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Case study

Evaluation of failures in mechanical crankshafts of automobile based on expert opinion

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ABSTRACT

In this study, mechanical crankshaft failures for automobiles are evaluated based on experts' opinion. This was done using data obtained using techniques based on oral interviews and questionnaire administration on mechanical failure of crankshafts from the experts working in the areas of automobile maintenance and crankshafts reconditioning. The data collected were analyzed using statistical methods based on probability. With this technique, probability of failure for each category of automobiles namely private, commercial cars and buses were evaluated. The results obtained show that private cars had lowest failure rate at the initial stage while commercial buses had the highest failure rate. At later periods all categories of automobile crankshafts considered had their failure rates converged steadily with stable reliability. Application of 6-sigma continuous improvement tool to the process indicated a further reliability improvement through improved oil lubrication system, especially in the thrust bearing. This showed that increased enlightenment campaign among the various stakeholders in automobile industries will improve on the choice of reliable mechanical crankshafts.

1. Introduction

Transportation is a very 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. Automobile such as lorries, buses, cars among others, are being used to carry out land transportation assignments. Therefore, automobile industry 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 [1].

The heart of an automotive vehicular system is the crankshaft because vehicular movement would seize if it fails. Automobile crankshaft failures and their associated problems have increased with the developments in automotive industries as many brands/models of vehicles are on sale in recent time [2]. The automobile crankshaft failures have led to increase in the death and disability rates of people in many quarters due to vehicular accidents they caused. Despite this development, awareness campaign on automobile safety was less than one given on some killer diseases such as malaria, tuberculosis infection among others, which have, in some cases, fewer reported cases of death or disability than the one reported from automobile crankshaft failures (accident) [3].

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The crankshaft is located below the cylinder on an in-line engine: at the base V on a V-type engine; and between the cylinder banks on a flat engine [4]. As the pistons move up and down, the crankshaft is turned. The piston travels down, on the intake stroke; up, on the compression stroke; down, on the power stroke; and up, on the exhaust stroke [4,5].

It is a general believe that crankshaft failure has been on the increase in recent years. The increase was attributed to rapid increase of car ownership, low expansion rate of roads, and poor engine maintenance culture. Laxity from monitoring authorities or agencies (police, road safety corps, etc.), to see to the compliance to the basic traffic rules especially in the areas of vehicular roadworthiness also contributed to the crankshaft failure [6]. Failure analysis of crankshaft has been dealt with by many researchers [4–7]. However, many of these efforts failed to consider practical aspect of failure analyses based on expert opinions. In this study, the automobile crankshaft failure and its associated factors are analyzed using experts' opinion. The outcomes are used to determine the level of monitoring and enforcement of maintenance rules by the concerned authorities at preventing premature failure of crankshafts.

2. Materials and methods

The survey of crankshaft failure using questionnaire administration and oral interviews of experts in the selected crankshaft maintenance shops in Akure, Nigeria was carried out. The brands/models (labelled k) of vehicles covered in this paper are private cars, commercial cars, and commercial buses. Private cars', commercial cars' and buses' crankshafts are maintained by maintenance shops A, B, and C, respectively. These maintenance shops were selected in Akure because they have necessary facilities and experts to carry out automotive maintenance/crankshaft inspection activities. The actual names of the vehicle brands/models and maintenance shops are concealed to safeguard their information and integrity. The average number of serviced vehicles was established per year based on throughputs in the stated shops for the years 2007–2013, and they are 49, 34 and 98 respectively for the brands categories – private cars, commercial cars, and buses. Total number of crankshafts required reconditioning or rejected after inspection (out of the stated categories of serviced vehicles) as a result of failure are recorded annually by experts. Causes of failure of crankshafts were also identified by the experts. The ages and kilometres travelled of the serviced vehicles were also estimated from which the vehicular ages 9–13 years (mean 11 years old) and/or kilometres covered 150,000–250,000 km (mean 200,000 km) were obtained. To be considerate in the analysis, the mean vehicular ages and/or distance covered were made constant across all brands throughout the periods of investigation. The data obtained from the maintenance experts are summarized in Table 1. Probability of crankshaft category k failure at year i, $P^k(i)$ was obtained using Eq. (1), while that of reliability or probability of success at year i, $R^k(i)$ was computed based on Eq. (2) [8–10]. Due to variable annual maintenance service demands (throughputs) across the mechanical workshops theoretical failure probability evaluation statistics based on certain standard distributions [11,12]

