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A Robust Regression Approach for Excess/Shortage Spare Parts Cost Estimation

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Abstract: *Spare parts management has been an area of increasing interest to service engineers in the current decade due to its potentials of improving business performance in terms of profit improvement, downtime minimisation and improved service deliveries through direct and indirect means. The present investigation deals with the development of a predictive model for estimating the amounts of spare parts holding and the cost effects of poor spare parts holding in a system. The model effectively uses an integrated methodology of the penalty cost and the wear technique for the unconstrained optimisation of the excessive spares using big-bang big-crunch (BB-BC) algorithm and the data of a petroleum products off-loading service company from shipping vessels. The model is validated by comparing the results obtained using the in-sample analysis with an out-sample approach. The results obtained show that the proposed spare parts monitoring model has the potential of predicting with high accuracy when used for in-sample and out-sample predictions. The developed excess spare parts model predicts that spare parts exhibit non-linearity under interest and inflation considerations. It shows that it is infeasible to track spares under changes in monetary polices of a country and in evaluating the cost of excess/shortage of stockings of multi-items in spare parts inventories.*

Keywords: *Wear rate, maximum wear, robust regression, big-bang big-crunch, spare parts*

1. Introduction

Just-in-time (JIT) spare parts supplies describe an arrangement in which spares are requested shortly before the time of need. Supplies are met without delay by the suppliers. In developing countries such as Nigeria, there is great difficulty in meeting up with the challenges and requirements of JIT systems due to the limiting factors such as erratic electricity supply, traffic congestion and poor delivery networks that militate against efficient JIT delivery systems. Consequently, the JIT system does not work properly; spare parts must be requested several days before needs to avoid interruptions in production or service activities due to spare shortages. Excess spares are therefore kept. Consequently, stocks are difficult to manage without keeping excess for the future periods. There are often problems of supply shortages, which lead to loss of production or service since the required spares for repairs of broken-down machineries or equipment/facilities may not be available when needed by the production plant or service.

Therefore there is a general understanding that keeping excessive spare stocks would stabilize production or service activities. However, it is widely known that excess/shortage stock handling is a cost to the organisation, which indirectly reduces the organisation's profit margin and may significantly increase maintenance expenditure. Consequently, it reduces spendings in other vital aspects of maintenance activities. Pressure is usually exerted on maintenance management to hold minimum amounts of excess stocks from purchases. The intention to minimise excessive quantities held is to keep the cost implication of maintenance stock to the minimum.

In this paper, the development of an analytical framework to evaluate excessive stocks kept by the organisation is pursued. The model's application will lead to the reduction in maintenance cost since approximate amounts of spare parts needed could be estimated with minimal errors. It reduces the amount of money spent on spare parts. This model will help in reducing the amount of money paid as interest since less amounts of spare parts will be tied down in inventory (spares). Also, in organisations that have loose controls, where pilferages and obsolescence of stored spares are common, the model will help in the proper tracking of spare parts as approximate amounts will be planned for. This will reduce or eliminate unaccounted cost in production/manufacturing as well as service costs. Given these motivations for the current work, the main objective of the current paper was to develop a mathematical model that addresses the gap of paucity of mathematical models and/or quantitative measures for estimating the cost of poor spare part stockings.

The structure of the paper is organised as follows:

Section two presents the literature review, and Section three describes the research methodology. A numerical example and discussion of results are contained in Section four. Section five presents the conclusions of this study.

2. Literature Review

In trying to manage spare part problems, different authors have presented a wide variety of spare part models that are problem-dependent. One technique, which has dominated spare parts literature is the use of optimisation models. Krenenbury and van Houtum (2009) developed an optimisation model that minimises multi-item, single-stage spare parts provisioning costs by considering the effects of commonality of spare parts. This was achieved using Dantzig-Wolfe decomposition, which aids the work in obtaining lower and upper bounds and heuristic solution for optimal costs.

In another contribution, Monte Carlo simulation was utilised by Lanza *et al*. (2009) to develop a stochastic optimisation algorithm that minimises the long-term cost of preventive maintenance for machine tools. The objective was achieved by solving the problem of fatigue failure of spare parts resulting from varying loads. Similarly, combined probabilistic simulation and genetic algorithm were utilised by Marseguerra *et al*. (2005) to develop a multi-objective Pareto optimisation model that maximises system revenue while minimising total spare parts volume. The use of probabilistic simulation aids the study in modelling system failure, repair and replacement while genetic algorithm was used as a solution method in solving the multi-objective problem.

