

Research Article

Modelling Failure Rate of Automobile Crankshafts based on Distance Travelled and Age

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Abstract

Automobile crankshaft failure, apart from poor maintenance culture, is caused by age and distance travelled. These attributes which caused crankshaft failure were investigated using expert opinion in the selected crankshaft maintenance shops in Akure, Nigeria. Information/data on failure rate and failure consequence thresholds were obtained to serve as decision rule on the basis at which optimal reconditioning process, replacement and interchangeability system of the crankshaft components were established based on failure frequency (rate) (R^1) and consequence (β^1). Experimental failure data from the experts were modelled using multivariate linear regression approach. Computer algorithm was developed for the software package, using Microsoft Visual C# computer language. The model and its software were tested to determine their level of performance. The results generated were categorized into six scenarios from which MC230 crankshaft gave the best result in term of lowest failure rate. Crankshaft TC generated the best income rate (failure consequence) for the workshop. The significant difference test result between the actual and predicted failure rate and consequence showed that both are similarly in good agreement. The model and the emerging computer program will be veritable tools in predicting crankshafts' failure for prompt maintenance attention.

Keywords: Automobile Crankshafts, Modelling, Failure Rate, Distance Travel, Vehicular Age.

1. Introduction

Transportation is an important factor in the economy of every country as every business transaction is made possible by means of transportation either by air, sea or land. Generally transportation by land is most common because of its low cost. Automobiles such as lorries, buses, cars, among others, are being used for land transportation assignments. Therefore, automobile industries have played a significant role in economic development of any nation in the areas of transportation of raw materials and finished goods to/from the production industries. Improved performance of the transportation sector therefore, will have positive effects on the national economy (Akinola and Ogedengbe, 2003).

The heart of an automotive vehicular system is the crankshaft because vehicular movement would cease if it fails (Kareem, 2015). The crankshaft is the part of an engine which translates reciprocating linear piston motion into rotation. Automobile crankshaft failures and their associated problems has increased with the developments in automotive industries as many brands/models of vehicles are on sales in recent time (Kareem, 2015). The failure of crankshaft is a very

severe problem faced by engineers recently. While some engineers believe that most of the failure are due to fatigue failure, other believe it that failure is beyond fatigue (Pratik and Manish 2015; Heisfer, 2005). Increase in crankshaft failure was attributed to rapid increase in car ownership, low expansion rate of roads, and poor engine maintenance culture (Kareem, 2015). Failure modelling of crankshaft has been dealt with by many researchers (Heisfer, 2005; Kareem, 2007; Fonte *et al.*, 2013). However, many of these efforts failed to consider practical aspect of failure rate modeling failure rate by considering distance travelled and age. In this study, the automobile crankshaft failure rate is modeled based on distance travel and age. The outcomes are used to predict failures of different brands of crankshafts in order to prevent any premature failure. Fig. 1 shows typical example of a vehicular crankshaft.

Crankshafts are manufactured with different materials and during its operation, due to cyclic loadings, cracks are produced on its surface, ultimately resulting into failure of crankshaft due to vibration (Amit *et al.*, 2014; Pratik and Manish, 2015). This study used expert information/data obtained from well-established maintenance job-shops to model the crankshaft failure under distance travel and age with

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the assumption that the causes of failure is random and the failure itself is randomly occurred and the magnitude is different over the years.

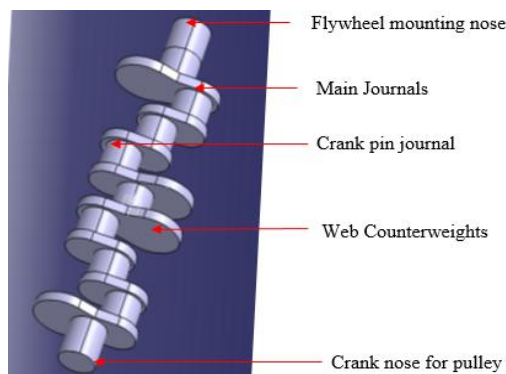


Fig. 1 Vehicular Crankshaft

Section 2 presents literature review related to critical causes/modes of crankshaft failure. Research methodology including modelling criteria is presented in section 3. Section 4 presents results and discussion, while conclusion & reference sections end this paper.

