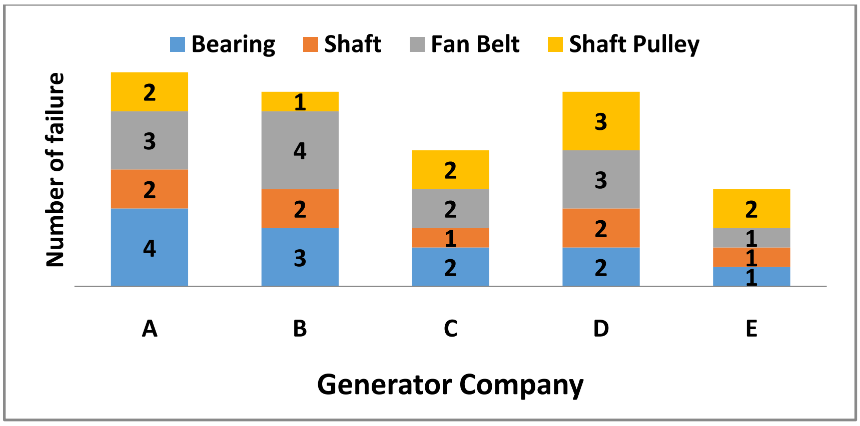

Figure 1: Plot of Numbers of Failure against Generator Company

The analysis of different generator company components were investigated for a period of three years in terms of failure occurrences. For company A, the bearing of the machine failed four times within the period investigated and this is the highest failure recorded for bearing component, followed by fan belt which failed three times within the period of evaluation and the number of failures of shaft and shaft pulley was recorded as the same. Company B recorded highest failure for fan belt which failed four times within the period of assessment. The bearing of company B failed three times, the shaft failed twice as established in Figure 1 and shaft pulley recorded one failure within the period of evaluation. For company C the bearing, fan belt and shaft pulley recorded the same number of failures as indicated in Figure 1 and the shaft component failed once within the period of assessment. For company D the bearing and shaft component failed twice within the three years of evaluation of performance while the fan belt and shaft pulley recorded three failures also. For company E, the bearing, shaft and fan belt components recorded one failure each within the three years of evaluation and the shaft pulley failed two times as of the period of assessment. This indicates that company E recorded the highest level of reliability based on number of failed generator components.

Figure 2 illustrates the relationship between the mean time between failures and the generator company examined. The computation of mean time between failures was plotted for the different generator components as shown above. The mean time between failures (MTBF) of the generator components were calculated for a study interval of three years and the following mean time between failures was established for each of the generator components investigated. For company E, it is observed that the bearing and shaft components has equal mean time between failures values, whereas fan belt and shaft pulley recorded same values within the study interval as well as the highest value recorded for bearing and shaft component. From Figure 2 it is seen that the mean time between failures for various generator company components investigated and the characteristics of mean time between failures in terms of order magnitude is given as Company E > Company C > Company B > Company D > Company A.

