A comparative analysis of different multi-criteria inventory control methods for a pump manufacturing company

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ABSTRACT

In today's highly competitive environment, several inventory control strategies are introduced in different manufacturing organizations or supply chain perspective. Multiple criteria based inventory control technique is required to achieve efficient inventory management system which contemplate the different aspects of inventory as well as supply chain management system. In this context, monthly demand, inventory consumption value and lead time are considered as the inventory performance measuring criteria. Here, different multiple criteria based 'ABC' inventory control methods have been utilized to categorize the stock items properly. In addition, the overall inventory service costs and average fill rate are computed for different MCIC techniques. These inventory control approaches have been applied to raw material inventories of a pump manufacturing company. Ng-model performs better than ZF and H-models where the overall fill rate of stock items has been considered. ZF-model and H-model ensure better results from Ng-model regarding total safety stock inventory cost.

1. Introduction

Inventory control strategies are used to classify stock items which have great significance on supply chain as well as production also. 'ABC' inventory classification is a common inventory control technique based on the consumption values of stock keeping units. This classification technique enumerates 'A' category for the inventory items of high consumption values, 'B' category for the moderate consumption values and 'C' category for the lower consumption values of stock items. This selective inventory control technique deals with single criterion only. Partovi and Anandarajan (2002) utilized the Artificial Neural Network (ANN) for 'ABC' inventory categorization of stock keeping units. Two learning methods have been used in ANN. Furthermore, a comparison was drawn with statistical techniques and the proposed inventory classification model to ensure the optimized logistics and supply chain management. Two data sets of a pharmaceutical company have been taken by them for stock analysis.

Mallick et al. (2012) proposed different inventory control techniques for cost optimization of a manufacturing organization. A comparative analysis of 'ABC', 'FSN' and 'XYZ' selective inventory control techniques have been performed to achieve optimum and cost effective inventory goals. 'AFX' study was also incorporated to ensure the accuracy of inventory management study. Rezaei and Davoodi (2005) applied Genetic Algorithm (GA) for an appropriate inventory control strategy of multiple products in stock. In this context, proper supplier selection strategy plays an important role to fulfill the demand of inventory items. In another work, researchers suggested an operation related grouping of inventory items for an automobile industry (Ernst & Cohen, 1990). Different statistical criteria have been considered for inventory classification also. The inventory control policy can be applied to the supply chain with large number of stock items. Flores et al. (1992) proposed multi-criteria 'ABC' classification technique to manage the inventory of a hospital. Analytic Hierarchy Process was used by the researchers to ensure the multiple criteria in selective inventory control strategy. Arikan and Citak (2017) introduced hybrid AHP-TOPSIS based multiple criteria 'ABC' inventory classification for an electronics firm. Inventory consumption values, lead time and criticality of inventory items were chosen as the analyzing criteria of this classification technique.

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Ramanathan (2006) proposed a multiple criteria based inventory control technique which is an 'AHP' based 'ABC' categorization procedure of stock keeping units. 'R-model' encompasses maximization problem for inventory control policy. Ng (2007) improved the Ramanathan's model or 'R-model' for inventory classification. Here, all weights for different criteria have been converted to normalized scores. Zhou and Fan (2007) suggested two sets of weighted linear optimization models to categorize the inventory items. Two sets of optimization problems were described as maximization and minimization model for the 'MCIC' system. Furthermore, overall scores of inventory items were calculated by two sets of weights. Hadi-Vencheh (2010) proposed a non-linear optimization technique for 'MCIC' analysis. This is a modified version of 'Ng-model'. Kaabi and Jabeur (2016) suggested a new hybrid technique for inventory classification which was combined with 'ZF-model' and 'H-model'. The proposed model was termed as 'Hybrid-ZF-H model'. A comparison was drawn with this proposed model and other 'MCIC' techniques.