2. Literature review

Silva (2003) investigated the crack produced in the two crankshafts of diesel van which were used for 30,000 km before regrind. After regrinding the crankshafts lasted for 1000 km before journal damage was witnessed. The study was also supported by examining the various failure modes of the crankshafts.

Becerra *et al.* (2011) studied 4-Cylinder reciprocating compressor used in climate control system. In visual investigation, material and hardness analyses were carried out along with simulation which consists of various sub-models such as thermodynamic model of refrigeration cycle, torque dynamical model, finite element model, and lumped system model. The study revealed that stress in the compressor is controlled by torque dynamics and the effect of gas force on stress is negligible. Jimenez (2009) studied failure of 4-stroke 18 V diesel generator's crankshaft used in electrical power plant. The crankshaft is running at speed of 1500 rpm before failure, and worked for 20,000 hrs of life. Failure of crankshaft was seen along the web between second journal and second crank pin. The presence of the beach mark shows fatigue fracture was produced along with a thin and hard zone which was found in the template surface showing crack initiation. Ahmed *et al.*, (2016) presented a Low cycle fatigue (LCF) tests which were carried out on forged carbon steel (AISI 4130) used in V12 Diesel engine crankshafts, at room temperature and 300 °C, under total strain control. These tests were performed in order to study the cyclic mechanical behavior, lifetime and damage mechanisms of the material.

Infante (2013) worked on finding out the causes of failure of aircraft engine crankshaft. The research was oriented from the failure of the crankpin journal due to fatigue. The investigation shows that the presence of beach marks. Optical and electronic microscopic technology was used for the investigation. Nadolny (2012) investigated and discussed the method of assessment of the grinding wheel cutting ability in the plunge grinding of crankshaft. Colin, (2015) worked and find out the technical developments in crankshaft failure. Katari (2011) carried out the investigation of the failure of three different crankshafts of 12 cylinders V-12 design engine used in trains. The engine run at nominal speeds of 1050 rpm and the periodic maintenance was carried out after 40000 km. Failure occurred due to reduction in hardness. Fracture toughness was also measured using standard Charpy V-notch (CVN) specimen. The average CVN shows that the fracture was brittle. Bhaumik (2002) worked on finding out the causes of failure of transport aircraft crankshaft. The failure was due to rubbing action between journal and bearing due to axial load on the shaft. Pandey (2003) investigation of crankshaft made up of forged carbon steel resulting into premature failure in the web regions.

Chien (2005) undergone fatigue failure analysis of cast iron crankshaft. The area where bending occurred was studied, along with residual stresses produced due to fillet rolling process. The study revealed that the fatigue crack produced was propagated through residual stress zone in the fillet regions. Wang (2005) carried out the analysis of the crankshaft which failed in a strange manner when it was under testing only for 20 min. Cracks were found on the edge of oil hole. Friction was caused due to improper repairs which led to failure. Xuanyang (2007) presented work for the effect of presence of slant crack in the crankpin of crankshaft and a model for vibration analysis was developed. The effect of crack depth on the transient response was investigated and numerical data validated for the simulation of the motion of the cracked crankshaft. Bayrakceken (2007) presented his work on the single cylinder diesel engine crankshaft used in the agricultural vehicles. The study shows that two different cases of crankshaft failures have been investigated and in both cases slight design differences were mentioned. The failure mechanism for both crankshafts was due to fatigue only.