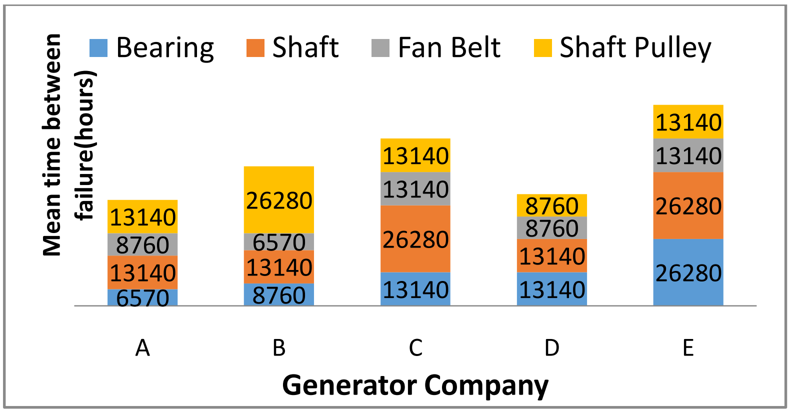

Figure 2: Plot of Mean Time between Failures against Generator Company

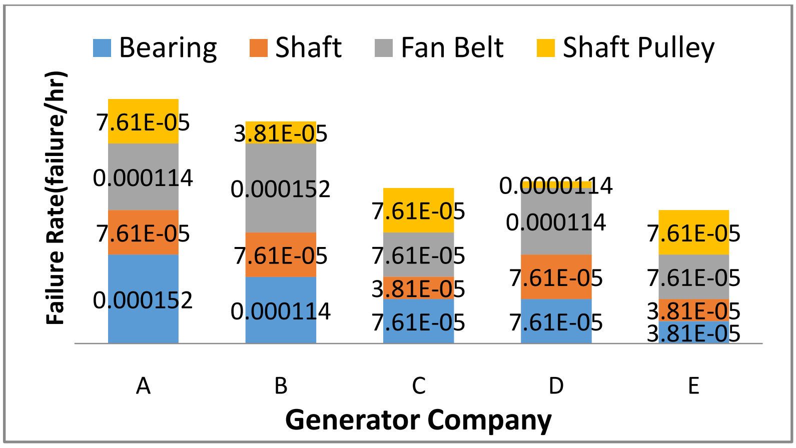

Figure 3: Plot of Failure Rate against Generator Company

Figure 3 demonstrates the failure rate of each generator component used by the various companies in servicing. The analysis of the failure rate of the bearing, shaft, fan belt and shaft pulley was carried out and the result obtained reveals that the failure rate of all generator company components examined is within the range of 0.0000114 to 0.0000761. The failure rate for the various components used by the generator company A, B, C, D and E is dependent on the number of failures.

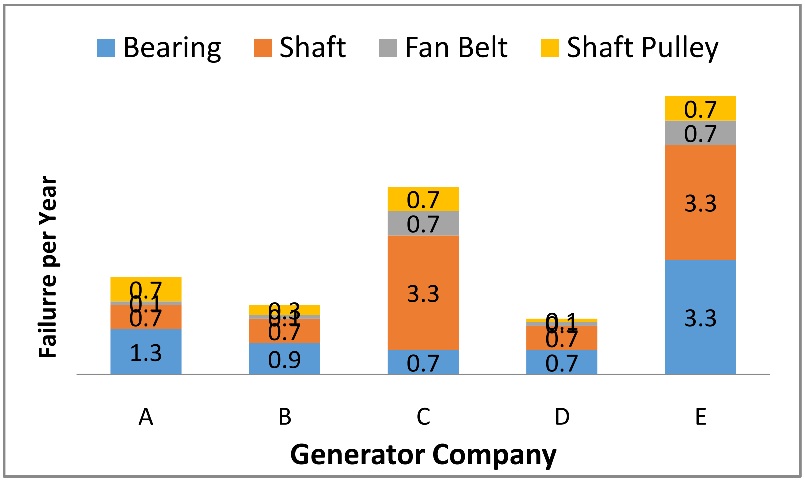

Figure 4: Plot of Failure per Year against Generator Company

The reliable assessment of different generator company components were investigated for a period of three years and the following failures per year was established for the various components as shown in Figure 4. The analysis conducted by means of application of a mathematical tool revealed the reliability magnitude order of failure per year of the generator components of the various companies studied, that is, company E components > company C components > company A components > company B components > company D components in terms of various components investigated.

