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Managing Spare Parts Inventory by Incorporating Holding Costs and Storage Constraints

Babatunde Omoniyi Odedairo
Senior Lecturer, Department of Industrial and Production Engineering, University of Ibadan, Ibadan, OYO. Nigeria. E-mail: bo.odedairo@ui.edu.ng

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Abstract: A key factor for motivating intending buyers of raw materials is vendor responsiveness. Therefore, to meet demand, a pre-approved level of stocks is often maintained. In contrast, the decision to keep an uncontrolled amount of stock could be counter-productive with cost components associated with holding often ignored unintentionally. In this study, the objective is to develop a spare parts inventory model that incorporates ignored holding costs with a storage constraint for a motorcycle assembly plant (MAP). The inventory policy, structure of holding costs, and spare parts sales reports were consulted for relevant data. The spare parts were categorized and selected using ABC analysis. A spare parts inventory model, which considers ignored holding cost, was formulated. The model was executed using Lingo optimisation software release 18.0.56 to determine the pair of the order quantity (Q) and reorder point (R). 177 spare part items were identified using ABC analysis. The parts categorisation revealed that 21, 31, 125 part items belong to categories A, B, and C with 81, 15 and 4% of annual sales value, respectively. From category A, nine items contributed significantly to overall sales. The demand pattern for these items was probabilistic based on their coefficient of variation. The pair (Q, R) for items N, Z, AY, K, AM, J, P, AL and AZ are (174,688), (71,147), (78,150), (86,163), (18,15), (88,170), (128,118), (33,43) and (87,152), respectively. These pairs yielded a total inventory cost of ₦2,177,363 when compared to the current total inventory investment of ₦6,800,000 resulting in a 67.9% cost reduction. A model to manage spare parts inventory with relevant holding cost components was developed for MAP to ensure the availability of items, maximize usage of storage space, and minimize total inventory cost.

Keywords: Inventory management, unknown holding cost, demand pattern, storage constraint.

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1. Introduction

In the design of an inventory system, relevant cost components include the item, ordering, holding, and shortage costs. Empirical experiences from literature indicated that the process of determining set-up and holding cost (HC) is complicated (Vidal-Carreras et al., 2016). This could be attributed to the complexities associated with inventory management in different industrial systems (Miller, 2001). HC is a variable cost and a necessary parameter in inventory management. The cost is also known as carrying cost which represents all costs associated with the safekeeping of inventories until it is either used or sold.

Azzi et al. (2014) concluded that whenever items are held in stock, it is difficult to explicitly determine total holding cost (THC) because some cost components are ignored unknowingly (or assumed irrelevant). Other reasons could be ease of approximation based on different rules of thumb and the decision to consider components peculiar to present conditions only.

In the determination of THC, Odedairo et al. (2020) compared twenty-seven (27) cost components identified by Foster (1964) with those suggested by 10 other authors. From the comparison, these components can be grouped under the following: capital cost, storage space, handling equipment, inventory risk, and inventory service. Also, the study identified the type of industry, product offerings, and scale of operations as some of the factors to consider in the determination of THC. For example, unnecessary inventory costs could be incurred when fast-moving items run out of stock while slow-moving items occupy available storage space. This could lead to events, which can disrupt existing decisions regarding after-sales services, warranty agreements, etc.

To forestall disruption and achieve the desired customer service level in manufacturing/service organisation, a pre-defined level of inventory is often maintained despite several limitations (Adeyeye et al., 2016; Etale and Bingilar, 2016; Vidal-Carreras et al., 2016). However, a contrary decision to hold an uncontrolled amount of stock over an extended period against constraints such as storage space, budget, and limits on physical resources could be counter-productive. Although, it is not necessary to hold all categories of inventory; Waters (2003) identified consumables, repair, service, and spare part items as additional material types required to support the production and service system. Spare parts inventories are required for repair and maintenance of equipment, automotive and industrial machines, and if available in the right quantities can increase product sales, enhance goodwill and foster customer satisfaction.

