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DEVELOPMENT OF A SPARE PART FAILURE INFORMATION MANAGEMENT SYSTEM FOR AUTOMOBILE MAINTENANCE INDUSTRY

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Abstract. The integration of information management into spare parts planning for Automobile maintenance cannot be overemphasized. Information on automobile spare parts under service condition from three selected automobile maintenance jobshops in South-western Nigeria was garnered in order to identify their levels of important and criticality. The known state of the spare parts condition with prior probability was used to determine conditional probability of failure based on the criticality conditions. The posterior failure probability spare parts was obtained for a future maintenance cycle time using the modified Bayesian probability model by integrating levels of spare parts criticality into the system. The computer software package was developed using Visual Basic (V.B) computer language and applied in the Automobile Industries for rapid information management as regards spare parts planning, to failure analyses and grouping and effective choice of maintenance policy. The system model was implemented on three jobshops that were responsible for the maintenance of three brands of vehicles selected for this study. The practical implication of the results showed that the developed computer software package is more efficient in term of effectiveness in maintenance operation planning and cost savings than the traditional methods being used in the jobshops.

Keywords: *spare parts failure, criticality, information management, modified Bayesian theory.*

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1. Introduction

The automobile maintenance industries in developing economy are being exposed to many challenges including updating records of the spare parts paucity as a result of fund inadequacy, expensiveness of spares and scarcity of spare parts. The stated challenges may be the outcome of inadequate information management and non-dynamism of maintenance operations. There is need to integrate information management and operational dynamism into spare parts planning for sustainable development in automobile industry. Hence, the need for development of a maintenance system model that will solve problems of information management and operational dynamism in spare parts planning for sustainable development in automobile industry. The study involves identification of the conventional maintenance systems in automotive maintenance industry, determination of alternative methods of identifying critical spare parts in automobile industry, development of dynamic model for the prediction of spare parts failure and development of spare part planning information management system. Maintenance is the combination of all technical and associated administrative actions intended to retain an item in or restore it to, a state in which it can perform its required function. The cost, quality, service and on-time delivery have been the competitive advantage gained by many companies (Pradhan & Bhol, 2006) Maintenance is needed in all areas of engineering covering mechanical, civil, electrical, computer engineering among others. The most critical area of need in mechanical engineering is the automobile system which is an integral part of the industry. Automobile system are been used in industry as intra-industrial and inter-industrial means of transportation. The change in automobile maintenance industry from auxiliary activities to full and independent centre calls for development of maintenance system to manage the complex situation resulting from wide range of vehicular components/spare parts transitional from old design configuration to the advanced. There were many challenges in spare parts management in the past. Among them are non- traceability of part information, non-centralised spare parts database, manual work in translating database information from one place to the other and unavailability of spare parts for imported vehicles (Kareem & Lawal, 2010). The development of a dynamic and information based maintenance system is an effort towards solving the stated challenges of spare part planning by taking into consideration changing nature of today’s technological advancement (Hong, *et al.*, 2014; Hu & Zhang, 2014). Bayesian model has ability to provide integrated decision making in relation to maintenance scheduling, inventory planning and cost which many of the existing model cannot accommodate (Weber *et al.,* 2012). The developed model through integration of dynamism and information management will take care of limitations of the previous planning strategies of the automotive maintenance industry. Information management has been used to support spare parts demand forecast in maintenance industries (Dekker *et al.,* 2013). This study was made to cover information on spare parts planning based on demand forecast, budgetary and cost maintenance. Many of the similar studies on spare parts failure prediction were devoid of the information management system (Kareem & Lawal, 2015). Besides, spare parts’ information management system has been extended to transitional failure probability prediction based on prior information as regards the initial components conditions.

2. Methodology

2.1. System Configuration

The framework for the system configuration is shown in Fig. 1. Maintenance time constraint gives different time level from the initial condition designated as quarter t_0, to the final state of spare parts transitional failure probability t_3. Space/inventory constraint of the spare parts indicates maximum number of highly critical spare parts that can be stocked during the period under review. The final level is the budgetary and maintenance cost system which serves as indicator for financial management information for the planning of maintenance activity based on spare parts criticality classification with levels of importance in relation with maintenance system under consideration.

2.2. System Development

Information on automobile spare parts under service conditions were collected from selected automobile maintenance job shops in South-Western Nigeria in order to identify criteria for classification of failure/ natures of the spare parts.