Fonte *et al.* (2016) investigated a failure analysis of two damaged crankshafts: one obtained from a diesel engine of a mini backhoe, and another from an automobile vehicle. Cevik and Gurbuz (2013) investigated the effects of fillet rolling on the fatigue behaviour of the ductile cast iron crankshaft used in diesel engines. Fillet rolling is a widely used process in automotive industry for improvement of the fatigue life of crankshaft by inducing compressive residual stress. By the application of fillet rolling, localized strain hardening occurred and residual stress developed at the deformed region. Jung *et al.* (2009) experimented

ductile crankshaft which is commonly used for lightweight truck. Other factors affecting crankshaft failure of motor vehicle are: Age/length of usage, mileage/extent of usage, condition of engine/transmission, body condition, tire condition, maintenance history and functionality of accessories (Ndirpaya, 2011; Kareem, 2010; Weaving, 1990).

The stated studies summarized the contributions of various researchers towards failure analysis of crankshafts due to fatigue stress. Other causes of crankshaft failure included oil leakage, crack on the oil sump, lack of maintenance and high temperature due to radiator fault were also considered. This paper addresses possibility of predicting crankshaft failure under the influence of distance travelled and age using modelling approach.

3. Methodology

The six brands of vehicular crankshafts investigated in this paper are TC, HC, MC230 Class, PG607, MZ626 and FC100. The names of the vehicles were concealed to safeguard the integrity of the manufacturers. The age and distance travelled, failure occurrence time and the cost of repair of the crankshafts were collected. The mean vehicular ages and/or distance covered were obtained across all brands throughout the periods of investigation. The data obtained from the maintenance experts were used to calculate crankshaft failure rate and cost consequence in the maintenance shops in operation for so many years (30 years). The model parameters used include: Age (A), Distance travel (S) and Time of occurrence (Y).

Failure rate based on ages and distance travel variation of the vehicular crankshafts modelled using multivariate linear regression approach. Therefore the parameters measured include: Failure rate (wear/day) and Failure consequence (N). The equations for calculating the failure rate and the failure consequence are given as follows:

$$R(t) = f(\text{Age}) + f(S) + f(Y) \tag{1}$$

$$\beta^{(N)}(f) = f(\text{Age}) + f(S) + f(Y) \tag{2}$$

where,

R(t), failure rate

$\beta^{(N)}(f)$, failure consequence

f(Age), vehicle age before failure (A) in year

f(S), vehicle distance travelled before failure (S)

f(Y), time of occurrence of the failure (in year)

The causes, mode and failure remedies were proposed using failure rate and failure consequence threshold approach which allow the arrival in order to arrive at manageable vehicular operation system based on replacement and interchangeability of the crankshaft component. The parameters not quantitatively measured include: Lubricity of crankshaft or engine, Genuineness of engine oil, Failure causes and Failure modes were carried out. The targets set were threshold

failure rate (allowable failure rate) and consequence determination beyond which there will be need for failure remedy either in the form of replacement or re-conditioning.

Computer program was developed which was written in Microsoft Visual C# computer Language (as Front end/engine) and Microsoft Structured Query Language (SQL) Server Compact Edition (as Back end/engine). The computer outputs generated and predicted failure rates were useful tools in taking decision on whether to replace/recondition or not. Paired t-test and Analysis of Variance (ANOVA) statistics was used to check the level of significant difference between the mean of actual failure rate and the predicated values.

Three (3) workshops A, B and C was visited to collect relevant data from experts on each vehicular crankshaft selected for analysis using questionnaire forms were prepared to collect data required for this and oral interview methods. The elements of questionnaire consist of number of failed crankshafts reported per day, cost of repair per failed crankshaft cost of re-grind, cost of interchange or replacement, average distance travelled by the crankshafts before failure and average age of the crankshaft. The response outcomes are shown in Tables 1 to 6 for the Workshop

Table 1 Crankshaft failure data for TC model

Year under review	TC				
	No. of crankshaft reported for repair per day	Cost of repair per crankshaft for:		Average Distance travelled before failure per crankshaft (Km)	Average Age of crankshaft per one (year)
		Re-grind per one (N)	Interchange or replacement per one (N)		
2001	4	300	6,500	220,120	11
2002	6	400	7,800	244,050	10
2003	8	500	8,000	250,000	12
2004	9	600	10,000	254,000	13
2005	13	600	10,000	210,000	9
2006	17	1,000	11,000	180,000	11
2007	6	1,200	11,300	210,000	12
2008	9	1,200	12,500	254,000	10
2009	10	1,300	12,500	200,000	11
2010	12	2,000	12,800	252,000	11
2011	12	2,000	13,000	222,000	11
2012	10	2,000	14,000	190,000	10
2013	12	2,200	14,500	260,000	10
2014	20	2,500	14,800	215,000	9
2015	16	3,000	15,000	251,000	11
2016	14	3,300	15,000	243,000	9

