Assessing Forecasting Techniques & Stock Replenishment Approaches for Optimal Inventory of Electronic Spare Parts

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Abstract

Inventory, a core component of the supply chain, contains several sub-items that depend onvarious factors. During pandemic situations like COVID-19, when customer demand is uncertain, keeping inventory is also very costly. It becomes quite difficult to maintain an adequate inventory level. Therefore, this study primarily focuses on maintaining the inventory level as efficiently as possible for the electronic component retailers in Bangladesh. To solve major issues regarding inventory, i.e., overstock, under stock, and inadequate forecasts, optimal systems have been proposed that include the application of various forecasting methods and replenishment guidelines. By utilizing selected forecasting techniques (i.e., Fuzzy logic, Simple exponential, and Adjusted exponential smoothing) and the proposed (s, Q) replenishment policy, around 14.3% of total inventory costs were saved. In addition to that, this research also highlights FSN analysis on selected items for better inventory flow. By implementing the proposed inventory policy that addresses all constraints and issues, the store can manage inventory effectively and efficiently.

Keywords
Inventory management, uncertain demand, fuzzy logic and replenishment policy.

1. Introduction

Inventory management under uncertain demand is a well-known event that is still going on at this time. It is a wide research field in which many research works have been done for the welfare of the world economy. However, a few inventory policies and approaches have been developed to address this matter, there are still some gaps in situations where it becomes difficult to maintain the inventory. For example, complications arise in the case of tackling stock out and overstock. "Black swan event" is an unexpected occurrence that causes severe damage to the world economy, (CFI 2020). Inventory management in such situations is a challenging task. A world crisis like COVID-19 has led to disrupting the smoothness of the supply chain which leaves no company unaffected. Even global giant Apple has forecasted a 10% reduction in iPhone shipments, (Potuck 2020). Given the heavy reliance on Chinese manufacturers, the majority of consumer goods companies have been severely affected by factory closures and slowed production. Meanwhile, some products have faced a tremendous decline in demand whereas some products have gained a skyrocketing demand.

In such circumstances, we have focused on the products that are facing severe uncertainty in their demand. The main cause of this fuzzy situation is due to irregular demand quantity, lead time variance, and lack of proper inventory management. Often uncertainty may be associated with these variables. In the conventional inventory model, uncertainties are treated as randomness and are handled by probability theory, (Rachmania and Basri 2013). If demand is underestimated, sales can be lost due to the supply of goods. On the contrary, if demand is overestimated the supplier is left with a surplus that can also be a financial drain. Through this study, we have highly emphasized creating a dynamic procedure of keeping a steady inventory. With the collaboration of different forecasting techniques and inventory policies, a clear path for inventory optimization has been established.

1.1 Objectives

The study problem, which this paper seeks to address, is to identify uprising problems in demand forecasting and inventory management for "Techno Electronics"a spare-parts retail shop. The main contribution of this work is to establish an outline between the existing and proposed systems that emphasizes depreciating total cost. The main objectives of this study are:

- To fulfill uncertain demands by selecting a proper forecasting method.
- To establish an efficient inventory level for avoiding overstock and stock out.
- To reduce the inventory cost

2. Literature Review

Several approaches can be followed to improve inventory to a certain level. As a starting point, economic order quantity and lot-based ordering can be used to maintain an improved version of inventory in the COVID-19 situation, (Rojas et al. 2021). With available data and real-time evaluation on military inventory (Bean et al. 2016) conducted research on inventory management with uncertain demand where fuzzy logic, stochastic, mixed programming problems, and inventory models were used as a solution tool.

This paper deals with the uncertainty created by extreme events in the military field where minimization of cost, shortage, and stock while the incorporation of demand uncertainty are the key focuses. A mathematical model with the collaboration of crisp and fuzzy constraints helped determine inventory level ammunition and rations during military operations. There are also several approaches considering replenishment techniques for inventory management. As an example, (Rachmania and Basri 2013) conducted research on Pharmaceutical Inventory for a hospital supply chain where they used (s, Q), (R, S) policies and forecasting methods to develop a solution for overstocking, unjustified forecasting in pharmaceutical inventory. Following the replenishment of inventory, research on inventory system with the periodic review (r, Q) focused on the implementation of asymptotic renewal theory to estimate the reorder point and cycle stock holding cost, (Johansen and Hill 2000). When dealing with periodic review the involvement of Fuzzy logic theory was used for the solution of optimum cost inventory level and shortage quantity,(Lin 2008). Besides this several types of research have been conducted on replenishment methods, for example, (Mohebbi and Posner 2002) used level crossing formulation (s, nQ) policy on continuous review model with multiple order outstanding.Several types of research have also been considered in the determination of proper forecasting using actual data (Kalekar and Bernard 2004), (B.Koehler et al. 2001) have studied the Time series forecasting method for demand forecasting using Holts-winter exponential smoothing. For further clarification of the proposed model error measures like MAPE, RAE and MSE have been used.