In spare parts management, major challenges include (i) intermittent and lumpy demand patterns (ii) storage constraint (iii) approximation on cost components and (iv) peculiarity of each item, which can influence order quantities and reorder instructions. Several organisations acknowledged these limitations and often seek for assistance to avoid low service levels and high cost of spare parts inventories (Mikalsen, 2015). In the case of a Motorcycle Assembly Plant (MAP), MAP is a newly established manufacturing company involved in sales of new motorcycles (MC), servicing, and sales of spare parts. MAP has two MC models currently being assembled. These are MC-YCR110 and MC-YFX110. For the latter, West Africa is the major market, while the former has its market within the country. The challenge is how to accurately determine and incorporate the appropriate components of unknown (or ignored) holding cost parameters within storage constraints.

Although, Vidal-Carreras et al. (2016) developed a practical approach to manage inventory with unknown holding costs, and budget constraints based on the economic production quantity model. However, the measurement of the costs is not defined in their study. Based on this reality, in this research, the objective is to develop a spare parts inventory model that incorporates ignored holding costs obtained from the value (or percentage) of annual holding costs with a storage constraint for a newly established MAP.

1.1. Measurement of Holding Cost

Azzi et al. (2014) commented that the choice of selecting a method to determine inventory holding cost would be influenced by expert opinions/academics, existing warehousing systems, and future goals of the organisation. On manual warehousing structure, the authors believe that most holding cost components are ignored because they are hidden in other costs.

In this research work, the measurement procedure proposed by Azzi et al. (2014) was adopted to cater for the manual warehousing system at MAP. Inventory holding cost was considered to be the sum of storage and opportunity costs. The storage cost was further divided into evident, semi-evident, and hidden costs as highlighted in Table.1.

2. Research Method

2.1. Notations and Terminologies

In Table 2, notations and terminologies used in this study and their definitions are presented.

2.2. Annual Inventory Holding Cost

Odedairo et al. (2020) depicted the value (or percentage) of inventory holding cost as υ shown in Eq. (1). TIHC is defined as the total inventory holding cost equivalent to annual inventory holding cost (AHC).

$$\upsilon = TIHC / I \tag{1}$$

From Eq. (1), AHC can be obtained as expressed in Eq. (2).

$$AHC = I * \upsilon \tag{2}$$

In Eq. (3), AHC was calculated as the product of inventory investment at hand (I) and the sum of components of holding cost (in percentage) explained in Table 1.

$$AHC = I * (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4) \tag{3}$$

2.3. Model Development

2.3.1 Assumptions

The following assumptions guided the development of the model.

1. The demand of part items is non- uniform.

2. The replenishment pattern is instantaneous.

3. The inventory is continuously reviewed, and when it falls to (or below) a reorder point level, an order quantity is placed.

4. The (R, Q) policy is used to decide R and Q.

5. The lead-time between order placement and order receipt is known and constant (3 months).

6. The demand during the lead-time is unknown but assumed to be normally distributed.

7. All demands must be satisfied; hence no shortages and backorders are allowed.

8. A customer service level, i.e. the probability of not incurring a shortage during any lead-time is determined as 95%.

8. The ordering cost per instantaneous replenishment is constant.

9. The required space (in square metres) to store order quantities for all part items cannot exceed the maximum storage space.

Table 1. Cost components of storage and opportunity costs

Cost	Components	Sub-components
Storage	Evident	Cost of insurance, taxes, power, cleaning, surveillance, direct labour, floor space, warehouse management systems software, material handling, and storage equipment.
	Semi-evident	Depreciation, obsolescence, product damage, indirect labour, supervision
	Hidden	Repacking and relabeling, remanufacturing, lost sales, inspection and counting
Opportunity	Not applicable	This is the sum of the interest paid on the loan used for investing in inventories and the rate of return if the capital was used for other investments.