Table 2 Crankshaft failure data for HC model

Year under review	HC				
	No. of crankshaft reported for repair per day	Cost of repair per crankshaft		Average Distance travelled before failure per crankshaft (Km)	Average Age of crankshaft per one (year)
		Re-grind per one (N)	Interchange or replacement per one (N)		
2001	4	350	5,500	198,600	10
2002	4	450	6,500	204,100	9
2003	5	500	7,000	193,000	10
2004	4	550	9,000	193,700	10
2005	6	600	11,000	244,300	12
2006	6	1,000	12,000	240,800	10
2007	5	1,200	12,300	211,000	11
2008	6	1,200	12,500	200,400	9
2009	7	1,300	12,800	199,000	9.5
2010	7	2,000	13,000	224,600	10
2011	8	2,000	13,500	239,800	12
2012	10	2,200	13,500	240,000	11
2013	9	2,000	14,500	244,200	10
2014	9	2,000	14,800	244,600	9
2015	10	3,000	14,800	200,700	9
2016	11	3,500	15,000	214,900	10

occurrence (Y) in year using Statistical Package for Social Science (SPSS) Software on the selected vehicular crankshaft were obtained. The parameters used are age, distance travelled and period of occurrence. The results obtained from the selected Crankshaft maintenance workshops are presented as follows:

The failure rate prediction for TC crankshaft using multivariate linear regression model shows that the number of vehicular crankshaft reported for repair depend on: the distance travelled (S) before failure, period of occurrence (Y) and age (A). The R-Square value was obtained as 0.512 (51.2%), while the regression coefficient for vehicular age, distance travelled, time in year and regression constant were; 0.522, $- 3.148 \times 10^{-5}$, 0.562 and 19.077, respectively.

The model for failure rate prediction of TC crankshaft is given as:

$$R(t) = -0.522A - 3.148 \times 10^{-5}S + 0.562Y + 19.077 \quad (R^2 = 0.512) \quad (3)$$

The stated regression equation is a good predictor of failure rates at a given age, distance travel, and time under investigation.

The regression model analysis for failure consequence $[\beta^{[M]}(f)]$ of TC crankshaft showed that the cost of repair in ₦ (Naira) depends on: the distance travelled (S) before failure, time of occurrence (Y) and age (A). The coefficient of determination (R-Square value) was obtained as 0.959 (95.9%) and the regression model's coefficient for vehicular age (A), distance travelled (S), time of occurrence (Y) and regression constant are 7.141, 0.002, 199.475 and $- 733.570$ respectively. The established model for failure consequence of the TC crankshaft is expressed as:

$$\beta^{[M]}(f) = 7.141A + 0.002S + 199.475Y - 733.570 \quad (R^2 = 0.959) \quad (4)$$

The regression equation (4) (with $R^2 = 0.959$) is an excellent predictor of cost consequence at a given age, distance travelled and failure time.

In the bivariate regression model analysis for TC, the following regression parameters were investigated, which namely: Linear, Logarithmic, Inverse, Quadratic and Cubic, Compound, Power, S, Growth, Exponential and Logistic. Comparing dependent variable (Number of vehicle reported for repair per day) R (t) and Independent variables (age in year). The predicted result showed that no correlation existed between the two variables because R-square values are as far below 50%. Similar results were obtained when failure rate is compared with distance travelled.

The results of TC crankshaft model using bivariate regression model between failure rate R(t) and failure consequence $\beta^{[M]}(f)$ showed that there is high correlation between the variables (R-square values) ranging from 0.622779 (62.2%) to 0.931 (93.1%).