Although there are some researches on different forecasting methods, the Fuzzy logic method is considered a new game-changer in dealing with uncertainty (Manoj and Shah 2014) conceptualize the use of fuzzy logic in determining short-term load forecasting. The literature discusses how they used MATLAB SIMULINK software for evaluating load forecast on basis of various environmental factors like Time, Temperature, and Similar previous day load. Following (Giannoccaro et al. 2003) inventory management with the conception of echelon stock and fuzzy set theory to model the uncertain market demand and inventory cost. While describing the methodology Fuzzy logic theory was applied to construct a model under uncertain market demand that aims to determine the very nature of fluctuating demand. (Peidro et al. 2009) found a way to maintain the supply chain planning by taxonomy model where artificial intelligence, fuzzy simulation, and hybrid method were used for determining the optimal results. (ZIUKOV 2015) attempted to create a model for inventory management under uncertainty.

The study focuses on the use of the fuzzy sets in determining inventory level with the help of economic order quantity (EOQ) and economic production quantity (EPQ).(Gallego et al. 2007) recommended an analytical solution to maintain the inventory in highly uncertain demand where they worked on a negative safety stock resulting in high service level during demand fluctuation. Following (Woosley and Wiley-Patton 2009) researched supporting inventory in health care supply chain using (s, S) inventory model as their key solution to control the demand refill.

3. Data & Methodology

The methodology comprises a sequential working process in which it moves forward by completing each segment and its sub-categories. The following Figure 1 illustrates the methodology that focused on delivering an optimal solution to inventory management.

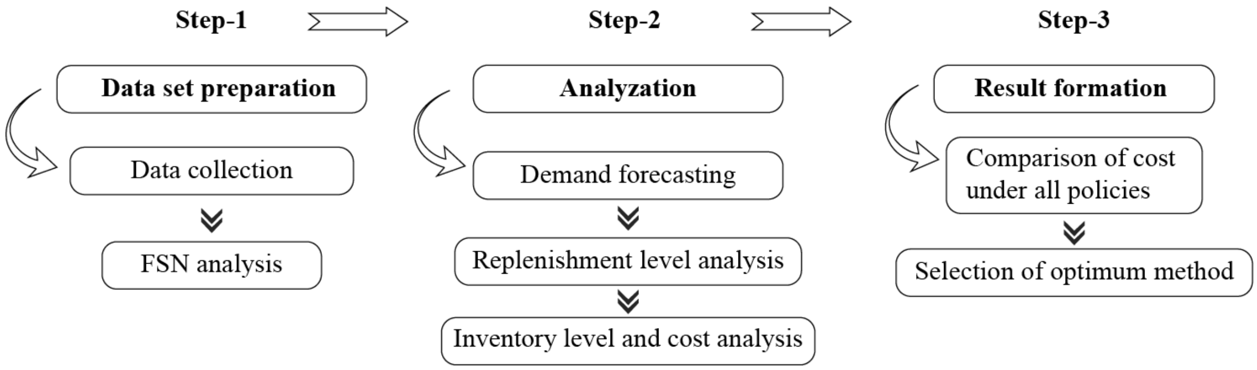

Figure 1. Research methodology

Considering the key objectives, i.e., optimization of the inventory, we have decided to divide our total working process into three segments. This process includes preparation of data sets, analyzation of those data and result determination upon cost basis analysis.

I. Data set preparation:
The following step contains a set of preliminary works like data collection, a proper understanding of the collective data, existing policy, and data sorting. Regarding the size of data samples taken from "Techno Electronics" that helped us to determine the existing policy which was naive method. Furthermore, to assist with the research, we decided to collect demand data for several products under the existing policy. Sample data had been collected on a weekly basis for six months in the span of June to December 2020. The source of data used for this study primarily focused on the demand of ten products in that time period. These data were collected through questionnaires including information like demand, safety stock, order quantity, reorder point, lead time, unit cost, and other relative cost.