Table 2. Definitions of basic notation and terminologies

Notation	Definition	Notation	Definition
i	Index for spare part item i = 1, 2, 3……j	j	Total number of spare part items
Ꝗ	Order quantity	Ꞓ	Ordering cost per instantaneous replenishment
Ꞧ	Reorder point	μ	Mean demand during the lead time (units)
Đ	Annual demand	σ	Standard deviation of demand (units)
L	Lead time (months)	α_1	Opportunity cost
v	Average rate of demand	α_2	Evident cost
$\hbar$	Holding cost per unit part item	α_3	Semi-evident cost
$\hbar_s$	Holding cost with storage constraint per unit part item	α_4	Hidden cost
A_i	Amount of space occupied by one unit of part item i (square metres)	M	Maximum storage space area (square meters)
N	Number of orders per year	IL	Inventory level (quantity of inventory at hand)
I	Inventory investment at hand	W_C	Additional cost related to the space area used by one unit of part item
O_C	Annual ordering cost	AHC	Annual inventory holding cost
AHC_S	Annual inventory holding cost with storage constraint	TC_S	Total cost of the inventory system
z	Standard deviation corresponding to the service level probability (95%)		

2.3.2 Model development

2.3.2.1 AHC with storage constraint

In a continuous review order quantity system, whenever the inventory position is at the reorder level (Ꞧ), an order quantity (Ꝗ) is placed. This order is received within the lead time and replenishment is instantaneous. Hopp and Spearman (2001) and Adamu (2017) equations for annual ordering cost and inventory level were adopted, respectively. The frequency of orders is shown in Eq. (4).

$$\boldsymbol{N} = \frac{Đ}{Ꝗ} \tag{4}$$

In Eq. (5), the annual ordering cost was calculated as the product of the number of orders per year and the cost of ordering per instantaneous replenishment.

$$O_C = \left(\frac{Đ}{Ꝗ}\right) * Ꞓ \tag{5}$$

The quantity of inventory at hand (i.e. inventory level) is the sum of the order quantity and reorder level, minus the expected lead time demand as shown in Eq. (6).

$$\mathrm{IL} = (Ꝗ + Ꞧ) - (\mu) \tag{6}$$

In Eq. (7), the holding cost per unit part item was obtained when the annual holding cost was divided by the quantity of inventory at hand.

$$\hbar = \frac{\mathrm{AHC}}{\mathrm{IL}} \tag{7}$$

Eq. (7) can be rewritten to form Eq. (8) when AHC and IL are replaced with Eq. (3) and (6).

$$\hbar = \frac{\mathrm{I}(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)}{(Ꝗ + Ꞧ) - (\mu)} \tag{8}$$

Similarly, holding cost with storage per unit part item describes the amount of space area occupied by 1unit of a part item A with additional cost (W_C) related to the space area. This is computed in Eq. (9).

$$\hbar_s = \hbar + (W_C * A) \tag{9}$$

Eq. (8) can be substituted into Eq. (9) to obtain Eq. (10).

$$\hbar_s = \frac{\mathrm{I}(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)}{(Ꝗ + Ꞧ) - (\mu)} + (W_C * A) \tag{10}$$

The AHC_s is the product of inventory cost with storage constraint ($\hbar_s$) and inventory at hand (IL). AHC_s is presented in Eq. (11) and expanded in Eq. (12).

$$AHC_s = \hbar_s * \mathrm{IL} \tag{11}$$

$$AHC_s = \left(\frac{I(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)}{((Ꝗ + Ꞧ) - (\mu))} + (W_C A)\right) * ((Ꝗ + Ꞧ) - (\mu)) \tag{12}$$

Eq. (12) can be rearranged as described in Eq. (13).

$$AHC_s = [I(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4)] + [W_C A * ((Ꝗ + Ꞧ) - (\mu))] \tag{13}$$

2.3.2.2 Reorder level

To calculate the reorder level for inventory with probabilistic demand pattern, Ponnuru and Karri (2014) model was utilised. The reorder points are expressed in Eq. (14)-(15).