Krenenbury and van Houtum (2009), Lanza *et al*. (2009) and Marseguerra *et al*. (2005) have all addressed critical issues on spare parts management. The question of how to evaluate the cost of excessive spare parts at various operational times in an inventory system was not adequately addressed in their studies. Solving this problem will help in tracking the frequency of disbursing funds for spare parts acquisition, thus, leading to proper management of organisational resources. This problem is considered in the current study. Also, a multi-objective model for machine and equipment that are repaired only by exchanging bad parts with good ones was proposed by Nosohi *et al*. (2011). In their work, a non-dominated solution was obtained for the model that minimised purchasing cost of spare parts, cost of preventive maintenance and production, residual lifetime of spare parts and corrective failure using minmax and e-constraint method.

From critique perspective, the issue of cost management of spare parts inventory as it affects business operations, using various optimisation concepts, was not addressed by Nosohi *et al*. (2011). The interest of business managers is what will be the monetary value for implementing a plan (i.e. how much will the company save on the long run?). An evaluation of long-run savings requires the use of simulation models that has the capacity of evaluating various instances of stock control impacts on business profits. Stock control with emphasis on excessive stocks at various times was not directly investigated in the aforementioned studies, which opens the way for investigation on excessive spare parts control. Thus, the current paper examines how much stock will be left out at the various instances in an inventory system.

Furthermore, Kumar and Knezevic (1997) and Wang (2012) have also proposed the use of optimisation technique in solving spare parts-related problem. In the work of Kumar and Knezevic (1997), the problem of maximising availability and spares requirements was solved using Excel solver and branch-and-bound procedure. They considered series-parallel structures for spare part management. However, incorporating excessive stock value in planning was not considered in the studies by Kumar and Knezevic (1997), although this would have made it more robust.

Wang (2012) presented an optimisation algorithm for solving spare parts inventory and preventive maintenance problem jointly. Optimal order quantities of spare parts and preventive maintenance intervals were determined using enumerative and stochastic dynamic programming algorithms. The use of stochastic dynamic programming algorithm aided modelling of the expected costs. Jilka *et al*. (2011) analyse logistic network optimisation problem for aircraft spare parts using prognostic health management concepts while Regaltieri *et al*. (2005) investigated the accuracy of twenty different forecasting techniques on lumpy demand for aircraft spare parts. They report that weighted moving averages, the Croston method and exponential weighted moving average models are the best for forecasting this kind of demand. Since spare parts failure rate is usually stochastic, maximising their availability may result in excessive stocking at an acceptable level. The estimation of such excess stocks needs to be considered in order to properly utilise business resources.

Several authors who apply similar and other approaches in solving this problem include the following. Lau *et al*. (2006) develop a mathematical model of multi-echelon systems for carrying out corrective maintenance under passivation. The model estimates time-varying expected back-order and operational availability correctly. When compared with the results from Monte Carlo simulation, the same outcome was obtained. Cobbaert and Van Oudheusden (1996) extend economic order quantity (EOQ) inventory model by considering the variation and constant obsolescence of spare parts under conditions where storages are allowed or not. This was achieved using probability concepts for both cost and risk that are associated with spare parts obsolescence. van Jaarsveld and Dekker (2011) develop an optimisation algorithm that minimises shortages using reliability-centered maintenance data. The model has the tendency of enhancing stocking decisions. Avoiding shortage of spare parts is one phase to spare parts stocking problem. The other phase which involves excessive stocking cost estimation was not addressed in their work.

de Smidt-Destrombes *et al*. (2006) estimate the expected values for maintenance time, operational time and lead time update for maintenance in developing two models that analyse the relation among spare parts inventory levels, repair capacity, maintenance policy and system availability for a *k*-out-of-*N* system. In order to demonstrate the superiority of partial pooling of spare parts over total pooling of spare parts, a multi-item, multi-location, single-echelon inventory system with lateral transshipment was developed. Kalchischmidt *et al*. (2003) present a framework for managing supply chains with different numbers of echelons, multi-model and extremely variable demand. They observe that improvements in supply chain performance can be achieved through proper collation of purchasing plans information. Haffer (1995) models the economic order quantity, economic order point, lag period and variations in monthly demand resulting from seasonal agriculture operations in order to aid the management of spare parts inventories of agriculture machineries dealership. The model was converted into software to ease usage.

