IASET: Journal of Business and
General Management (JBGM)
ISSN(P): 2319-2267; ISSN(E): 2319-2275
Vol. 1, Issue 2, Jul – Dec 2016; 1-10

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

OPTIMIZING MULTIPLE-MATERIALS INVENTORY AND Q/R OPERATING DOCTRINE WITH RESPECT TO FUNCTION: THE CASE OF INNOSON TECHNICAL AND INDUSTRIAL COMPANY LIMITED, ENUGU, NIGERIA

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ABSTRACT

The study focused on optimizing multiple-materials inventory control system for resource allocation in the Plastic Manufacturing Industry in Nigeria with a focus on Innoson Technical and Industrial Company Limited, Enugu. Effective inventory management is concerned with making pertinent policies that border on inventory procurement and allocation of resources. The objective of the study was to optimize cost and production efficiencies of inventory materials for the production of Honour plastic chair. The study employed a statistical design, of which secondary production and cost data were used. Data collected were estimated using regression models. Ordinary Least Square (OLS) formed the basis for estimation. The study showed that the optimal values for Copolymer, Homoplymer, Filler, and Colour were 2,704.90kg, 25.058.20kg, 1,022.11kg, and 1,661.891kg, respectively. Furthermore, under optimality condition, Filler as an inventory material minimized most the total cost of inventory, followed by Colour, Copolymer, and Homoplymer in that order. The optimal (functional) values were compared to, and contrasted from the discrete EOQ values. The comparison did suggest that the Economic Order Quantity (EOQ) values obtained using the discrete methods overestimated the "optimal" values. The study concluded that optimization method minimized the total cost of inventory relative to discrete Economic Order Quantity (EOQ).

KEYWORDS: Optimization, Economic Order Quantity (EOQ), Inventory, Q/R Operating System, Plastic, Ordering Cost, Carrying Cost, Total Cost, Polynomial

INTRODUCTION

The dynamic nature of business environment and the level of customer awareness presuppose that manufacturing firms place emphasis on effective control of inventory. Organizations exert considerable efforts in making pertinent decisions that border on inventory procurement and efficient allocation of resources in an attempt to meet the demands of the changing environment (Scott, 2007). Every resource, including inventory is limited in its supply. In some cases, demand for inventory is also limited. Demand for inventory might not be unlimited given that a firm's production capacity is limited. Supply and demand limitations on inventory resource therefore call for efficiency in inventory usage. Minimization of total cost is the basic tenet of efficient inventory management policy or goal. The inventory management problems of when to replenish the inventory and how much inventory to order for replenishment becomes absolutely imperative that organizations such as Innoson Technical and Industrial Company attempt to align it's operations and inventory management to ensure smooth, efficient, and uninterrupted production. Inventory management is among the most important operations management functions because it requires a great deal of capital and affect the timely delivery of goods to customers (Abara, 2011). It is the most expensive and important assets to many manufacturing firms representing a good percentage of invested capital.

Innoson Technical and Industrial Company Limited is a subsidiary of Innoson group of companies and was incorporated in 2002 with it's head office/factory situated at plot W/L Industrial Layout, Emene, Enugu State. The company commenced full-scale production in October 2002. It manufactures plastic chairs, tables, trays, plates, spoons, cups, and jerrycans of different varieties every day. The chairs come in different forms and shapes amongst which are: Honour, Pest, Val, Victory, Teenage, View Delux, Odessy, Duke, etc. Their products have gained wide acceptance among different customers and therefore serve as the revenue base of the organization. The Company operates 3 shifts which account for three production runs per day. The plastic plant has grown to be one of the successful plastic manufacturers in the Nigeria Plastic Industry. Due to the rapid demand of their products, the company's production lines of injection moulds have since been increased in an attempt to meet the timely demand of their products. Over one thousand indigenous staff and few expatriate staff work in the organization. Innoson Technical and Industrial Company Limited maintains the following inventories for the production of plastic chairs: Copolymer, Homoplymer polypropylene, Filler, and Colour (master batch).

