Performance Evaluation Model for Used Motor Vehicle

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ABSTRACT— ***In Nigeria, the need for reliability of performance of engines of used vehicles has become a major concern for a number of reasons ranging from safety pollution and degradation of environment to high cost of repairs. It is therefore imperative to find a means to determine the level of performance of these fairly used imported vehicle engines, Sequel to this, a mathematical model was developed. The mathematical model (PINDEX) is a specialized model for determining the performance level of the engine of fairly used imported vehicle. The model was validated using Mathematics Laboratory (MATLAB) program with data from 1990 model Nissan Primera. The result from validation gave the performance index value, for the vehicle used, of 8.8019 x 10^{-29} . This implies that the reliability of this vehicle model is almost nil after twenty years of usage.***

Keywords— Reliability; Performance; Used Engine

1. INTRODUCTION

Many factors contribute to economic and social progress, but mobility is especially important because the ingredients of a satisfactory life, from food and health to education and employment are generally available only if there is adequate and reliable means of moving people, goods and ideas [1]. Transport is different from other needs, such as the need for food or housing in that it is required only to enable other activities to take place [2]. It is also identified as an important element in the process of modernization, sometimes allowing and perhaps accelerating development, at other times acting as a brake on progress [3]. The role of transport in the economic progress is further highlighted by observation that the cost of transporting goods in Africa being the highest in the world was one of the reasons for the low economic growth being witnesses in the continent [4].

The long years of military rule in Nigeria had a devastating effect on the economy, the integral part of which is the transportation sector. Economic planning was haphazard and implementation processes were undermined [5]. The productive and technological base became weak, outdated, narrow, inflexible and externally dependent after about four decades of economic mismanagement [6].

The birth of the Fourth Republic became a reality after a prolong military rule. It is interesting to note that the performance of the Nigerian economy in 1999 was mixed. At this period and up to the second half year 2000, a dollar was exchanged for ₦135.00. This shows a decrease of about 50 percent in the value of the Naira [7]

In Nigeria today, the most popular means of transportation is road transport, as other options such as rail, sea or air are either non-function or not within the economic reach of the majority of the population. The introduction of Structural Adjustment Programme (SAP) in 1984 to tackle economic challenge marked the entry of used vehicles referred to as “Tokunbo” in local parlance, imported mainly from Europe and America, into the road transportation system in Nigeria.

The reliability of performance of these vehicles has become a major concern for a number of reasons, ranging from pollution and degradation of environment to high cost of repairs and maintenance.

Reliability, in simple term, is the probability that an item will perform a required function, under stated conditions, for a stated period of time [8]. It is equally defined as the property of an object to retain in time, within the predetermined limits, all the parameters ensuring the performance of the system required in the preset service conditions [9]. This definition is broken down into four basic parts: probability-adequate performance, time and operating condition [10].

Bottom – up method was used and this method involves evaluating from component failure mode to system failure rate and the models used for this method are Competing Risk Model, Series Model, Parallel Model, R out of N model and Complex Model. The present work makes use of the Series, Parallel and Complex Models.

2. METHODOLOGY

The steps involved in this analysis are:

- Identification of components that directly affect reliability of performance.
- Classification of identified components into 'major' and 'minor' based on function and arrangement.
- Development of model base on the arrangement of the component parts.
- Validation of model using MATLAB software with 1999 model of Nissan Primera

2.1 Model Building

The model follows "Bottom-up" method that is component failure to system failure. The network employed is complex mode. For easy development some assumptions were made which include that:

- Sub-assemblies of the engine work together in a series mode
- Major component parts for each sub-assembly work together in a series mode
- Minor component parts work in a parallel mode with major components for each sub assembly.

2.2 Design of Block Diagrams for the Sub-Assemblies

Figure 1 shows the block diagrams constructed for the sub-assemblies and for the engine as a unit, based on the assumptions made.