Dohi *et al*. (1995) present two mathematical models for dealing with stochastic lead time and expected ordering options for spares inventory. The work analysed optimal ordering policy that minimises long-run average cost. Ghobbar and Friend (2003) develop a forecasting model for dealing with random nature of aircraft maintenance repair parts demand. The model enhanced the selection of appropriate forecasting method for critical demand of spare parts. The problem of reorder point for spare parts inventory was solved by Chang *et al*. (2005) while Chang and Tsao (2010) work on the determination of the quantities of spare parts for rolling components using analytical network process (ANP) in determining the ratio of preventive to corrective maintenance. We focus the current work on excessive spare parts stocking cost which the above studies lack. Another difference between these studies and the current paper is that we provide a structure that can be used in simulating spare parts usage with spreadsheets while others did not provide relevant information in this direction.

Peres and Noyes (2006) investigate the use of maintenance support system for on-the-spot-demand and manufacturing. Kargari *et al*. (2012) consider Euclidean distance function, order concurrency and lot size in developing three different clustering algorithms for automobile spare parts. The work of Ke and Wang (2007) applies direct search algorithm in minimising total cost function for two kinds of spare parts.

From the reviews, no documented work was found on modelling the cost of excessive stocking of spare parts. As the overwhelming importance of understanding this aspect of research has been stated from the results of the above review, there is an urgent need to investigate the quantitative implications of keeping excessive stocks. This is particularly important in environments where business turbulence has led to closure of factories while many more are on the verge of collapse. The case in the manufacturing sector of the Nigerian economy is an example, which demands urgent attention to this gap. This work is motivated by the need to bridge this knowledge gap in order to save the failing industries from collapse and enrich the spare parts literature. The current paper considers wear rate of machine parts in proposing a mathematical model for determining level of spare parts in an inventory system and none of the previous studies has considered this approach. The introduction of this approach serves as a contribution to spare parts inventory literature.

3. Research Methodology

In this section, brief explanations of the assumptions used in facilitating the development of the proposed predictive model and the various mathematical expressions used in modelling cost of poor spare parts management are presented.

3.1 Model Assumptions

The assumptions used in the development of the proposed model are as follows:

1) The factory (system) has enough space to stock excess spare parts. This creates the opportunity for purchasing excess spares when there is a known reduction in the unit cost of spares. This helps in reducing the production cost. However, associated with this benefit is the problem of what level of excess spares should be allowed in a system? The proposed model provides insights on how to manage this problem.
2) The problem of spare parts obsolescence is insignificant. By considering this assumption, the problem of excess stocking of spares may exist in an organisation.
3) Production time or usage of equipment can stretch beyond the timeframe specified for them. This implies that the total volume of spares wear-out at the end of a planning period may vary from the expected to another value.
4) Spare parts are believed to have the same initial level of wear before usage. This assumption is applicable to spares which can be reconditioned.

3.2 Model Development

From Figure 1, the area of the rectangle ABCD gives the total cost of excess stocks of spare parts. By using accounting and maintenance records, the values of spare parts ordering cost (P_1), holding cost (P_2) and purchasing cost (P_3) are used to determine the expected excess spare parts (E_s) for a system. Traditionally, it is difficult to estimate due to its stochastic nature. However, to obtain the value of EN_s, mathematical model may be required. This study proposes a mathematical model for computing EN_s in manufacturing industries. To know the amount of excess spare parts for machinery and equipment that undergo wear and tear, the volume of wear and tear in a unit period need to be estimated. Equation 1 gives the derivation for the amount of wear per hour (m^3/h). This equation was obtained using dimensional analysis.

$$Dw = \frac{T}{Ht} \quad \text{…. Eq.1}$$

where T is Torque of an equipment (Nm), H is hardness of material that undergoes wear (N/m^2) and t is the observation time (h).