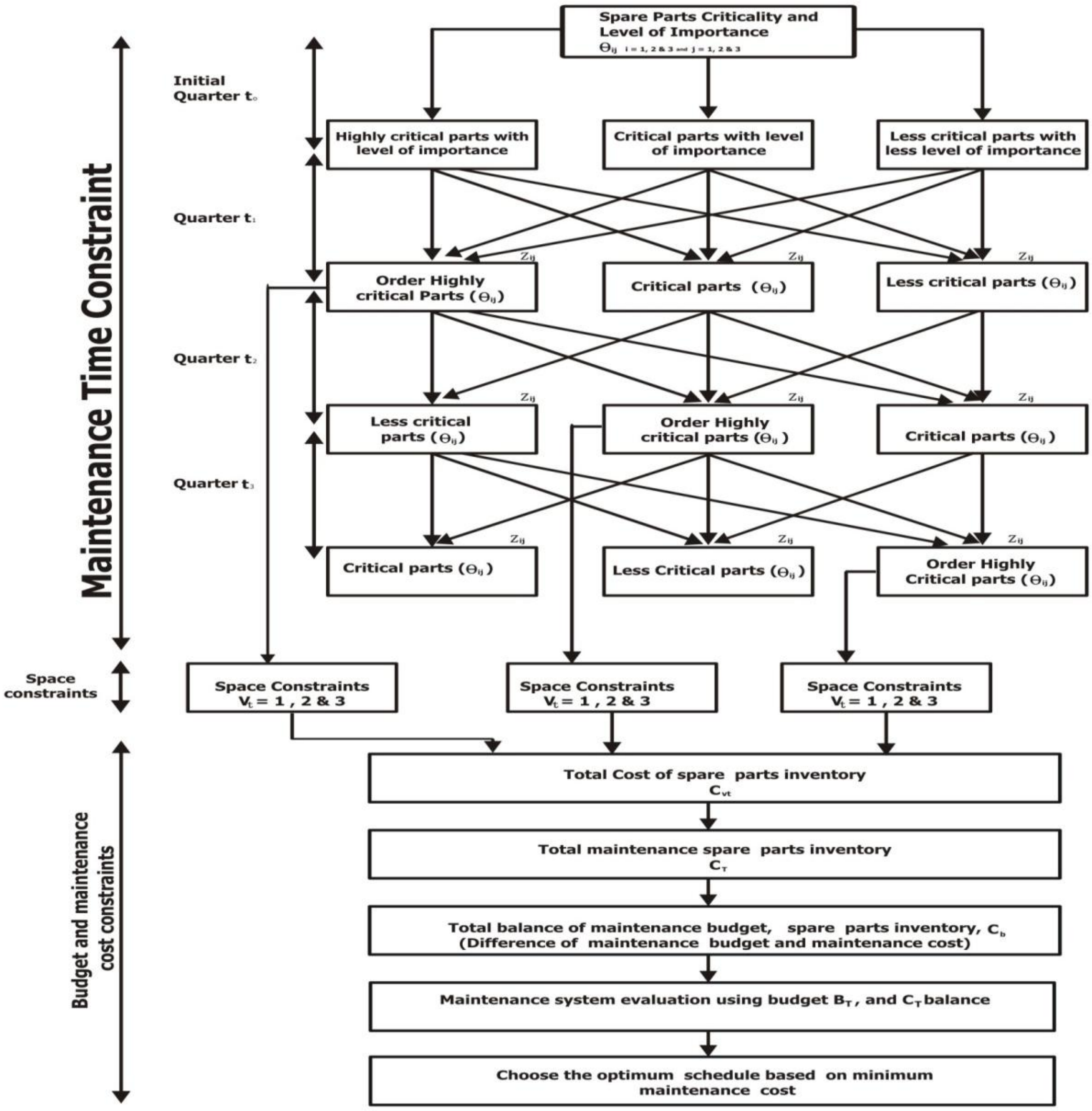

Figure 1. Framework for the system model development

The identified criteria (use rate and failure integrity) were used to group the spare parts of the automobile into criticality; highly critical, critical and less critical (θ_{m1}, θ_{m2} *and* θ_{m3}) with associated hidden behavior based on the level of importance grouped as; highly important, important and less important (θ_{k1}, θ_{k2} *and* θ_{k3}). Spare parts are assumed to fail stochastically (Ilman & Barizy, 2015; Kareem, 2015) or take any form of failure at a given period. Spare part of a given criticality categories is expected to fail independently at a given maintenance cycle with its emerging failure probability (Emmanuel & Adekunle, 2013; Flage, 2014). At this level, the required spare parts can be determined based on budgetary allocation and capacities of inventory with response to their level demand criticality. Therefore, the outcomes of the randomised failure system of the spare parts can fall into the following scheme under a sample of three based on the inventory limitation and to satisfy three levels of criticality condition all of the items are highly critical; two of the items are highly critical; one of the items is highly critical; all of the items are critical; two of the items are critical; one of the items is critical; all of the items are less critical; two of the items are less critical; one of the items is less critical; and each of the items are highly critical, critical and less critical.

The successive maintenance circle time 't' (service demand or service call) is usually determined as result of deteriorating effect of the spare parts/components based on three scenarios, namely; temperature, vibration and pressure (oil-viscosity). Based on expert opinions (Adeyeri *et al.,* 2012; Kareem *et al.,* 2011) temperature was made prominent in the deterioration evaluation.

The decision support system that could be utilized in determining the choice of maintenance strategies to be adopted and number of spare parts involved is based on heuristics given in Equation (1);

If

$$\begin{cases} 0.5 \le P\left[Z_{ij}/\theta_{ij}\right]^{tf} \le 1.0 \ \ carryout\ replacement\ and\ count\ part \\ 0.3 \le P\left[Z_{ij}/\theta_{ij}\right]^{tf} \le 0.49\ carryout\ repair\ and\ count\ parts \\ 0.0 \le P\left[Z_{ij}/\theta_{ij}\right]^{tf} \le carryout/preventive\ \ ma\ int\ encne\ and\ count\ parts \end{cases}$$

The corresponding inventory constraints for replacement policy in Equation (1) based on allowable capacity at time t, v_t can also be determined using the heuristics presented in Equation (2) as;

If,

$$v_t \begin{cases} < v_t - Inventory\ capacity\ is\ not\ exceeded \\ = v_t - Capacity\ is\ filled\ up \\ > v_t - Inventory\ capacity\ exceeded\ and\ update\ system\ with\ penalty\ cost \end{cases} \quad (2)$$

For a budget constraints(B^{T}) being imposed on the system having expected inventory expenditure, C_{T} on the spare parts at maintenance time't' (quarters) for a planned period (year), the following condition can be applied;

If,

$$C_T \begin{cases} \le B^T - maintenance\ /\ inventory\ operation\ is\ allowed \\ > B^T - maintenance\ \ /\ inventory\ operation\ is\ not\ allowed \end{cases} \quad (3)$$

The condition stated in Equation (3) warrants maintenance system decision information update and review. This will give room to the flexibility and robustness of the system. The first condition in which $C_T \le B^T$ (that is positve C_T) warrants system reports and updates (if necessary), while the case $C_T \ge B^T$ will result into two decisions: either to stop and report; or carryout upward review of the budget B^T.

Performance based on budget saving (P_{btm})given as :

$$P_{btm} = \frac{B^T - C_T}{B^T} = \frac{C_b}{B^T} \quad (4)$$

Equation 4 can be evaluated against industrial maintenance performance (P_{bts}) based on the prevailing spare parts planning method using similar criteria as presented in Equation 5.

$$P_{bts} = \frac{B_s^{\ T} - C^s{}_T}{B_s^{\ T}} = \frac{C^s{}_b}{B_s^{\ T}} \quad (5)$$

where:
B_S^T, total maintenance budget for all the operating branches.
C_T^S, total maintenance expends for all the operating branches.
C_B^S, total budget balance for all the operating branches.
Equation (5) can be applied to maintenance operation system of maintenance centres used as case studies to measure their performance. If$P_{bts} \leq P_{btm}$ that shows that the proposed method is better than prevailing method used in the maintenance centre, otherwise that of maintenance centres is superior to the new scheme.

2.3. System Implementation, Testing and Results

The computer software development comprises development of flowchart, algorithm and software coding/interfaces. Flowchart is a diagram that represents the sequence of operations in a process of the computer software development. It shows the commencement of the program, display main menu screen, perform main menu operation, setup, analyze and update the program among others. The flowcharts used for the developed computer software package are as presented in Fig. 2.