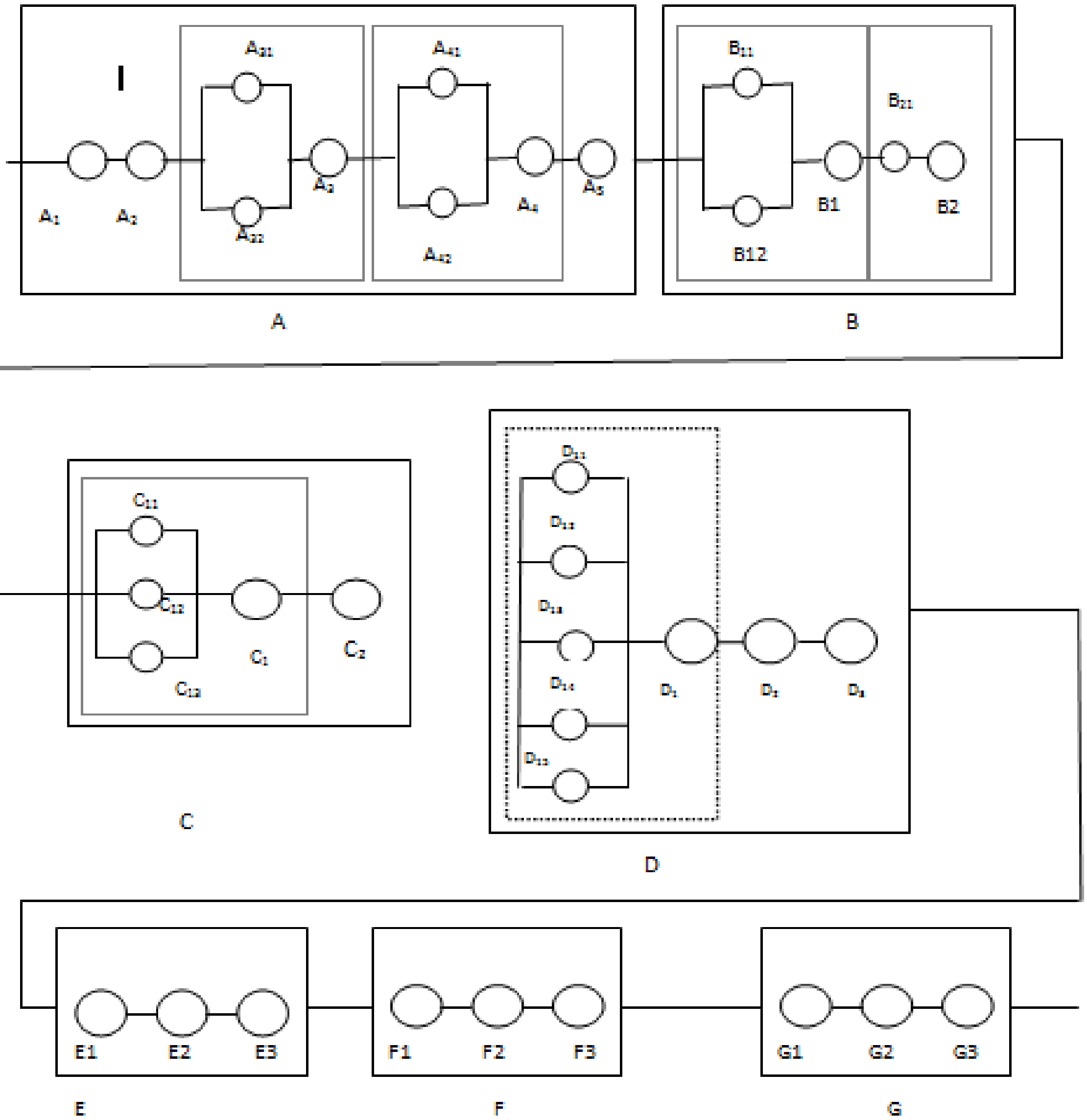

Figure 1: Reliability Block Diagram for Automobile Engine

The elements presented in Figure 1 are:

A [Piston Sub-Assembly] :	A_1 - Engine Block	
	A_2 - Cylinder Head	
	A_3 - Cylinder (Bore)	A_{31} - Cylinder Gasket
		A_{32} – Stud
	A_4 - Piston Ring	A_{41} – Compression Ring
		A_{42} - Scrapper Ring
		A_5 - Piston
B [Connecting Sub-Rod Assembly]:	B_1 - Connecting rod	B_{11} – Bushing
		B_{12} – Bearing
	B_2 - Gudgeon Pin	B_{21} - Circlip Ring.
C [Crankshaft Sub-Assembly]:	C_1- Crankshaft	C_{11}- Journal bearing
		C_{12} - Thrust washer
		C_{13} - Main bearing
	C_2 - Flywheel	
D [Camshaft Sub-Assembly]:	D_1- Camshaft	D_{11}- Timing chain
		D_{12} - Timing cover
		D_{13} – Gasket
		D_{14} - Chain adjuster
		D_{15} - Pump driving pinion
	D_2 - Engine Valves	
	D_3- Cams	
E [Rocker Sub-Assembly]:	E_1- Rockers	
	E_2 - Push Rods	
	E_3 - Tappets	
F [Pumping Sub-Assembly]:	F_1 - Oil Pump	
	F_2 - Oil Sump	
	F_3 - Oil filter	
G [Cooling Sub-Assembly]:	G_1 – Radiator	
	G_2 – Fan	
	G_3 - Water Pump	

