A Procedure for Scheduling Inventory of an Industry by Merging Forecasting and Linear Programming

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Abstract

In this paper, we develop a mathematical model combining forecasting and linear programming for a business organization of Bangladesh to calculate optimum order quantity and inventory cost. We test the model using raw data of the demand for the raw materials and spare inventory for the industry and find out minimum total inventory cost along with ordering cost and inventory holding cost. The developed model make a match between the forecasted demand of raw materials and spare inventory and the minimum total cost of inventory. Finally comparing minimum cost, we observe that our estimated appropriate forecasting method gives optimal inventory cost.

Keywords: Forecast; Inventory management; Linear programming; Error measurement.

I. Introduction

To achieve reliable customer service with right goods, in sufficient quantities, in the right place, at the right time with minimum cost every business organization has to set policies and controls to monitor levels of inventory and determine what levels should be maintained. On the other hand, the inventory management depends on reliable forecasting for the demands of finished products and supply of raw materials. On the basis of the number of purchasing times, the inventory system is classified into single and multiple-period inventory systems. In single period inventory system the firm decides to purchase just a one-time to cover a fixed period of time and the item will not be reordered. In multiple period inventory systems an item will be available on an ongoing basis throughout the planning horizon. Multi period inventory systems is divided in to two parts known as fixed-order (economic order) quantity models (EOQ) which are event based models and fixed-time period models which are time based models. Every production department, be it a factory, a workshop or an engineering department, has to handle materials with the objective of achieving maximum customer’s service and minimum cost. Forecasting and optimization have traditionally been approached as two distinct, sequential components of inventory management. The random demand is first estimated using historical data, then this forecast is used as input to the optimization module. In particular, time series analysis is a tool for developing mathematical models by assessing past data. These models are used in making forecasting decisions where the goal is to predict the next period’s observation as precisely as possible.

There are many research articles which introduced different forecasting approaches to generate forecast of demand for inventory control purpose. In this section, some relevant articles are reviewed.

Kerkkanen et al.⁹ observed that the demand forecasts based on historical demand are usually quite accurate for relatively smooth and continuous, pattern. Chandra and Grabis⁴ studied the impact of the forecasting method selection on inventory performance. K. Skouri & S. Papachristos¹⁴ studied on a continuous review of inventory models. They considered deterioration, inventory holding cost, shortage cost and the replenishment cost which is linear dependent on the lot size. Gutiérrez et al⁷ analyzed the storage capacity of dynamic lot size problem. Computational results were reported for randomly generated problems. Forecasting and errors reduction was discussed in ¹, ⁶, ¹⁰. Impact of interaction between demand forecasting and inventory control was presented in ⁴, ¹⁶, ¹⁷. Evaluation of forecasting methods for different industries were analyzed in ², ⁵, ¹², ¹⁵. The objective of this paper is to identify an appropriate forecasting method and a linear programming (LP) model which can help the manager to achieve target of reorder quantity that is to maintain the suitable inventory level and which will give the optimal inventory cost. Here, we develop a mathematical model combining forecasting and LP for a business organization of Bangladesh which make a match between the forecasting of demand and supply and the minimum total cost of inventory. We test the model using raw data of the demand for the raw materials and spare inventory for the industry and find out minimum total inventory cost.

The rest of the paper is organized as follows. In Section II, existing forecasting techniques are discussed. In Section III we develop the linear programming (LP) model for optimal inventory cost calculation. In Section IV, we analyze a real life problem from the data of a Bangladeshi company. Section V concludes the paper.

II. Existing Forecasting Techniques

To develop a mathematical model collaborated with product manufacturing through which we can find out optimal inventory cost first we have to use forecasting methods. For forecasting the following techniques are used.

