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Development of a Heterogeneous Based Spare Parts Planning in Automobile Maintenance Industry

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ABSTRACT : *The proper operating condition of automobiles could only be achieved withappropriate planning of spareparts which are needed to retain or restore failed equipment in maintenance Industry. This studyutilized essential components of spare parts planning in the previous studies, such as spare parts demand, inventory, and at the same time extend them to take care of heterogeneous nature of critical parts in automotive maintenance industry. The model developed has made use of simple exponential smoothing method to forecast for spare parts requirement in the automobile maintenance industry. The reliability of critical parts and failure pattern were considered for the formulation of the generalized spare parts inventory model, under negative exponential distribution. Also, economic order quantity, optimum number of order and optimum period of supply for critical specific parts were considered in the process of developing the model for heterogeneous spare part inventory planning. The data collected on D6c manual Caterpillar in one Maintenance Industry in Nigeria was used in validated the model. ABC analysis was used to analyze the data from which the most critical parts called class A were identified which served as input into the model. Thereafter, the model was numerically analyzed using linear multiple regression method. The finding generally shows that the cost of critical specific spare part varies with maintenance scheduling time and quantity of order, number of order, and time of order, for heterogeneous planning.*

KEYWORDS *spare parts, demand, inventory,failure pattern, maintenance.*

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I. INTRODUCTION

Spare parts planning in Nigeria maintenance industry has been inadequate. The inadequate of spare parts planning has industrial systems to be malfunctioning and many of them have closed down. The worst case is in automotive industry, where many vehicles have been abandoned because of non-availability of spare parts [1].

A generalized spare parts model that will take the peculiarity of Nigeria problems into consideration will be necessary to solve problems of spare parts availability and planning. Many models were developed on spare parts planning in literature but were overwhelmed with some unrealistic assumptions related to spare parts homogeneity, this has made the model impracticable in heterogeneous industrial maintenance environment [2, 3, 4, 5].

However, few research efforts were also identified that takes care of heterogeneity of spare parts [6, 7, 8]. These efforts would have contributed immensely in solving problems of spare parts planning in developing country, but their contributions are not quantitative-based. This non-provision of quantitative- based system would make it difficult for proper assessment of its efficiencies. Therefore, this study, that is based on a generalized spare parts planning model for automotive maintenance industry will relax many of the assumptions made in previous works, and, at the same time provides quantitative expressions required in solving maintenance spare parts planning problems in the heterogeneous environment.

II. MODEL DEVELOPMENT

The first stage in spare parts planning is to forecast for the need of it. Simple exponential smoothing forecasting system is found to be most appropriate because it depends on the previous demand data. It estimates

the average forecast for the next period by using the actual and the forecasted demand for the previous period [9, 10, 11].
Mathematically,

$$\lambda_{cg(t)}^{d1} = \Sigma \frac{\{d_{t-1}^{f} + \alpha(d_{t-1}^{a} - d_{t-1}^{f})\}}{\Sigma(T_{t-1})} \quad (1)$$

Where: λ = failure rate, d = demand pattern

cg = critical general, d_{t-1}^{f} = previous forecast spare part demand

d_{t-1}^{a} = previous actual spare parts demand, T_{t-1} = previous times of need of the part.

α = smoothing constant.

Equation (1) is related to Economic Order quantity as follows;

$$Q_{cg/cs}^{dn} = \sqrt{\frac{2P(t)_{cg}^{dn}\lambda_{cg}^{dn}C_{cg}^{o}}{C_{cg}^{p}I}} \quad (2)$$

Where: $P(t)_{cg}^{dn}$ = Probability of failure at scheduled time t, cs = critical specific parts,

λ_{cg} = Failure rate of the critical general parts, C_{cg}^{o} = Ordering costs

C_{cg}^{p} = Price per unit, I = Annual Inventory Investment

λ_{cs}^{dn} = failure rate of valued critical specific spare part with a certain demand pattern, and other parameters are as defined before. A relation between the total costs and economic order quantity, maintenance schedule time, and other parameters, as well, was formulated using linear multiple regression model as;

$$Y^{total} = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k \quad (3)$$

Where; Y^{total} = dependent variable which is the total inventory cost for either critical specific spare parts or critical general parts. $X_1, X_2, \ldots, X_k$= Independent variable are parameters on which inventory cost is determined e.g. economic other quantity, optimal number of order and optimal time of order.
$b_0, b_1, \ldots, b_k$= Coefficient of linear multiple regression relationship.