Table 1
Crankshaft failures data from maintenance experts (2007–2013).

k	Brand/category k of vehicle specialized on	Maintenance workshop	Years	i	Serviced vehicles per year, S_i	No. of failure per year, f_i	Identified causes of failure	Proposed remedy
1	Private cars	Workshop (A)	2007	1	49	12	OL, OD, TBM, PR, AO, OPP, SSF, PM, BOF, OPS	IOLS, IAI, IMS
			2008	2		10		
			2009	3		8		
			2010	4		7		
			2011	5		5		
			2012	6		4		
			2013	7		3		
2	Commercial cars	Workshop (B)	2007	1	34	10	OL, OD, TBM, PR, AO, OPP, SSF, PM, BOF, OPS	IOLS, IAI, IMS
			2008	2		8		
			2009	3		6		
			2010	4		2		
			2011	5		1		
			2012	6		3		
			2013	7		4		
3	Commercial buses	Workshop (C)	2007	1	98	30	OL, OD, TBM, PR, AO, OPP, SSF, PM, BOF, OPS	IOLS, IAI, IMS
			2008	2		26		
			2009	3		16		
			2010	4		10		
			2011	5		7		
			2012	6		5		
			2013	7		4		

OL, oil leakage; OD, overloading; TBM, thrust bearing misalignment; PR, poor reconditioning; SSF, poor shaft surface finish; AO, adulterated oil; OPP, oil pump problem (i.e. improper oil supply to the engine); PM, poor maintenance practice; BOF, bad oil filter; OPS, oil pan seal problem; IOLS, improved oil lubrication; IAI, improved automotive innovations; IMS, improved maintenance system.

will be cumbersome. Instead, heuristic evaluation based on the ratio of observed failed crankshafts over the number of serviced vehicles (Eq. (1)) per year in the respective shop will be reasonably unbiased in determining the normalized crankshaft failure probability [11,18].

$$P^k(i) = \frac{f_i}{S_i} \quad (1)$$

$$R^k(i) = 1 - P^k(i) \quad (2)$$

where f_i is the number of crankshaft failure per year i, S_i is the total number of vehicle serviced per year i, the index i denotes counter for year ($i = 1, 2, 3, \ldots, n$), and the index k is counter for vehicular category ($k = 1, 2, 3, \ldots$) respectively.

With reference to the stated conditions and Table 1, in year 2007 ($i = 1$) for instance, the crankshaft failure probabilities and the reliabilities over the serviced vehicles in the respective shops are given as follows:

For shop (A)/vehicle brand/model category $k = 1$, apply Eq. (1) for failure probability, then Eq. (2) for reliability:

$$P^1(1) = \frac{12}{49} = 0.244898 \approx 0.25, \quad R^1(1) = 1 - 0.25 = 0.75$$

Similarly, shop (B)/vehicle model category $k = 2$,

$$P^2(1) = \frac{10}{34} = 0.29412 \approx 0.29, \quad R^2(1) = 1 - 0.29 = 0.71$$

Shop (C)/vehicle model $k = 3$,

$$P^3(1) = \frac{30}{98} = 0.30612 \approx 0.31, \quad R^3(1) = 1 - 0.31 = 0.69$$

The crankshaft failure probabilities and reliabilities for other years (2008–2013, $i = 2, 3, \ldots, 7$) were obtained in similar way at constant age limit and the results are presented in Tables 2 and 3, respectively.