The whole data was then evaluated through FSN analysis and got sorted (Kumar et al. 2017). With FSN analysis, products with the greater consumption rate were selected as F(Fast moving) category and less consumed products were given the S (Slow moving) category. During the analysis we encountered some non-moving products whose consumption rate was below S category. For achieving good results, we decided to focus on F&S category products leaving N category behind. From the consideration of these

Table 1. Item selection under FSN analysis

Demand level	Selected items	Total percentage
Fast-moving (F)	Remote, LED lamp, Flyback transformer	71.01%
Slow-moving (S)	LED board, Transformer, TV kit	25.82%
Non-moving (N)	TV display, Magnetron, Solar battery, Solar pane	3.17%

Table 1 displays the proportion of F, S categories scored 71.01% and 25.82% respectively, where demand for non-moving products was around 3.17%.

We focused on six selected products from FSN analysis by comparing their actual demand and the forecast demand under existing method, where we found significant variations between them. Figure 2 visualizes the comparison between the actual demand and the forecasted demand under existing method

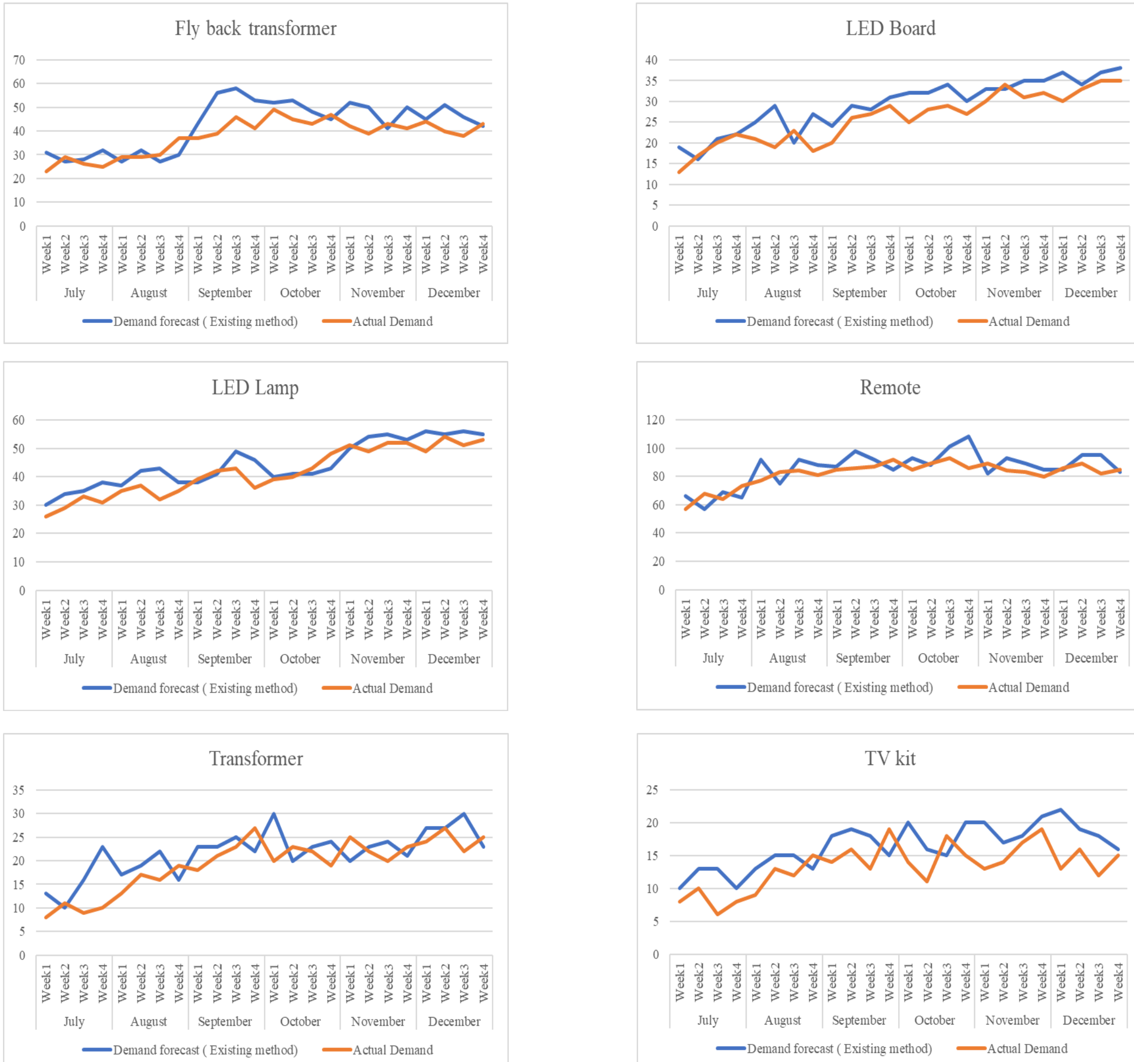

Figure 2. Demand pattern of selected products

II. Analyzation:

In this section the collected data were analyzed through several preceding steps followingDemand forecasting using selected methods, Inventory level under replenishment policy, Inventory cost analysis. At first,forecast analysis for two categories of products had been conducted through several methods like Exponential smoothing,Adjusted exponential smoothing, and Fuzzy logic analysis. After developing forecasts for twenty-eight weeks error analysis was done for further justification of the right forecasting technique under each product.

In addition to the prior phase, optimization of the inventory was taken under consideration. We calculated replenishment levels for the reviewed forecasting method under both continuous review policy (s, Q) and periodic review policy (R, S)(Chopra and Meindl 2015).

Finally, we analyzed both inventory level and cost for the selected replenishment policies. Considering the economic order quantity achieved for both replenishment policies and ordering level, we evaluated the total cost assigned to each product.

III. Result formation:
In this section, the total cost for six selected products were compared between their existing and proposed cost. The comparison between costs under all policies helped us to gain overall visualization on gross margin. Finally, we have selected a suitable technique for inventory management considering the optimum cost.

3.1. Demand forecasting:

