

Alternate Maintainability Evaluation Technique for Steering System of Used Automobiles

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ABSTRACT: Automobile is an essential means of transporting people, goods and services which has impacted significantly on economic development of any nation. Maintainability and reliability in vehicles are design considerations that has the capacity to influence user's choice of owned vehicle for both private and commercial uses. Beyond the rigorous methods of evaluation maintainability of technological systems popular experience based opinion of operators of different makes of automobiles have proved to provide acceptable qualitative approach on critical decision making safe and moistureable vehicle. To demonstrate the application of participatory approach in maintainability structured questionnaires were developed and administered to operators (drivers and auto-mechanics) of selected vehicles (1997 models of Nissan Primera, Toyota Camry and Honda Accord) commonly used for private purposes in the study area. Prevailing system faults and the time to repair were determined and analysis were carried out to ascertain the significance of the result obtained which were also used to simulate some maintainability criteria of the steering system. From the result, Nissan Primera 1997 has the least Mean Time to Repair (MTTR) and Maximum Maintenance Time (M_{max}) of 30.4 and 52.6 minutes respectively, followed by Toyota Camry 1997 with MTTR and M_{max} of 39.9 and 128.9 minutes while Honda Accord 1997 has the highest MTTR and M_{max} of 93.2 and 143.4 minutes respectively. This work has demonstrated the evaluation of maintainability based on popular opinion of operators the system from the consideration of maintainability of steering system.

Key Words: Analysis of Variance, Maintainability, Repairable system, Participatory Approach.

1. Introduction

The automobile is an important means of transporting materials, machine, men and commodities from one place to another (Lucas and Onawumi, 2013). In Nigeria, road transportation is majorly used compared to other modes of transportation (Fapetu and Akinola, 2005; Azate et al 2016; Omoruyi et al 2018). As essential as transportation is to economic life only few Nigerian have financial strength to buy new vehicles to serve these purposes (Oke, 2012). The continuous use of motor vehicles reduces the life span as a results of general wear, tears and breakdowns (Akpakpavi, 2015). Maintainability of this complex system plays a vital role on the life cycle and its performance. Maintainability and durability of these vehicles have been of great concern to the owners owing to the fact that the cars have significant impacts on their economic life (Nwoke et al 2017; Ezugwu et al 2016). The US Military publication ML-STD-721 defines maintainability as the measure of the ability of an item to be retained or restored to specified conditions when maintenance is performed by a personnel having specified skill level using prescribed procedures and resources at each prescribed level of maintenance and repair. Ding (2009) and Okokpuije et al (2017) also defines maintainability as an important character which is given by product design, it makes easy to be repaired for the mechanical system. Abdullah *et al* (2006) reported that maintainability has unique effect on maintenance cost of mechanical system. Chen and Cai (2003) identified maintainability has a significant factor in the economic success of engineering systems and products



while Gironimo *et al* (2004) viewed maintainability as synthesis of several characteristics. Coulibaly *et al* (2008) believed that maintainability criteria comprise of Intrinsic and Contextual, Intrinsic criteria includes repair-ability (ability to be repaired after failure or damage), accessibility, assemble-ability, disassemble-ability, standardization, interchangeability and survivability while contextual criteria include redundancy, competencies, tooling's, logistics, environment, detectability, testability and maneuverability.

Many researchers have worked on evaluation of maintainability, Chen and Cai (2003) used vector projection method (VPM) to evaluate maintainability of mechanical system in design review, VPM is a multi-objective assessment and is developed based on fuzzy set theory. Gong (1999) evaluated automobile maintainability base on the calculation repair time and maintenance cost. Blanchard *et al* (1995) identified Mean Time to Repair and limit for maximum repair time as the key feature of merit for maintainability. Vujosevic and Raskar (1995) developed procedures for identifying sequence of disassembly, animation of maintenance personnel while carrying out the process while Wanni and Gandhi (2002) considered tribology aspect. Ajide and Adegbola (2011) investigated maintainability of imported second hand (*Tokunbo*) gear drives from different sources and the outcome of the study shown that the same gear drive manufactured from different sources have different maintainability. Akinyemi *et al* (2015) worked on optimal repair time of municipal transit vehicle's clutches and come up with optimum repair time for clutches of municipal vehicle. Since the vehicle cannot remain new forever, the need to carry out necessary maintenance becomes necessary. Akinola and Ogedengbe (2005) defines Maintenance as repair activity carried out on vehicles and other equipment to keep them in good working condition, and if faulty, to restore it to a functioning state. In most engineering systems, repair is a common operation since the cost of repair or replacing constituent part is less than replacing the entire system and the system can be made available for a long period (Sukhwinder and Wadhwa, 2004). An automotive system is a group of related parts and assemblies that perform a specific function and deviation from its function leads to dissatisfaction, loss of man-hour, and can cause danger.