Failure mode(s) on the crankshaft was qualitatively determined from hierarchical relationships among the causes of failures as identified by the experts based on the weighted severity (Fig. 1). According to the experts the crankshaft failures in Table 1 occurred at vehicular service age limit of 9–13 years (mean 11 years old) and/or the kilometre (km) travelled at 150,000–250,000 km (mean 200,000 km). Based on this constant age limit for the studied cases, analysis was carried out on various components of the crankshaft and the component with highest contribution to failure was selected for system improvement. The outcomes of the analysis indicated how the thrust bearing (due to absence of oil film) has greatly influenced the crankshaft failure due to weak oil lubrication system (Fig. 1). The proposed improvement strategy that can sustain the life of the oil lubricating system is shown in Fig. 2.

Table 2
Automotive crankshafts failure probabilities.

Years	i	Probability of failure		
		$k = 1$ (A)	$k = 2$ (B)	$k = 3$ (C)
2007	1	0.25	0.29	0.31
2008	2	0.21	0.24	0.27
2009	3	0.16	0.18	0.16
2010	4	0.14	0.12	0.10
2011	5	0.10	0.09	0.07
2012	6	0.08	0.05	0.05
2013	7	0.06	0.03	0.04

Table 3
Automotive crankshafts reliability analysis.

Years, i	Reliability or probability of success, $R(t_i)$		
	$k = 1$ (A)	$k = 2$ (B)	$k = 3$ (C)
2007	0.75	0.71	0.69
2008	0.79	0.76	0.73
2009	0.84	0.82	0.84
2010	0.86	0.88	0.90
2011	0.90	0.91	0.93
2012	0.92	0.95	0.95
2013	0.94	0.97	0.96

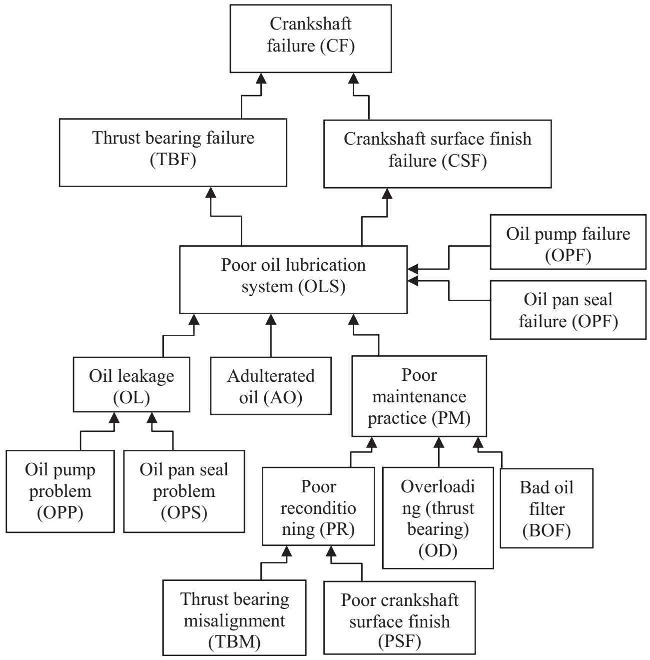

Fig. 1. Hierarchical causes and modes of crankshaft failure.

2.1. Improvement strategy

The identified causes of crankshaft failure, call for the evolution of innovative automobile manufacturing system through adoption of the total quality management (TQM) system. The modern continuous improvement strategy such as sigma quality approach will improve the reliability of the critical component failure (thrust bearing/shaft surface finish) through improved oil lubrication system (Table 1). Poor oil lubrication system due to oil leakages, oil adulteration, poor maintenance and overloading, has adverse effects on crankshaft finish and thrust bearing alignment, which eventual caused crankshaft failure (Fig. 1). Therefore, poor oil lubrication system played a prominent role in crankshaft failure. Introduction of foolproof systems and the use of advanced materials will provide improved strategy leading to the achievement of TQM system (Fig. 2).