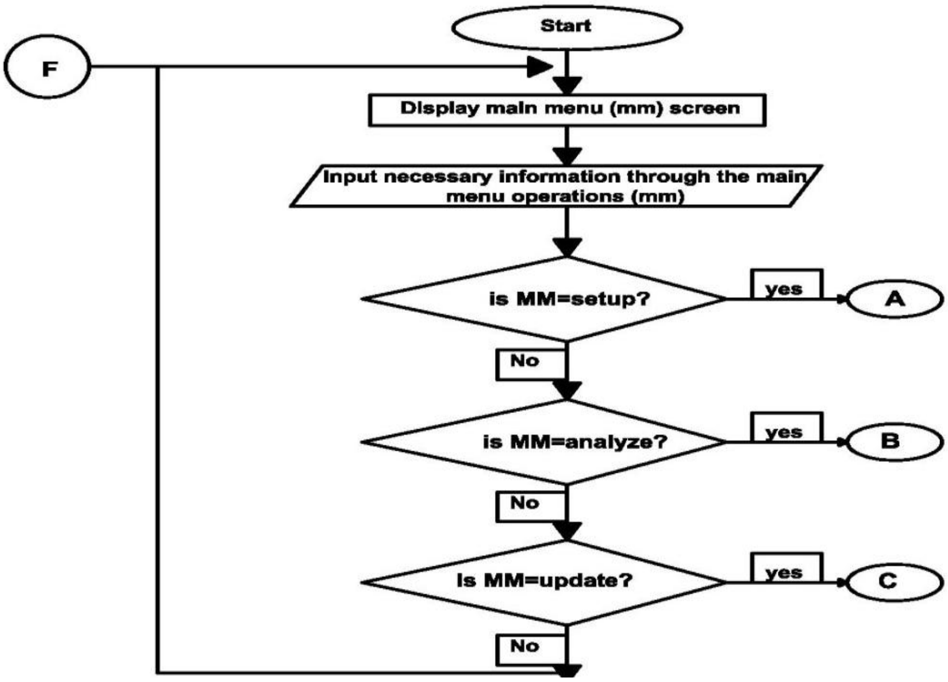

Figure 2a. Maintenance System Development Flowchart

It consists of a data setup flows $(A, B \& C, F)$, data setup/operations flow $(A \& F)$, data input analysis and operational flows $(B, D \& E)$, data performance analysis and update operational flows $(C \& F)$ and data planning, analysis, operational and inventory cost reports flow $(D, E$ and STOP). The computer coding is the set of instructions that is used in programming. It interprets flowchart and follow the sequences and algorithms. The Visual Basic (VB) version 6.0^R programming language was considered to be appropriate for the implementation of the model because of its user friendly to interpret graphical user interfaces that were designed. Also, VB is a language that has rapid application development environment which gives fast and insightful tools to develop Window applications and interface database system required by the study. Based on the stated facts, VB was used to develop the computer software package named software for spare parts planning system (SPPS - 2015). The SPPS is planned in such a way that the user interacts with the system through sequence of input and dialogue forms. The forms enable the user to neither select required parameters from predefined lists, nor to enter them manually.

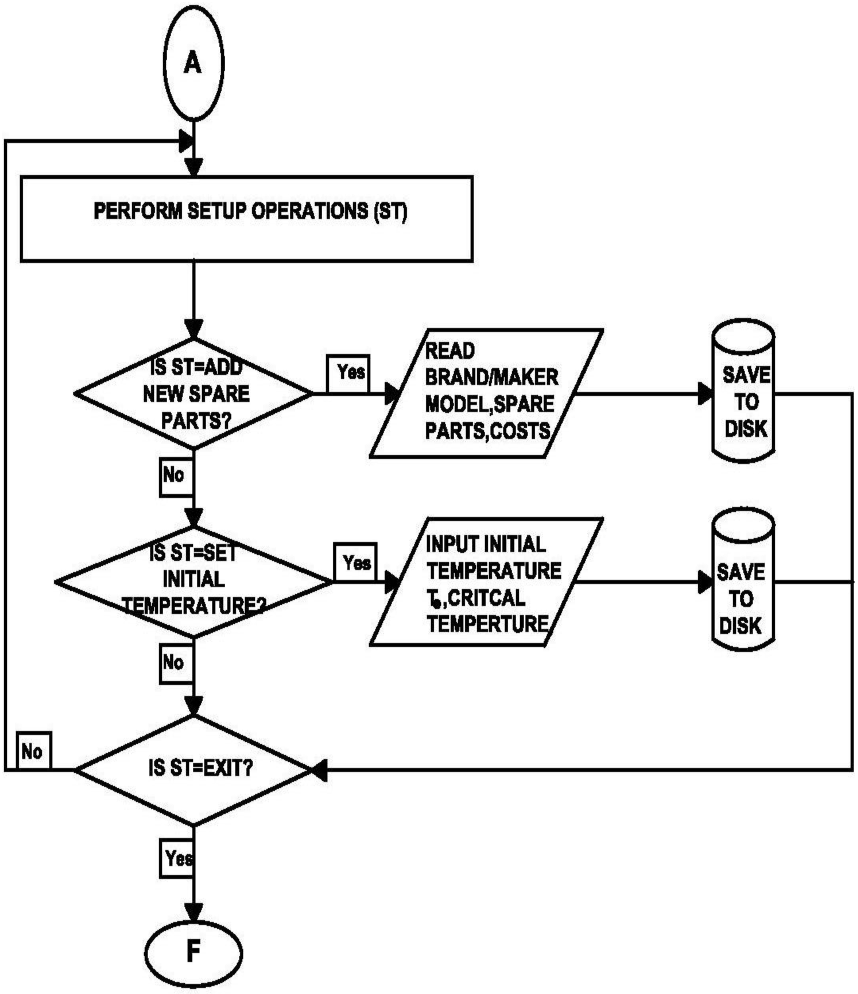

Figure 2b. Maintenance system development flowchart (Contd).

The system may not require the user to enter complete data in the forms in some instance. It may only require the user to input present information available to him/her while the system will utilize the inputted data from data bank to automatically generate the required results on the user interface. The SPPS analysis and validation were done with respect to the following brand of vehicles: Vehicle A, 2007, Vehicle B, 2000 and Vehicle, 2000. The results from maintenance data analysis of the three brand of vehicles (A, B, and C) were used to test the performance of the developed system and comparison were made among the vehicles. Performance of the system was also obtained by comparing it with the outcome of the maintenance inventory strategy in use in the studied cases. Variability/validation of the system was also carried out using statistical significance test based on paired-t test using Statistical Package for the Social Science (SPSS) version 15.0.