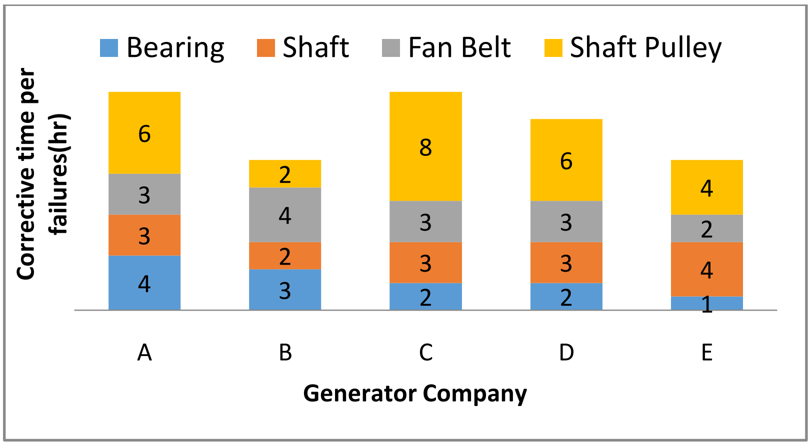

Figure 5: Graph of Corrective Time per Failures against Generator Company

The analysis of different generator company components were conducted for a study interval of three years and the following corrective time per failure (CTPF) was established for the various components as shown in Figure 5. For company A the bearing CTPF of 4 hours was recorded, corrective time per failures of six hours was recorded for shaft pulley which is the highest corrective time per failure established, whereas shaft and fan belt has the same corrective time per failure of three hours each. For company B the recorded highest corrective time per failure of four hours in the case of fan belt, CTPF for bearing component is three hours while shaft and shaft pulley recorded CTPF of two hours within the study interval of evaluation. For company C the fan belt and shaft recorded the same CTPF of three hours as indicated in Figure 5 and the shaft pulley component recorded the highest corrective time per failure of eight hours within the period of assessment while lowest CTPF was recorded for bearing as shown by Figure 5. For company D the fan belt and shaft component has CTPF of three hours within the three years of the performance evaluation. The highest CTFP was established for shaft pulley component of six hours of corrective time per failure and the lowest corrective time per failure of two hours established for bearing component. For company E the shaft and shaft pulley components recorded four hours corrective time per failure within the three years of evaluation and the fan belt CTPF was two hours and that of bearing one hour as of the period of assessment. This indicates that company E recorded high level of reliability in terms of corrective time per failure.

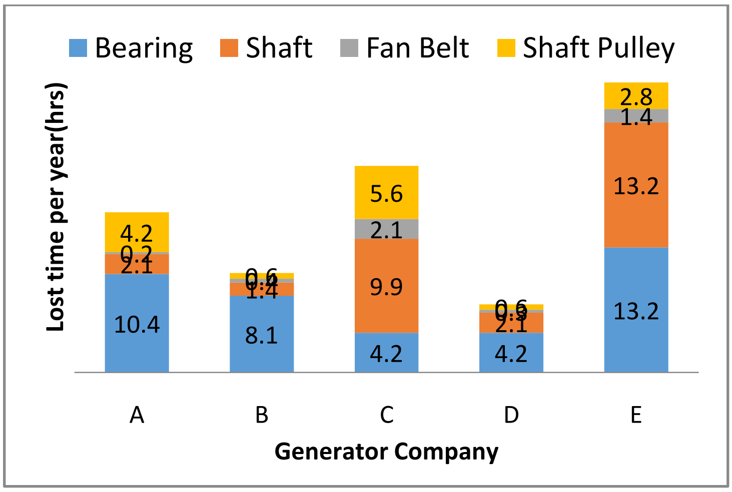

Figure 6: Plot of Lost Time Per Year against Generator Company

Result presented in Figure 6 illustrates the relationship between lost time per year and generator company components investigated. The lost time per year depends on the number of failures of generator components and the man hour required to repair the failed component. Setting work priorities only on the basis of failure "body counts" can be misleading. It is important to determine average corrective times for failures to make good estimates for total downtimes and lost production time for the plant is also money. Analysis indicate that in terms of maintenance services a reasonable time is lost for Company E and this can be attributed to the coupling nature of the generator. The order of magnitude of lost time per year during maintenance services of the various component investigated is of company E components > company C components > company A components > company B components > company D components as indicated in Figure 6.