$$Ꞧ = \mu + z\sigma \tag{14}$$

$$\mu = vL \tag{15}$$

2.3.2.3 Spare parts inventory with ignored costs and a storage constraint

Since shortages are not allowed, the total cost of the inventory system (TC_s) is the sum of the annual ordering cost and annual holding cost with storage constraint as expressed in Eq. (16). The storage and non-negativity constraints are shown in Eq. (17) and (18), respectively.

$$TC_S = \left[\left(\frac{Đ}{Ꝗ}\right) Ꞓ\right] + [I(\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4) + W_C A(Ꝗ + Ꞧ - \mu)] \tag{16}$$

$$\sum_{i=1}^{j} (Ai * q_i) \leq \mathrm{M} \tag{17}$$

$$q_i \geq 0 \tag{18}$$

2.3.3 Data collection

The MC-YCR110 motorcycle model domiciled within the country was chosen for further analysis. Usually, the spare parts are ordered from an original equipment manufacturer.

Data obtained from MAP as inputs into the proposed model were I, C^*, M, W, and A_i ($i = 9$). The model was solved using LINGO optimisation software release 18.0. 56.

2.3.3.1 Categorization of spare parts

The spare parts were categorized using Muller's approach (2011).

i. 177 spare part items were identified.

ii. The monthly sales quantity of each part item for 12 months was obtained.

iii. The unit price of each part item was identified.

iv. Annual sales value was calculated by multiplying the annual sales quantity and unit price of each part item.

v. The part items were sorted in descending order of annual sales value.

vi. The cumulative annual sales value was calculated and expressed as a cumulative sales percentage for each item.

vii. The cumulative sum of the part items was calculated and expressed as a cumulative percentage for each item.

viii. The part items that made up 80%, 15%, and 5% of the total sales value were categorized as "A", "B" and "C" items, respectively.

2.3.3.2 Selection of spare parts

Due to a large number of part items, few items were selected by comparing the number of parts and usage frequency (Iwu et al. 2014). Therefore, the focus will be on the first 5% part items in category A.

2.3.4 Determination of demand pattern for selected spare parts items

Samak-Kulkarni and Rajhans (2013) proposed the use of the coefficient of variation (CoV) to determine the demand pattern. The following guidelines govern the determination of the pattern.

a. The demand is deterministic and constant if the average monthly demand is approximately constant for all months and CoV is less than 20%.

b. The demand is deterministic and varying if the average monthly demand varies appreciably for different months but CoV is less than 20%.

c. The demand is probabilistic and constant if the average monthly demand is approximately constant for all months and CoV is greater than 20%.

d. The demand is probabilistic and varying if the average monthly demand and CoV vary appreciably over time.

To determine the demand pattern for the 9 part items selected, the mean ($\overline{x}$), standard deviation (s), and coefficient of variation (CoV) were calculated (Iwu et al., 2014). The Coefficient of variation is given as:

$$\mathrm{CoV} = \frac{s}{\overline{x}} * 100 \tag{19}$$

3. Results

3.1 Categorisation and Selection of Items

Spare part categorisation revealed that 21, 31, 125 part items belong to categories A, B, and C with an annual sales value of 81%, 15% and 4%, respectively. From category A, 9 part items with significant contribution to overall sales value were identified as shown in Table 3. Parts PN000042 and PN000008 has the highest annual sales but with the lowest unit price in class B and C, respectively.

3.2 Determination of Demand Pattern of Selected Spare Items

In Table 4, the demand pattern for 12 months, mean, standard deviation, and coefficient of variation for the selected part item is not constant as the coefficient of variation is greater than 20%. Therefore, it can be deduced that the demand for each item is probabilistic.

3.3 Model Application

The estimated values (in percentage) of evident, semi-evident, hidden, and opportunity costs as obtained from the MAP are presented in Table 5.

In Table 6, with C^* = ₦12,000, M = 15 m^2, W= ₦1.0/m^2, lead time of 3 months, the customer service level of 95% and z obtained from normal distribution table; the order quantity and reorder level for selected items are summarised.