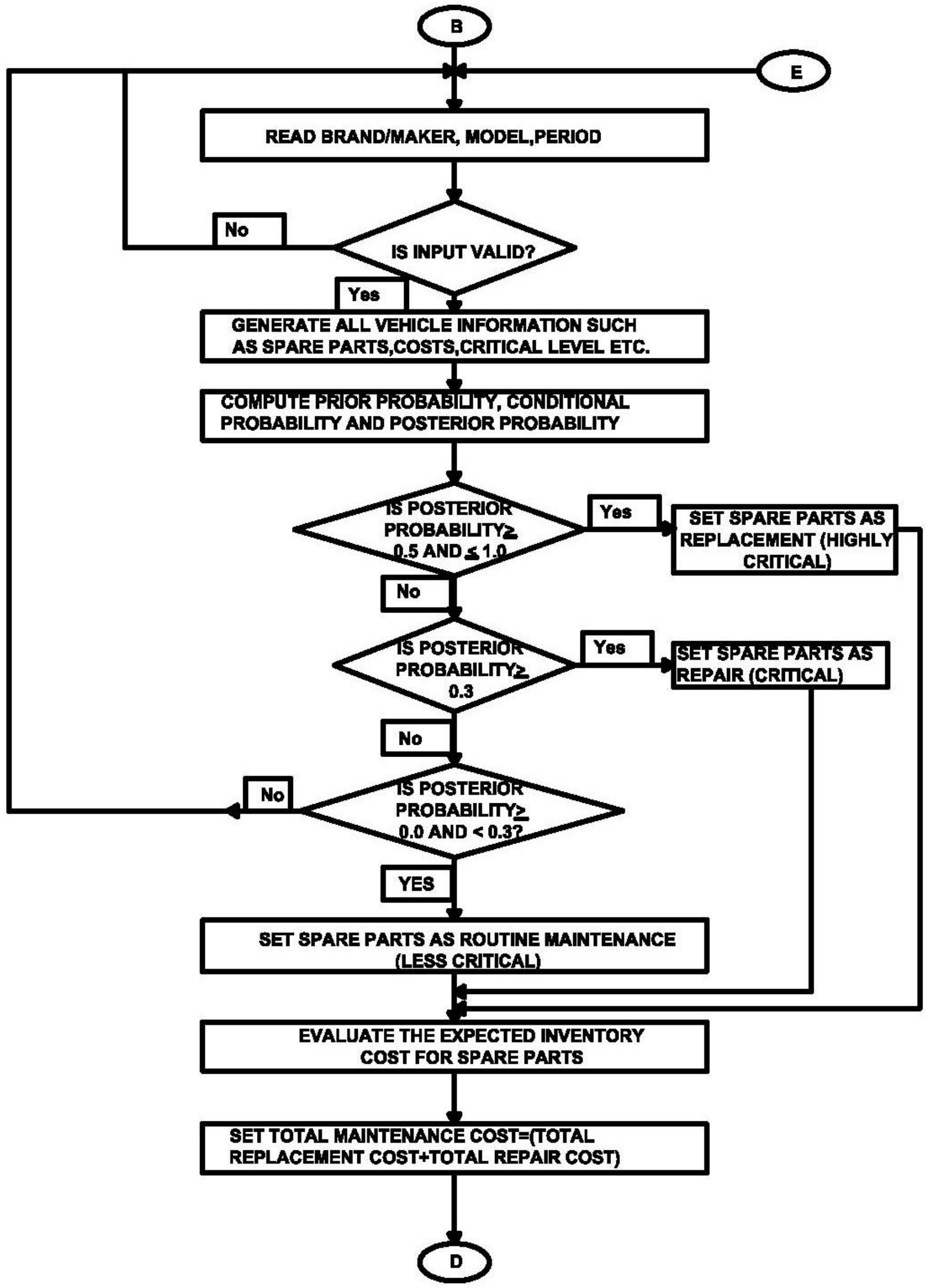

Figure 2c. Maintenance System Development Flowchart (Contd)

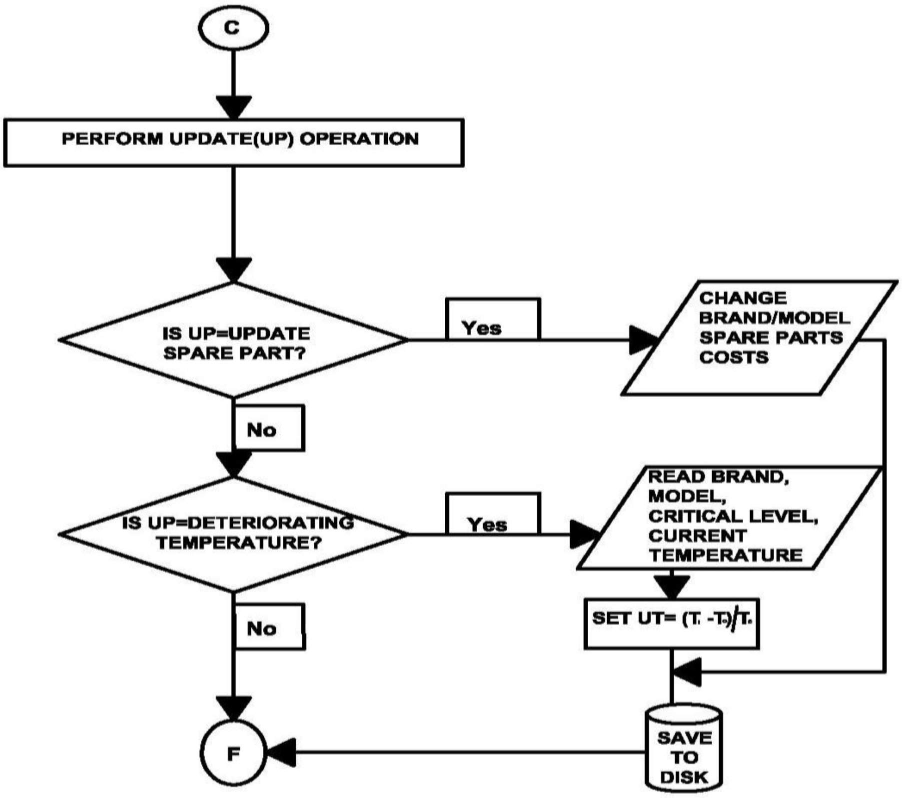

Figure 2d. Maintenance System Development Flowchart (Contd)