Single Moving Average (SMA): The following formula is used to compute the forecast

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\[ F_t = MA_n = \frac{\sum_{i=1}^{n} A_{t-i}}{n} = \frac{A_{t-n} + \cdots + A_{t-2} + A_{t-1}}{n} \]

where,
\( i = \) An index that corresponds to time period
\( n = \) Number of periods in the single moving average
\( A_{t-1} = \) Actual value in period \( t - 1 \)
\( F_t = \) Forecast for time period \( t \)
\( MA_n = n \) Period moving average

Double Moving Average (DMA): Five equations are used in the double moving average:

\[ M_t = F_{t+1} = \frac{Y_t + Y_{t-1} + Y_{t-2} + \cdots + Y_{t-n+1}}{n} \]

Double moving average of \( n \) periods:
\[ M^*_t = \frac{M_t + M_{t-1} + M_{t-2} + \cdots + M_{t-n+1}}{n} \]

Level at time \( t \):
\[ a_t = 2M_t - M^*_t \]
Slope at time \( t \):
\[ b_t = \frac{2(M_t - M^*_t)}{n - 1} \]
Forecast at time \( t + m \):
\[ F_{t+m} = A_t + m \cdot B_t \]

where,
\( n = \) The number of period in the double moving average
\( Y_t = \) The actual series value at time period \( t \)
\( m = \) Number of period ahead to be forecast

Weighted Moving Average (WMA): The weighted moving average can be computed by the following formula
\[ F_t = \sum_{i=1}^{n} w_i A_{t-i} + w_{n-1} A_{t-(n-1)} + w_{n-2} A_{t-(n-2)} + \cdots + w_2 A_{t-2} + w_1 A_{t-1} \]

Satisfying \( \sum_{i=1}^{n} w_i = 1 \) and \( w_1 \neq w_2 \neq w_3 \cdots \neq w_n \)

where,
\( F_t = \) Forecast for time period \( t \)
\( w_n = \) Weight for the period \( n \).

Single Exponential Smoothing (SEM): The following formula is used to compute the forecast
\[ F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \]
where,
\( F_t = \) The new smoothing value or the forecast value for time period \( t \)
\( F_{t-1} = \) Forecast for the previous time period.
\( \alpha = \) The smoothing constant \((0 < \alpha < 1)\)
\( A_{t-1} = \) Actual value in the previous period

Double Exponential Smoothing (DES): Five equations are employed:

Simple exponential smoothing forecast:
\[ F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \]
Double exponential smoothing forecast:
\[ F^*_{t} = F^*_{t-1} + \alpha(F_{t-1} - F^*_{t-1}) \]
Level at time \( t \):
\[ L_t = 2F_t - F^*_{t} \]
Slope at time \( t \):
\[ T_t = \frac{\alpha(F_t - F^*_{t})}{1 - \alpha} \]
Forecast at time \( t + m \):
\[ F_{t+m} = L_t + m \cdot T_t \]
where,
\( F_t = \) The exponentially smoothed value of \( A_t \) at time \( t \)
\( F^*_{t} = \) The double exponentially smoothed value of \( A_t \) at time \( t \)
\( F_{t+k} = \) The new smoothed value or the forecast value at the end of \( t \) period
\( \alpha = \) The smoothing constant \((0 < \alpha < 1)\)
\( A_{t-1} = \) Actual value in the previous period

Holt’s Method (HM): At the end of the \( t \) period Holt method estimate the base level \( L_t \) and the pre-period trend \( T_t \) as follows
\[ L_t = \alpha A_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \]
\[ T_t = \beta (L_t - L_{t-1}) + (1 - \beta)T_{t-1} \]
where, \( \alpha \) and \( \beta \) are smoothing constants and range is \( 0 \leq \alpha \leq 1 \) and \( 0 \leq \beta \leq 1 \)

Then the forecast \( F_{t+k} \) for \( A_{t+k} \) period is made at the end of \( t \) period by the formula
\[ F_{t+k} = L_t + kT_t \]

III. Development of Linear Programming Model in Inventory Management

In this section, we develop a mathematical model through which we find out optimal inventory cost using the forecasted demand of raw materials and spare inventory.
Figure 1 represents the flowchart of the research model. Firstly, demand of raw materials and spare inventory are collected. Collected database are analyzed through forecasting techniques. For convenience, the nearest integer values are considered. Then LP model is used for analyzed data to get the optimal inventory.