Automobile steering system has the sole aim of giving the driver a means of controlling the direction of motion of the vehicle. It is an input to suspension system (Reza, 2015) and works with suspension system to provide directional control with a comfortable amount of steering efforts. An interaction between the driver and of the steering system is a closed loop system (Marcos, 2007). Power steering was introduced to meet demands for low steering wheel torque and comfort. A traditional power-assisted steering system uses hydraulic power to assist the driver, referred to as Hydraulic Power Assisted Steering (HPAS). This system is a pure hydro-mechanical system and lacks the possibility to be activated other than by driver input (Alessandro, 2013). The rack-and-pinion system is mostly found in lighter vehicles and passenger cars while the worm gear steering box is found in heavy vehicles. The rack-and-pinion steering system is lighter, more compact, has higher efficiency and gives the driver a more accurate feeling of the tyre-ground interaction, Giancarlo and Lorenzo (2009). Some of the advantages of rack and pinion over other steering mechanism include its simplicity, having a play free and robust gear contact between rack and pinnion (Jazar, 2008).

Steering system of an automobile can be categorized as repairable system since repair action can be performed on the system. Lindqvist (2008) defined repairable system as system that can be repaired to original working condition when repair action is performed. For repairable systems, generally there are two main repair assumptions, either "as good as new" or "as bad as old" but Doyen (2005) reported that the system lies somewhere in between these two conditions, "better than old, but worse than new". Therefore, this study evaluated maintainability of steering system of selected vehicles in the study area with a view to establishing their repair ability.

2. Methodology

In this study, Pilot survey was conducted to identify three most common second hand cars (1997 model of Nissan Primera, Toyota Camry and Honda Accord). After the identification of these common cars, two

types of questionnaire were designed for users/owners of the identified cars. The first questionnaire was designed to capture information on automobile system with common fault, its severity and occurrence, road impact on their vehicle, the action taken on the faulty system were distributed to owners of three common second hand cars, frequency distribution were used to analyze the result of pilot survey.

The second questionnaire was designed for experienced mechanics to capture information on maintainability of the steering system. The steering faults were categorized into three: Noise, Harshness and Vibration, Performance and Fluid Issue. The second questionnaires were mechanics that have similar experience. (Ding, 2009) highlighted four approaches in evaluating maintainability, this study adopted maintainability evaluation using quantitative approaches. (Dhillon 2008) identified Mean Time to Repair (MTTR), mean active preventive maintenance time, mean active corrective maintenance time, maximum corrective maintenance time, and mean maintenance downtime as measures used in maintainability analysis.

Analysis of Variance (ANOVA) was used to ascertain the significance of the data obtained on maintainability of selected vehicles at $p = 0.05$. The time to repair the faults of the steering system of the common vehicle was processed using SPSS Software 16.0 version. The time taken to repair were subjected to further analysis using the under-listed maintainability mathematical indices (Dhillon, 2008)

$$M_{ct} = \sum_{i=1}^N M_{cti} \quad 1$$

$$MTTR = \frac{\sum_{i=1}^N M_{cti}}{N} = \frac{M_{cti}}{N} \quad 2$$

For a log normal distribution

$$MTTR_G = \text{antilog} \left[\frac{\sum_{i=1}^N \log M_{cti}}{N} \right] \quad 3$$

$$M_{\max} = \text{antilog} (\log MTTR_G + 1.645 \Delta \log M_{cti}) \quad 4$$

Where

$$\Delta \log M_{cti} = \sqrt{\frac{\sum_{i=1}^N (\log M_{cti})^2 - \left(\sum_{i=1}^N \log M_{cti} \right)^2 / N}{N-1}} \quad 5$$

$$M = 1 - \exp (-t/MTTR) \quad 6$$

NOTATIONS

M_{ct} : Corrective Maintenance Time
 MTTR : Mean Time to Repair

$MTTR_G$: Geometric Mean Time to Repair
 M_{max} : Maximum Maintenance Time
 $M(t)$: Maintainability factor