2.3 Formulation of mathematical Model

The reliability of system is determined from the product of all the reliabilities of the sub-units that make up the system [9]. A mathematical model was formulated to represent reliability of each of the sub-assemblies identified in the previous section and for the engine as a unit. This is shown in the following equation:

$$R = R_A \cdot R_B \cdot R_C \cdot R_D \cdot R_E \cdot R_F \cdot R_G \quad (1)$$

where: R - Reliability of Engine, R_A - Reliability of the Piston Sub-Assembly, R_B - Reliability of the Connecting Rod Sub-Assembly, R_C - Reliability of the Crankshaft Sub-Assembly, R_D - Reliability of the Camshaft Sub-Assembly, R_E - Reliability of the Rocker Sub- Assembly, R_F - Reliability of the Pumping Sub-Assembly, R_G - Reliability of the Cooling system Sub-Assembly.

Mathematical model for Piston Sub-Assembly in series/parallel as shown in Figure 1 (A) and the formulated equation is shown in equations (2) and (3).

$$R_A = [(1 - (1 - R_{A31})(1 - R_{A32}))(1 - (1 - R_{A41})(1 - R_{A42}))]R_{A1} \cdot R_{A2} \cdot R_{A3} \cdot R_{A4} \cdot R_{A5} \quad (2)$$

$$R_A = \left[1 - \prod_{j=1}^{2}\left(1 - R_{A3j}\right)\right]\left[1 - \prod_{j=1}^{2}\left(1 - R_{A4j}\right)\right]\left[\prod_{j=1}^{5} R_{A_i}\right] \quad (3)$$

Mathematical model for Connecting Rod Sub-Assembly in parallel/series as shown in Figure 1 (B) and the formulated equation is shown in equations (4) and (5).

$$R_B = [1 - (1 - R_{B11})(1 - R_{B12})]\ R_{B1} \cdot R_{B21} \cdot R_{B2} \quad (4)$$

$$R_B = \left[1 - \prod_{j=1}^{2}\left(1 - R_{B1j}\right)\right] R_{B_{21}} \left[\prod_{i=1}^{2} B_i\right] \quad (5)$$

Mathematical Model for Crankshaft Sub-Assembly in parallel/series as shown in Figure 1(C) and the formulated equation is shown in equations (6) and (7).

$$R_C = [1 - [(1 - R_{C11})(1 - R_{C12})(1 - R_{C13})]]R_{C1} \cdot R_{C2} \quad (6)$$

$$R_C = \left[1 - \prod_{j=1}^{3}\left(1 - R_{C1j}\right)\right]\left[\prod_{i=1}^{2} C_i\right] \quad (7)$$

Mathematical Model for Camshaft Sub-Assembly in parallel/series as shown in Figure 1 (D) and the formulated equation is shown in equations (8) and (9).

$$R_D = ((1 - (1-R_{D11})(1 - R_{D12})(1 - R_{D13})(1 - R_{D14})(1 - R_{D15})\ R_{D1} \cdot R_{D2} \cdot R_{D3} \quad (8)$$

$$R_D = \left[1 - \prod_{j=1}^{5}\left(1 - R_{Dij}\right)\right]\left[\prod_{i=1}^{3} R_{D_i}\right] \quad (9)$$

Mathematical Model for Rocker Sub- Assembly in series as shown in Figure 1 (E) and the formulated equation is shown in equations (10) and (11):

$$R_E = R_{E1} \cdot R_{E2} \cdot R_{E3} \quad (10)$$

$$R_E = \prod_{i=1}^{3} R_{E_i} \quad (11)$$

Mathematical Model for of the Pumping Sub-Assembly as shown in Figure 1 (F) and the formulated equation is shown in equations (12) and (13):

$$R_F = R_{F1} \cdot R_{F2} \cdot R_{F3} \quad (12)$$

$$R_F = \prod_{i=1}^{3} R_{F_i} \quad (13)$$

Mathematical Model for Cooling system Sub-Assembly as shown in Figure 1 (G) and the formulated equation is shown in equations (14) and (15) .