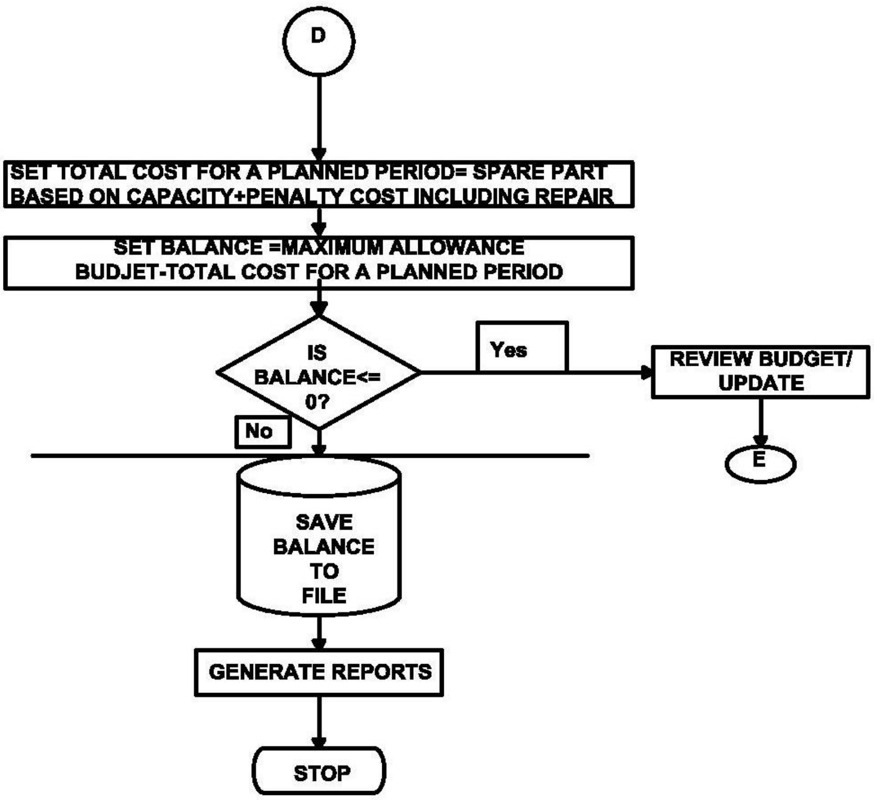

Figure 2e. Maintenance System Development Flowchart (contd.)

3. Results and discussion

3.1. Operational Output Interface Results

The opening window called main menu is shown in Fig. 3. It contains set-up, analysis and updating of spare parts' levels of criticality and important. It is versatile in setting up, analyzing and updating different brands of vehicular spare parts as related to their criticality in term of cost and scarcity. The choice of brand/maker of vehicle, model and year (period), criticality and important levels of spare parts analysis is done in Fig. 4. From the interface, the output results for a chosen vehicular brand under criticality and level of important analysis for a period of one year are displayed. In Fig. 5, the intended brand was selected and analysed to know the categories of the spare parts and their level of criticality (highly critical, critical and less critical/ highly important, important and less important). There is also a data bank where a new spare parts can be accommodated through update menu. The choice of spare part based on criticality level for a selected vehicular is demonstrated in interface presented in Fig. 6. From the interface it can be seen that cylinder block is at the critical level (highly critical and highly important) for the vehicular brand in focus with attendant replacement cost of N4000.00. The interface can accommodate spare parts update in case of change in technology level and environment of operation as corroborated by Fig. 7, where initial and critical temperatures of operations on spare parts are displayed. From the interface, spare parts initial temperature of the vehicle and its components (T_o) is given as 35^{o}C while spare parts critical or failure temperature is 40^{o}C. The periodic deteriorating factor computation interface is displayed in Fig. 8. It shows the current (operation) temperature of components as 32 ^{o}C, spare parts initial temperature is 30^{o}C, spare parts critical temperature, 40^{o}C, and deteriorating factor (failure rate) of components 0.05 for the period of two year under consideration for the selected vehicular brand. The interface is highly robust by allowing spare parts updating due to technology advancement and climatic change.