In this research work, we emphasize applying different forecasting methods such as Simple Exponential smoothing, Adjusted Exponential smoothing (Halt's Method) & Fuzzy Logic and show the different forecasting values by comparing the data, which leads to the best-forecasted values through the individual method's formula. The formula of different forecasting methods, which are used here are given below:

Simple Exponential Smoothing (Russell and W Tsylor lll 2010):

$$F_{t+1} = \alpha D_t + (1-\alpha)F_t \quad (1)$$

Usually, the value of α lies between 0.0 and 1.0, which reflects the weighted priority to the most recent demand data.Whenα is greater than 0.6 or closer to 1 the difference between the results is often overwhelming. For this study we selected 0.2, 0.3 and 0.5 as the value of α for consistent result.

Adjusted Exponential Smoothing (Halt's Method) (Russell and Tsylor 2010):

$$AF_{t+1} = F_{t+1} + T_{t+1} \quad (2)$$

$$T_{t+1}= \beta(F_{t+1}-F_t) + (1-\beta)Tt \quad (3)$$

The adjusted exponential smoothing forecast consists of the exponential smoothing forecast with a trend adjustment factor added to it. The trend-corrected exponential smoothing (Holt's model) method is appropriate when demand is assumed to have a level and a trend in the systematic component, but no seasonality. Here 0.2, 0.3, 0.4 values were provided for Trend factor (β) and 02,0.3 and 05 value for smoothing constant (α) that was found from previous exponential smoothing method.

In the above equations (1), (2) & (3), the term F_t refers to a previously determined forecast for the present period and F_{t+1} describes forecast for the following period. Here D_t stands for Actual demand. T and T_t represent trend factors for the present and past periods. α is considered as a smoothing constant and β is a smoothing constant for trends.

Forecasting using Fuzzy logic (Kaufmann and Gupta 1988):
There are many different types of fuzzy sets, and how quantities are described will determine the types and shape of the membership function being used. The term fuzzy refers to things that are not clear or are vague. In the Boolean system, the absolute truth value is represented by 1.0 where 0.0 donates the absolute false value. But in the fuzzy system, there is no logic for the absolute truth or false value. Here, intermediate values are presented as partially true and false.

Here we used different factors like previous demand, pandemic intensity, service level, and other considerable ones in fuzzification. For calculation purposes, we used MATLAB simulation software for the fuzzification method (Figure 3). Some rules and methods were established depending on the factors to achieve the expected forecast demand. Primarily three deciding factors were determined and depending on their nature different kinds of membership functions were takeninto consideration. For instance,the gaussian functionswere used to reflect the pattern of previous demand and pandemic intensity, where else triangular membership function was used for service level. For individual factors a range of parameters were set to achieve the future forecast (Figure 4).