$$R_G = R_{G1} \cdot R_{G2} \cdot R_{G3} \quad (14)$$

$$R_G = \prod_{i=1}^{3} R_{G_i} \quad (15)$$

Substituting equations (3), (5), (7), (9),(10), (11) and (13) into equation (1) provides the reliability of engine of fairly used vehicle:

$$R = \left[1-\prod_{j=1}^{2}\left(1-R_{A3j}\right)\right]\left[1-\prod_{j=1}^{2}\left(1-R_{A4j}\right)\right]\left[\prod_{j=1}^{5}R_{A_i}\right]\left[1-\prod_{j=1}^{2}\left(1-R_{B1j}\right)\right]\left[R_{B_{21}}\prod_{i=1}^{2}B_i\right]$$
$$\left[1-\prod_{j=1}^{3}\left(1-R_{C1j}\right)\right]\left[\prod_{i=1}^{2}C_i\right]\left[1-\prod_{j=1}^{5}\left(1-R_{Dij}\right)\right]\left[\prod_{i=1}^{3}R_{D_i}\right]\left[\prod_{i=1}^{3}R_{E_i}\right]\left[\prod_{i=1}^{3}R_{F_i}\right]\left[\prod_{i=1}^{3}R_{G_i}\right] \quad (16)$$

The equation above represents the mathematical model to determine reliability of fairly used vehicle. The reliability of the fairly used engines can be expressed in terms of failure rate as shown in equation (17):

$$R = \left[1-\prod_{j=1}^{2}\left(1-e^{\left(\frac{a}{b}-1\right)t}\right)_{A_{3j}}\right]\left[1-\prod_{j=1}^{2}\left(1-e^{\left(\frac{a}{b}-1\right)t}\right)_{A_{4j}}\right]\left[\prod_{i=1}^{5}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{A_i}\right]$$
$$\left[1-\prod_{j=1}^{2}\left(1-e^{\left(\frac{a}{b}-1\right)t}\right)_{B_{1j}}\right]\left[\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{B_{21}}\prod_{i=1}^{2}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{B_i}\right]\left[1-\prod_{j=1}^{3}\left(1-e^{\left(\frac{a}{b}-1\right)t}\right)_{C_{1j}}\right]\left[\prod_{i=1}^{2}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{C_i}\right] \quad (17)$$
$$\left[1-\prod_{j=1}^{5}\left(1-e^{\left(\frac{a}{b}-1\right)t}\right)_{D_i}\right]\left[\prod_{i=1}^{3}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{D_i}\right]\left[\prod_{i=1}^{3}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{E_i}\right]\left[\prod_{i=1}^{3}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{F_i}\right]\left[\prod_{i=1}^{3}\left(e^{\left(\frac{a}{b}-1\right)t}\right)_{G_i}\right]$$

3. VALIDATION OF THE MATHEMATICAL MODEL

The model developed for determining reliability of engines of used vehicles was validated using data obtained from laboratory test and experiments carried out on the major and minor components that were considered in building the model. The test carried out was hardness test, a Non Destructive Test (NDT), using the Micro Hardness Testing machine installed in the Material Testing laboratory of the Engineering Materials Development Institute, Akure, Ondo state, Nigeria.

The car model used for the validation was a Nissan Primera 1990 model and the procedure adopted in validating the proposed mathematical model was as follows:

(i) The automotive parts considered in building the model were sourced for from an automobile workshop.

(ii) The parts were prepared into samples for use on the hardness testing machine.

(iii) Using the GRANTA engineering software, the hardness value for each of the basic material for the automotive parts was established. This value was taken as Standard Value (b).

(iv) Using the Micro Hardness Testing machine, the hardness value for each of the samples was determined. This value was taken as Investigated Value (a).

(v) The ratio of Investigated Value to Standard Value was calculated and taken to be the Reliability for each of the sample:

R = a/b (18)

(vi) Using the established relationship in theory of reliability that is:

Probability of Survival + Probability of Failure = 1

R + F = 1 (19)

(vii) The probability of failure was determined for each of the samples.

(viii) The values of F obtained in equation (16) were used as failure probabilities in the reliability model earlier developed in this study.

(ix) The time period considered for the validation of the model was twenty (20) years.

4. RESULTS AND DISCUSSION

The hardness values, reliability and failure rates obtained from the test for the various components are as presented in Table 1.