3. Results and Discussion

The time to repair (TTR) was subjected to Analysis of Variance (ANOVA) indicated significant difference at $p = 0.0224$ and TTR was processed using maintainability mathematical indices. The results are shown in the Tables 1 and 2. The repair process of steering system starts with identifying the faulty component followed by removal of constituent parts, mending or replacing the faulty parts and re-assembling. It seen from the Table 1 shows that time to perform the repair operations varied from one vehicle to the other. The total time required in performing Disassembly, Accessibility and Manipulability analysis based on the type of suspension used on the repairability of steering system as shown in Table 2 Nissan under study uses multi links type for its independent suspension, Toyota that uses MacPherson strut for its suspension system while Honda uses Double Wish borne type also contributed variance in repair action as maintainability of any equipment has a direct link on design. The outcome of maintainability mathematical indices was presented in Table 2.0 Nissan Primera 1997 has the least maximum corrective time (52.6minutes) for repair of steering system, fault followed by Toyota Camry 1997 (128.9minutes) while Honda Accord has the highest maximum corrective time (143.4minutes) for repair. The time include time to locate the parts/components requiring repair, time to perform the needed repair and time to verify that the repair has been performed successfully

Table 1: Average time taken to repair faults in steering system of three selected vehicles in Minutes

Fault number	Nature of fault	Toyota Camry 1997	Nissan Primera 1997	Honda Accord 1997
1	Objectionable whistle while turning steering wheel when stationary or moving slowly	121	93	235
2	Rattle or Excessive clunk	45	32	99
3	Popping noise	42	30	125
4	Chirp or Squeal (power steering pump)	11	16	48
5	Whine, Growl, or Groan (Power Steering Pump)	5	4	6
6	Steeringwheel or Column has freeplay/lash/loosenes	94	72	219
7	Steering wheel has fore and aft looseness	15	14	67
8	Steering catches, surges or sticks or difficult to turn	16	10	50
9	Steering wheel does not return to centre	15	16	25
10	Fluid issues (leak, aerated, contamination)	25	17	58

Table 2: Summary for Maintainability Parameters

Parameter	Toyota Camry 1997	Nissan Primera 1997	Honda Accord 1997
M_{CT}	399	304	932
MTTR	39.9	30.4	93.2
$MTTR_G$	25.27	20.87	62.36
M_{max}	128.9	52.6	143.4
$M(t)$	0.9605	0.8227	0.7852

4. Conclusion

In this study, quantitative approaches have been used to evaluate maintainability of steering system of common cars, the results have shown that Nissan Primera 1997 has the least MTTR, $MTTR_G$ and M_{max} , while Honda Accord 1997 has the highest MTTR, $MTTR_G$ and M_{max} . It was deduced from the study that despite using the same steering system maintainability of selected vehicles differ as a result of types of suspension system used. The study also revealed that the steering system faults of all the selected vehicles can be repaired effectively but at different duration (repair time) while type of suspension used contributed to variance in time to repair. This study will be beneficial to intending car owners on life cycle while repair limit should be evaluated before embarking on repair of steering system.