As effective operating system is always used to allocate inventory resources, it is therefore expedient that operations managers, especially in Innoson Technical and Industrial Company, have a basic understanding of the Quantity-Reorder-Point (Q/R) inventory phenomenon, its associated benefits, as well as its related cost components for effective control of inventory. Thus, the objective of this paper is to estimate the cost functions and optimize therefrom values of inventories required for the minimization of total costs associated with Copolymer, Homoplymer, Filler, and Colour materials in Innoson Technical and Industrial Company, Enugu, Nigeria. This paper is sequel to the study by Ewans, Abara, and Nwekpa (2015) who had determined the Economic Order Quantity (EOQ) of the studied materials in a discrete manner.

The Problem

Innoson Technical and Technical Company Limited presently experiences inventory management problems in determining when to order its material inventories and how much of each inventory to order. The personnel responsible for inventory management has little inventory control skill for effective inventory decision making but does so primarily by intuition Managing inventory system by intuition in Innoson Company makes it absolutely difficult for the firm to determine accurately the optimal order quantity that would have minimized the total cost (carrying costs plus ordering costs) components of their materials. The organization therefore incurs unnecessary carrying costs (C_c) and ordering costs (C_o) which subsequently leads to an increase in per unit cost of production. Increases in production cost, holding other variables constant, certainly will reduce the revenue derivable to the firm.

This method of intuitive control system in Innoson Company also results in unnecessary disruption of production process that could lead to increase or decrease stock of materials neither of which is profitable to the company. Stocks out costs are often present. Abara (2011) argues that stock out cost reflects the economic consequence of running out of stock where sale is lost, if material is not on hand. Aside profit lost from lost sale, goodwill in the form of future sales may also be lost. It is therefore against this backdrop that this study is designed to determine how the operating characteristics of Q/R inventory system could be adopted to enhance effective control of inventory in Innoson Company.

Theoretical Framework: Optimization

Abara (2011) argued that the objective of most inventory models is to minimize the total cost of holding inventory. The significant costs are the ordering cost and carrying cost. Other costs, such as the cost of inventory itself are constant. Therefore, the moment ordering cost and carrying cost are minimized; the total cost of the inventory is minimized. The optimal order size, q* is the quantity that minimizes the total costs. In other words, as the quantity ordered increases, the total number of orders placed per year decreases. As the quantity ordered increases, the annual ordering cost decreases. But as the order quantity increases, the carrying cost increases resulting in larger average inventories that the firm has to maintain. The theory of optimization is illustrated in Figure 1 which shows the relationships. The minimum point along the total cost curve approximates the optimal quantity, q*. At this optimal level also is where the ordering cost equals the carrying cost.

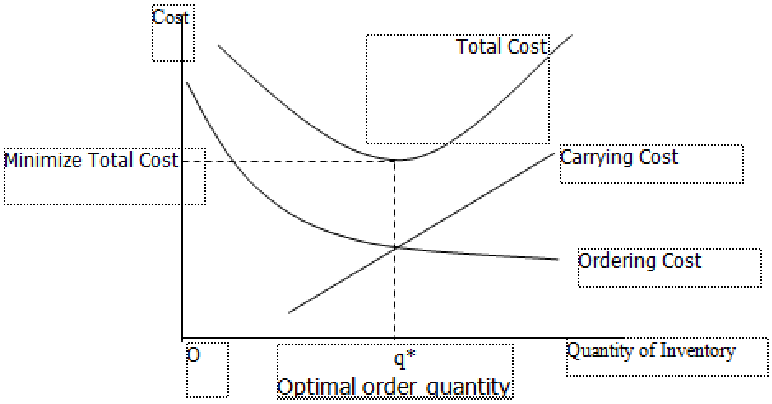

Figure 1: Optimality Condition

This paper hypothesizes that it is only the optimality criterion that minimizes total cost of holding inventory in a given period. Thus, it has an advantage over the Economic Order Quantity model, as the latter tend to overestimate the optimal quantity required.