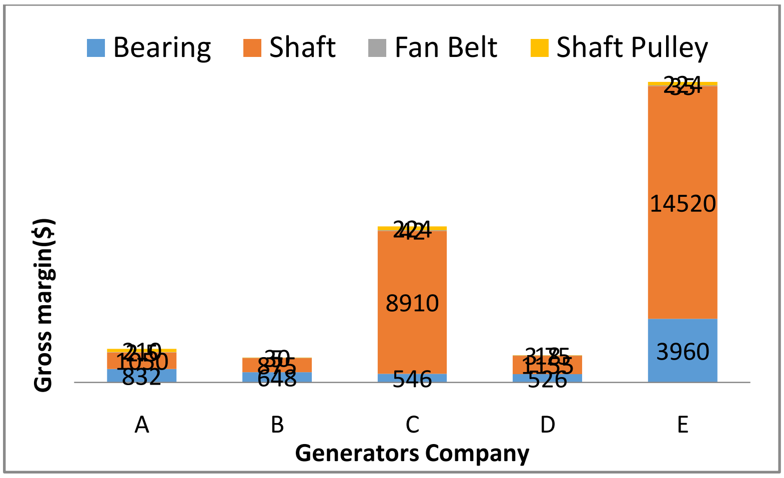

Figure 7: Plot of Gross Margin against Generator Company

The relationship between the gross margin and Generator Company is illustrated in Figure 7 for the various generator components investigated. It is seen that company E make more profit followed by company C whereas company A, B and D gross margin profit is low when compared with the gross margin profit of C and E. This means that replacing the failed generator components with the company C and E material will usually cost more money in terms of maintenance whereas the service provider will make more profit on the business as well as more man hour lost will be experienced, but the revise will be the case for generator components used by company A, B and D.

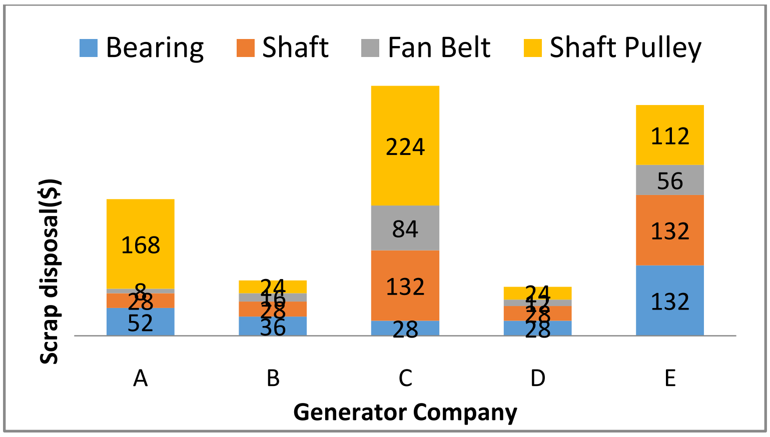

Figure 8: Graph of Scrap Disposal against Generator Company

Figure 8 demonstrates the relationship between scrap disposal and Generator Company. The financial involvement needed to dispose scraps generated after maintenance services within the study interval of three years increases with increase in scrap generated and it is seen that the cost of scrap disposal influences the business as a result of current failure of generator components. The order of magnitude of financial involvement needed to dispose scrap is as follows: company E components > company C components > company A components > company B components > company D components.