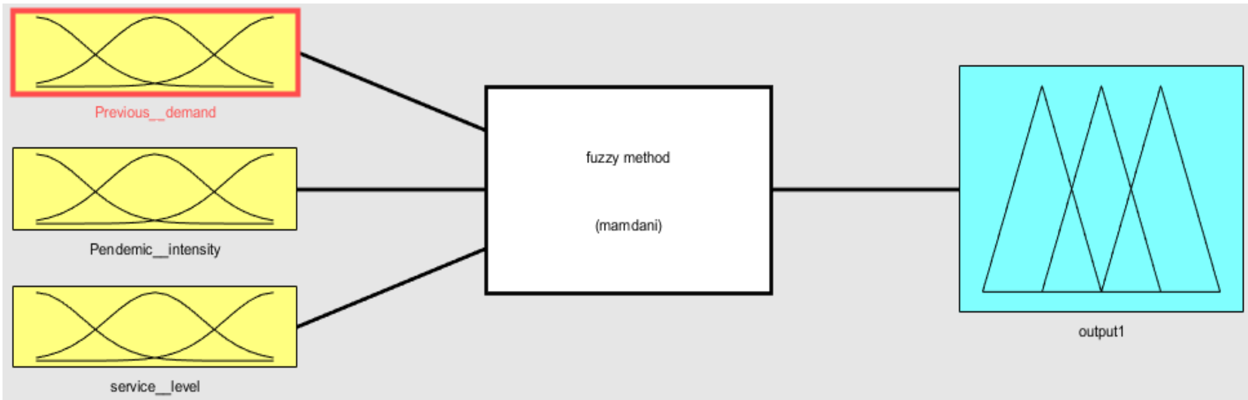

Figure 3. Rules for Fuzzification in MATLAB

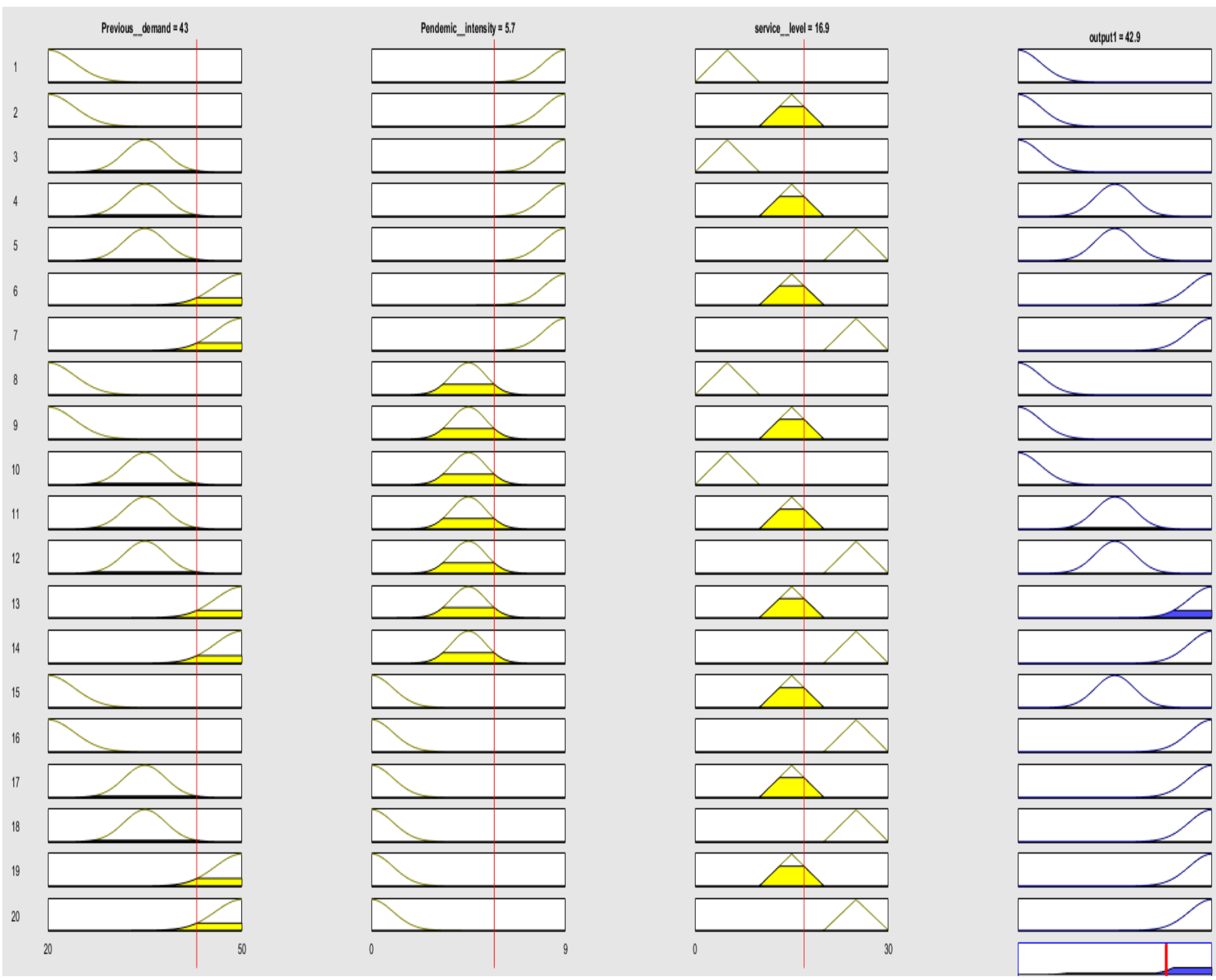

Figure 4. Graphical output of Fuzzification process in Matlab

After the determination of future forecast under 3 forecasting methods forecasting errors were conducted to justify the accuracy. Several error evaluations like MAD, MSE, and MAPE were incorporated in this study. Depending on the error resultforecast methods were selected for individual products. Then the values were taken into consideration for the next stage i.e., replenishment level analysis.

3.2. Inventory control and cost analysis

Replenishment level analysis:
In the study, two replenishment policies were used for determining the safety stock under different cycle service levels.They are as follow-

I. Continuous review policies
II. Periodic review policies

Inventory under Continuous (s, Q) policy.(Chopra and Meindl 2015)

$$SS = F_S^{-1}(CSL) \times \sigma_L = NORMSINV(CSL) \times \sqrt{L}\sigma_D \tag{4}$$

$$ROP = D_L + SS \tag{5}$$

$$Q^* = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2DS}{hC}} \tag{6}$$

$$\text{AIL} = \frac{1}{2}Q + SS \tag{7}$$

Inventory under Periodic review (R, S) policy.(Chopra and Meindl 2015)

For equations (4 to 12), we had considered some common assumptions such as CSL for cycle service level, SS for

$$SS = F_S^{-1}(CSL) \times \sigma_{R+L} = NORMSINV(CSL) \times \sigma_{R+L} \tag{8}$$