Economic Order Quantity (EOQ)

This model was developed by F.W Harris in 1915 and adopted by Ewans, et al. (2015) in their study. Economic order quantity is the order quantity that is economically sustainable, with respect to annual demand for inventory, total inventory holding and ordering costs. The formula may be expressed as,

$$EOQ = \sqrt{\frac{2C_o d}{C_c}} \quad (1)$$

Where, C_o is the ordering cost, d is demand, and C_c is the carrying cost. Interest charge and other costs are usually assumed constant. The economic order quantity model (Equation 1) does not yield optimal values for effective decision making. Moreover, its numerous assumptions make its application very restrictive.

Methodology

The research design attempted to build statistical regression models that captured the real interactive variables patterns. The focus of the models was on raw material inventories, relative costs, and demand requirements. Thus, the costs associated with the Q/R inventory control system was divided into two: carrying cost and ordering cost. The material inventories to which the models were applied include Copolymer, Homoplymer polypropylene, Filler and Colour. The inventory materials served as the basis for comparison with respect to economic order quantity (EOQ). Ordinary Least Squares (OLS) therefore formed the estimation basis of the regression models such that:

$$X_i = a_o + a_1 Y + \varepsilon, \text{ (for cost of each raw material)} \quad (2)$$

Where X_i is carrying cost or ordering cost, of the $_i$th (i = 1, 2… 4) material, Y = quantity of material (kg), a_o and ai are coefficients to be estimated and ε is the random (stochastic) disturbance term.

Equation 2 and the OLS used were predicted on the assumption that the dependent variable is a random variable while each of the independent variables could take on fixed or random values. Furthermore, the OLS technique assumes that each value of the dependent variable has a probability distribution of the possible values of the random variable. The number of observations or scores (n) exceeds the number of parameters to be estimated by at least 1, and that the data, hence error terms, are normally distributed, are independent, have zero mean, and have constant variance such that $\varepsilon \sim N(o, \delta^2, I)$.

Inventory decisions revolve around minimization of total cost of inventory where the total cost equals the sum of carrying cost and ordering cost. Therefore, the total cost (TC) of the system may be represented as,

$$\text{Total Cost (TC)} = C_o \, {}^{d}/_{q} + C_c \, {}^{q}/_{2} \quad (3)$$

Where: d is demand for the production run, q is lot size or amount ordered (annually) such that d<q, $C_o \, {}^{d}/_{q}$ is carrying cost (Cc), $C_c \, {}^{q}/_{2}$ is ordering cost (Co).

Estimating Carrying and Ordering Cost Functions

In order to model these functions for estimation, let the carrying cost component be represented as X_1.

$$\text{Therefore, Carrying Cost component } (X_1)\ C_o \, {}^{q}/_{2} \quad (4)$$

Also,

$$\text{Ordering Cost component } (X_2)\ C_c \, {}^{d}/_{q} \quad (5)$$

If the carrying cost component, $C_o \, {}^{q}/_{2}$, is represented as X_1 and the ordering cost component, $C_c \, {}^{d}/_{q}$, as X_2, it is pertinent to note that C_c, q, C_o, and d, are discrete parameters whose estimates or values were deduced from historical (Company) data. Thus, for each production run/period, Equations 4 and 5 would yield data observations for the respective cost components involved. Based on the aggregative nature of $C_c \, {}^{q}/_{2}$ in Equation 4, and $C_o \, {}^{d}/_{q}$ in Equation 5, the variables X_1 and X_2 were used to denote the decomposed values of the various cost components. Thus, Equation 3 was expressed as:

$$TC = X_1 + X_2 \quad (6)$$

Generally, Equation 6 is additive. In order to use Equation 6 to predict the implications of X_1 on TC, X_2 on TC, the sum of X_1 and X_2 on TC, and X_1 and X_2 on the Economic Order Quantity (EQO), each cost component (Xi, i=1,2) became a function of quantity material (Y) used. Therefore, the general cost functions were expressed as,

$$X_1 = f(Y) \quad (7a)$$

and

$$X_2 = f(Y) \quad (7b)$$

Where, Y is the amount of input or material. Estimating Equations 7a and 7b required the introduction of a stochastic error term in order to minimize the variance of the scores. Therefore, Equations 7a and 7b were specifically rewritten as:

$$X_1 = a_o + a_1 Y + \varepsilon \quad (8a)$$

and

$$X_2 = b_o + b_1 Y \ \varepsilon \quad (8b)$$

Where, ε is the stochastic error term.