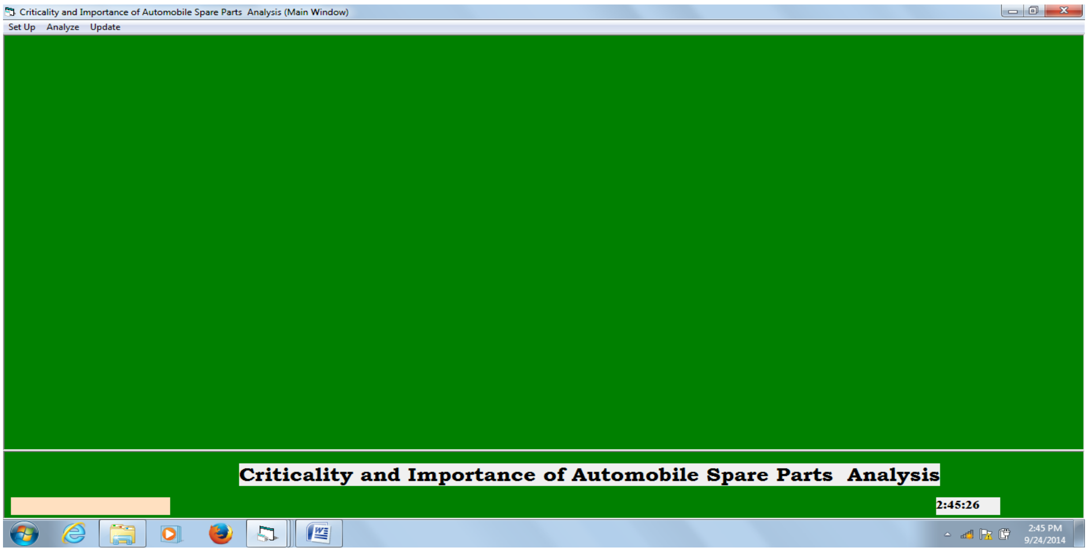

Figure 3. Criticality and important spare parts main menu

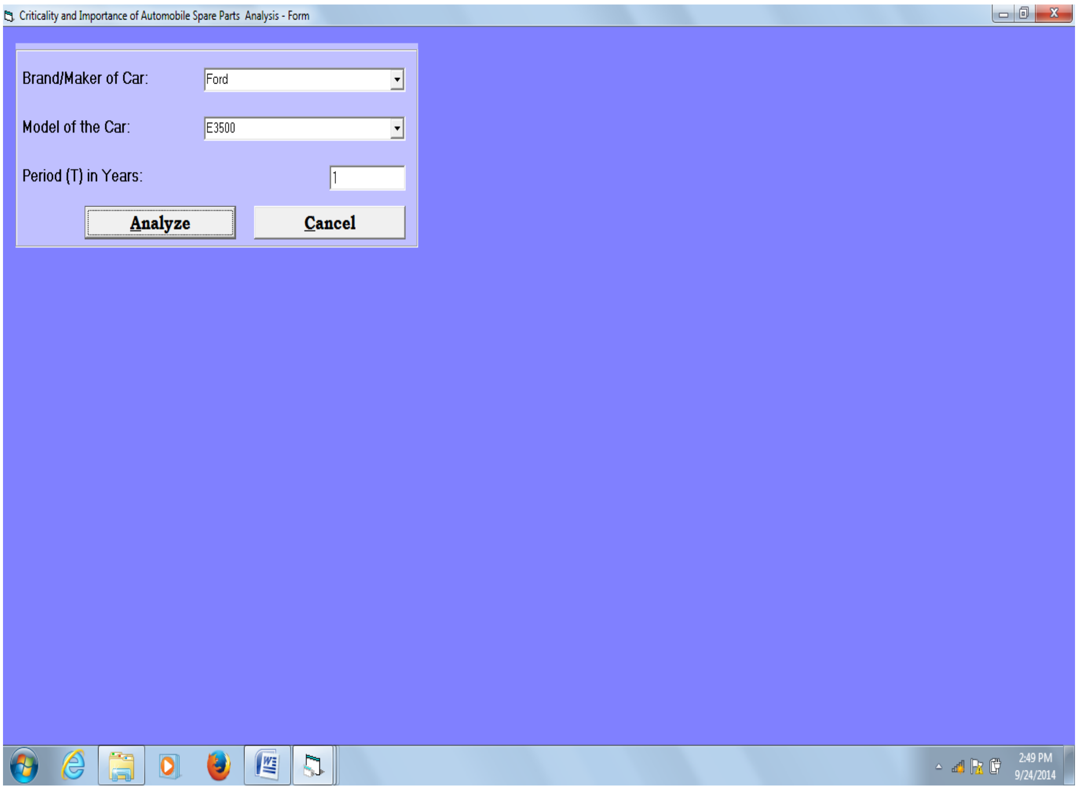

Figure 4. Criticality and importance of automobile spare parts analysis

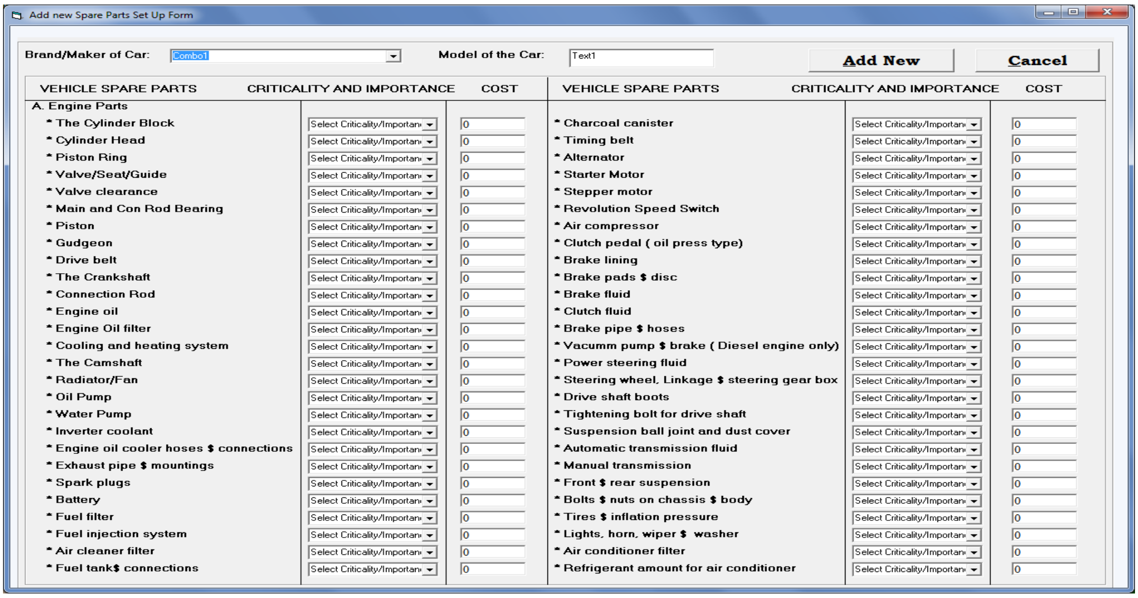

Figure 5. New spare parts setup

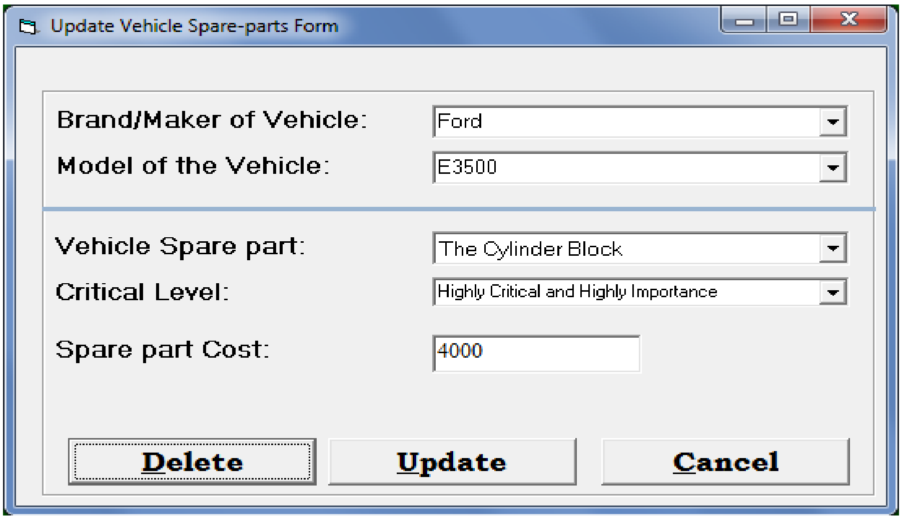

Figure 6. Update of vehicle spare parts

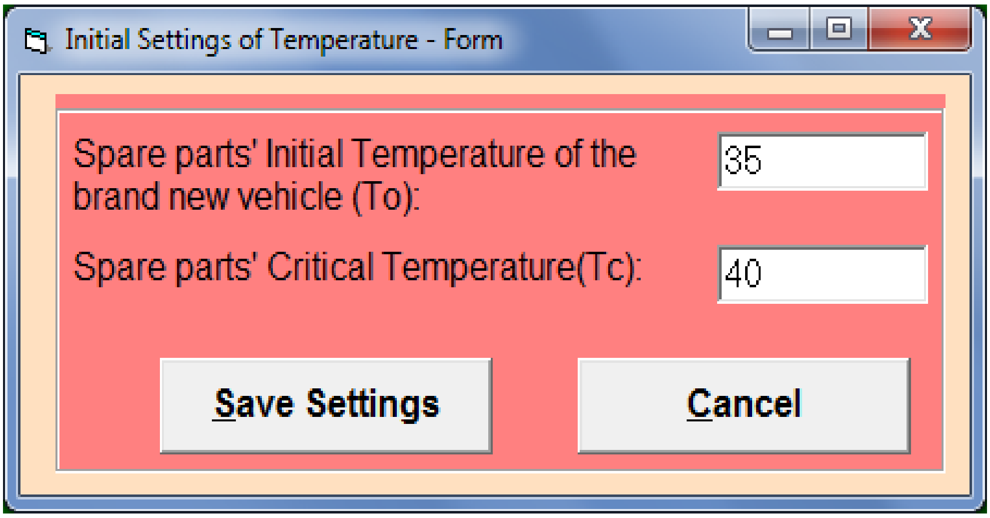

Figure 7. Initial settings of temperature

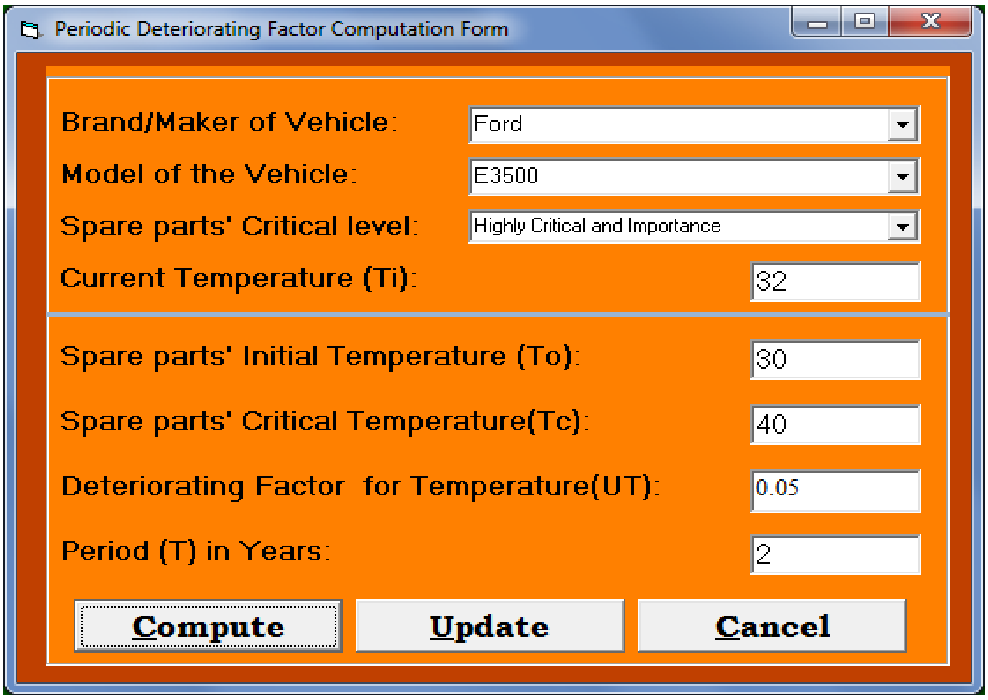

Figure 8. Periodic deteriorating factor computation

3.2. System Implementation with a Case Study

Implementation results of the developed spare parts planning system in the workshops used as case study are presented in tables 1, 2 and 3 on the bases of the stated conditions given in figures 1-8. The outcomes from the model were compared with the traditional approach current used in the workshops that did not consider information management related to spare part failure probability. As shown in table 1, all the spare parts for the reported failed vehicles were considered highly critical with failure probability of 1.0 under the stated operation conditions. In table 2, it was shown, under the consideration of failure rate information, that 18, 0 and 21 components were found highly critical and highly important in the years 1, 2 and 3 respectively. It accounted for 33%, 0% and 38% of the spare parts needed under traditional approach currently operating by the workshops respectively (Table 3). The outcomes have demonstrated improvement of about 67%, 100% and 62% in spare parts condition monitoring as provided by the developed SPPS-2015 model. The stated outcomes can be translated to low maintenance cost and hence high reduction in maintenance operation budget.

Table 1. Highly critical automobile components in the workshops and operation conditions

SYSTEM/COMPONENT	Workshop 1	Workshop 2	Workshop 1
(A) Engine Parts	✓	✓	✓