Table 1: Hardness, Reliability and Failure Rates

S/N	Name of Component	Hardness (Pa)		Reliability, R	Failure, F
		Investigated (A)	Standard (B)	R = (A/B)	(1-R)
A	**Piston Assembly**				
1	Engine block	1.70E+09	2.12E+09	0.80	0.20
2	Cylinder head		1.47E+09	0.68	0.32
3	Cylinder gasket		1.13E+09	0.68	0.32
4	Stud	2.94E+09	4.90E+09	0.60	0.40
5	Compression ring	7.78E+08	8.94E+08	0.87	0.13
6	Oil scrapper ring	1.68E+09	3.24E+09	0.52	0.48
7	Piston	5.45E+08	8.94E+08	0.61	0.39
8	Cylinder bore		2.06E+09	0.68	0.32
Average		**1.53E+09**	**2.09E+09**	0.68	0.32
B	**Connecting rod assembly**				
1	Bearing (Brass)		1.65E+10	0.72	0.28
2	Bushing (metal)		2.84E+09	0.72	0.28
3	Connecting rod	4.66E+09	6.76E+09	0.69	0.31
4	Gudgeon pin	1.93E+09	2.84E+09	0.68	0.32
5	Circlip ring	2.43E+09	3.24E+09	0.75	0.25
Average		**3.01E+09**	**6.44E+09**	0.71	0.29
C	**Crankshaft Assembly**				
1	Crankshaft	1.78E+09	2.65E+09	0.67	0.33
2	Journal bearing		1.08E+09	0.70	0.30
3	Thrust washer	3.62E+08	4.47E+08	0.81	0.19
4	Main bearing		1.65E+10	0.70	0.30
5	Flywheel	8.63E+08	1.37E+09	0.63	0.37
Average		**1.00E+09**	**4.41E+09**	0.70	0.30
D	**Camshaft assembly**				
1	Camshaft	1.79E+09	2.30E+09	0.78	0.22
2	Timing chain	1.45E+09	1.86E+09	0.78	0.22
3	Timing cover		1.72E+08	0.79	0.21
4	Gasket	8.24E+08	1.03E+09	0.80	0.20
5	Chain adjuster		1.24E+09	0.79	0.21
6	Pump driving pinion	4.66E+11	8.03E+11	0.58	0.42
7	Engine valves	2.85E+08	3.65E+08	0.78	0.22
8	Cam	7.50E+08	1.23E+09	0.61	0.39

Average		**7.85E+10**	**1.01E+11**	0.74	0.26
E	**Rocker assembly**				
1	Rocker shaft	5.56E+08	7.94E+08	0.70	0.30
2	Push rods		7.94E+08	0.70	0.30
3	Tappets	9.32E+08	1.37E+09	0.68	0.32
Average		**1.27E+09**	**1.55E+09**	0.70	0.30
F	**Pumping assembly**				
1	Oil pump		3.92E+09	0.58	0.42
2	Sump	1.22E+09	2.10E+09	0.58	0.42
3	Oil filter		3.24E+08	0.58	0.42
Average		**1.22E+09**	**2.11E+09**	0.58	0.42
G	**Cooling assembly**				
1	Radiator		1.54E+09	0.67	0.33
2	Fan	5.09E+08	8.34E+08	0.61	0.39
3	Water pump	3.45E+02	4.72E+02	0.73	0.27
Average		**2.54E+08**	**7.91E+08**	0.67	0.33

From the value of reliability of the engine obtained, 8.8019 x 10^{-29}, from using the proposed mathematical model, which tends to zero, it implies that the reliability of a used 1990 Nissan Primera model is almost nil after 20 years of usage. The value of reliability obtained from the validation is observed to be greatly influenced by the type of connection assumed to exist among the components making up each sub-assembly. From the results obtained, it indicated that the optimal performance of any system depends solely on the arrangement of the components that make up the system, whether they are in serial, parallel or combined connections.

Sub-assembly groups having major and minor components in both series and parallel (complex) connection modes have values of reliability close to unity. This supports the theory of reliability that a system having components in parallel continues to perform until the last components fails. Such sub-assembly included the Piston, Connecting Rod, Crankshaft and Camshaft assemblies.

Sub-assembly groups having their components in only series mode have values of reliability close to zero. This supports the theory of reliability that a system having components in series mode fails at the failure of the first component. Such sub-assembly included the Rocker Arm, Pumping and Cooling assembly.

4.0 CONCLUSION

The developed mathematical model is capable of computing performance index of a used engine and it can be adapted to compute reliability of many mechanical systems. Reliability of the engine of a motor vehicle is determined more by the number, failure probability and arrangement (series, parallel or complex) of those components (major and minor) that directly affect the working stroke of the engine (i.e. power cycle) rather than by time period. Though a motor vehicle engine consists of about four hundred and twenty five different components, the number of these components that are actually responsible for the reliability is less than ten percent of the total. It should, however, be noted that the remaining components are equally required to be in good condition to obtain fully the best result in the performance of engine.

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