Table 3. Part items and their contribution

Part No	Part description	Annual sales quantity (units)	Unit price (₦)	Total sales value (%)	Total items (%)
PN000014	N	2,125	344	10.1	0.6
PN000026	Z	463	1,384	8.9	1.1
PN000028	AY	480	1,221	8.1	1.7
PN000011	K	475	1,174	7.7	2.3
PN000040	AM	39	13,612	7.3	2.8
PN000010	J	491	982	6.7	3.4
PN000016	P	350	1,084	5.2	4.0
PN000041	AL	116	2,342	3.8	4.5
PN000027	AZ	497	439	3.0	5.1

Table 4. Demand pattern for selected part items

	Items (i)								
Month	N	Z	AY	K	AM	J	P	AL	AZ
1	15	72	72	27	0	17	72	0	72
2	195	23	24	25	5	24	29	3	24
3	155	40	40	21	0	21	23	4	39
4	140	51	40	10	0	9	10	1	40
5	325	52	62	57	3	34	45	12	45
6	25	0	6	2	2	0	8	6	6
7	175	43	38	50	9	47	27	13	49
8	85	34	21	84	7	65	9	7	23
9	260	51	44	51	10	83	44	13	67
10	210	51	63	39	1	40	25	15	40
11	240	26	35	87	2	97	46	29	55
12	300	20	35	22	0	54	12	13	37
Total demand	2125	463	480	475	39	491	350	116	497
Mean	177.08	38.58	40.00	39.58	3.25	40.92	29.17	9.67	41.42
Std.Dev.	95.29	18.34	17.98	25.94	3.49	28.43	18.63	7.67	17.73
CoV	54%	48%	45%	66%	107%	69%	64%	79%	43%

Table 5. Value of cost components

Annual opportunity cost (%)	Storage (%)		
α_1	Evident (α_2)	Semi-evident (α_3)	Hidden (α_4)
7	Floor space = 3.44	Part item depreciation = 0.47	Inspection and counting during the year = 0.18
	Insurance = 0.18	Stocklist execution = 0.18	
	Taxes = 1.35	Indirect labour and Supervision = 0.83	
	Surveillance = 0.66		
	Power = 1.51		
	Cleaning = 1.19		
	Direct labour = 1.82		
	Warehouse management system software = 0.12		
	Material handling/ software equipment = 4.27		
Total = 7	Total = 15.54	Total = 1.48	Total = 0.18
Value of inventory holding cost = 24.2			

Table 6. Order quantity and reorder point for selected part items (in units)

i	A_i (m^2)	v	μ	Q	R
N	0.021	177	531	174	688
Z	0.027	39	117	71	147
AY	0.023	40	120	78	150
K	0.019	40	120	86	163
AM	0.035	3	9	18	15
J	0.019	41	123	88	170
P	0.006	29	87	128	118
AL	0.032	10	30	33	43
AZ	0.019	41	123	87	152

From Table. 6, the pair (Q, R) for Items N, Z, AY, K, AM, J, P, AL, and AZ were (174,688), (71,147), (78,150), (86,163), (18,15), (88,170), (128,118), (33,43), and (87,152), respectively. This infers that for Item N, an order of 174 units should be placed when the stock level falls to or below 688 units. Also, for Item AZ, an order quantity of 87 units should be requested when the stock level falls to or its below 152 units.

The total inventory cost from these pairs is equivalent to ₦2,177,363 while the current inventory investment is ₦6,800,000. A savings of ₦4,622,637 can be realized if the model is adopted. Also, if the maximum storage space (M) for the 9 items is increased by $1m^2$, total inventory cost will increase by ₦39,981 (i.e. dual price). Invariably, the larger the storage space area, the higher the total inventory cost.

Therefore, to ensure efficient and effective ordering policy, increase vendor responsiveness, and maximize usage of available storage space, the developed (R, Q) model can be used to analyze the remaining 168 items.