$$OUL = D_{R+L} + SS \tag{9}$$

$$\text{Q} = \text{R}\times\text{D} \tag{101}$$

$$\text{AIL} = \frac{1}{2}DR + SS \tag{112}$$

$$\text{R*} = \sqrt{\frac{2A}{hCD}} \tag{12}$$

safety stock, reorder point considered as ROP. Demand and lead-time were considered as D and L respectively. Q and AIL stand for lot-based quantity and average Inventory level. Here R denotes review interval, C and h were considered as unit-cost of a product, and annual holding cost as a fraction of product cost.

Cost analysis. (Chopra and Meindl 2015)
In this section, the total cost related to individual items were calculated by considering their Holding cost (H), Ordering cost (S), Unit cost (C), Ordering quantity (Q).

$$\text{Annual material cost} = CD \tag{13}$$

$$\text{Annual ordering cost} = \left(\frac{D}{Q}\right)s \tag{14}$$

$$\text{Annual holding cost} = \left(\frac{Q}{2}\right)H = \left(\frac{Q}{2}\right)hC \tag{15}$$

$$\text{Total annual cost, } TC = CD + \left(\frac{D}{Q}\right)s + \left(\frac{Q}{2}\right)hC \tag{16}$$

4. Results

To gain an overview of the data used in this study, a summary of the results was created. An overview of the forecasting selection process alongside their accuracy, inventory selection process, and all-over cost analysis were represented sequentially. In addition, the comparison between selected processes costs provides a clear mapping of sequential activities involved in inventory management.