Evolution of innovations in automotive manufacturing sectors is required to improve the reliability of the system. These innovations are achievable from continuous improvement programmes (total quality management (TQM) and total productive maintenance (TPM)) needed to be deployed on the system at source. Alternatively, the continuous

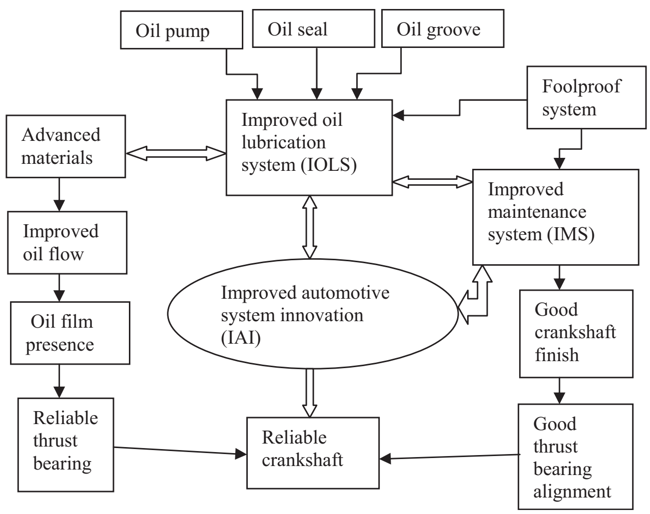

Fig. 2. Proposed crankshaft reliability improvement strategy.

improvement system can be addressed by developing/installing the error proof systems in the critical areas prone to failure (oil lubrication system) by early detection of errors. Undetected mal-functioning of oil lubrication system due to bad lubrication oil, oil leakages, poor oil flow, poor maintenance, and/or overloading can lead to thrust bearing misalignment and/or poor crankshaft finish. The bearing misalignment and subsequent crankshaft wear can lead to failure. Overloading is created by the owner of the vehicles, but the manufacturer can prevent the failure at overloading through foolproof provision that triggers automatic stop anytime the maximum load limit is exceeded.

To improve reliability of the critical contributor to failure, oil lubrication system, failure mode(s) generated by it need to be identified and the continuous improvement strategy applied to reduce or eliminate the failures. The failure probability results from the heuristics based on experts (Eq. (1)) can adequately represent the prior knowledge of failure probability behaviour of the crankshafts.

2.2. System improvement analysis

The biggest contributor to failure, the oil lubrication system, is a critical component that requires the attention of the automotive manufacturers at providing an improved and innovative technology that will enhance the reliability and system performance. Standard performance can be achieved by adopting methodology based on continuous quality improvement using sigma quality statistics [13–15]. The crankshaft failure outcomes were subjected to the improvement strategies moving from the prior quality state, 3-sigma to 6-sigma quality statistics. These improvement strategies will reveal the trend of continual improvement (in reliability) of the system. The 6-sigma quality of 99.99966% of flawless, less than 1% nonconformance per million opportunities, and 3-sigma quality statistics of 93.3% conformance, less than 6.7% nonconformance [16,17], were applied as continuous improvement tools in the automotive sectors. The sigma quality measurements were applied to establish where the automotive sectors are and where they should be in the advanced manufacturing of quality product/system [16,17].

