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Research Article

# Development of a Strategy for Economic Classification of Spare Parts in Maintenance Based on Criticality

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**Abstract**

*The effective maintenance will minimize the chance of failure of spare parts and thereby maximize overall profit of operations, which is required for economic manufacturing. The study has strategically classified spare parts in related to the inventory cost(s) utilizing schedule maintenance period, economic order quantity, optimum period of supply and optimum number order. The model developed to forecast for spare parts requirement in the automobile maintenance industry has made use of simple exponential smoothing method. The reliability of critical parts and failure pattern were considered for the formulation of the generalized spare parts inventory model, under negative exponential distribution. The model was tested with data collected on D6c manual in a Maintenance Organization. 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. Besides, the study also shows that it is profitable to schedule maintenance annually than lesser periods.*

**Keywords:** *maintenance, failure, spare parts, criticality, inventory, strategy*

## 1. Introduction

The need for maintenance in automotive industry is indisputable. The spare parts used in most of the automotive will not survive over the required life of the system (due to degradation) without maintenance. Hence, the design and operation of a maintenance system must usually meet one of two objectives: (i) minimize the chance of failure where such failure would have undesirable consequences; and (ii) Mminimize overall cost or maximize overall profit of an operation (John, *et al*, 2005). Proper management of spare parts is very important for the successful execution of maintenance activities, especially in large organization. Also, information on spare parts availability, location, and transfer are needed in the factories. This encourages management of service network and provides inventory visibility (Alemam, *et al*, 2000),(Okah –Avae, 1996). During the past decades, research efforts have produced a vast amount of theories for modeling different inventory control situations. The most basic inventory theory and model such as economic order quantity (EOQ),ABC analysis, have been widely applied (Pradhan and Bhol, 2006), (Cyplik, *et al*, 2009). In practice, spare parts inventories are often managed by applying general inventory management principles (Janne, 2001). Many of these principles are deficient in the area of concideration of heterogeneous nature of spare parts in automotive maintenance industry. The demand for spare parts largely depends on the output of maintenance activities, and is typically based on meantime to failure (MTTF), and factors such as wrong operation or failure to perform a routine maintenance activity(Seraj, 2008), (Ferreira, 2007).

This unplanned maintenance situation may result in spare part demand which may require the maintenance of buffer inventory leads to demand with no assignable predictable causes, thereby imposing a need to maintain buffer inventory (Ingrid, *et al*, 2009), (Dunlop, 1990). The spare parts planning was viewed in two ways; spare parts demand planning, and spare parts replenishment planning (Dilay, *et al*, 2008). Spare parts demand planning means forecasting parts demanded by location, inventory stocking hierarchy, time based on historical consumption patterns, and condition monitoring which based on probabilistic model. Spare parts replenishment planning is the planning for replenishment based on ordering parameters like lead time, order lot size, forecasted consumption rate (schedule based, as in the case of

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routine periodic changes of items such as filters, seals and bearings; consumption based, as in the case of breakdown and preventive activities; equipment life cycle based; etc), substitution rules, safety stock requirements (statistical safety stock or rule based safety stock) and the possible sources of supply (Martand, 2007), (Eti and Emovon, 2005), (Taha, 1987).

## 2. Methodology

Methodology adopted in this study comprises model development and the validation of the model using data collected on caterpillar spare parts (Bulldozer D6c Manual) from a maintenance agency.

### *2.1 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 (Peter and Chris, 2003), (Aderoba, *et al*, 2009).

Mathematically,

$$\lambda^{d1}_{cg(t)} = \Sigma \frac{\{d^f_{t-1} + \alpha(d^a_{t-1} - d^f_{t-1})\}}{\Sigma(T_{t-1})} \quad (1)$$

Where: $\lambda$ = failure rate,

$d$ = demand pattern

$cg$ = critical general,

$d^f_{t-1}$ = previous forecast spare part demand

$d^a_{t-1}$ = previous actual spare parts demand,

$T_{t-1}$ = previous times of need of the part.

$\alpha$ = smoothing constant.

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

$$Q^{dn}_{cg/cs} = \sqrt{\frac{2P(t)^{dn}_{cg}\lambda^{dn}_{cg}C^{o}_{cg}}{C^{p}_{cg} I}}$$

Where;

$P(t)^{dn}_{cg}$ = Probability of failure at scheduled time t,

$cs$ = critical specific parts,

$\lambda_{cg}$= Failure rate of the critical general parts,

$C^o_{cg}$ = Ordering costs

$C^p_{cg}$ = Price per unit,

$I$ = Annual Inventory Investment

$\lambda^{dn}_{cs}$ = 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;

$$Y^{total} = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k \quad (2)$$

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

$b_0, b_1, ..., b_k$ = Coefficient of linear multiple regression relationship.