III. MODEL VALIDATION

The data on caterpillar spare parts (Bulldozer D6c Manual) were collected from one maintenance Agency Nigeria. The data covered maintenance activities carried out on certain equipment in the last four years. This were analyzed to validate the model. The parts of engines, electric unit, transmission, hydraulic system, and under carriage, of the equipment were listed. The total number of usage per period unit cost and usage value were found. The summary of the items identified are presented in Table 1.

Table 1: The Identified Parts of Caterpillar

S/n	Description of items	Total no of usage per period	Unit cost	Usage value (Total cost = unit cost x usage per period)
	A. ENGINE		**N :K**	**N :K**
1	Cranks shaft	2	550, 000.00	110, 000.00
2	Set of piston sleeve and seals	1	192, 000.00	192, 000.00
3	Set of piston (6 nos)	6	15, 500.00	93, 000.00
4	Set of piston and ring (6 nos)	6	10, 500.00	63, 000.00
5	Set of conrod bearing (6 nos)	12	4, 500.00	54,000.00
6	Set of Main bearing (7 nos)	14	5500.00	77, 000.00
7	Overhauling Gasket	1	120, 000.00	120, 000.00
8	Oil pump	1	150, 000.00	150, 000.00
9	Thrust water	2	3500.00	7, 000.00
10	Oil Filter	24	3000.00	72, 000.00
11	Fuel Filter	24	6000.00	144, 000.00
12	Air cleaner pry/sec.	1	18,000.00	18, 000.00
13	Engine oils & gallons	24	7500.00	180, 000.00
14	Servicing injector pump	1	250,000.00	250,000.00
15	Set of nozzles (6 nos)	24	10, 000.00	240, 000.00

16	Radiator hoses	2	15, 000.00	30,000.00
			Total	**2790,000.00**
	B. ELECTRIC UNIT		**N :K**	**N :K**
1	Alternator	2	60, 000.00	120, 000.00
2	H/D Battery and water	2	58, 000.00	116, 000.00
3	Heating assembly	1	12, 000.00	12, 000.00
4	Kick starter	1	85, 000.00	85, 000.00
5	Complete turbo charger	1	320, 000.00	320,000.00
6	Set of fan belt	1	7,000.00	7, 000.00
7	Electrical servicing	1	25,000.00	25, 000.00
			Total	**685,000.00**
	C. TRANSMISSION UNIT		**N :K**	**N :K**
1	Transmission pump	1	450, 000.00	450, 000.00
2	Transmission filter	8	4, 500.00	36, 000.00
3	Magnets filler	8	4, 500.00	36, 000.00
4	Set of hoses	1	100, 000.00	100, 000.00
5	Oil cooler	1	140, 000.00	140, 000.00
			Total	**762,000.00**

Table 1: The Identified Parts of Caterpillar (Continued)

S/n	**Description of items**	**Total no of usage per period**	**Unit cost**	**Usage value (Total cost = unit cost x usage per period)**
	D. HYDRAULIC UNIT		**N :K**	**N :K**
1	Hydraulic pump	1	420, 000.00	420, 000.00
2	Set of arm seals	2	30, 000.00	6, 000.00
3	Set of blades	1	120, 000.00	120, 000.00
4	Cutting edge	1	50, 000.00	50, 000.00
5	Hydraulic filter	8	12, 000.00	96, 000.00
			Total	**746, 000.00**
	E. UNDER CARRIAGE		**N :K**	**N :K**
1	Complete set of tracks (2 nos)	1	1, 250, 000.00	1, 250, 000.00
2	Segment (10 nos)	1	250, 000.00	250, 000.00
3	Up rollers (4 nos)	1	80, 000.00	80, 000.00
4	Down rollers (10 nos)	1	450, 000.00	450, 000.00
5	Track adjuster nipper (2 nos)	2	50, 000.00	50, 000.00
6	Track adjuster seal (2 nos)	2	80, 000.00	80, 000.00
7.	Body works	1	40,000.00	40,000.00
			Total	**2, 330, 000.00**

Table 1b: Summary of the identified Spare Parts Value Analysis

S/N	Spare Parts	Cost value
I	Engine	#2,690,000.00
Ii	Under-carriage	#2,330,000.00
Iii	Transmission	#762,000.00
Iv	Hydraulic system	#746,000.00
V	Electrical unit	#685,000.00
	Total	**#7,313,000.00**