Babai et al. (2014) investigated inventory performance measuring approaches for different multiple criteria inventory control techniques. Data sets were taken from the Netherland based retailer. The investigation was completed with sensitivity analysis of computed results. Iqbal et al. (2017) considered different statistical approaches for selective inventory control techniques. The analysis was carried out with forecasting demand and actual demand of stock items. Parnianifard et al. (2020) proposed a sequential simulation method to optimize an inventory control system. Moreover, a robust optimization technique was developed to fulfill the market demand. Das and Das (2016) proposed a green supplier selection problem for an East Indian pump manufacturing organization. Hybrid AHP-TOPSIS technique was used as the analyzing method. Rao and Lakshmi (2021) developed a multi-attribute decision making method based on the importance of different objectives. This decision making algorithm is termed as R-method. Some researchers compared the 'R-program' to the AHP and TOPSIS methodologies in multi-criteria inventory management perspective (Mallick et al., 2019). Das and Das (2019) suggested traditional 'ABC' inventory analysis and 'MCIC' 'ABC' analysis for the pump manufacturing organization. Ramanathan's model was utilized for multiple criteria inventory analysis. Further, the analysis was followed by the inventory performance measurement procedure to ensure the optimized inventory control strategy.

The main objective of this paper is to evaluate multi-criteria based inventory control policies (Ng-model, ZF-model and H-model) for a pump manufacturing organization. Overall fill rate and total safety stock inventory costs have been calculated for different inventory control strategy. These computational results enhance the optimal inventory control strategy for the pump manufacturing organization.

2. Inventory Control Models

This paper represents ABC inventory classification for a pump manufacturing organization. Different 'MCIC' approaches have been conducted with the data set of the pump manufacturing organization previously used by Das and Das (2016, 2019). In this context, Inventory consumption values, Demand and Lead time have been chosen for inventory analyzing criteria.

Here, a linear optimization. MCIC model has been considered for 'ABC' analysis. This analyzing technique is termed as 'Ng-model'. The Ng-model is illustrated below:

$$\text{Max } S_i = \sum_{j=1}^{J} w_{ij} y_{ij} \qquad \text{..................(1)}$$

$$\text{State that, } \sum_{j=1}^{J} w_{ij} = 1$$

$$w_{ij} - w_{i(j+1)} \geq 0, j = 1, 2, ..., (J\text{-}1)$$

$$w_{ij} \geq 0, \ j = 1, 2, ..., J$$

where, j = criterion for inventory analysis, i = finished goods inventory items for the pump manufacturing organization, w_{ij} = Weight of ith stock item over criterion j, y_{ij} = Performance of ith stock item under criterion j, S_i = Optimum solution for the maximization function.

The weights are normalized and the summation of weights for each criterion is equal to 1. Weight corresponding to the first criterion is more important than the second criterion. Mathematically, it can be described as $w_{i1}>w_{i2}>w_{ij}$. The computed optimal solutions are utilized to classify the stock items in 'A', 'B' or 'C' category.

ZF-model is carried out with the most favourable index and least favourable index for each criterion. The combinations of both indices give better results for inventory classification. Good index is computed by the maximization linear programming problem given by equation (2).

$$gI_i = \max \sum_{n=1}^{N} w_{in}^{g}\, y_{in} \qquad \text{.................(2)}$$

Stated that, $\sum_{n=1}^{N} w_{in}^{g}\, y_{mn} \leq 1, m = 1, 2, \ldots, M$

$$w_{in}^{g} \geq 0$$

Bad index is calculated by the minimization of linear programming problem shown in equation (3).

$$bI_i = \min \sum_{n=1}^{N} w_{in}^{b}\, y_{in} \qquad \text{...................(3)}$$

$$\sum_{n=1}^{N} w_{in}^{b}\, y_{mn} \leq 1, \mathrm{m} = 1, 2, \ldots, \mathrm{M}$$

$$w_{in}^{b} \geq 0$$

where, n = criterion corresponding to inventory categorization, i = finished goods inventory items for the pump manufacturing organization, y_{in} = Performance of ith stock item under criterion n, w_{in}^{g} = most favourable weight of ith stock item under criterion n, gI_i = Optimum solution for the maximization function, w_{in}^{b} = least favourable weight of ith stock item under criterion n, and bI_i = Optimal score for the minimization function.

Composite index or final optimal score can be computed by equation (4).

$$nI_i(\lambda) = (\lambda(gI_i - gI^-) / (gI^* - gI^-)) + ((1 - \lambda)(bI_i - bI^-) / (bI^* - bI^-)) \qquad \text{.................(4)}$$

This optimal score is used to categorize the inventory items.

Where, gI^* = highest value of good solution, gI^- = lowest value of good solution, bI^* = highest value of bad solution, bI^- = lowest value of bad solution, λ = control parameter that is specified by the decision makers, nI_i= composite index or final optimal solution for an item i.