The first stage in the system improvement is to utilize known success/failure (prior) probabilities, $R^k(i)/P^k(i) = P\{\theta_y = \theta_1/(=\theta_2)\}$of crankshafts (Tables 2 and 3) as the bases for projecting improvement using Bayesian philosophy [11,12]. For any vehicle reported for maintenance at any mechanical workshop, there are two principal decisions on crankshaft, z_j to arrive at after inspection; that is, passed (conformance), z_1 or failed (nonconformance), z_2. By this new information, statistic based on binomial distribution probability [12] will be good for analyzing the conditional probability of the system $P\{z_y\backslash\theta_y\}$. Where $P\{\theta_y = \theta_1/(=\theta_2)\}$ indicating prior probability of success or failure of crankshaft as indicated by Eqs. (1) and (2), respectively. The joint probabilities $P\{\theta_y,z_y\}$ can be computed by multiplying the conditional probabilities $P\{z_j\backslash\theta_y\}$ by the prior probabilities $P\{\theta_y\}$:

$$P\{\theta_y, z_j\} = P\{z_j\backslash\theta_y\}P\{\theta_y\} \tag{3}$$

$P\{z_j\}$ was determined from Eq. (5).

$$P\{z_j\} = \sum_{y=1}^{2} P\{\theta_y, z_j\} \tag{4}$$

Posterior probabilities (of success/reliability or failure of crankshafts) based on new improved manufacturing quality information (3-sigma and/or 6-sigma) are obtained from using Eq. (5) at a given period *i*.

$$P^i\{\theta_y\backslash z_j\} = \frac{P\{\theta_y, z_j\}}{P\{z_j\}} \tag{5}$$

With reference to Tables 2 and 3 for numerical computation example on only workshop A for the first year, 2007 where prior probability of success (failure) is given as $P\{\theta_y = \theta_1 = 0.75/(=\theta_2 = 0.25)\}$, then based on binomial distribution and a unit trial on crankshaft leading to decisions; conformance (passed) or nonconformance (failed), the conditional probabilities of an outcome z_j when the stated 6-sigma quality improvement is imposed are as follows:

$$P\{z_1\backslash\theta_1\} = C_1^1(0.99999)^1(0.00001)^0 = 0.99999$$
$$P\{z_2\backslash\theta_1\} = C_0^1(0.99999)^0(0.00001)^1 = 0.00001$$
$$P\{z_1\backslash\theta_2\} = C_1^1(0.99999)^1(0.00001)^0 = 0.99999$$
$$P\{z_2\backslash\theta_2\} = C_0^1(0.99999)^0(0.00001)^1 = 0.00001$$

The probabilities can be tabulated as $P\{z_j\backslash\theta_y\}$,

	z_1	z_2
θ_1	0.99999	0.00001
θ_2	0.99999	0.00001

The joint probabilities $P\{\theta_y, z_j\}$ are computed from the tabulated probabilities by multiplying its first row by $\theta_1 = 0.75$ and its second row by $\theta_2 = 0.25$. The outcomes are tabulated as follows $P\{\theta_y, z_j\}$;

	z_1	z_2
θ_1	0.7499925	0.0000075
θ_2	0.2499975	0.0000025

$P\{z_j\}$ are obtained using Eq. (5) as $P\{z_1\} = 0.99999$, $P\{z_2\} = 0.00001$.

Posterior probabilities are obtained using Eq. (6) by dividing the columns of the last tabulated probabilities with the corresponding $P\{z_j\}$

	z_1	z_2
θ_1	0.75	0.75
θ_2	0.25	0.25

The final results indicate that the crankshaft was found passed (reliable) with probability of 0.75, while the failure tendency has been improved upon and yielding a success probability of 0.75. The same procedure was used to compute other parameters. The outcomes were used to determine improvements in crankshaft reliability (in percentages) over the years, *i*. Then the overall probability improvement in crankshaft reliability was heuristically estimated using Eq. (6).

$$\text{New probability of success (reliability)} = \text{probability of success} + \frac{\text{probability of success in failure} \times \text{num. of failure}}{\text{total sampled}} \quad (6)$$

With reference to sampled and failure data in Table 1, most especially for 2007 in workshop A, the new (improved) probability of success was estimated using Eq. (6) as:

$$\text{New probability of success(reliability)} = 0.75 + \frac{0.75 \times 12}{49} = 0.93367$$

This shows that the reliability/success probability (0.93367) of crankshafts has improved by 0.18367 from the 0.75 improvement level based on the applied quality and maintenance improvement strategy (TQM & TPM). The other parameters for the studied cases ($k = 1, 2, 3$) were estimated in similar way.