IV. DATA ANALYSIS

ABC analysis which is based on praetor's law [12] was used to analyze the data. He suggests that there are a few items which contributed most to the inventory costs (item A) and a large number of items whose cost is relatively low (item C) known as 80/20 rule and was applied in analyzing the data collected in Table 2. The most critical parts of Engine, under carriage, transmission, hydraulic system, and electrical unit were identified to be; Crack shaft, complete set of tracks, transmission pump, hydraulic pump and complete turbo charge. Also, the unit cost of the critical parts was the sum of items contained in each part. Usage value is the product of unit cost and usage per period. Cumulative of usage value were calculated and percentage of the value was determined. Also, nature of the parts shows that only electrical parts are general others are specific in nature. ABC analysis test shows that engine crankshaft (Part 1) and complete set of tracks for under carriage (Part 2) are found to exhibit class A parts called critical specific parts. These critical specific parts are those parts that can only be provided by original Equipment manufacturer (Caterpillar manufacturer). Table 2, contained the parts/items, and identified critical parts, unit cost, usage value and nature of parts among others.

Table 2 – Spare Parts in sub-group based on ABC analysis

S/N	Items, n	Critical Parts	Unit cost (₦)	Usage per annum	Usage value (₦)	Cumulative of usage value(₦)	Percentage value	Nature of parts
1	Engine	Crankshaft	2790,000	2	5,580,000	5,580,000	55.25	Specific
2	Under-carriage	Complete set of tracks	2,330,000	1	2,330,000	7910,000	78.29	Specific
3	Transmission	Transmission pump	762,000	1	762,000	8672000	85.83	Specific
4	Hydraulic system	Hydraulic pump	746,000	1	746,000	9418000	93.21	Specific
5	Electrical unit	Complete turbo charge	685,000	1	685,000	10103000	100.00	General

E

The class A critical specific part obtained where further analyzed using developed model (Equation 1- 3). The results obtained are presented in Tables 3 to 5.

Table 3: Economic order quantity for critical specific (cs) parts in respect to demand

Scheduling Period	Annual Inventory cost	Annual Inventory cost	Total cost	Total average cost	Economic order quantity	Economic order quantity	Average economic order quantity
¼	5352363.96	4830917.87	10183281.83	5091640.91	1.121	0.621	0.871
½	3901170.35	3460207.61	7361377.96	3680688.98	1.538	0.867	1.202
¾	3276897.87	2868068.83	6144966.70	3072483.35	1.831	1.046	1.438
1	2919708.02	2516778.52	5436486.54	2718243.27	2.055	1.192	1.623

Table 4: Optimum number of orders for critical specific parts

Scheduling Period	Annual Inventory cost	Annual Inventory cost	Total cost	Total average cost	Economic order quantity	Economic order quantity	Average economic order quantity
¼	5352363.96	4830917.87	10183281.83	5091640.91	1.121	0.621	0.871
½	3901170.35	3460207.61	7361377.96	3680688.98	1.538	0.867	1.202
¾	3276897.87	2868068.83	6144966.70	3072483.35	1.831	1.046	1.438
1	2919708.02	2516778.52	5436486.54	2718243.27	2.055	1.192	1.623

Table 5: Optimal period of supply per optimal order for critical specific parts

Scheduling Period	Total cost (₦)	Total average cost (₦)	Optimum period of supply	Optimum period of supply	Average optimum period of supply
¼	10183281.83	5091640.91	2.242	2.487	2.364
½	7361377.96	3680688.98	3.076	3.472	3.274
¾	6144966.70	3072483.35	3.663	4.184	3.923
1	5436486.54	2718243.27	4.115	4.784	4.449

The results in Table 3 - 5 were further analyzed using statistical multiple regression method under SPSS platform utilizing the homogeneity and heterogeneity behaviors of the parts and the resulting Equations were given in sections 3.2.1 to 3.2.4.