Generally, economic theory suggests that cost functions are not necessarily linear. In order to estimate the carrying cost, ordering cost, and the total cost functions that was used to evolve an optimal inventory value, Equations (8a) and (8b) were re-specified. Therefore, the actual cost functions estimated would not be linear but curvilinear for the carrying and ordering costs. Thus, de````````termining the functional forms of Equations 8a and 8b was a necessary condition for this study. Doti and Adibi (1988) have shown that when dealing with relationships that involve a constant rate of growth (or decline/depletion) in the dependent variable, which is assumed, an exponential relationship of the following type was postulated for both the carrying and ordinary cost functions.

$$X_k = bo \ \mathbf{e}^{biYk} + \varepsilon \quad (9)$$

Where, X_k is the carring or ordering cost component, Y is input for the kth (carrying or ordering) cost function, and **e** is the base of natural logarithm and ε is the error term.

By Euler’s Theorem, the following assumptions apply:

- Rate of decay is proportional to the current value of Y.
- μ (random error) is multiplicative rather then additive.

Equation 9 is usually used to represent the functional relationship between equal changes (increasing/ decreasing) in the level of the independent variable, and a constant rate of growth or decline/depletion in the dependent variable. The sign before the parameter bi, for i= 1,2, was determined for carrying cost and for ordering cost. Theoretically, b parameter if estimated should be positive (b>o) for carrying cost and negative (b<o) for ordering cost. Equation 9 required linearity before estimation. Thus, Equation 9 was transformed to its linear partial logarithmic form obtained through logarithmic transformation. Thus:

$$\text{Log } X_i = \text{Log } b_o + b_1 Y + \varepsilon \text{ (for carrying cost, where } b_1 > o) \quad (10a)$$

and

$$\text{Log } X_i = \text{Log } b_o + b_2 Y + \varepsilon \text{ (for ordering cost, where } b_2 < o) \quad (10b)$$

Where, “Log” is the natural logarithm, X_i, i = 1,2, represent ordering and carrying cost, respectively, Y is the quantity of material, and ε is the error term. The data for estimating Equation (10a) and (10b) were sourced from the study by Ewans, et al. (2015).

Estimating Total Cost Function

Estimation of the Total cost curve, theoretically speaking, requires a polynomial function, say of the third order. However, the sum of the carrying cost and ordering cost functions in Equations 4 and 5 would approximate the Average Cost Curve. The AC curve when estimated will form a convex parabola (to the origin of a graph) and was used to estimate the optimal inventory usage. To accomplish this estimation, both the carrying and ordering costs (data) were aggregated such that:

$$TC\ AVC = C_c\,{}^{q}/_{2} + C_o\,{}^{d}/_{q} = X^* \text{ (11a) Thus, } X_1 + X_2 = X^* \quad (11b)$$

where, TC is the cost; AVC is average variable cost, and X* is the horizontal sum of the costs. If the sum of the costs in relation to quantity of material used (Y) is modeled, then the model to be estimated becomes:

$$X^* = f\,(Y) \quad (12a)$$

Which translates to $X_k^* = g_o + g_i\, Y_k + \varepsilon$ (12b) where, Y_k is the Kth material item, for i = 1,2…4.

Infact, polynomial functional form is a more complex functional relationship that describes the association between variables. A polynomial relationship is given generally as:

$$Y_t = b_o + b_i X_{it} + b_2 X_{2t}^2 + \ldots + bn\ Xnt^n \quad (13)$$

Where Y is the dependant variable and $\sum X_i$ is a vector of explanatory variables.