3. Results and discussion

From this study it was discovered that many factors contributed to the sudden fracture/failure in mechanical crankshafts when the ages of and/or kilometres covered by the vehicles are at the mean limits of 11 years old and/or 200,000 km. These factors include poor crankshaft surface finish, misalignment of trust bearing, overloading on thrust bearing, oil leakages in oil pump and oil pan, adulterated oil and misassembling of the shaft, poor maintenance practice and thrust bearing failures (Table 1). The mean limits of vehicular ages and/or distances covered before crankshaft failure records may be attributed to unequal attitude of vehicular users in following standard maintenance practice as directed by the automotive manufacturers. It can be shown from Fig. 1 that the thrust bearing failure has highest impact on crankshaft failure because its failure has direct effect on the crankshaft while other factors are secondary. Besides, lackadaisical attitude of the users towards installing effective maintenance practice as prescribed by the manufacturers of the vehicles may also cause crankshaft premature failure. Many of the vehicles when overloaded beyond its designed capacity may sometimes lead to misalignment of crankshaft due to excessive torque pressure, improper main bearing alignment and excessive rearward crankshaft load pressure. Oil leakage is caused by improper maintenance of the oiling system or use of bad (adulterated) engine oil. Improper maintenance of engines is very common with the users of cars and buses for commercial purposes (Table 1).

It was not only mechanical factors that caused crankshaft failure, some human factors also caused it. These factors include attitude of drivers on car maintenance and general conditions of roads. Many roads networks are saddled with pot-holes, which are supportive to automobile crankshaft fracture. Unstable weather such as alternation of fog, rain, moist and sun which caused coldness and hotness environments adversely affected the life of crankshafts. Other factors that caused failure are material and incompetence of maintenance personnel (Fig. 1). Crankshafts made of poor quality material are expected to fail unnoticed. Failure was also expected from the maintenance personnel without improved training and education in thrust bearing installation and maintenance.

The results obtained from the failure analysis showed that number of crankshaft failures was decreasing steadily with time for all brands of automobile (Table 1), except vehicular brands on commercial usage categories. This, besides overloading, could be as a result of poor maintenance culture on the part of the users or the use of adulterated engine oil; this contributed to the weakening of oil lubrication system. Generally, the results show that probabilities of crankshaft failures decreased steadily with time for all three categories of vehicles investigated (Tables 2 and 3). The users of the automobile were dynamically maintaining their vehicles and/or advancement in technology had produced crankshafts which are more

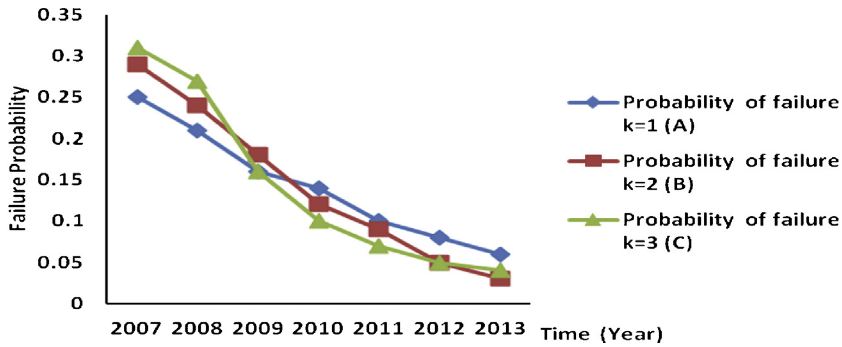

Fig. 3. Failure analysis of vehicles' crankshafts.