To develop the linear programming model the following notations are used:

\[
\begin{align*}
    d_t & = \text{The demand of raw materials in period } t \text{ ( } t = 1, 2, \ldots, T ) \\
    S & = \text{The warehouse storage capacity in item units} \\
    x_t & = \text{The order quantity in period } t \\
    l_t & = \text{The inventory level at the end of period } t \\
    c_t x_t & = \text{The ordering cost incurred in period } t \\
    h_t l_t & = \text{The holding cost in period } t \\
    x_t (t = 1, 2, \ldots, T) & \text{ represent the decision variables.}
\end{align*}
\]

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Taking into account the above notation the LP equation formulated here is as follows:

\[
\text{Min } z = \sum_{t=1}^{T} (c_t x_t + h_t l_t)
\]

Subject to,

\[
\begin{align*}
    l_{t-1} + x_t - d_t & = l_t \\
    x_t & \in \mathbb{Z^+} \\
    l_t & \in \mathbb{Z^+}
\end{align*}
\]

The first set of constraints in (1) represents the well-known material balance equations which determine the inventory levels from the previous decisions. The second set of constraints indicates that the sum of the inventory level and the order quantity in period \( t \) must be smaller than or equal to the storage capacity in items units, and it avoids the order quantity exceeding the free storage capacity. The last set of constraints forces the order quantities and the inventory levels to be nonnegative integers. Assumed that the inventory level at the beginning of the first period and at the end of the final period are not zero. Then the first and second set of constraints in (1) can be used to obtain the following new constraints:

\[
d_t + l_t \leq S
\]

That is, \( l_t \leq S - d_t \) \quad \text{for } t = 1, 2, \ldots, T

Therefore the problem is reformulated as shown below.

\[
\text{Min } z = \sum_{t=1}^{T} (c_t x_t + h_t l_t)
\]

Subject to,

\[
\begin{align*}
    l_0 & \neq l_T \neq 0 \\
    x_t & = l_t \\
    0 & \leq l_t \leq S - d_t \\
    x_t, l_t & \in \mathbb{Z^+} \quad t = 1, 2, \ldots, T
\end{align*}
\]

Since the inventory level must be nonnegative and considering the second constraint of (2), the problem reaches a feasible solution whenever \( d_t \leq S, t = 1, 2, \ldots, T \). The warehouse must contain \( d_t \) units of item at the beginning of period \( t \), but this would be impossible since the inventory level would exceed the capacity \( S \).

IV. Detail Experimentation for a Typical Instance

Example 1: The industry considered in this research has two sections named as Warehouse-1 and Warehouse-2 where inventories are stored. The capacity of store area for each month of the industry is 4500 units. The industry needs approximately 600-1000 and 1500-2000 units’ order of quantities for Warehouse-1 and Warehouse-2 in each month respectively. The actual demand of quantities and spare inventory with ordering cost for different warehouses and holding cost of the industry for one year period is:

| Month | Demand (In total) | Ordering Cost (Per unit) | Spare Inventory (In total) | Holding Cost (Per unit) |
|-------|------------------|-------------------------|---------------------------|------------------------|
| Jan   | 2370             | 15                      | 17                        | 1340                   | 4                      |
| Feb   | 2400             | 22                      | 20                        | 1430                   | 8                      |
| Mar   | 2410             | 17                      | 16                        | 1440                   | 6                      |
| Apr   | 2370             | 23                      | 21                        | 1300                   | 6                      |
| May   | 2450             | 25                      | 22                        | 1350                   | 9                      |
| Jun   | 2500             | 16                      | 19                        | 1250                   | 7                      |
| Jul   | 2430             | 13                      | 15                        | 1400                   | 8                      |
| Aug   | 2470             | 18                      | 17                        | 1370                   | 4                      |
| Sep   | 2560             | 19                      | 21                        | 1430                   | 3                      |
| Oct   | 2520             | 16                      | 18                        | 1260                   | 5                      |
| Nov   | 2550             | 17                      | 19                        | 1320                   | 6                      |
| Dec   | 2540             | 18                      | 20                        | 1390                   | 7                      |

Forecasts obtained from different methods: The table 2 given in the below represents the forecasts of demand of raw materials and spare inventory obtained from forecasting models such as SMA, DMA, SES, DES, WMA and HM. Since demand of materials and quantity of spare inventory must be in integer form, we have considered here approximately nearest integer of the forecasted value for the different forecasting methods in Table 2.
Table 2. Forecast values in nearest integer form