### *2.2 System Model Implementation*

#### *2.2.1 Data Collection and Analysis*

Thevalidation of the model was done using data collected on caterpillar spare parts (Bulldozer D6c Manual) from a maintenance agency. This data covered maintenance activities carried out on the equipment in the last four years. The parts of engines, electric unit, transmission, hydraulic system, and under carriage, of the machine 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 | | ₦ K | ₦ K |
| 1 | Crank shaft | 2 | 220,000.00 | 110,000.00 |
| 2 | Set of piston sleeve and seals | 1 | 192,000.00 | 192,000.00 |
| 3 | Set of piston (6 nos) | 6 | 12,200.00 | 92,000.00 |
| 4 | Set of piston and ring (6 nos) | 6 | 10,200.00 | 62,000.00 |
| 5 | Set of conrod bearing (6 nos) | 12 | 4,200.00 | 24,000.00 |
| 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 | 120,000.00 | 120,000.00 |
| 9 | Thrust washer | 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 | 220,000.00 | 220,000.00 |
| 15 | Set of nozzles (6 nos) | 24 | 10,000.00 | 240,000.00 |
| 16 | Radiator hoses | 2 | 15,000.00 | 30,000.00 |
| | | | Total | 1790,000.00 |
| | B. ELECTRIC UNIT | | ₦ K | ₦ K |
| 1 | Alternator | 2 | 60,000.00 | 120,000.00 |
| 2 | N/S 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 | 220,000.00 | 220,000.00 |
| 6 | Set of fan belt | 1 | 7,000.00 | 7,000.00 |
| 7 | Electrical servicing | 1 | 22,000.00 | 22,000.00 |
| | | | Total | 582,000.00 |
| | C. TRANSMISSION UNIT | | ₦ K | ₦ K |
| 1 | Transmission pump | 1 | 420,000.00 | 420,000.00 |
| 2 | Transmission filter | 8 | 4,200.00 | 30,000.00 |
| 3 | Magnetic filter | 8 | 4,200.00 | 30,000.00 |
| 4 | Set of hoses | 1 | 100,000.00 | 100,000.00 |
| 5 | Oil cooler | 1 | 140,000.00 | 140,000.00 |
| | | | Total | 720,000.00 |
| | D. HYDRAULIC UNIT | | ₦ K | ₦ K |
| 1 | Hydraulic pump | 1 | 420,000.00 | 420,000.00 |
| 2 | Set of arm seals | 2 | 35,000.00 | 6,000.00 |
| 3 | Set of blades | 1 | 120,000.00 | 120,000.00 |
| 4 | Cutting edge | 1 | 38,000.00 | 38,000.00 |
| 5 | Hydraulic filter | 8 | 12,000.00 | 96,000.00 |
| | | | Total | 740,000.00 |
| | E. UNDER CARRIAGE | | ₦ K | ₦ K |
| 1 | Complete set of tracks (2 nos) | 1 | 1,220,000.00 | 1,220,000.00 |
| 2 | Segment (10 nos) | 1 | 220,000.00 | 220,000.00 |
| 3 | Up rollers (4 nos) | 1 | 85,000.00 | 85,000.00 |
| 4 | Down rollers (10 nos) | 1 | 420,000.00 | 420,000.00 |
| 5 | Track adjuster nipple (2 nos) | 2 | 20,000.00 | 20,000.00 |
| 6 | Track adjuster seal (2 nos) | 2 | 85,000.00 | 85,000.00 |
| 7. | Body works | 1 | 40,000.00 | 40,000.00 |
| | | | Total | 2,220,000.00 |

ABC analysis which is based on paretor's law 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 Table1. 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 |

The class A critical specific part obtained where further analyzed using developed model (Equations 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 | 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 |

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

| Scheduling Period | Total cost (₦) | Total average cost (₦) | Optimum number of order | Optimum number of order | average optimum number of order |
|---|---|---|---|---|---|
| ¼ | 10183281.83 | 5091640.91 | 0.446 | 0.402 | 0.424 |
| ½ | 7361377.96 | 3680688.98 | 0.325 | 0.288 | 0.306 |
| ¾ | 6144966.70 | 3072483.35 | 0.273 | 0.239 | 0.256 |
| 1 | 5436486.54 | 2718243.27 | 0.243 | 0.209 | 0.226 |

## 3. 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.

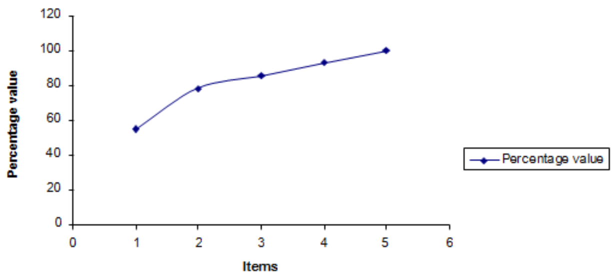


**Fig 1: Items and Percentage value**

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. 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 N5352363.96 to N2,919708.02 for the first Class A spare part (part 1); and N4,830917.87 to N2, 516778.52 for the second (spare part 2). Also, total cost decreases with increases in scheduled maintenance time. Table 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. 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.

## Conclusions

The study has classified spare parts in related to the inventory cost(s) utilizing schedule maintenance period, economic order quantity, optimum period of supply and optimum number order. 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 annual inventory cost decreases with increases in scheduling maintenance period. The least cost was found when scheduling maintenance on annual basis. Also, 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 finding also shows that it is profitable to schedule maintenance annually than lesser periods.

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