1. The Cylinder Block	✓	✓	✓

2. Cylinder Head	✓	✓	✓
3. Piston Ring	✓	✓	✓
4. Valve/Seat/Guide	✓	✓	✓
5. Valve clearance	✓	✓	✓
6. Main and Con Rod Bearing	✓	✓	✓
7. Piston	✓	✓	✓
8. Gudgeon pins	✓	✓	✓
9. Drive belt	✓	✓	✓
10. The Crankshaft	✓	✓	✓
11. Connecting Rod	✓	✓	✓
12. Engine oil	✓	✓	✓
13. Engine Oil filter	✓	✓	✓
14. Cooling and heating system	✓	✓	✓
15. The Camshaft	✓	✓	✓
16. Radiator/Fan	✓	✓	✓
17. Oil Pump	✓	✓	✓
18. Water Pump	✓	✓	✓
19. Engine coolant	✓	✓	✓
20. Inverter coolant	✓	✓	✓
21. Engine oil cooler hoses & connections	✓	✓	✓
22. Exhaust pipe & mountings	✓	✓	✓
23. Spark plugs	✓	✓	✓
24. Battery	✓	✓	✓
25. Fuel filter	✓	✓	✓
26. Fuel injection system	✓	✓	✓

27. Air cleaner filter	✓	✓	✓
28. Fuel tank & connections	✓	✓	✓
29. Charcoal canister	✓	✓	✓
30. Timing belt	✓	✓	✓
(B) Electric Parts Details	✓	✓	✓
31. Alternator	✓	✓	✓
32. Starter Motor	✓	✓	✓
33. Stepper motor	✓	✓	✓
34. Revolution Speed Switch	✓	✓	✓
35. Air Compressor	✓	✓	✓
(C) CHASSIS & BODY	✓	✓	✓
36. Clutch pedal (oil press. type)	✓	✓	✓
37. Brake lining	✓	✓	✓
38. Brake pads & discs	✓	✓	✓
39. Brake fluid	✓	✓	✓
40. Clutch fluid	✓	✓	✓
41. Brake pipe & hoses	✓	✓	✓
42. Vacuum pump & brake (Diesel engine only)	✓	✓	✓
43. Power steering fluid	✓	✓	✓
44. Steering wheel, Linkage & steering gear box	✓	✓	✓
45. Drive shaft boots	✓	✓	✓
46. Tightening bolt for drive shaft	✓	✓	✓
47. Suspension ball joint and dust cover	✓	✓	✓

48. Automatic transmission fluid		✓	✓	✓
49. Manual transmission		✓	✓	✓
50. Front & rear suspension		✓	✓	✓
51. Bolts & nuts on chassis & body		✓	✓	✓
52. Tires & inflation pressure		✓	✓	✓
53. Lights, horn, wiper & washer		✓	✓	✓
54. Air conditioner filter		✓	✓	✓
55. Refrigerant amount for air conditioner		✓	✓	✓
TOTAL		55	55	55
Criticality probability		1.0	1.0	1.0
Temperature	T_0	T_i^0C	T^0C	U_T
Temperature of Operation	35^0C	32^0C	40^0C	0.05

Key: T_0 – Initial temperature (Manufacturer), T_i – Operating temperature, T_c – Critical temperature (as given by the Manufacturer).