| Month | Demand of Materials | Spare Inventory |
|-------|---------------------|-----------------|
|       | Actual SMA DMA WMA SES DES Holt | Actual SMA DMA WMA SES DES Holt |
| Jan   | 2370 2400 2556 1340 1430 | 2393 2470 2405 1440 1408 1430 1403 |
| Feb   | 2400 2385 2430 2450 1430 | 1385 1520 1364 |
| Mar   | 2410 2393 2470 2405 1440 | 1408 1340 1403 |
| Apr   | 2370 2393 2399 2401 2400 2388 1300 1403 1417 1424 1430 1433 |
| May   | 2450 2393 2388 2386 2423 2357 1350 1390 1368 1362 1468 1358 |
| Jun   | 2500 2410 2432 2418 2418 2365 2395 1250 1363 1318 1353 1356 1260 1345 |
| Jul   | 2430 2440 2491 2459 2459 2472 2455 1400 1300 1198 1290 1303 1293 1274 |
| Aug   | 2470 2460 2507 2455 2445 2568 2446 1370 1333 1336 1345 1352 1166 1332 |
| Sep   | 2560 2467 2487 2464 2457 2470 2466 1430 1340 1371 1355 1361 1380 1352 |
| Oct   | 2520 2487 2518 2507 2509 2496 2534 1260 1400 1484 1406 1395 1393 1404 |
| Nov   | 2550 2517 2570 2522 2514 2631 2546 1320 1353 1331 1333 1328 1481 1323 |
| Dec   | 2540 2543 2599 2543 2532 2587 2568 1390 1337 1283 1324 1324 1235 1312 |

Error Measurement. Many common techniques such as Mean absolute deviation (MAD), Mean squared error (MSE), Mean absolute percentage error (MAPE) and Root mean squared error (RMSE) are adopted to assess the accuracy of the forecasting methods. Smaller forecasted error gives the more the accuracy of forecasting methods. Among the all technique MAPE is one of the popular forecasting measurement tools. The formula for MAPE is as bellow,

\[
MAPE = \frac{\sum |A_t - F_t|}{A_t} \times 100\%
\]

Using the formula calculated error in percentage for different forecasting techniques are given below in Figure 2.

Figure 2 shows the error percentages for different forecasting methods. It is clear that SES technique is the most appropriate technique for forecasting both for the demand of raw materials and sphere inventories since it gives the lowest error.

![Error for demand forecast in %](image)

![Error for spare inventories in %](image)

Fig. 2. Error Percentage in MAPE

Inventory Cost Calculation: For the numerical formulation of the case study of the industry considered here, we start the calculation of the equations from the beginning of the month and the demand of present month. The parameters for calculation are identified as in Table 3

Table 3. Variables and Parameter for Calculation

| Time | -1 | 0 | 1 | 2 |
|------|----|---|---|---|
| Demand | \(d_0\) | \(d_1\) | \(d_2\) |
| Warehouse 1 | \(x_{10}\) | \(x_{11}\) | \(x_{12}\) |
| Warehouse 2 | \(x_{20}\) | \(x_{21}\) | \(x_{22}\) |
| Spare Inventory | \(l_{-1}\) | \(l_0\) | \(l_1\) | \(l_2\) |

Ordering cost for every month is different depending on their circumstances. The cost parameters for calculation are identified as in Table 4.

Table 4. Cost Parameters for Calculation

| Time | 0 | 1 | 2 |
|------|---|---|---|
| Warehouse 1 | \(c_{10}\) | \(c_{11}\) | \(c_{12}\) |
| Warehouse 2 | \(c_{20}\) | \(c_{21}\) | \(c_{22}\) |
| Holding Cost | \(h_0\) | \(h_1\) | \(h_2\) |
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Here,

\[ x_{10}, x_{11}, x_{12} = \text{Order quantities for October, November and December month of Warehouse 1} \]
\[ x_{20}, x_{21}, x_{22} = \text{Order quantities for October, November and December month of Warehouse 2}. \]

\[ I_{-1}, I_0, I_1, I_2 = \text{Spare inventory at the end of September October, November and December}. \]

\[ d_0, d_1, d_2 = \text{Demands of material for the October, November and December}. \]

\[ c_{10}, c_{11}, c_{12} = \text{The ordering cost per unit for October, November and December of Warehouse 1}. \]

\[ c_{20}, c_{21}, c_{22} = \text{The ordering cost per unit for October, November and December of Warehouse 2}. \]

\[ h_0, h_1, h_2 = \text{The holding cost per unit for October, November and December}. \]

Using the all above parameters the equation models that can solve problem of raw materials and inventory control of the industry can be summarized as bellow:

\[ \text{Min } z = c_{10}x_{10} + c_{11}x_{11} + c_{12}x_{12} + c_{20}x_{20} + c_{21}x_{21} + c_{22}x_{22} + h_0I_0 + h_1I_1 + h_2I_2 \]