'H-model' is the extended version of 'Ng-model'. Here, weights are normalized in such a way that it converts into a non-linear maximization problem. The maximization problem is represented by equation (5).

$$\text{Max } S_i = \sum_{j=1}^{J} y_{ij}\, w_j \qquad \text{...................(5)}$$

Such that, $\sum_{j=1}^{J} w_j^2 = 1$

$$w_j \geq w_{j+1} \geq 0,\ \mathrm{j} = 1, 2, \ldots, (\mathrm{J} - 1)$$

$$w_j \geq 0,\quad \mathrm{j} = 1, 2, \ldots, \mathrm{J}$$

where, w_j = relative importance of weight corresponding to jth criterion, y_{ij}= performance of ith inventory item over criterion j, S_i = Final optimum solution for the non-linear model.

The first constraint enumerates that the sum of the squared values of all weights (for each criterion) is equal to 1. The second constraint represents that priorities of all weights are in ascending order. The final optimal score helps to categorize the inventory item.

3. Inventory Performance Measurement

This paper represents the Multi criteria inventory control policy for an East Indian pump manufacturing organization. The performance analysis for those particular inventory control policy is necessary to ensure the optimum results. The safety stock inventory cost and fill rate of inventory items have been used as the performance measuring parameters.

It is assumed that,

Number of finished goods stock items = N

Average Demand of item i (Per unit time) = D_i

Standard deviation of the average demand of item i = σ_i

Procurement Lead time of item i = L_i

Inventory holding cost or carrying cost of item i = h_i

Unit constant ordering cost of item i = W_i

Economic order quantity of item i = Q_i

Cycle service level of inventory item i = CSL_i

Safety factor of item i = k_i

Standard normal probability distribution function = $\varphi(.)$

Loss function of standard normal distribution = $G(k_i)$

Fill rate of item i = FR_i

Total safety stock inventory cost of the finished goods inventory items = C_{Ts}

Table 1
'ABC' analysis using 'Ng-model', 'ZF-model' and 'H-model'.

Description	Order quantity	Inventory consumption value (Rs.)	Procurement Lead time (days)	Ng-model classifi-cation	ZF-model classifi-cation	H-model classifi-cation
FLEX. CPLG. (EQV/LOVEJOY MODEL: RB-800-14)	4	661240	14	A	A	A
THRUST PAD (CENTRE PIVOTED)- 15 SNT	24	67200	5	A	A	A
RATCHET (12TBH) HARDENED 300-350 BHN	15	165000	7	A	A	A
PIN CAGE	10	230000	10	A	A	A
RATCHET (8TBH- NEW)- TH. HRND. 300-350BHN	10	52500	7	A	A	A
FLEX. CPLG. (LOVEJOY MODEL: RB-320-12)	4	1500	14	A	A	A
FLEX. CPLG. (LOVEJOY MODEL: RB-198)	4	920	14	B	B	B
PACKING BOX (HP)- 5", 9"P/REG.	5	33975	6	B	B	B
PINCAGE -Ø2.15/16"- 6TBH (MH/ML)	3	1200	12	B	B	B
AIR RELEASE VALVE- 80NB	5	16250	5	B	C	C
PACKING BOX (HP)- 7.3/4", 13.1/2"RG.	3	4800	10	B	B	B
TUBING ADAPTER- 3.1/2"X 3"X 8.13/16"	4	3400	7	B	C	C
FLEX.CPLG. (UPPER)- B7, TYP.- 80MM BORE	2	5000	12	B	B	B
FLEX. CPLG. (LOWER)	2	3700	12	B	B	B
FLEX. CPLG. (LOVEJOY MODEL: RB-285-11)	1	375	14	C	B	B
RATCHET (12TBH) HARDENED 300-350 BHN	3	3600	8	C	C	C
T.T. NUT COMB. PKG. BOX-3.1/2"X1.15/16", 7"R	3	8400	7	C	C	C
PINCAGE (12TBH)- 3.3/16"SHAFT	2	3600	10	C	B	B