Equation 13 is difficult to justify on theoretical grounds. This functional relationship is usually not generally tested unless a theoretical basis (framework) can be established a priori for its possible presence. Thus, the total cost function was approximated by the polynomial.

$$AVC = b_o + b_1\, X^* + b_2\, X^{*2} \quad (14a)$$

Which translate to $X_i^* = g_o + g_1\, Y + g_2 Y^2 + \varepsilon$ (14b)

Where X_i^* (i = 1,2,…,4) is the total cost of each material and Y is quantity of each material in inventory. Equations 14a and 14b are theoretically plausible polynomials of the U- shape average cost function for this study such that g_1<o and g_2>o. That is, where the parabola reaches a minimum point, the value of g_1 and hence dX*/ dY is hypothesized to be negative (i.e. g_1< o), while the value of the second derivative d^2X^*/dY^2 is hypothesized to be positive (i.e, g_2> o) from the minimum point of the curve up. Theoretically, average and marginal cost functions assume these polynomial characteristics and shape, hence the adoption (polynomial) here.

Data obtained from the study by Ewans, et al. (2015) enabled functional estimation of Equations (10a), (10b), and (14a), (14b) for each material. Application of calculus to Equation (14b) could minimize the total cost of each material studied. However, the optimal values obtained by equating the estimated ordering cost function of a particular material to its carrying cost function and solving same. Finally, the optimal values were compared to, and contrasted from the discrete EOQ values obtained by Ewans, et al. (2015).

RESULTS

To get the estimated optimal quantity for each of the studied inventory materials, the ordering cost Equation for each material was equated to its carrying cost and the quantity of the associated optimal value obtained. The result was further transformed to it's partial logarithm form.

Copolymer

Ordering Cost: Log $C_o = 2.367 – 0.034X_c$

Carrying cost: Log $C_c = 1.574 + 1.801X_c$

Total Cost: Log $TC_c = 2.671- 0.114X_c + 3.546X_c^2$

Thus, $X_c = 0.432152588$, and, Anti-log of 0.43252588 = 2.7049

As the data were measured in 1000 kg, 2.7049 was multiplied by 1000 to obtain the required optimal quantity of Copolymer as 2,704.90 Kg.

Homoplymer Polypropylene

Ordering Cost: Log $C_o = 1.888 – 0.016X_h$

Carrying cost: Log $C_c = 1. 355 + 0.365X_h$

Total Cost: Log $TC_h = 2.384 - 0.581X_h + 0.135X_h^2$

Therefore, $X_h = 1.398950$

Thus, Anti-log of 1.398950 = 25.058207 The optimal quantity of Homoplymer Polypropylene becomes 25,058.20kg kg.

Filler

Ordering Cost: Log $C_o = 1.700 – 50.059X_f$

Carrying cost: Log $C_c = 1. 224 + 0.045X_f$

Log $TC_f = 2.504 – 0.137X_f + 6.679X_f^2$

Thus, $X_f = 0.009500239$, and Anti-log of 0.009500239 = 1.022116

The Optimal Quantity of Filler becomes 1,022.11kg kg.

Colour

Ordering Cost: Log $C_o = 2.337 – 2.188X_{cl}$

Carrying cost: Log $C_c = 1.799 + 0.251X_{cl}$

Log $TC_{cl} = 3.106 – 0.003X_{cl} + 0.060X^2_{cl}$

Thus, X_{cll}= 0.220582205, and Anti-log of 0.220582205 = 1.6618132

Therefore, Optimal Quantity of Colour is 1,661.81kg.

The Economic Order Quantity (EOQ) of Copolymer, Homoplymer, Filler and Colour based on discrete (deterministic) estimation obtained previously by Ewans, et al. (2015) using the same data were 61,212.244kg, 78,836.31kg, 502,89ikg and 40,353.29kg, respectively. Table 1 shows the Discrete and Estimated Economic Order (Optimal) Quantity of the Inventory items.