Therefore, the model is a good predictor of failure consequence. The threshold value is determined from the data collected for the selected vehicular crankshaft brands from year 2001 to 2016 as shown in Table 8.

The threshold failure rate of the selected vehicular brands/models: TC, MZ626, MC230 Class, HC, PG607 and FC100 of Workshop A are 14, 11, 10, 3, and 6 (based on number of re-grind per day) respectively. The threshold value for the failure consequence for the same vehicular brands/models selected are ₦3500, ₦3500, ₦3200, ₦3000, ₦3000 and ₦8000, respectively. Therefore, any value(s) beyond the threshold failure rate and the consequence/cost as shown in Table 8 is calling for immediate attention of the user on the need to replace or interchange the crankshaft. It also shows from Table 8 that the maximum allowable income generated by the workshop for the vehicular brand/models selected are: ₦49000, ₦38500, ₦32000, ₦9000, ₦18000 and ₦48000 respectively.

Table 8 Crankshaft failure thresholds for workshop A

Vehicular crankshaft brand	Maximum No. of Re-grind per day/ Threshold failure rate [a]	Possible No. of Re-grind / vehicle at Threshold failure rate [b]	Cost of Re-grind per Threshold Failure consequence (₦) [c]	Cost of Replacement or Interchange / Standard size of crankshaft (₦) [d]	Maximum Allowable Income per day (₦) [a×c]
TC	14	1 – 4	3,500	15,000	49,000
HC	11	1 – 4	3,500	15,000	38,500
MC230 Class	10	1 – 4	3,200	12,000	32,000
PG607	3	1 – 4	3,000	20,000	9,000
MZ626	6	1 – 4	3,000	15,000	18,000
FC100	6	1 – 4	8,000	16,500	48,000

From Table 9 it shows that the failure rate of the crankshafts of the vehicular brands selected varied across the brands. The predicted results from the model also showed that the failure consequence of the models have excellent correlation with all independent variables under investigation. The bivariate regression model analysis for the selected vehicular brands shows that the age and distance travel did not depend on the number of crankshaft reported for repair. However cost of repair is highly dependent on the number of crankshaft reported for repair (failure rate) except MC230 Class which showed low correlation.

Table 9 Regression model results for workshop A

Vehicular crankshaft brand	Failure analysis	R Square value	Correlation agreement		Multivariate Regression Model Analysis Comparison		
			Correlated / Not correlated	Agreement	No. of Crankshaft reported and Age	No. of Crankshaft reported and Distance travelled	Cost of repair per day and No. of Crankshaft reported
TC	Failure rate	0.512	correlated	Good	Not correlated	Not correlated	correlated
	Failure consequence	0.959	correlated	Highly			
HC	Failure rate	0.930	correlated	Highly	Not correlated	Not correlated	correlated
	Failure consequence	0.942	correlated	Highly			
MC230 Class	Failure rate	0.384	correlated	Good	Not correlated	Not correlated	Not correlated
	Failure consequence	0.985	correlated	Very Highly			
PG 607	Failure rate	0.900	correlated	Very Highly	Not correlated	Not correlated	correlated
	Failure consequence	0.972	correlated	Very Highly			
MZ 626	Failure rate	0.577	correlated	Good	Not correlated	Not correlated	correlated
	Failure consequence	0.971	correlated	Very Highly			
FC 100	Failure rate	0.715	correlated	Good	Not correlated	Not correlated	correlated
	Failure consequence	0.958	correlated	Very Highly			

Computer output sample for failure prediction is shown in Fig. 3. The selection of vehicular crankshaft TC under the age of 10 years, distance travelled of

200,000 km and time of failure of 8 years yielded a failure rate and failure consequence thresholds of 13 and ₦3500 per day, respectively. The output results from the computer program (software) gave the failure rate and consequence as 11.4272 and ₦1373.64 per day respectively. Therefore, since the output results obtained for both failure rate and failure consequence are less than their threshold values, then crankshaft re-grind/reconditioning process will be established. The results of the software and manually calculated failure rate and failure consequence values were found to be similar. This proved that the software developed is reliable. Manual method of computation took 15 minutes 29 seconds while the computer processing and data loading time took only 2 minutes 5 seconds. The computer output sample as shown Fig. 3 enabled sensitivity analysis of the failure process at varying age, distance travelled or failure time, while other parameters were kept constant. The sensitivity results are discussed under scenarios 1 to 6.