Table 2. Highly critical parts for Vehicles in the Workshops based on failure probability

Maintenance category	Quarter 1	Quarter2	Quarter 3
Highly critical vehicular parts in workshop A that need replacement	NILL	Radiator/fan, fuel injection system, fuel tank & connections, Alternator, Starter motor, stepper motor, Revolution speed switch, Air compressor, clutch pedal (oil press type), Brake lining, Brake pads and Discs, brake fluid, clutch fluid, vacuum pump and brae (Diesel Engine only), steering wheel, linkage and steering gear box, drive shaft boots, manual transmission, front and rear suspension	NILL
Total	**NILL**	**18**	**NILL**
Highly critical vehicular parts in workshop B that need replacement	NILL	NILL	NILL
Total	**NILL**	**NILL**	**NILL**

Highly critical vehicular parts in workshop C that need replacement	Nil	Nil	Cylinder block, Cylinder head, piston ring, Valve/Seat/Guide, Valve clearance, main & con-rod bearing, piston, Gudgeon pins, and Drive belt, Connecting rod, Crankshaft, Engine oil & Engine oil filter, Cooling & Heating system, Camshaft, Radiator/Fan, oil pump, Water pump, Brake pads & discs, Steering wheel, linkage & steering, gear box, Suspension ball joint and dust cover,
Total	**Nil**	**Nil**	**21**

Table 3. Improvement over the current method of operation in the workshops

Workshops	**Number of Highly Critical Parts**						
	Traditional Methods	**Spare Parts Planning System (SPPS - 2015) Approach**					
	All years, AQ	**Year 1**	**Year 2**	**Year 3**	**Total, TY**	**Percentage, (TY/AQ)%**	**Improvement 100-(TY/AQ)%**
1	55	-	18	-	18	33%	67%
2	55	-	-	-	-	0%	100%
3	55	-	-	21	21	38%	62%

4. Conclusions

This study has developed a Spare Parts Planning System (SPPS - 2015) model that combines analytical knowledge obtained from mathematical models for the automobile maintenance industry and expert opinions using modified Bayesian approach. The system was developed in an attempt to solving emerging problem of updating records of the spare parts in certain automobile maintenance centers with due consideration of inventory limitation and usage criticality. Integration of information management and operational dynamism into spare parts planning system has positively impacted development in the automobile maintenance industry. Information gathered on use rate and availability of automobile spare parts under service condition from three selected automobile maintenance job shops in South-western Nigeria was utilized in classifying the failures of spare parts into their levels of criticality. The computer software package developed using V.B. was used to facilitate rapid information management as regards spare parts planning system related to failure analyses and grouping, choice of maintenance policy, inventory capacity, expected cost of maintenance and budgeting. The system model was implemented on three jobshops that are responsible for the maintenance of the brands of vehicles, and outcomes showed a good improvement in terms of providing spare parts information management system concerning spare parts requirement rate, retrieval, updating and condition reporting. From the results generated the following conclusions can be drawn.

i.The system developed is capable of identifying the criticality and level of important of spare parts of different models of vehicles, predicting imminent failures of spare parts based on conditional probability, generating cost reports and monitors and control maintenance budget to aid the decision making on maintenance policy to adopt, and solve problem of managing the complex spare parts requirement by providing information based system for effective spare parts retrieval, updating and reporting.

ii. This system developed can be a veritable tools for spare part planning in other organizations that are making use of machinery other than transportation equipment that are liable to random failures including production equipment, ancillary equipment, material handling equipment, and office equipment.

References

Adeyeri, M.K., Kareem, B., Aderoba, A.A., Adewale, S.O. (2012). Temperature based embedded programming algorithm for conventional machines condition monitoring. *The Third Inter. Conference on Computational Logics, Algebras Programming Tools, and Benchmaking (IARIA),* France, 51-57.

Dekker, R., Pince, C., Zuidwijk R. & Jalil M.N. (2013). On the use of installed base Information for spare parts logistic: A review of ideas and industry practice. *Int. J. Production Economics,143*(2), 536-545.

Emmanuel, C.O., Adekunle, Y.A. (2013). Basic concepts of expert system shells and an efficient model for knowledge acquisition. *Int. Journal of Science and Research, 2*(4), 1-12.

Flage, R. (2014). A delay time model with imperfect and failure inducing inspections. *Reliability Engineering and System Safety*, 124, 1-12.

Hong, H.P., Zhou, W., Zhang, S. & Ye, W. (2014). Optimal condition –based 7 maintenance decisions for system with dependent stochastic degradation of components. *Reliability Engineering and System Safety*, 121, 276-288.

Hu, J., Zhang L. (2014). Risk based opportunistic maintenance model for complex mechanical systems. *Expert System with Applications, 41*(6), 3105-3115.

Ilman, M.N., Barizy, R.A. (2015). Failure analysis and fatigue performance evaluation of a failed connecting rod of reciprocating air compressor. *Engineering Failure Analysis,* 56, 142-149.http://dx.doi.org/10.1016/j.engfailanal.2015.03.010

Kareem, B. (2015). Evaluation of failures in mechanical crankshafts of automobile based on experts opinion. *Case studies in Engineering Failure Analysis*, 3, 25-33. www.elsevier.com/locate/csefa

Kareem, B., Lawal, A.S. (2010). Development of a generalized spare parts planning for automotive maintenance industry. *International Conference on Maintenance of Engineering Infrastructure in Developing Countries,* University of Botswana, Gaborones Botswana.

Kareem, B., Lawal, A.S. (2015). Spare parts failure prediction of an automobile under criticality condition. http://dx.doi.org/10.1016/j.engfailanal.2015.04.011.

Kareem B., Ogendengbe T.I. &Jewo A.O. (2011). A condition based model for maintenance planning on critical equipment in the petrochemical industry. *Proceedings of 2011 Inter. Conference on Instrumentation, Measurement, Circuits and Systems (ICIMCS 2011),* 529-533.

Pradhan, M.K., Bhol, J.B. (2006). Trend and perspectives in industrial maintenance management. *Proceeding of National Symposium on recent Development in Industrial Maintenance Management*, SIET, Dhenkanal, 27-35.

Weber, P., Medina-Oliva, G., Simon ,C. & Lung B. (2012). Overview on Bayesian networks applications for dependability, risk analysis and maintenance areas. *Engineering Applications of Artificial Intelligence*, 25(4), 671-682.