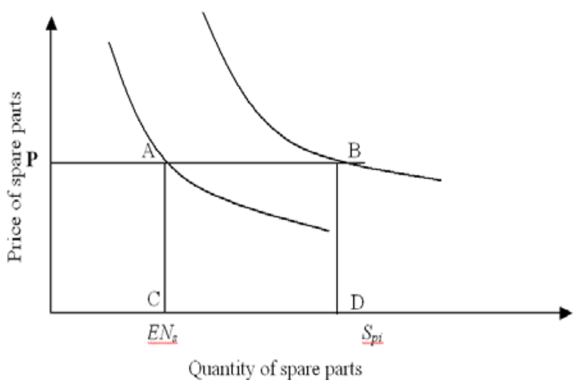

Figure 1. Evaluating excess stocks of spare parts

With the knowledge of Equation 1, the amount of spare parts that will be required at different production or service periods can be estimated. The excess wear computations could be made using the maximum allowable wear (W_{max}), the number of time corrective maintenance is carried out, testing time for restored equipment, the service time for unit output or the production time unit output as well as the estimated annual demand for organisation service. Since the unit time required by a team to produce a batch of product or render service to prospective customer varies from one team to another, to estimate the total time that the equipment is put into use, the total productive and unproductive times could be estimated using a stochastic expression.

Equation 2 is used in estimating the expected productive time for equipment. In this study, we present Equation 3 as a means for estimating the expected unproductive time of equipment (U_t) using the average number of times that corrective maintenance is carried out in a month (η) and the average time required to test and restore equipment back to service state during corrective maintenance (w). Thus, the total time that the equipment (A_t) is used in a particular period can be represented as Equation 4.

$$P_t = \delta \int_{-\infty}^{\infty} \mu f(x)dx \quad \text{….. Eq.2}$$

$$U_t = \eta \int_{-\infty}^{\infty} wf(v)dv \quad \text{….. Eq.3}$$

$$A_t = U_t + P_t \quad \text{….. Eq.4}$$

where, δ is the periodic demand for a service, $f(x)$ is the probability density function of time that a machine is used for productivity tasks and $f(v)$ is the probability density function of time a machine is run during maintenance activities.

By combining Equations 1 and 4, the total volume of materials (V_i) that will wear and tear if the operating conditions (wear coefficient, contact area) are constant and the materials used for the spare manufacture is the same, is given as Equation 5.

$$V_i = D_w A_t \quad \text{….. Eq.5}$$

Using the maximum wear (w_{max}) allowable (i.e. the extent to which a part will wear up before it will be changed), the number of spare parts (N_i) that will be required in a given period can be represented as Equation 6.

$$N_i = \frac{V_t}{w_{\max}} \quad \text{….. Eq.6}$$

The problem of spare part sometimes involves wastages during replacement of parts in maintenance system. To address this loss in the proposed model, we consider fixed quantity spare parts loss (Ψ) as a proportion of the quantity be required in a particular period. Thus, Equation 7 is a modified version of Equation 6 that considers what-if condition when dealing with spare parts losses in a maintenance system.

$$N_i = \begin{cases} (1+\Psi)\dfrac{V_t}{w_{\max}} & \text{If loss is considered,} \\ \dfrac{V_t}{w_{\max}} & \text{Otherwise} \end{cases} \quad \text{….. Eq.7}$$

At the beginning of an operation year, the amount of spare parts in a system (S_i) may be expressed as Equation 8. For other periods, the amount of inventory in a system will be based on the decision on whether or not to order for spare parts and what quantity of spare parts in a system currently exists. This decision is often based on the reordering point (RP) for inventory in a particular system. The mathematical expression for this decision is presented as Equation 9.

$$S_i = B_i / \phi_i \quad \text{….. Eq.8}$$

$$S_i = \begin{cases} Q & \text{if } S_i > RP \\ Q + \dfrac{B_i}{\phi_i} & \text{Otherwise, } S_i < RP \end{cases} \quad \text{….. Eq.9}$$

where, B_i is the amount budgeted for a particular spare part, Q is the quantity of inventory in a system before reordering and ϕ_i is the forecast unit cost price for spare part *i*.

The three costs associated with inventory management are ordering cost (P_{1i}), holding cost (P_{2i}) and purchasing cost (P_{3i}). These costs are used in evaluating the cost of excess stocking of spare parts in an organisation. A linear interrelation is assumed among these costs, and this relationship is represented as Equation 10. The computation of quantities of excess spare parts (E_i) *i* in a system, which is a function of the differences between S_i and N_i is given as Equation 11. The cost of stocking excess spare parts for a single item in a system is presented as Equation 12.

$$P_{it} = P_{1i} + P_{2i} + P_{3i} \qquad \text{….. Eq.10}$$

The penalty cost (PC_{it}) and the unit cost of keeping excess spare parts in a system can be used to jointly analyse the spare parts management of a system. This thought is presented as Equation 12.