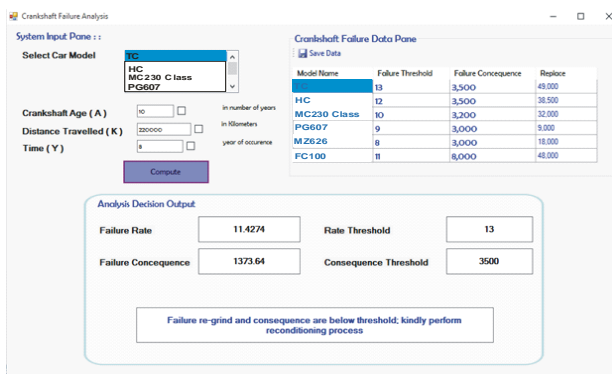


Fig. 3 Failure analysis output interface

Scenario 1: The failure rates obtained at varying time of occurrence (in year) for vehicular brands at constant distance travelled and age (100,000 km; 5 years) were considered. Crankshaft MC230 gave the best result because its failure rate was negligible. This was followed by crankshaft FC100 having noticeable failure rate after 3 years and increased steadily to 2.285 failures per day in 10 years. MZ626 came third with wear rate of 3.859 per day in the first year and increased steadily to 4.948 in 10 years. The fourth is PG607 that had a very high rate of wear of 11.218 wear/day but decreased rapidly to 2.245 in 10 years. HC was the fifth with initial wear rate of 7.823 which increased steadily to 11.936. Fig. 4 shows the failure rate sensitivity results under the failure time consideration.

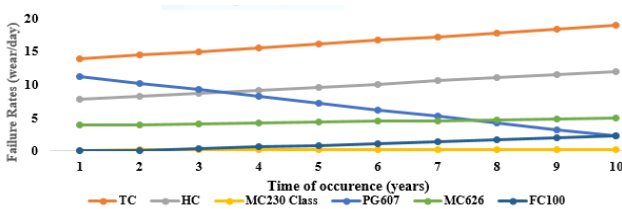


Fig. 4 Failure rate with time of occurrence

Scenario 2: The results of the sensitivity analysis of Failure consequence plotted against Time of occurrence (in year) for vehicular brands at constant distance travelled and Age (100,000 km; 5 years). The results shown that crankshaft HC had the highest Failure consequence which increased from ₦618.272 in the first year of failure to ₦2,488.67 in the 10 years. This was followed by the Peugeot 607 with the same failure time (in year) and constant parameters. Crankshafts MC Class, TC and MZ 626, maintained very low failure consequence for 2 years, after which they increased to ₦1779.353, ₦1493.874 and ₦2,488.67, respectively. Crankshaft FC100 gave the least failure consequence and therefore considered as the best results while compared to other vehicular crankshafts. The detailed sensitivity behaviour is shown in Fig. 5.