Table 1: Discrete Versus Estimated (Functional) Economic Order (Optimal) Quantity of Inventory Materials

Inventory Materials	Discrete EOQ Quantity	Optimal (Functional) Values	Difference	Average
Copolymer	q* = 61,212.24kg	2,704.90Kg	58,507.344kg	31,958.57kg
Homoplymer	q* = 78,836.31kg	25,058.20 kg	53,778.103kg	51,947.25kg
Filler	q* = 502,891.64kg	1,022.12 kg	504.869.524 kg	251,196.88kg
Colour	q* = 40,353.29kg	1,661.81kg	38.691.48kg	21,007.55kg

Table 1 shows the results of the estimated optimal (functional) values of Copolymer, Homoplymer, Filler, and Colour as 2,704.90kg, 25,058.20kg, 1,022.12kg, and 1,661.81kg, respectively. The Economic Order Quantity (EOQ) of the inventory materials based on discrete (deterministic method) estimation obtained previously by Ewans, et al. (2015) using the same data were 61,212.24kg, 78,836.31kg, 502,891.64kg, and 40,353.29kg for Copolymer, Homoplymer, Filler, and Colour, respectively. Conversely, the average quantities were 31,958.57kg, 51,947.25kg, 251,198.88kg, and 21.007.55kg for Copolymer, Homoplymer, Filler, and Colour, respectively. However, the optimal (functional) values were compared to, and contrasted from the discrete EOQ values, and the differences were 58,507.344kg, 53,778.103kg, 504.869kg, and 38,691.48kg for Copolymer, Homoplymer, Filler, and Colour respectively. Based on optimality condition, Filler as an inventory material minimized most, the total cost associated with inventory, followed by Colour, Copolymer, and Homoplymer that minimizes the least of the total cost of inventory. The implication is that Innoson Technical and Industrial Company does not require much Colour and Filler as an inventory material to produce Honour plastic chairs. In real life situations, the demand for white plastic chairs is higher than colored plastic chairs. The Company uses more of Homoplymer, and Copolymer, respectively, in their production runs for required specification necessary for market driven quality of their products.

From the foregoing, the obvious result that could be considered novel in this study is that optimizing (minimizing) the total cost of inventory gives a more realistic value of the desired Economic Order Quantity (EOQ), vis-à-vis obtaining Economic Order Quantities (EOQ) of inventory items through discrete (deterministic) methods. The deterministic approach over-estimates the Economic Order Quantity of materials because it does not take into account possible variants in inventory management. Such variants as changes in production technologies, price of materials, product prices, government policies, etc. create risk and uncertainty in inventory management. Conversely, the estimated functional approach incorporates these risks and uncertainties through their error terms, and therefore yields more realistic (Lower) values of Economic Order Quantity (EOQ).

SUMMARY AND CONCLUSION

Inventory is one of the most expensive and important assets to many organizations, representing a good percentage of total invested capital. Inventory management is pivotal in efficient allocation of resources in an attempt to balance the conflicting economics of overstocking or stockout of inventory materials, as well as manage inventory levels in the best interest of the organization. Every resource, including inventory is limited in its supply and demand. Thus, demand and supply limitations on inventory resource call for efficient inventory management. Minimization of total cost of inventory is the basic tenet of efficient inventory management policy. The study was designed to optimize cost and production efficiencies of resource allocation in the production of Honour plastic chair. The study employed a quantitative statistical research design. Secondary data were used. Data collected were estimated using regression models such that Ordinary Least Square (OLS) formed the basis for estimation. The results from optimality conditions were respectively compared to, and contrasted from the discrete (deterministic) Economic Order Quantity (EOQ) results. It was not surprising that optimal (functional) estimations yielded lower values that minimized the total cost of inventory relative to discrete (EOQ) approach.

The limitations of the EOQ model are many and this may explain the reason why the model overestimates optimal values that may be required. Demand (d) is assumed known and constant whereas in many real-life situations demand varies. Variations in demand will of lot material is assumed to be instantaneous, and arrive all at once, but in require modification or non-applicability of the EOQ. Unit cost is known and assumed constant, but in practice quantity discount (price breaks) could apply for large quantity purchases. Delivery real life situations materials could also be placed in inventory continuously as it is produced. Finally, a single product is usually assumed by the EOQ model but often multiple items or materials (as in this study) are produced and/or purchased from a single produced and/or supplier and the items are all shipped at the same time.

Effective and efficient management practices should incorporate optimality conditions which will yield the desired amounts of inventory materials or products. Optimal inventory quantities are not quantities will reduce both ordering and carrying costs substantially thereby enabling minimization of the total cost of inventory in stock. When total cost of inventory is minimized, the dual, profit maximization, is implied.

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