PINCAGE-Ø6"SFT. (15SNT/38MTPB)	1	3400	10	C	C	C
PINCAGE (15SNT)- 5" SHAFT	1	3400	10	C	C	C
TUBING ADAPTER- 3.1/2"X 3"X 8.13/16"	2	1700	7	C	C	C
DIFFUSER CONE- 24PO	2	1020	7	C	C	C
T.T.PLATE- 4"TUBE, 7"REG.	1	1620	8	C	C	C
TUBE TENSION PLATE	1	1210	8	C	C	C
TUBING ADAPTER- 3.1/2"X 2.1/2"X 8.13/16"	1	150	7	C	C	C
PACKING BOX (HP)- 6.1/2", 11.3/4"REG.	1	1500	6	C	C	C
NUT FOR ADJ. FLG CPL- 7.1/2"DIA.HD.SET.	1	1600	4	C	C	C
NUT FOR ADJ.FLG CPL- 270 MM. DIA. MT. SFT.	1	1500	4	C	C	C

Fill rate or demand satisfaction rate of each inventory item of the pump manufacturing industry is measured by the following equation:

$$FR_i = 1-\frac{\sigma_i}{Q_i}\sqrt{L_i}G(k_i) \quad \text{......................(6)}$$

where,

$$G(k_i) = \frac{1}{\sqrt{2\pi}}e^{\frac{-k_i^2}{2}} - k_i[1-\varphi(k_i)] \quad \text{......................(7)}$$

$$Q_i = \sqrt{\frac{2W_iD_i}{h_i}} \quad \text{......................(8)}$$

Safety factor 'k_i' of each item 'i' is represented as equation 9.

$$k_i = \varphi^{-1}(CSL_i) \quad \text{......................(9)}$$

The total safety stock inventory cost of the finished goods inventory items is computed by equation 10.

$$C_T = \sum_{i=1}^{N} h_i\, k_i\sigma_i\sqrt{L_i} \quad \text{...................(10)}$$

4. Results and Discussion

In this paper, three different MCIC techniques are used to analyze inventory items of finished goods of a pump manufacturing organization. The data set was previously used in conventional 'ABC' analysis and multi-criteria 'ABC' analysis based on 'R-model'. The data set consists of 30 inventory items. The periodic review system of inventory analysis has been applied for the pump manufacturing industry. Order quantity or demand of stock items, inventory consumption values in rupees and lead time in days have been considered as the stock analyzing criteria of each item in data set. MCIC analysis shows that among 30 items, 6 numbers of first ranked items are considered as 'A' category items, next 9 items are recognized as 'B' category items and remaining 15 items are termed as C category items. The 'ABC' inventory classifications with Ng-model, ZF-model and H-model are presented in Table 1. Results show that the inventory classifications using ZF-model and H-model are similar. Inventory classification using Ng-model is different from the other two classifications.

It is considered that inventory carrying cost or holding cost (h_i) for item 'i' is 20% of the unit inventory cost. The inventory set up cost or ordering cost (w_i) for item i is fixed and it is considered to Rs. 1,000/- for unit order. Cycle service level is assumed to be 99% for 'A' category items, 95% for 'B' category items and 90% for 'C' category items. Fill rate for a particular stock keeping unit is computed by equation (6) and safety stock inventory cost is calculated by the equation 10. Overall fill rate (FR_T) and total safety stock inventory cost (C_T) for a particular inventory control model ensure the performance of inventory. It is shown from the computed results that FR_T becomes 0.9767 for Ng-model and 0.9758 for other two MCIC models (ZF-model and H-model). Higher fill rate is achieved by the inventory control policy of Ng-model. The value of C_T is Rs. 959,369/- for inventory control analysis by Ng-model. The value of C_T is Rs. 958,187/- for inventory analysis using both the ZF-model and H-model. These two types of inventory analysis procedures outperform the inventory analysis by Ng-model regarding optimum safety stock inventory costs.

5. Conclusion

In this work, Inventory analyzing techniques such as Ng-model, ZF-model and H-model are utilized with the data set of a pump manufacturing organization. ZF-model and H-model represent similar ranking for 'ABC' categorization of finished goods inventory items of a pump manufacturing organization. Ng-model represents different ranking in stock keeping units from other two inventory control models. Here, Ng-model performs better than other two models where the overall fill rate of stock items has been considered. ZF-model and H-model ensure better results from Ng-model regarding total safety stock inventory cost. So, optimized inventory control policy can be achieved in terms of stock fill rate and safety stock inventory cost. Furthermore, inventory analysis for the pump manufacturing organization may be carried out with other MCIC techniques. A sensitivity analysis may also be introduced in a future work to achieve better inventory control policy.

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