rugged (resistance to failure) than before (Fig. 2). Results obtained further showed that private cars have lowest probability of failure in the first three years after 2007; this was followed by commercial cars while commercial buses had the highest failure rate (Fig. 3). In the subsequent years (after 2010), a steady change was noticed, but the changes (for the three scenarios) were steadily converged in the year 2013. This convergence of failure probabilities indicated an improvement in technology, maintenance, personnel training and retraining. Fig. 4 further explains how reliabilities of crankshafts have increased tremendously over all categories of serviced vehicles, and it reached the peak in the year 2013. This corresponds to the time of least failure rate. This showed that there were improvements over the years on automobile crankshaft reliability. The results obtained from the applied continuous improvement scheme based on 3-sigma and 6-sigma quality improvements on oil lubrication system at the stated age (year) and/or kilometre (km) limits, are presented in Tables 4 and 5, respectively. This analysis was carried out to know whether there is any further improvement opportunities or not, in sustaining the life expectancy (reliability) of the thrust bearing. From the outcomes, it can be deduced that both 3-sigma and 6-sigma performed well when applied on the successful crankshafts to establish probability trend of continuous improvement over the years with maximum reliabilities of: 0.9520 and 0.9400; 0.9764 and 0.98; and 0.9682 and 0.9600 achieved respectively for the categories of the vehicles (Table 4). However, 3-sigma quality improvement demonstrated steady lower continuous reliability improvement over the years than the 6-sigma which attained the highest possible reliability at the early stage of the analysis (Table 5). The steadily slow 3-sigma reliability improvement was not sustainable over previous reliability performance of the crankshafts. The differences in reliabilities of the two schemes (prior

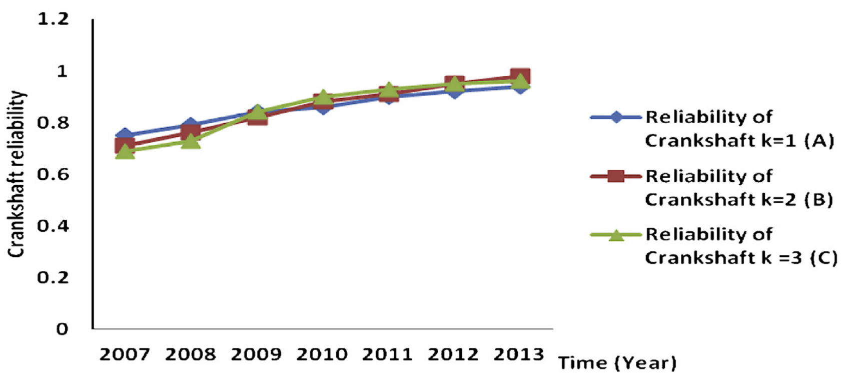

Fig. 4. Reliability analysis of vehicles' crankshafts.

Table 4
Crankshaft reliability/success improvement using sigma quality system.

Years, *i*	Workshop A ($k=1$)		Workshop B ($k=2$)		Workshop C ($k=3$)	
	3-Sigma	6-Sigma	3-Sigma	6-Sigma	3-Sigma	6-Sigma
2007	0.7917	0.75000	0.7562	0.71000	0.7382	0.69000
2008	0.8265	0.79000	0.8004	0.76000	0.7740	0.73000
2009	0.8693	0.84000	0.8523	0.82000	0.8693	0.84000
2010	0.8861	0.86000	0.9028	0.88000	0.9194	0.90000
2011	0.9194	0.90000	0.9276	0.91000	0.9439	0.93000
2012	0.9358	0.92000	0.9601	0.95000	0.9601	0.95000
2013	0.9520	0.94000	0.9764	0.98000	0.9682	0.96000

Table 5
Crankshaft reliability/success improvement on failure using sigma quality system.