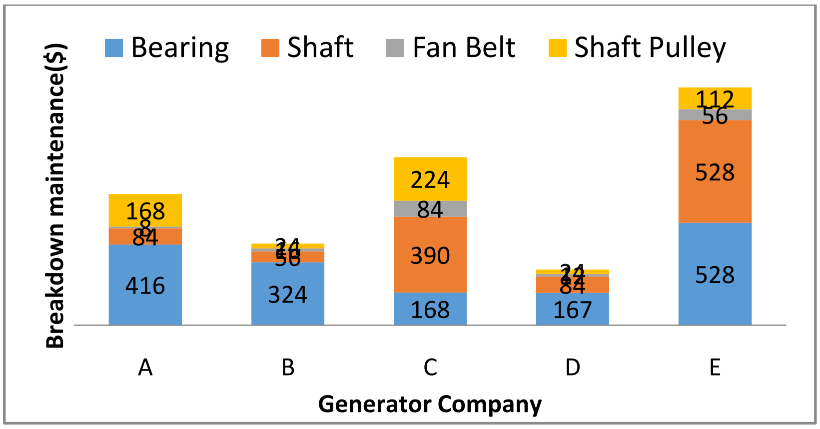

Figure 9: Plot of Breakdown Maintenance against Generator Company

The plot of breakdown maintenance on the various generator company components was examined and the financial implications during the breakdown maintenance was evaluated using the application of mathematical tools and techniques and the result obtained from the analysis revealed that the order of financial involvement experienced by the various company is in the following order of magnitude, such as, company E components > company C components > company A components > company B components > company D components as indicated in Figure 9 as well as more money is required to maintain generator used by the service company of E and C because of high rate of component failure experienced.

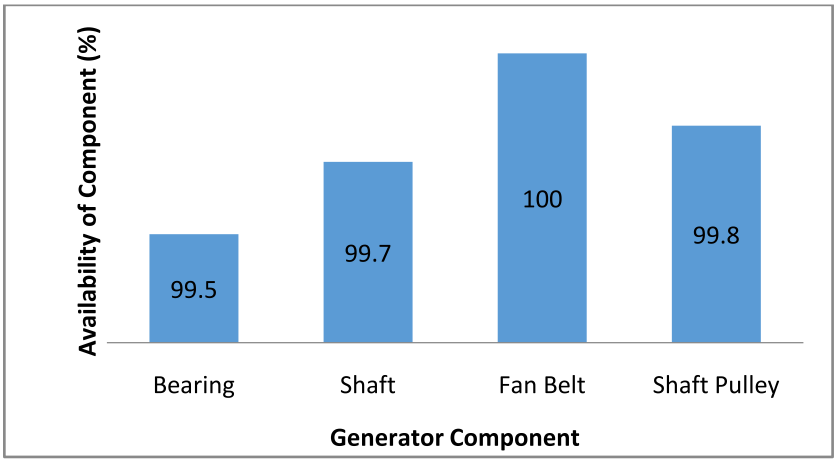

Figure 10: Plot of Availability against Generator Component

Figure 10 illustrates the relationship between availability and generator component investigated within the study interval of three years by application of useful mathematical tools and techniques to compute the availability of various components examined. The analysis revealed that all components investigated are available for replacement once failure is established.

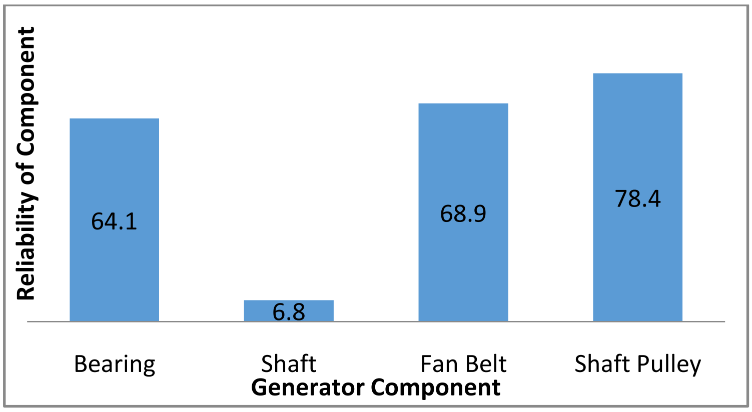

Figure 11: Plot of Reliability against Generator Component

The research conducted revealed that all generator company components used for investigation are of high quality and low value, the reliability of the shaft can be attributed high in errors during installation which resulted to increase in failure. Performance evaluation of generator components considered during the study interval was analysed and the reliability of the component computed is as shown in Figure 11. The bearing, fan belt and shaft pulley component indicate an acceptable reliability of these components within one year and indicate that low value pointing low reliability of the shaft component within one year.