3.2.3 HOMOGENOUS CRITICAL SPECIFIC SINGLE (PART 1)

i. Relationship of total cost with cost of inventory and economic order quantity of critical specific parts

$$Y_{cs1} = 10794278 + 3937844.9\ T_{schedule} - 5740502\ Q_{cs1} \qquad (3.21)$$

Where: $Ycs1$ = total cost of critical specific (part 1)

$T_{schedule}$ = schedule period

Q_{cs1} = Economic order quantity of critical specific (parts 1)

ii. Relationship of total cost with schedule period and number of order of critical specific parts

$$Y_{cs1} = -8901.174 + 8245.197\ T_{schedule} + 12016420\ Np_{cs1} \qquad (3.22)$$

Where: Np_{cs1} = Number of order of critical specific parts 1

iii. Relationship of Total cost with schedule period and optimum period of order / supply of critical specific parts

$$Y_{cs1} = 10838284 + 4029975.2\ T_{schedule} - 2899964\ T_{cs1} \qquad (3.23)$$

Where: T_{cs1} = Optimum period of order / supply of critical specific parts 1

3.2.4 HOMOGENOUS CRITICAL SPECIFIC SINGLE (PART 2)

i. $$Y_{cs2} = 10034914 + 4797279.9\ T_{schedule} - 10321224Q_{cs2} \qquad (3.24)$$

Where: Y_{cs2} = total cost of critical specific (part 2)

$T_{schedule}$ = schedule maintenance period

Q_{cs2} = Economic order quantity of critical specific (parts 2)

ii. $$Ycs2 = -44240.457 + 28384.438\ T_{schedule} + 12110697\ Np_{cs2} \qquad (3.25)$$

Where Np_{cs2} = Number of order of critical specific parts 2

iii. $$Y_{cs2} = 10193656 + 5109924\ T_{schedule} - 2671231\ T_{cs2} \qquad (3.26)$$

Where: T_{cs2} = Optimum period of order / supply of critical specific parts 2

3.2.5 HOMOGENOUS CRITICAL SPECIFC MULTIPLE PARTS (AVERAGE)

(i) Relationship of average total cost with schedule period and average economics order quantity of critical specific parts

Y_{csv}= 10415082 + 4216321.1 $T_{schedule}$ - 7331140 Q_{csv} (3.27)

Where: Y_{csv} = Average Total cost of critical specific parts

$_{csv}$= Critical specific average

$T_{schedule}$ = Schedule period

Q_{csv} = Average economic order quantity of critical specific parts

(ii) Relationship of average total cost with schedule period and average number of order of critical specific parts

Y_{csv} = 16098.550 - 6396.663 $T_{schedule}$ + 11975787 Np_{csv} (3.28)

Where Npcsv = Average number of order of critical specific parts

(iii) Relationship of Average total cost with schedule period and average optimum order/ supply of critical specific parts

Y_{csv} = 10516320 + 459329.2 $T_{schedule}$ - 2782694Tcsv (3.29)

Where T_{csv} = Average optimum order/ supply of critical specific parts

3.2.6 HETEROGENOUS CRITICAL SPECIFIC MULTIPLE PARTS (GENERALIZED MODEL)

i. Relationship of total cost with schedule period and economic order quantity of critical specific total

Y_{cst} = 20951269 + 10002306$T_{schedule}$ - 21386132 Q_{cs2} (3.30)

Where Y_{cst} = Total inventory cost of critical specific part

Q_{cs2} = Economic order quantity of critical specific (parts 2)

ii. Relationship of total cost with schedule period and number of order of critical specific total parts

Y_{cst} = 70143.647 + 118949.72 $T_{schedule}$ + 2508620 Np_{cs2} (3.31)

Where Np_{cs1} = Np_{cs2} (Statistically)

Np_{cs} = Number of order of critical specific parts

iii. Relationship of total cost with schedule period and optimum order / supply of critical specific total part

Y_{cst} = 21278996 + 10648136 T schedule - 5534281 Ts_{cs2} (3.32)

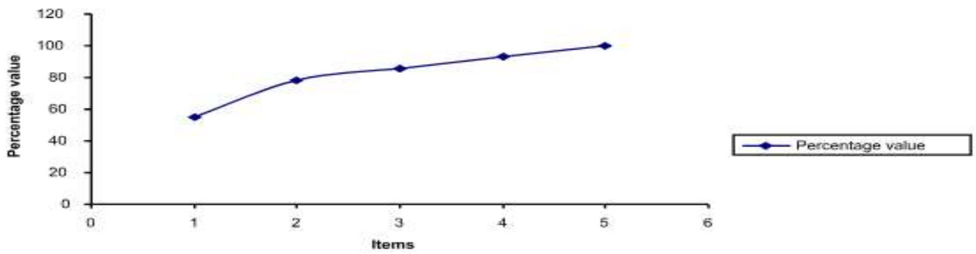
Where T_{cs1} = T_{cs2} (statistically)

T_{cs} = Optimum order / supply of critical specific total parts

In heterogeneous critical specific multiple parts, the economic order quantity was assumed to be not necessarily similar as in the case of spare parts under homogeneous situation. The same assumption is extended to number of order and optimal order time of the spare parts. The equations formed from regression analyses were used for the development of programmable algorithm. These equations were further subjected to sensitivity test by varying scheduled maintenance time from 0.25 to 1 year and economic order quantity from 1, 2… to n, in steps.