References

- [1] Abdullah. B, Yusoff. M, and Ripin. Z (2006) Integration of Design for Modularity and Design for Assembly to Enhance Product Maintainability, *Proceedings of 1st International Conference 7th AUN/SEED-Net Field-wise Seminar on Manufacturing and Materials Processing*, 263-269.
- [2] Ajide, O.O. and Adegbola, A. A (2011) Equipment Maintainability Using Simulation, *Global Journal of Researches in Engineering*. 11(6): 8-16.
- [3] Akinola, B. and Ogedengbe, T. (2005), Basic Automobile Technology, Olajuyin Printers, Akure, Nigeria
- [4] Akinyemi, O. O., Ajayeoba, A.O., Adebisi, K.A., Akintan. A. L and Jolaoso J.T, (2015), Optimal Repair Time for Municipal Transit Vehicle's Clutches, *International Journal of Science and Engineering and Technology*
- [5] Akpakpavi, M. (2015), Modern automobile vehicle repair practice in Micro, Small and Medium Scale Garage in Ghana, *International Journal of Science, Technology and Society*, 2(6): 216-222
- [6] Alessandro D. (2013). Pressure Control in Hydraulic Power Steering Systems, M.Sc Thesis, Linkoping University, Sweden
- [7] Azeta, J., Okokpujie, K. O., Okokpujie, I. P., Osemwegie, O., & Chibuzor, A. (2016). A Plan for Igniting Nigeria's Industrial Revolution. *International Journal of Scientific & Engineering Research*, 7(11), 489.
- [8] Blanchard, B.S., Dinesh V. and Elmer L.P. (1995) Maintainability: A key to Effective Management, Prentice-Hall, Eaglewood, Cliffs, New Jersey.
- [9] Chen L. and Cai J. (2003) Using Vector Projector Method to evaluate maintainability of mechanical system in design review, *Journal of Reliability Engineering and System Safety*: 147-154 retrieved on 24th June, 2012 available at: www.sciencedirect.com
- [10] Coulibaly. A, Houssin. R, and Mutel, B (2008). Maintainability and Safety Indicators at Design Stage for Mechanical Products. *Computers in Industry* 59(5):438- 449.
- [11] Dhillon, B.S. (2008) Engineering Maintainability Elsevier
- [12] Ding Y, (2009) Product Maintainability Design Method and Support Tool Based on Feature Model, *Journal of Software Engineering and Applications*. 2:165-172
- [13] Doyen, L., (2005). Repair Efficiency Estimation in the ARII imperfect repair model. *Mod. Statist. Meth., Reliability* 10:15
- [14] Ezugwu, C. A., Okonkwo, U. C., Sinebe, J. E., & Okokpujie, I. P. (2016). Stability Analysis of Model Regenerative Chatter of Milling Process Using First Order Least Square Full Discretization Method. *International Journal of Mechanics and Applications*, 6(3), 49-62.
- [15] Fapetu, O.P. and Akinola, A.O. (2008), Optimizing Auto -Repair Practice: Akure Metropolis as a case study, *A U J.T* 11(4): 232-238

- [16] Giancarlo G. and Lorenzo M. (2009), The Automotive Chassis, Volume 1, Component Design, Springer, London.
- [17] Gironimo G, Monacellia G and Palato S (2004), A Design Methodology for Maintainability of Automotive Components in Virtual Environment, *International Design Conference*
- [18] Gong L. (1999). Study on the Evaluation of Automobile Maintainability. *Liaoning Transportation Technology*, 8 :46- 80
- [19] Jazar, R.N. (2008), *Vehicle Dynamics: Theory and Application*, Springer.
- [20] Lindqvist, B.H (2008), Maintenance of Repairable Systems, *Complex System Maintenance Handbook*, Springer, London: 657.
- [21] Lucas, E. B and Onawumi, A.S. (2013). Ergonomic Evaluation of In-Vehicle Interface Design of Taxicabs in Nigeria. *International Journal of Engineering Research and Applications*, 3(4):566-572.
- [22] Marco R. (2007), *Hydraulic Power Steering in Road Vehicles: Analysis, Testing and Enhanced Functionality*, PhD Thesis, Linkoping University, Sweden.
- [23] Military Standardization (1966), *Definition of terms for Reliability and Maintainability*, US Department of Defense.
- [24] Nwoke, O. N., Okokpujie, I. P., & Ekenyem, S. C. (2017). Investigation of Creep Responses of Selected Engineering Materials. *Journal of Science, Engineering Development, Environmen and Technology (JOSEDET)*, 7(1), 1-15.
- [25] Okokpujie, K. O., Abayomi-Alli, A., Abayomi-Alli, O., Odusami, M., Okokpujie, I. P., & Akinola, O. A. (2017). An automated energy meter reading system using GSM technology.
- [26] Omoruyi, O. N., Omoruyi, M. G., Okokpujie, K. O., & Okokpujie, I. P. (2018). Electronic Fare Collection Systems in Public Transits: Issues, Challenges and Way-Forward. *COVENANT JOURNAL OF ENGINEERING TECHNOLOGY*, 2(1).
- [27] Reza, A. (2015), *Topology Based Optimization of Suspension and Steering Mechanism of Automobiles*, M.Sc Thesis, University of Waterloo.
- [28] Sukhwinder, S.J and Wadhwa,S.S (2004),Reliability, Availability and Maintainability Study of High Precision Special Purpose Manufacturing Machines. *Journal of Scientific and Industrial Research* 63:512-517
- [29] Vujosevic, R and Raskar,R.(1995), Simulation, Animation and Analysis of Design Disassembly for Maintainability Analysis. *Prod Res*; 33(11): 2999-3022.
- [30] Wanni, M.F and Gandhi O.P (2002), Maintainability Design and Evaluation Mechanical System based on Tribology . *Reliability Engineering System Safety*; 77:181-188