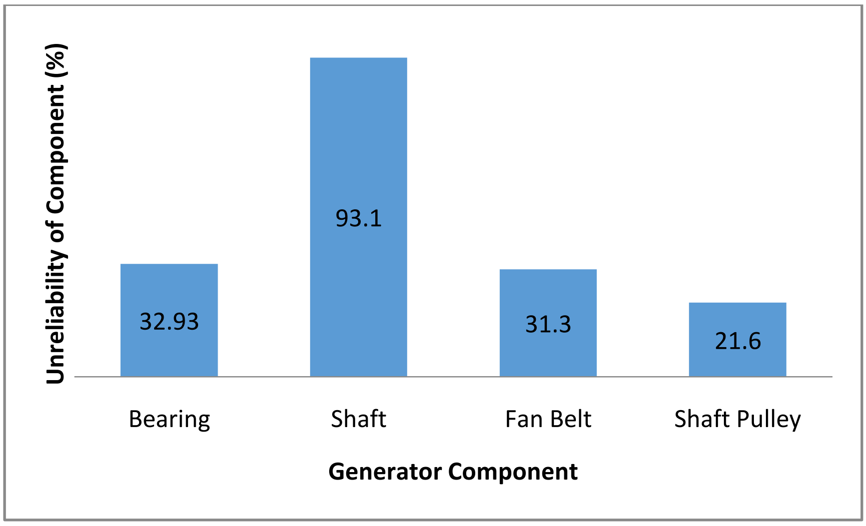

Figure 12: Plot of Unreliability against Generator Component

Figure 12 illustrates the relationship between unreliability and generator components investigated and among all the components evaluated the shaft component is more unreliable with maximum value of 93.1% unreliability. The increase on the unreliability of the shaft can be attributed to improper installation errors experienced during maintenance execution.

Conclusion

The following conclusion was drawn from the research work as stated below:

- The results obtained illustrates that the generator component from company E has the highest reliability.
- Company E made more profit, followed by company C whereas company A, B and D has low gross margin profit when compared with the gross margin profit of company C and E. This is experienced as a result of constant failure of generator components of company C and E as well as the cost of maintenance increases.
- Increase in scrap generated increases the cost of scrap disposal and financial involvement experienced by the various companies are in the following order of magnitude, such as, company E components > company C components > company A components > company B components > company D components.
- The study presented here affirmed that the aims and objectives have been achieved with some key results using the Monte Carlo model for evaluating the reliability, unreliability and availability of failed generator components. The method allows determination of failure rate, mean time between failures, failure per year, corrective time per failures, lost time per year, gross margin, scrap disposal cost, breakdown maintenance for the various generator components of various companies used in Nigeria.
- The analysis of generator components shows that the reliability tools and techniques method adopted in this study allows considerable justification in computing reliability, unreliability and availability as well as the functional parameters that determine generator components quality and man hour lost for repair of failed components. Decrease in reliability with corresponding increase in study interval, as well as increase in unreliability with corresponding increase in study interval was observed for all the components considered in this research work.

- The reliability tools and techniques approach adopted is a model based concepts for monitoring and predicting the controlling factors that influence failure, quality of components and cost implication. However, in practical applications especially when considering multiple generator components failure or a complex failure system, the straight forward application of such reliability tools and techniques may be difficult to give a good judgment of generator components reliability.