$$E_{it} = S_{it} - N_{it} \qquad \text{….. Eq.11}$$

$$CSP_{it} = \begin{cases} P_{it}\ E_{it} & \text{If excess spares parts exist in period } t \\ PC_{it} E_{it} & \text{Otherwise, shortage in spares parts exist in period } t \end{cases} \qquad \text{….. Eq.12}$$

By considering the amount of money paid as interests for loans used in acquiring and keeping excess spare parts, this study modifies Equation 10 to incorporate the prevalent interest rate (τ) and the inflation rate (*f*). According to Ardalan (2000), the interrelationship among τ, *f* and *i* is given as Equation 13. By the combination of Equations 12 and 13, the actual cost for stocking excess spare parts (CE_i) in a single item is obtained as Equation 14.

$$i = \frac{\tau - f}{1 - f} \qquad \text{….. Eq.13}$$

$$CSP_{it} = \begin{cases} P_{it}\ E_{it}\left(\dfrac{1+\tau-2f}{1-f}\right) & \text{If excess spares exist in period } t \\ PC_{it} E_{it} & \text{Otherwise, shortages in spare parts exist in period } t. \end{cases} \qquad \text{….. Eq.14}$$

With Equation 14, the cost of excess spare parts for multiple spares in a system can be estimated. We considered Equation 15 in evaluating the cost of excessive multiple spare parts for a system. The cost for poor spare part management, which incorporates excess spare parts and penalty costs for spare parts shortages is given as Equation 16.

$$MCE_S = \sum_{i=1}^{N}\sum_{t=1}^{T} P_{it} E_{it}\left(\frac{1+\tau-2f}{1-f}\right) \qquad \text{….. Eq.15}$$

$$CSP = \sum_{i=1}^{N}\sum_{t=1}^{T} CSP_{it} \qquad \text{….. Eq.16}$$

The inclusion of *τ* and *f* into Equation 14 introduces non-linearity into this equation. This non-linearity becomes more obvious in a system where spare parts are obtained from different environments. The changes in the monetary policies of a country may result in a drastic rise or fall in the cost of excess spare parts obtained from overseas. Thus, it may be deduced that spare parts cost may exhibit non-linearity tendency under interest and inflation considerations. With significant variations in the amounts of spare parts used in a particular period, there may be the tendency for the cost of excess spares to follow as a fluctuating trend. To the control the number of spare parts that will be changed, there is the need to optimise the level to which a part must wear before being changed during maintenance activities. This problem motivates the optimisation of w_{max} using the Equation 17. This equation is considered as an unconstrained optimisation model, where bounds will be set for the various w_{max} in this equation. We select the big-bang big-crunch (BB-BC) algorithm as a solution method in this study due to its low computational time and high quality solution abilities. Since the value for V_i will vary from one period to another, the current study sets the bound for V_i in order to obtain realistic values for w_{max}.

$$\text{Min Z} = \sum_{i=1}^{n} P_i\left(\frac{(1+\tau-2f)(w_{\max}B_i - V_i\phi_i)}{(1-f)(w_{\max}\phi_i)}\right) \qquad \text{….. Eq.17}$$

BB-BC algorithm is a meta-heuristic which employs the principle of population-based stochastic search in obtaining optimal values for decision variables based on assigned solution space assigned to decision variables in a combinatorial problem. This is achieved by computing the center-of-mass for each decision variable (big-bang) and updating the value of decision variables (big-crunch). From the BB-BC literature (Rao and Yesuratnam, 2012; Sakthivel *et al*. 2013), the centre-of-mass for a decision variable can be estimated as Equation 18 or simply taken as the global solution.

$$w_{jg}^{c} = \frac{\sum_{i=1}^{P} w_{ij(g-1)} / f_{i(g-1)}}{\sum_{i=1}^{P} 1/f_{i(g-1)}} \qquad \text{….. Eq.18}$$

To generate a new particle using centre-of-mass of decision variables in BB-BC algorithm, the current study utilises Sakthivel *et al*.'s (2013) approach using Equation 19.

$$w_{jg+1} = w_{jg}^{c} + \frac{r\alpha(w_j^{\max} - w_j^{\min})}{g} \qquad \text{….. Eq.19}$$

where, *g* is known as step size, *r* is a normal distribution which lies between -1 and 1, and α is a parameter used to control the search space of decision variables.