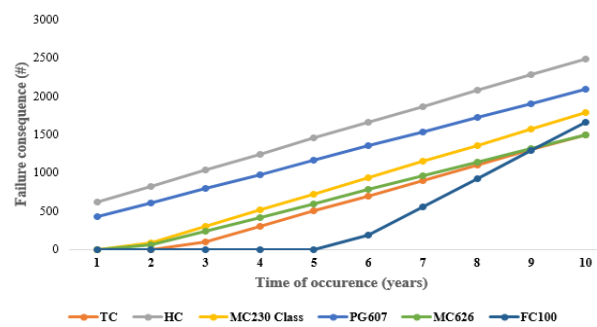


Fig. 5 Failure consequence with time of occurrence

Scenario 3: Results of the sensitivity analysis of crankshaft failure rate obtained from the software developed was plotted against Age (in year) starting from the first year to the tenth year under constant distance travelled and time of occurrence (in year) (100,000 km; 8 years) as shown in Fig. 6. From the results, it can be shown that the Failure rate of crankshaft MC 230 Class gave the best result, having least failure rate ranging from 0.068 to 0.99 per day; followed by FC100 having failure rate decreased from 2.611 to 0.592 in 10 years. MZ 636 came third with wear rate of 2.41 in the first year and increased to 7.576 in 10 years. The fourth is PG 607 that had a high rate of wear of 7.355 but decreased rapidly to 0.344 in 10 years. HC was the fifth with initial wear rate of 10.566 and increased slightly to 11.592, while TC came last under this scenario.

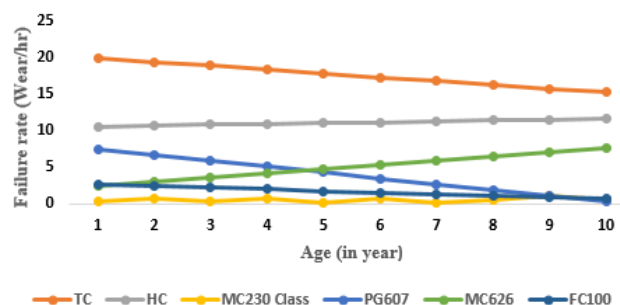


Fig. 6 Failure rate with age

Scenario 4: sensitivity analysis showed that crankshaft HC had the highest failure consequence which increased from ₦1,680.034 in the first year to ₦2,564.266 in 10 years; followed by PG 607 in which the failure consequence decreased very slightly with failure time from ₦1,817.909 in the first year to ₦1,591.289 in the 10 years. In MC230 Class, the failure consequence decreased from ₦1,418.695 to ₦1,279.915 in 10 years. In case of the TC and MZ 626, both maintained somewhat increase in failure consequences from ₦1,069.371 and ₦845.284 through ₦1,113.64 and ₦1,499.494, respectively. FC 100 gave the least failure consequence value and therefore the best result. The detailed sensitivity analysis is shown in Fig. 7.

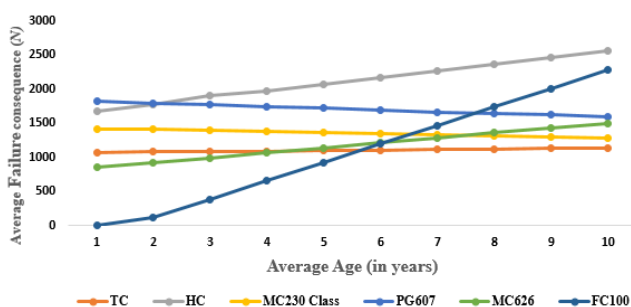


Fig. 7 Failure consequence with age

Scenario 5: The results of failure rate sensitivity analysis were plotted against distance travelled (in km) from 50,000 km to 140,000 km under constant age and failure time (in years) [10 years; 5 years] as shown in Fig. 8. From the results, crankshaft MC230 class gave the best result in term of having the least failure rate. It was followed by PG607 and FC100 having similar failure rate under varying distance travelled. Their failure rates decreased from 3.9835 and 4.1375 in 50,000km to 0.8542 and 0.8029 in 140,000 km, respectively. The three stated vehicular crankshafts maintained the same failure rates in 140,000 km. MZ636 came fourth with wear rate of 5.748 wear/day at the 50,000 km and decreased slightly to 4.308 wear/day at time of 140,000km. HC was the fifth with initial failure rate of 8.809 and increased steadily to 14.438, while TC came last under this scenario.