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APPENDIX A

MODEL FORMULATION AND DEVELOPMENT

Company A, B, C, D and E: generator components investigated are bearing, shaft, shaft pulley and fan belt and the mathematical expression is as stated below:

The evaluation of the bearing mean time between failure (MTBE) and failure rate (FR) for the various company generator components is presented in Table A.1 and the block diagram for process is illustrated in Figure A.1.

Block Diagram of Generator Components

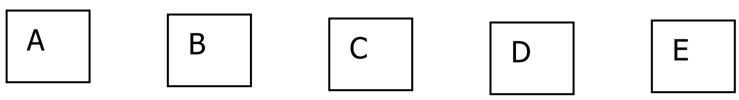

Figure A.1: **Block Diagram of Generator Components**

Table A.1: Computational Values for Study interval, number of failure recorded, Mean Time Between Failure and Failure Rate

Components	A	B	C	D	E	Summary
Study Interval	26280	26280	26280	26280	26280	8760 hr/yr
Number of failure (NF)	4	3	2	2	1	4 failures 1 yr
MTBF	6570	8760	13140	13140	26280	2190 hrs/failure
Failure rate (FR)	1.52×10^{-4}	1.14×10^{-4}	7.6×10^{-5}	7.6×10^{-5}	3.81×10^{-5}	4.56×10^{-4} failure

APPENDIX B

EVALUATION OF SOME FUNCTIONAL PARAMETERS FOR BEARING COMPONENTS

The evaluation of time lost from unreliability is presented in Table B.1 and the block diagram for bearing time lost from unreliability is presented in Figure B.2

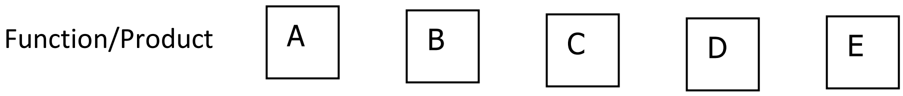

Figure B.2: **Block Diagram for Bearing Time lost from unreliability**

Table B.2: Computational values of some of the Functional Parameters for various company products.

Components	A	B	C	D	E	Summary
Failure Rate	$1.53\text{x}10^{-4}$	$1.14\text{x}10^{-4}$	$7.6\text{x}10^{-5}$	$7.6\text{x}10^{-5}$	$3.8\text{x}10^{-5}$	$4.56\text{x}10^{-4}$ failure/hr
Failure per year	1.3	0.9	0.7	0.7	3.3	6.9
Corrective time failure	4	3	2	2	1	5.81 hrs
Lost time per year	10.4	8.3	4.2	4.2	13.2	40.1hrs

Table B.3: Computational parameters values of Gross Margin, Scrap Disposal and Breakdown Maintenance for Bearing Components

Components	A		B	C	D	E	Summary
Gross margin		832	648	546	526	3960	6512
Scrap disposal	52	36	28	28	132	276	
Breakdown maintenance	416	324	168	167	528	1603	
Total $		1300	1008	742	721	4,620	$8391

Bearing Availability, Reliability and unreliability

Table B.4: Computational Values for Study interval, number of failure recorded, Mean Time Between Failure and Failure Rate for shaft

Components	A	B	C	D	E	Summary
Study interval	26280	26280	26280	26280	26280	8,760 failure /yr
Numbers of failure	2	2	1	2	1	2.67 failure /yr
MTBF	13140	13140	26280	13140	26280	3,284 hours/failure
Failure Rate (FR)	$7.61\text{x}10^{-5}$	$7.61\text{x}10^{-5}$	$3.81\text{x}10^{-5}$	$7.61\text{x}10^{-5}$	$3.81\text{x}10^{-5}$	$3.05\text{x}10^{-4}$ failure/hr

Evaluation Procedures for some Functional parameters of the Shaft Components

Table B.5: Computational Values for some Functional Parameters of Failure rate, Failure per year and Corrective Time Failure and Lost Time per year for shaft.