After generating the cost of poor spare parts management in a system for different planning periods, the information obtained is used in developing a predictive model that can be easily applied by decision makers in a system. The proposed predictive model is controlled mainly by the amount of spare parts in a system as a dependent variable and the expected volume of wear of a spare part during a planning period as an independent variable. This study then applies robust regression models using STAT software.

The flowchart for the proposed predictive model used in this study is presented as Figure 2, while a summarised implementation procedure for the model is presented as follows:

Step 0: Determine the optimal value of wear that spare parts will experience before being repaired or replaced using the BB-BC algorithm.

Step 1: Determine the number of working hours per day, the number of working days per year and the total overtime periods in a production/ service year.

Step 2: Determine the initial wear of spare parts, the maximum wear allowable and the wear rate per day of spare parts.

Step 3: Determine the quantity of spare parts stocked at the start of a production/service period and unit cost of spares.

Step 4: Determine the quantities the spare parts used in a production/service period.

Step 5: Determine the quantities of excess spare parts, if none, go to step 6.

Step 6: Determine the cost of excess spare part. Repeat steps 2 to 6 for multi-item spare parts.

Step 7: Sum the cost of poor spare parts management in the system.

Step 8: Develop a predictive model using the cost obtained in step 1 as dependent variables, spare parts level and the amount of wear as independent variables.

Step 9: Validate the developed predictive model using out-of-sample approach.

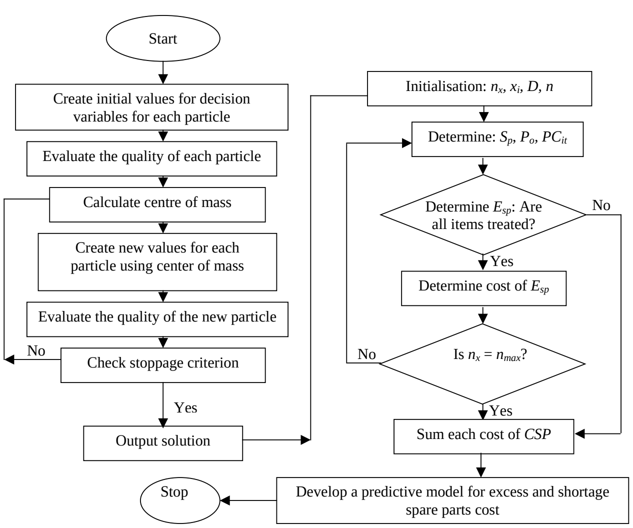

Figure 2: Flowchart computing cost of excess spare parts

4. Numerical Example and Discussion of Results

To validate the proposed model in this study, a case study of a haulage company spare parts inventory system is considered. This study focuses on marine unloading arm of mechanical and hydraulic spare parts. The company studied unloads vessels from ships that arrive from other locations. The unloading arm is engaged during this operation and the mechanism of operation of this unloading arm is electrically-, mechanically-, and hydraulically controlled. From our observations, the most frequently used spare parts for marine unloading arm are mechanical and hydraulic spare parts majorly D1¼" balls and V-seal VA-0040, respectively. The part numbers for these spare parts are 70V400080534 and 246153040894 for D1 ¼" balls and V-seal VA- 0040, respectively. Due to the difficulty in obtaining the ordering costs and holding costs for the two spare parts, these costs were taken as 5% of the unit cost for each of the items based on one of the authors' industrial experiences. At the time of conducting this study, one United States dollar is approximately ₦165. We compliment the practical datasets obtained with laboratory simulation. This aids the applicability of the proposed model.

The determination of the range for wear volume for the two spare parts considered are 0.01 to 0.04 and 0.01 to 0.03 mm^3 for D1¼" balls and V-seal VA-0040, respectively. The total wear volume expected at the end of a planning period for D1¼" balls and V-seal VA-0040 are taken as 6 and 0.5 mm^3, respectively. Using the maximum epoch of (100) as the stoppage criterion for the BB-BC algorithm, the optimisation of Equation 16 gives the results of the optimal wear volume for D1¼" balls and V-seal VA-0040 as 0.046 and 0.034 mm^3, respectively.

With the knowledge of the optimal total wear volume for D1¼" balls and V-seal VA-0040 spare parts and the amount of wear that a spare part could experience before it is replaced, the amount of spare parts to order for D1¼" balls and V-seal VA-0040, based on Equation 6 are 118 and 20 units, respectively. From the above discussion, the proposed model has the potential for determining the minimum amount of spare parts inventory for a system given that actual parameter values in Equation 16 are available to decision makers.