V. RESULTS AND DISCUSSION

The results from ABC analysis of the caterpillar' components (Table 2, Fig.1) showed that crankshaft (named spare part 1) and complete set of tracks (named spare part 2) are found to exhibit class A spare parts called critical specific parts.



The results of the inventory cost for the class A, critical specific spare parts, when the developed models (Equations 1 to 3) were applied to it are shown in Tables 3 to 5. The details of the inventory cost analysis were showed in Appendix I. In Table 3, scheduled maintenance time varied from 0.25 years to 1 year and it was found that the annual inventory cost decreases from ₦5352363.96 to ₦2,919708.02 for the first Class A spare part (part 1); and ₦4,830917.87 to ₦2, 516778.52 for the second (spare part 2). Also, total cost decreases with increases in scheduled maintenance time. Table 3.4 displays the schedule maintenance period and optimum number of orders for critical specific parts. This follows the same trend as in the Table 3. The optimum number of order decreases with increases in scheduled maintenance time. When it is 0.25 years, the optimum number was 0.446 in (spare part 1) and it was 0.243 when scheduled maintenance period was 1 year. In the same vein, when scheduled maintenance time was 0.25 years, the optimum number of order was 0.402 and 0.209 when scheduled maintenance time was 1 year (spare part 2). Also in Table 5, the optimum period of supply in spare part 1 was 2.242 years when scheduled maintenance period was 0.25 years, and 4.115 years when scheduled maintenance time was 1 year. Similarly, it was 2.487 years with scheduled maintenance time of 0.25, and 4.784 with scheduled maintenance time of 1 year. The outcome models, when the results in Tables 3 - 5 were numerically analyzed, using statistical linear multiple regression method, from Statistical Package for Social Sciences (SPSS Version 15.0 for Windows ^{R}), presented in Equations 3.27 to 3.32 taking into consideration the homogeneity and heterogeneity behaviors of the spare parts. The coefficients of determination, R^2 obtained from the regression analysis under spare parts homogeneity and heterogeneity considerations were in the range of 0.9 and 1.0. These R^2 results showed that more than 70 % of that is happening in the spare parts inventory planning system can be represented by the numerical models. Therefore the use of numerical models were good enough for predicting the optimal cost of inventorying critical specific spare parts in the maintenance industry at a specified scheduled maintenance time, based on future economic order quantity, number of order, and time of order, under both homogenous and heterogeneous spare parts environment. This is an indication that spare part are more economically managed under the heterogeneous environment than the homogeneous platform.

VI. CONCLUSION

The work had provides quantitative expressions required in solving maintenance spare parts planning problems in the heterogeneous environment which has not been possible in homogeneous environment. The model was versatile in estimating the spare parts demand forecast for the next period by using the actual and previous demand. The coefficient of determination values obtained from the model showed that the numerical and the experimental values are highly correlated. It shows that the model derived predicted experimental results accurately; hence, indicated that the model is valid. The use of ABC analysis enables effective control of spare part inventory by providing the required valuable few items that can be economically stocked. The ABC analysis results showed that crankshaft and complete set of tracks exhibit critical specific parts. These critical specific parts are those parts that can only be provided by original equipment manufacturer (caterpillar manufacturer). The result showed that, economic order quantity increases with increase in scheduling maintenance period. Optimum number of order decreases with increases in scheduling maintenance period; and optimum period of supply increases with increase in scheduling maintenance period, as well. The main conclusion to be drawn from the findings is that it is profitable to schedule maintenance annually than lesser periods. Annual scheduling has brought in least cost of inventory of identified critical spare parts for both homogeneous and heterogeneous systems of spare parts planning. The finding generally shows that the cost of critical specific spare parts varies with schedule maintenance period and quantity of order, number of order, or ordering time for both homogeneous and heterogeneous planning, but the latter is more sensitive to change than the former.

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