Components	A	B	C	D	E	Summary
Failure Rate	$7.61\text{x}10^{-5}$	$7.61\text{x}10^{-5}$	$3.81\text{x}10^{-5}$	$7.6\text{x}10^{-5}$	$3.81\text{x}10^{-5}$	$3.05\text{x}10^{-4}$ failure/hr

Failure per year	0.7	0.7	3.3	0.7	3.3	8.7
Corrective time failure	3	2	3	3	4	3.3hrs
Lost time per year	2.1	1.4	9.9	2.1	13.2	28.7 hrs

Determination of some Functional parameters of the shaft

Table B.6: Computational Parameters of Gross Margin, Scrap Disposal and Breakdown Maintenance

Components	A	B	C	D	E	Summary
Gross margin	1,050	875	8910	1155	14520	26,510
Scrap disposal	28	28	132	28	132	348
Breakdown maintenance	84	56	390	84	528	1142
Total $	1162	1063	9328	1267	15,180	$28,000

Table B.7: Computational Values for Study interval, number of failure recorded, Mean Time Between Failure and Failure Rate for Fan Belt

Components	A	B	C	D	E	Summary
Study interval	26280	26280	26280	26280	26280	8760 failure/yr
Numbers of failure	3	4	2	3	1	373 failure/yr
MTBF	8760	6570	13140	8760	13140	2,349 hours /failure
Failure Rate (FR)	$1.14x10^{-4}$	$1.52x 10^{-4}$	$7.61x10^{-5}$	$1.14x10^{-4}$	$7.61x10^{-5}$	$4.26x10^{-4}$ failure/hr

Evaluation on some of the Functional Parameters

Table B.8: Computational Values for Failure Rate, Failure per year, Corrective time Failure and Lost Time per year for Fan Belt

Components	A	B	C	D	E	Summary
Failure rate (FR)	$1.14x10^{-4}$	$1.52x10^{-4}$	$7.61x10^{-5}$	$1.14x10^{-4}$	$7.61x10^{-5}$	426 failure/yr
Failure per year	0.1	0.1	0.7	0.1	0.7	1.7
Corrective time failure	3	4	3	3	2	2.35 hrs
Lost time per year	0.2	0.4	2.1	0.3	1.4	4.0 hrs

Evaluation of some Functional parameters for Fan Belts

Table B.9: Computational Values of some functional parameters for gross margin, scrap disposal and breakdown maintenance for Fan Belt

Components	A	B	C	D	E	Summary
Gross margin	2.5	5	42	3.75	35	88.25
Scrap disposal	8	16	84	12	56	176
Breakdown maintenance	8	16	84	12	56	176
Total $	18.5	37	210	27.5	147	1440.25

Table B.10: Computational Values for Study interval, number of failure recorded, Mean Time Between Failure and Failure Rate for Shaft Pulley

Components	A	B	C	D	E	Summary
Study interval	26280	26280	26280	26280	26280	8760 failure/yr
Numbers of failure	2	1	2	3	2	2.43 failure/yr
MTBF	13140	26280	13140	8760	13140	3605 hours /failure
Failure Rate (FR)	$7.61x10^{-5}$	$3.81x 10^{-5}$	$7.61x10^{-5}$	$1.14x10^{-5}$	$7.61x10^{-5}$	$2.78x10^{-4}$ failure/hr

Evaluation of some Function Parameters of Shaft Pulley

Table B.12: Computational Values on some of the functional parameters of Gross Margin, Scrap Disposal and Breakdown Maintenance for Shaft Pulley

Components	**A**	**B**	**C**	**D**	**E**	**Summary**
Gross margin	210	30	224	18	224	706
Scrap disposal	168	24	224	24	112	552
Breakdown maintenance	168	24	224	24	112	500
Total $	546	78	672	66	448	$1,818