4.1 Demand forecasting:

To control appropriate inventory, forecasting is an essential element, (Rachmania and Basri 2013). The major forecasting techniques used to tackle uncertainty are Simple exponential smoothing (SES), Adjusted exponential smoothing (AES), and Fuzzy logic. These methods were applied to fast and slow-moving items selected by FSN analysis. Table 1 shows the selected items for forecasting analysis

Now, by adapting forecasting techniques, twenty-eight week's forecasts were prepared. We had selected the proper forecasting techniques for each product by evaluating individual errors, where the minimum errors had been prioritized. Table 2 describes the selected forecasting techniques for the products. Considering error values Fuzzy logic was selected for the Flyback transformer, LED lamp, and Transformer. Adjusted exponential smoothing was selected for LED board and Remote. Where else Simple exponential smoothing was chosen for TV kit. It was concluded that Fuzzy logic and Adjusted exponential smoothing were more preferable in demand forecasting for uncertain situations.

Table 2. Demand forecasting for electronics spare parts

Product	Forecasting method	MAD	MAPE (%)	MSE
Remote	SES (α=0.5)	4.43	5.55	26.84
	AES (α=0.5,β=0.3) ♦	4.08	5.16	23.15
	Fuzzy logic	4.22	5.32	29.25
LED lamp	SES (α=0.5)	3.55	9.12	16.43
	AES (α=0.5,β=0.4)	2.95	7.66	11.95
	Fuzzy logic ♦	2.57	6.71	11.80
Flyback transformer	SES (α=0.5)	3.22	8.56	15.49
	AES (α=0.5,β=0.4)	3.27	8.67	13.62
	Fuzzy logic ♦	3.14	8.64	13.29
LED board	SES (α=0.5)	2.58	11.55	8.97
	AES (α=0.5,β=0.2) ♦	2.37	9.95	7.70
	Fuzzy logic	2.85	11.76	12.28
Transformer	SES (α=0.5)	2.61	14.02	9.13
	AES (α=0.5,β=0.3) ♦	2.48	13.38	8.57
	Fuzzy logic	2.43	14.77	8.89
TV kit	SES (α=0.3) ♦	2.33	17.78	8.10
	AES (α=0.3,β=0.2)	2.36	18.18	7.89
	Fuzzy logic	3.23	25.91	16.13

4.2. Inventory control and cost analysis:

Following the above forecasting data, replenishment levels for the six items were calculated through Continuous review policy (s, Q) and Periodic review policy (R, S). In (s, Q) review policy the inventory is replenished with a predetermined quantity (Q*) when inventory drains to a certain point called Reorder point (ROP). For periodic review, the inventory is replenished after every review interval (R, unit in time) by raising the inventory position to order up to level (OUL), (Chopra and Meindl 2015). Cycle service level (CSL) were considered as same as the existing policy, which differs as per product. A summary of inventory replenishment levels has been represented in the following Tables 3 & 4.

Table 3. Replenishment level for the products under (s, Q) policy

Product	D	CSL (%)	D_L	σ_L	Ss	ROP
Remote	81.13	95.73	27	5	9	37
LED lamp	43.45	95.84	14	5	9	23
Fly back transformer	39.16	95.15	13.1	4.5	7.5	20.6
LED board	25.13	95.22	8	4	6	14
Transformer	18.62	96.32	6	3	6	12
TV kit	12.80	94.18	4	2	3	7

Table 4. Replenishment level for the products under (R, S) policy

Product	D	CSL (%)	D_{R+L}	σ_{R+L}	Ss	OUL
Remote	81.13	95.73	327	19	33	360
LED lamp	43.45	95.84	175	17	30	205
Fly back transformer	39.16	95.15	158	16	26	184
LED board	25.13	95.22	101	12	20	122
Transformer	18.62	96.32	75	12	21	96
TV kit	12.80	94.18	52	6	9	61

From Tables 3 & 4 safety stock and replenishment level were determined under the same cycle service level of existing method. A significant difference after calculating the replenishment levels, we analyzed the total cost related to individual items to differentiate values for each replenishment policy. Table 5 describes the cost difference under each policy and Figure 5 visually represents the cost difference among existing and selected policy.