Since the amount of service rendered to prospective clients in a shipping business does not always follow a linear distribution, the current study simulates the amount of total wear to expect at the end of each planning period (month) using Monte Carlo simulation. The application of classical inventory models like economic order quantity model can be used to determine the reorder point for each spare part in a system. The information used in estimating the cost of excess/shortage in spare parts for the case study is presented in Table 1.

Table 1. Spare parts information

	D1¼" balls	V-seal VA-0040
Unit cost	₦1694.92	₦450
Unit excess spare cost	₦1844.92	₦4650
Unit shortage cost	₦1800	₦4600
Inflation	11 %	11 %
Interest rate	16 %	16 %
Re-order point	60	7

This information is combined with the results obtained in the previous paragraphs in this section. The cost of excess/shortage in spare parts for the mechanical spares (i.e. D1¼" balls) is first considered. The results for the cost of excess/shortage in D1¼" balls spare part when simulated are presented in Table 2.

A negative value for the cost of excess/shortage in spares for the system as shown in Table 3, implies that the system is experiencing shortages in spare parts during that particular period while a positive value for the cost of excess/shortage in spare for a system indicates excess spare parts in the system.

Table 2. Simulation results for D1¼" balls spare parts

Period	Budget (₦)	Quantity purchase	Quantity in the system	Wear (mm^3)	Quantity used	Spare part in the system	Excess/shortage cost (₦)
1	200000	118	118	1.22	26	92	169732.20
2	0	0	92	5.01	109	-109	-196200.00
3	200000	118	9	2.09	45	73	134678.81
4	0	0	73	2.32	50	-50	-90000.00
5	200000	118	68	5.61	122	-4	-7200.00
6	200000	118	114	3.64	79	39	71951.69
7	200000	118	157	5.16	112	6	11069.49
8	200000	118	124	2.97	64	54	99625.42
9	200000	118	172	4.56	99	19	35053.39
10	200000	118	137	4.31	94	24	43200.00
11	200000	118	142	1.36	30	88	162352.54
12	0	0	88	1.26	27	-27	-48600.00
13	200000	118	91	4.9	106	12	22138.98
14	200000	118	130	2.73	59	59	106200.00
15	200000	118	177	3.57	78	40	73796.61
16	200000	118	158	2.92	63	55	101470.34
17	200000	118	173	1.39	30	88	162352.54
18	0	0	88	1.86	40	-40	-72000.00
19	200000	118	78	2.51	55	63	116229.66
20	0	0	63	2.53	55	-55	-99000.00
21	200000	118	63	1.26	27	91	167887.29
22	0	0	91	2.04	44	-44	-79200.00
23	200000	118	74	2.02	44	74	136523.73
24	0	0	74	1.61	35	-35	-63000.00

Table 3. Simulation results for V-seal VA-0040 spare parts

Period	Budget (₦)	Quantity purchase	Quantity in the system	Wear (mm^3)	Quantity used	Spare part in the system	Excess/shortage cost (₦)
1	90000	20	20	0.08	2	18	83700.00
2	0	0	18	0.19	6	12	55800.00
3	0	0	12	0.47	14	-2	-9200.00
4	90000	20	18	0.42	12	6	27900.00
5	90000	20	26	0.52	15	11	50600.00
6	0	0	11	0.32	9	1	4600.00
7	90000	20	21	0.20	6	15	69750.00
8	0	0	15	0.26	8	8	37200.00
9	0	0	8	0.26	8	0	0.00
10	90000	20	20	0.26	8	13	59800.00
11	0	0	13	0.24	7	6	27900.00
12	90000	20	26	0.45	13	12	55800.00
13	0	0	12	0.43	13	0	0.00
14	90000	20	20	0.09	3	17	78200.00
15	0	0	17	0.07	2	15	69750.00
16	0	0	15	0.24	7	8	37200.00
17	0	0	8	0.06	2	6	27900.00
18	90000	20	26	0.53	16	10	46500.00
19	0	0	10	0.13	4	6	27900.00
20	90000	20	26	0.38	11	15	69750.00
21	0	0	15	0.43	13	3	13950.00
22	90000	20	23	0.22	7	16	74400.00
23	0	0	16	0.30	9	7	32550.00
24	0	0	7	0.19	6	2	9300.00

To evaluate the performance of the proposed model for hydraulic system spare parts, which undergoes wear, V-seal VA-0040 spare parts information is used and the results obtained is depicted in Table 4. The ability of the proposed model to detect when shortages in spare parts occur has also been verified from the results in Table 4. Thus, it can be inferred that the proposed model has the capacity to be used as a simulation model when studying spare parts management for both mechanical and hydraulic spare parts.