4 Conclusion

In this study, a spare part inventory model, which incorporates ignored holding cost components within storage constraints to enhance decision-making was developed. The operations of the spare part division, inventory policy, and spare parts sales reports at MAP were analyzed. The holding cost parameters and space area occupied by each unit of the selected part items were incorporated into the model. The spare parts categorisation, selection and simultaneous determination of order quantity and reorder points for the selected parts using the model minimized total inventory cost.

Although this study contributed to research in spare parts management, the limitation of the model can be attended to in future studies by varying the value of inventory holding cost and considering other inventory control policies. Also, a computer-based graphical user interface can be developed to cater for rigors (or complexities) of mathematical computations and to aid decision making in larger situations.

References

Adamu, I. I. (2017). Reorder Quantities for (Q, R) Inventory Models. *International Mathematical Forum*, 12(11), 505-514.

Adeyeye, J. O., Ogunnaike, O., Amaihian, A., Oludokun, M., and Inelo, F. (2016). Inventory Control and Performance of Manufacturing Firms. *Journal of Engineering and Applied Science*, 11(2), 199-203.

Azzi, A., Battini, D., Faccio, M., Persona, A., and Sgarbosas, F. (2014). Inventory Holding Costs Measurement: A Multi-case Study. *The International Journal of Logistics Management*, 25(1), 109-132.

Etale, L. M., and Bingilar, P. F. (2016). The Effect of Inventory Cost Management on Profitability: A Study of Listed Brewery Companies in Nigeria. *International Journal of Economics, Commerce and Management* 4 (6), 446-455.

Foster, R.S. (1964) What Does It Cost to Carry Inventory? National Association of Wholesalers.

Hopp, W. J., and Spearman, M. L. (2001). *Factory Physics- Foundations of Manufacturing Management.* New York. .2nd Ed.

Iwu, H. C., Ogbonna, C. J., Jude, O. and Onuma, K. G. (2014). Application of Inventory Model in Determining Stock Control in an Organization. *American Journal of Applied Mathematics and Statistics* 2 (5), 307-317.

Mikalsen, M. M. (2015). Managing the Demand for Spare Parts. *Implement Consulting Group* Retrieved from http://implementconsultinggroup.com/ on April 20, 2020.

Miller, G. J. (2001). Inventory Carrying Costs: Is there a "Right" Way to Calculate Them?. *Inventory Reduction Report* 8(1). 9-12.

Muller, M. (2011). *Essentials of Inventory Management.* New York: AMACOM - Book Division of American Management Association.

Odedairo, B. O., Emilola H.A., and Edem, I. (2020). A System Dynamics Model to Determine the Value of Inventory Holding Cost. *Journal of Engineering Studies and Research,* 26 (3), 112-123.

Ponnuru, R. K., and Karri, J. (2014). Deterministic and Probabilistic Models in Inventory Control. *International Journal of Engineering Development and Research* 2 (3) 3100-3105.

Samak-Kulkarni, S. M., and Rajhans, N. R. (2013) Determination of Optimum Inventory Model for Minimizing Total Inventory Cost. *Procedia Engineering* 51. 803-809.

Vidal-Carreras, P. I., Garcia-Sabater, J. P., and Garcia-Sabater, J. J. (2016). A practical model for managing inventories with unknown costs and a budget constraint. *International Journal of Production Research,* 55(1). 118-129.

Waters, D. (2003). *Inventory Control and Management.* England: John Wiley & Sons Ltd.

Babatunde Omoniyi Odedairo obtained his B.Sc. and Ph.D. in Industrial and Production Engineering from the University of Ibadan, Nigeria, and M.Sc. in Product Engineering from the University of Northumbria at Newcastle upon Tyne, UK. Babatunde is a registered Industrial Engineer, a certified SAP Application Associate, and a member of SAP University Alliances. He is a senior lecturer at the Department of Industrial and Production Engineering in the University of Ibadan. His research interests include project and activity scheduling, optimisation model development and enterprise resource planning.