Years, i	Workshop A ($k = 1$)		Workshop B ($k = 2$)		Workshop C ($k = 3$)	
	3-Sigma	6-Sigma	3-Sigma	6-Sigma	3-Sigma	6-Sigma
2007	0.3750	0.93367	0.3289	0.91882	0.3080	0.90122
2008	0.4293	0.95122	0.3878	0.93882	0.3510	0.92367
2009	0.5122	0.97714	0.4767	0.96471	0.5122	0.97714
2010	0.5513	0.98286	0.5946	0.93176	0.6429	0.99184
2011	0.6552	0.95696	0.6691	0.93676	0.7266	0.99643
2012	0.6970	0.99510	0.7917	1.0	0.7917	0.99847
2013	0.7581	0.99755	0.8673	1.0	0.8276	0.99918

Table 6
Expected Crankshaft reliability improvement on failures over the years (Tables 3–5).

Years, i	Workshop A ($k = 1$)			Workshop B ($k = 2$)			Workshop C ($k = 3$)		
	3-Sigma	6-Sigma	% Improvement	3-Sigma	6-Sigma	% Improvement	3-Sigma	6-Sigma	% Improvement
2007	NTI	0.18367	18.367	NTI	0.20882	20.882	NTI	0.21122	21.122
2008	NTI	0.16122	16.122	NTI	0.17882	17.882	NTI	0.19367	19.367
2009	NTI	0.13714	13.714	NTI	0.14471	14.471	NTI	0.13714	13.714
2010	NTI	0.12286	12.286	NTI	0.05176	05.176	NTI	0.09184	09.184
2011	NTI	0.05696	05.696	NTI	0.02676	02.676	NTI	0.06643	06.643
2012	NTI	0.07510	07.510	NTI	0.08382	08.382	NTI	0.04847	04.847
2013	NTI	0.05755	05.755	NTI	0.11529	11.529	NTI	0.03918	03.918
Total			≈80			≈81			≈79

NTI, no tangible improvement.

and the posterior) showed no tangible improvement (NTI) (Tables 5 and 3) as the outcomes are negative. Instead, 6-sigma continuous improvement scheme performed excellently over the years and steadily reached optimal reliability performance (close to 100%) in the later years (Table 6). This improvement, while applied, implies that life expectancy and/or kilometre (km) covered of the vehicles before record of any crankshaft failure are expected to increase and reach the peak almost twice the previous values in the year 2013.

4. Conclusions

Following the views and analyses of opinions of the experts, it can be concluded that the failure of crankshafts in automobile is largely caused by oil leakages in engines, overloading, misalignment, poor surface finish, misassembling, poor reconditioning of thrust bearing and adulterated engine oil. Production of crankshafts from locally sourced materials, improvement on the maintenance of roads, good maintenance practice and educating the users of the vehicles among other measures could reduce mechanical failure on crankshafts. Besides, monitoring authorities or agencies should be set on track to check the production, distribution and sale of quality engine oil, in order to prevent adulteration of the oil. Appropriate authorities should be in place to ensure that vehicles are roadworthy before been allowed to be on roads. If the above listed steps and recommendations are adhered to, the crankshaft failure could be reduced tremendously. Other areas of improvement are enlightenment programmes such as training, educating and maintaining upgraded structures that are directed towards combating automobile crankshaft failures. The stated measures of improvement among others are condensed into improved automotive system innovation in the aspects of oil lubrication system and maintenance. Application of statistic based on Bayes's probabilities further indicated that there are rooms for improvement in crankshaft reliability under 6-sigma platform. The findings generally show that the advancement in technology has brought improvement into automobile crankshaft reliability over the years.

Effects of varying (class of) ages of and covered distances by the vehicles on the mechanical failure of the crankshafts are good research areas to be looked into in future. The critical hypotheses to be tested in such studies are to determine whether (class of) ages of and/or distances covered by the vehicles before service can affect crankshaft failure significantly or cannot significantly affect it. The expected outcomes of the study will demonstrate the levels and conditions at which vehicle age and/or distance covered before service will serve as dominance of crankshaft failure.

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