Subject to,

\[ x_{10} + x_{20} + I_{-1} = d_0 + I_0 \]
\[ x_{11} + x_{21} + I_0 = d_1 + I_1 \]
\[ x_{12} + x_{22} + I_1 = d_2 + I_2 \]
\[ x_{10} + x_{20} + I_{-1} \leq 4500 \]
\[ x_{11} + x_{21} + I_0 \leq 4500 \]
\[ x_{12} + x_{22} + I_1 \leq 4500 \]
\[ 600 \leq x_{10}, x_{11}, x_{12} \leq 1000 \]
\[ 1500 \leq x_{20}, x_{21}, x_{22} \leq 2000 \]
\[ x_i, I_i \in \mathbb{Z}^+ \]

Using TORA Software and choosing Linear Programming we get optimal order quantities for every warehouse for the last three months using all forecasting methods. The results with ordering and holding costs are given as Table 5 below:

We observe that, the SES method yields the lowest inventory cost as it was judged the most appropriate forecasting method for the industry.

**Example 2.** Let, The industry considered in typical example 1 uses three warehouses and it needs approximately 600-1000, 800-1200 and 1000-15000 units’ order of quantities for Warehouse-1, Warehouse-2 and Warehouse-3 in each month respectively. Let, \( x_{30}, x_{31}, x_{32} \) be the order quantities and \( c_{30}, c_{31}, c_{32} \) be the ordering cost per unit for Warehouse-3 for the month October, November and December. We consider the ordering cost and holding cost per unit as follows:

\[ c_{10} = 16 \quad c_{11} = 18 \quad c_{12} = 25 \]
\[ c_{20} = 15 \quad c_{21} = 22 \quad c_{22} = 17 \]
\[ c_{30} = 21 \quad c_{31} = 20 \quad c_{32} = 15 \]
\[ h_0 = 8 \quad h_1 = 7 \quad h_2 = 5 \]

Solving all LP problems, we get the output as summarized in Table 6.

**Table 6. Inventory cost calculation for three warehouses**

| Forecasting Methods | SMA | DMA | WMA | SES | DES | HM |
|---------------------|-----|-----|-----|-----|-----|-----|
| \( x_{10} \)       | 600 | 600 | 600 | 600 | 600 | 600 |
| \( x_{11} \)       | 670 | 617 | 649 | 647 | 641 | 717 |
| \( x_{12} \)       | 600 | 600 | 600 | 600 | 600 | 600 |
| \( x_{20} \)       | 947 | 1031| 958 | 943 | 909 | 1006|
| \( x_{21} \)       | 800 | 800 | 800 | 800 | 800 | 800 |
| \( x_{22} \)       | 800 | 800 | 800 | 800 | 800 | 800 |
| \( x_{30} \)       | 1000| 1000| 1000| 1000| 1000| 1000|
| \( x_{31} \)       | 1000| 1000| 1000| 1000| 1000| 1000|
| \( x_{32} \)       | 1127| 1151| 1134| 1128| 1041| 1157|
| Ordering Cost      | 139970| 140636| 139862| 139511| 142592| 142151|
| Holding Cost       | 27356 | 27604| 27199| 27076| 27686| 27053|
| Inventory Cost     | 167326| 168240| 167061| 166587| 170278| 169204|

From Table 6, it is also clear that the SES methods yields the minimum inventory cost. Therefore, we recommend that, the manager of the industry will first forecast for raw materials and spare inventory by SES method and then will optimize the inventory cost by applying the developed LP.

**V. Conclusion**

The aim of this paper was to develop a mathematical model combining forecasting and linear programming for a business organization of Bangladesh. For this, we first applied forecasting models such as single-moving average (SMA), double-moving average (DMA), single-exponential smoothing (SES), double-exponential smoothing (DES), weighted moving average (WMA) and Holt’s method (HM) to forecast the demand of raw materials and spare inventory. Using the error measurement techniques, we
observed that SES produced the most reliable forecasts. We then developed an LP model to minimize the inventory cost and calculating the optimal order quantity. We tested the model using raw data of the demand for the raw materials and spare inventory for the industry and find out minimum total inventory cost along with ordering cost and inventory holding cost and observed that the minimum inventory cost was yielded by SES.

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