Table 5. Final cost reduction for the selected products

Product	CSL (%)	Cost under existing policy	Cost under (s, Q) policy	Cost under (R, S) policy
Remote	95.73	168562	159197	159200
LED lamp	95.84	163473	159339	159396
Flyback transformer	95.15	461639	425876	425927
LED board	95.22	914440	786880	786941
Transformer	96.32	86630	74543	74584
TV kit	94.18	870226	678685	678727
Total		2664970	2284520	2284775

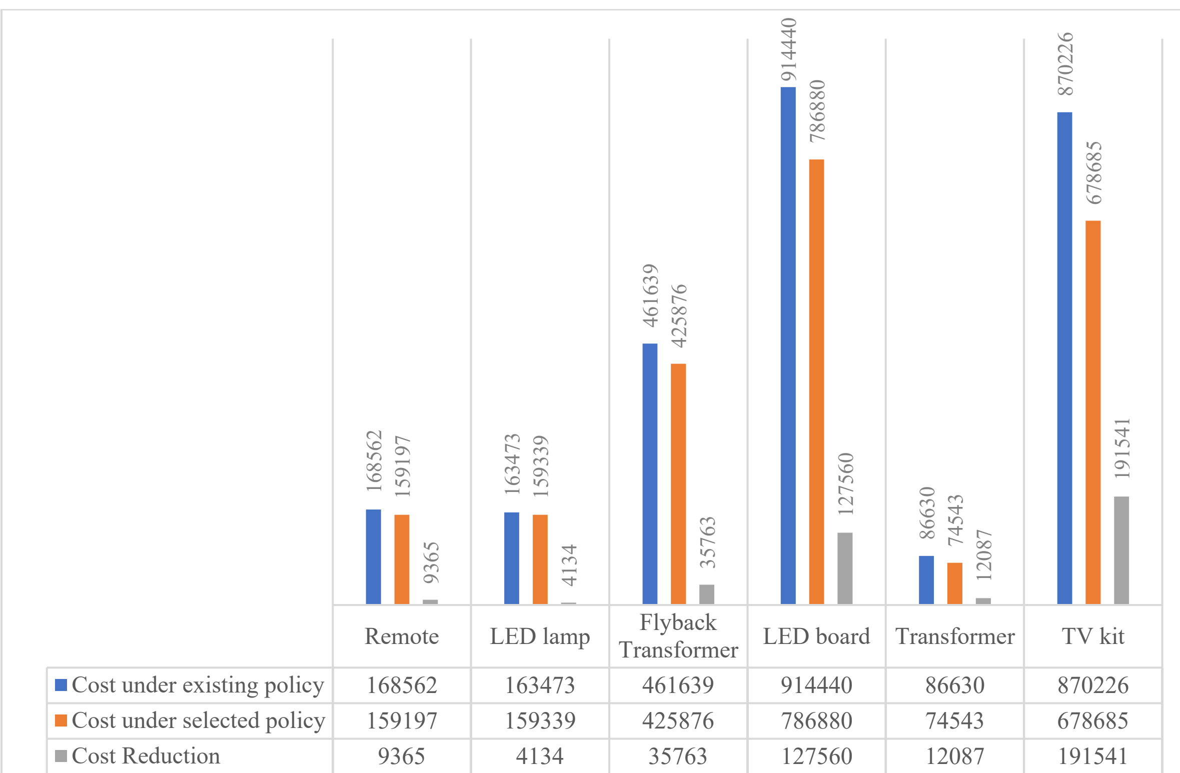

Figure 5. Graphical representation of reduced cost for the products

Based on the calculation above, we can see the differences in total cost under existing and proposed policies. The existing policy carries a higher cost than the other two policies (s, Q) and (R, S). Among the three policies continuous review policy i.e. (s, Q) has the lowest cost. Thus, it is better to adapt (s, Q) policy for inventory maintenance.

5. Conclusion

In the introduction section of this paper, we have identified the key goals i.e., cost minimization of inventory with proper forecasting and replenishment policies. Regarding this, we have come to an optimum solution for inventory management. From the above cost comparison, we can visualize the differences in values for each policy. Historical data of inventory showed that existing policy followed by "Techno Electronics" results in a higher cost than the proposed policies. With the same cycle service level (CSL), continuous review policy (s, Q) has saved up to 14.3% of inventory cost. Considering this value several forecasting methods have been undertaken to seek the most suitable one for forecasting. Where adjusted exponential smoothing and fuzzy logic method showed fewer errors than the other ones.

This study has emphasized how to fulfill the Cycle service level (CSL) under uncertain demand using the combination of forecasting techniques and replenishment policies. To maintain the inventory efficiently our proposed model would be more effective than the existing one. By exploring the factors responsible for inventory depreciation, "Techno Electronics" can apply the proposed model for efficiency. The study can be expanded by linking more suitable simulation-based forecasting methods and hybrid replenishment policies. More optimum policies can be used to increase the cycle service level.

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