The applicability of robust regression model in modelling the cost of excess/shortage in spare part for marine unloading arm is carried out. The robust regression model used is implemented using STATA /STA 11.0 software. The quantity of spare parts in the system, the amount of wear at the end of a planning period and the volume of spare parts at the planning period are taken as explanatory variables in determining the cost of excess/shortage in spare part for the system. Table 4 shows the results for in-sample datasets for the first 18 periods.

In order to validate the performance of the robust regression model, information in Tables 2 and 3 (periods 19 to 24) was used in carrying an out-sample datasets validation of the robust regression model. The results obtained are presented in Table 5.

Table 4. In-sample comparison of robust regression model results with simulated results

Periods (Month)	D1¼" balls		V-seal VA-0040	
	Actual value	Forecasted value	Actual value	Forecasted value
1	169732	169732	83700	83700
2	-196200	-199299	55800	55800
3	134679	134679	-9200	-9300
4	-90000	-90449	27900	27900
5	-7200	-7379.7	50600	51150
6	71951.7	71951.7	4600	4650
7	11069.5	11069.5	69750	69750
8	99625.4	99625.4	37200	37200
9	35053.4	35053.4	0	1.14E-10
10	43200	44278	59800	60450
11	162353	162353	27900	27900
12	-48600	-48016	55800	55800
13	22139	22139	0	-2.15E-10
14	106200	108850	78200	79050
15	73796.6	73796.6	69750	69750
16	101470	101470	37200	37200
17	162353	162353	27900	27900
18	-72000	-72000	46500	46500

Table 5. Out-sample comparison of robust regression model results with simulated results

Periods (Month)	D1¼" balls		V-seal VA-0040	
	Actual value	Forecasted value	Actual value	Forecasted value
1	116229.7	116224.4	27900	27900
2	-99000	-99673.7	69750	69750
3	167887.3	167887.3	13950	13950
4	-79200	-79379.7	74400	74400
5	136523.7	136523.7	32550	32550
6	-63000	-62775.4	9300	9300

The prediction results for D1¼" balls spare part show that the robust regression model has the capacity to predict the cost of spare part shortages as indicated with the negative costs in Table 5. The mean absolute percentage error (MAPE) of the robust model when used for predicting in-sample datasets for D1¼" balls and V-seal VA-0040 are 0.6 and 0.06 %, respectively. These results show that the robust regression model has high predictive accuracy. To further test the suitability of the robust regression model, the MAPE for out-sample dataset obtained for D1¼" balls prediction is 0.21 % while it is 0 % for V-seal VA-0040, respectively. Thus, it can be deduced that robust regression model is well suited as a predictive tool for the case study under concurrent occurrence of excesses and shortages in spare parts in a system. The application of this predictive model will reduce the burden of service engineers in evaluating the different equations in order to obtain excess/surplus spare part cost.

4. Conclusions

In this study, a mathematical model that can be used in estimating the cost of excess/shortage of spare parts, the level of spare parts in a system and the quantities of spare part to order has been successfully developed. Also, a predictive model for the cost of poor spare parts management was presented. The quest to determine the optimal level of spare parts wear before it can be changed was successfully carried out using the proposed model as an unconstrained optimisation model. This affords the opportunity to experiment the potentials of BB-BC algorithm as a solution technique for the unconstrained model and satisfactory results was obtained. A combined real and laboratory simulated datasets are used in evaluating the performance of the model and we observed that the proposed model is effective and efficient in estimating the cost, number of excess stocking of spares. We conclude that the proposed model can be used in evaluating the cost of excess/shortage of stockings of multi-items in spare parts inventories.

The proposed model can be used as a simulation tool in observing variations in spares usage for production/service that are either repairable or changed once failures occur. This work deepens our understanding of the negative and positive influences of excessive stock in the economy of organisations. Thus, excess/shortage costs could retard the economic progress of organisation by causing more charges on usage. From the review of literature, the cost of excess spare parts using conventional algorithm and computational intelligence does not exist. Thus, future research can be conducted on these since spares are used in maintenance activities, joint optimisation of maintenance activities and spare usage can be modelled in future investigations.

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