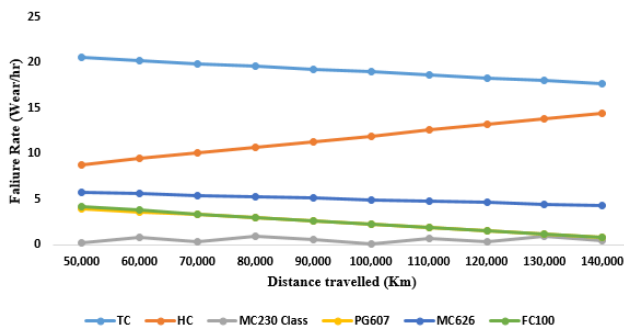


Fig. 8 Failure rate with distance travelled

Scenario 6: The results of sensitivity analysis of the crankshaft failure consequence was plotted against distance travelled from 50,000 km to 140,000 km under constant age and failure time as shown in Fig 9. The results showed that the crankshaft HC had the highest failure consequence followed by PG 607. However, MC 230 Class vehicular crankshafts increased steadily from ₦1,629.353 in 50,000 km to ₦1,899.353 in 140,000 km. Crankshafts TC and MZ 626 maintained nearly the same failure consequence throughout the distance travelled from 50,000 km to 140,000 km.. The last was crankshaft FC 100 that initially had a negligible failure consequence cost.

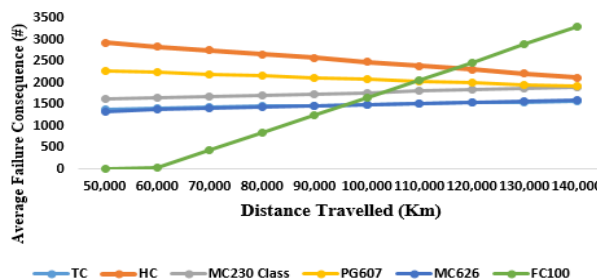


Fig. 9 Failure consequence and distance travelled

In general, crankshaft MC230 Class had the lowest failure rate followed by crankshafts FC100 and PG607 respectively. Crankshaft TC had the highest wear/failure rate followed by crankshaft HC. Also, crankshaft TC generated the highest failure consequence in the workshop amounted to ₦49,000 per day and followed by crankshafts FC100 (₦48,000) and HC (₦48,000), respectively.

The validation of the developed computer program showed that the model can adequately predict the failure rate (consequence) of the crankshafts. The actual and predicted values obtained from Regression models are shown in Table 10.

Table 10 Failure rate and consequence prediction

No	Failure Rate		Failure Consequence	
	Actual values	Predicted values	Actual values	Predicted values
2001	4	6.581	300.000	34.559
2002	6	7.157	400.000	234.118
2003	8	7.748	500.000	433.677
2004	9	8.339	600.000	633.236
2005	13	8.930	600.000	832.795
2006	17	9.521	1000.000	1032.354
2007	6	10.112	1200.000	1231.913
2008	9	10.703	1200.000	1431.472
2009	10	11.294	1500.000	1631.031
2010	12	11.885	2000.000	1830.590
2011	12	12.476	2000.000	2030.149
2012	10	13.067	2000.000	2229.708
2013	12	13.658	2200.000	2429.267
2014	20	14.249	2500.000	2628.826
2015	16	14.840	3000.000	2828.385
2016	14	15.431	3500.000	3027.944

Conclusions

Age and distance travelled were used as major criteria that influence the failure rate of crankshaft at a normal condition. The stated parameters were used to develop regression model for the prediction of failure in automobile crankshafts. A Statistical Package for Social Science (SPSS) software was used to develop

regression model that relates variables. Analysis of variables demonstrated very high correlations between predicted failure rate and failure consequence and the actual data. However, some variables were poorly correlated, and then adjudged to be poor predictors of crankshafts' failure rate and failure consequence. The validation of the developed computer program and the established statistical analysis of variance indicated a strong agreement between the mean of actual failure rate / failure consequence) and the predicted results under 5 % level of significant difference test. This confirmed that the model is reliable. The findings will help maintenance practitioners in the choice of the best crankshaft to procure in terms of low failure rate and low failure consequence. Further study is expected in extending the investigation to the crankshaft(s) of more vehicles as related to operational conditions and materials failure. The outcome will serve as indicator on the basis at which sensitivity of the process employed in this study will be determined.

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