STATISTICAL ANALYSIS OF THE BULLWHIP EFFECT IN A SPECIAL SUPPLY CHAIN STRUCTURE

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Abstract - The bullwhip effect (BWE) argues that demand variability grows as customer orders go up the supply chain. A specific two-stage supply chain with one manufacturer and one retailer is used to forecast, quantify, and measure the bullwhip effect. A single product is assumed relative to ABC analysis which represents the highest annual consumption in class "A" items. The retailer uses "order-up-to" inventory policy for replenishment of stocks and utilization. Statistical analysis is employed. Retailers utilize moving average and exponential smoothing forecasting algorithms to predict demand in advance. The findings indicate that the magnitude of the increase in variability is dependent on the forecasting method used. Furthermore, information sharing and customer loyalty are regarded as two methods for reducing the bullwhip effect.

Keywords - Supply Chain Management, Bullwhip Effect, Exponential Smoothing Forecast, Moving Average Forecast, ABC Analysis

I. INTRODUCTION AND RELATED WORK

Supply chain management (SCM) is the coordination and linking of production plants, retailers, wholesalers, and distribution centers [1,2,3]. The advantage of having proper SCM is to reduce expenses, increase revenues, and affect the bottom line of the company.Supply chain companies contract with more than one supplier to provide orders requested by customers. If the forecasting is too high, it will cause loss to the company. In addition to the accumulation of products not sold which will add inventory cost. On the other hand, when the forecasting is very low, the company will not be able to fulfill all incoming orders. "Bullwhip effect" suggests that demand variability increases as customer orders pass up stream through a supply chain [4]. The bullwhip effect is concerned for many suppliers , manufacturers, and retailers because the increased demand variability in the order process (1) requires to increase safety stock in order to maintain a given service level, (2) also, increased costs, and (3) lead to an inefficient use of resources, such as labor and transportation [4]. To reduce the impact of the "bullwhip effect" in a supply chain, its causes must be studied and understood. These are demand forecasting, batch ordering, price variations, and lead time.

*Chen, F., et al. (1999),*Shows that the supply chain has two stages (maker and retailer) that use demand forecasting techniques like exponential smoothing and moving average forecast to calculate inventory levels and order quantities. This study quantifies the increase in supply chain variability at every stage [4]. A two-stage supply chain including demand forecasts and order lead times was explored *by Chen et al. (2000).* It explains how to reduce the bullwhip effect by centralizing demand data[5]. *Chen, F., J.K. Ryan, and D. Simchi-Levi (2000)* quantified the bullwhip effect in simple two-stage supply chain. Bullwhip effect is caused by using retailer exponential smoothing method. A correlated and linear trend demand processes are considered [5]. *Wright, D. and X. Yuan (2008)* research was concentrated on bullwhip effect which is explored under the Holt and Brown forecasting methods and the ordering policies. In a four-stage supply chain, simulation analysis is utilized to determine the impact of enhanced forecasting methods [6]. *Sunil Agrawal et al. (2009)* investigated the bullwhip effect and on-hand inventories. The supply chain has two tiers (warehouse - retailer). The results demonstrate that reducing lead time is more useful than sharing knowledge in reducing the bullwhip effect[7].*Ghaffari, M. and N. Javadian (2013)* proposed a new methodology based on demand forecasting technique and uses a simple moving average to reduce the bullwhip effect in a multi-echelon and multiple products supply chain with correlated market demands.The result showed that using a moving average forecast demand for smooth product market demand, retailers bullwhip effect in a multi-product supply chain is unavoidable [8].*Michna, Z. and P. Nielsen (2013)* The supply chain topology in this study is a simple two-stage with one supplier and one retailer. In this two-stage model, we also measure the bullwhip effect when demand and lead times are projected. Under uncertainty conditions it is necessary to estimate the lead time for a member of the supply chain to place an order. The results shown that lead time forecasting is a critically contributing cause to the bullwhip effect and its impact cannot be omitted in the management of supply chains [9]. *Sadeghi, A.,(2015)* considered structure of supply chain as a two-product (Demands of the products are correlated) and two-echelon is considered in order to quantify the bullwhip effect. The bullwhip effect measure has been done when two main forecasting methods Exponential smoothing and Moving average forecast

are used. In addition, a cost analysis is conducted based on shortage and holding cost under different bullwhip effect measures. The result shown that moving average forecast creates less fluctuation than exponential smoothing in the supply chain. When smoothing constant and lead-time increased, the difference between bullwhip effects of two products increased. So, smaller measure of α and L is better for stability of bullwhip effect of both the products, simultaneously [10].According to *Zarandi, at.el (2008)*, the bullwhip effect is decreased in multi-stage supply chains where lead time, demand, and orders are ambiguous. To replicate the bullwhip effect, a modified Hong fuzzy time series is employed. Then, for defuzzification, a neural network is deployed.An agent-based system is developed to reduce the bullwhip effect and total cost. Discovering the best available ordering policies show that the proposed system excel than the analytical system [11].

Customer Relationship Management (CRM) is a model that is used to manage the interaction of the company with the potential and current customers. Data analysis is often used to identify and improve the relationship between the company and the customer [12].When CRM is integrated in supply chain, many benefits would be gained. It can be summarized as; "the right product will be reached for the right customer, in the right place, at the right time, in the right quantity, in the right condition, and at the right cost"[13, 14]. Therefore; inventory will be reduced practically by half, increase on-shelf availability to almost one hundred percent, reduce the overall cost of supply chain, increase the accuracy of the demand forecast, and growth of revenue. Indeed, the bullwhip effect will be decreased.

II. THE PROPOSED METHODOLOGY

A special product is assumed relative to ABC analysis -which is a technique for inventory categorization. Specifically, class "A" product has been selected because it has 80% of the annual demand consumption. Demand is forecasted using moving average and exponential smoothing forecasting techniques. Occasionally, when retailers submit orders with manufacturers, errors occur and demand increases. This will result in a cost increase, an increase in inventory, and a drop in profitability.So, reducing these errors is important in order to get the best supply chain. Mean square error (MSE), mean absolute deviation (MAD), and mean absolute percentage error (MAPE) are used to quantify andmeasure the percentage of error in each forecasting method and see what the case that has the lowest and higher predicting error. Then, information sharing and customer loyalty considered as two means for make reduction to bullwhip effect. Figure (1) shows the flow chart of the proposed methodology.

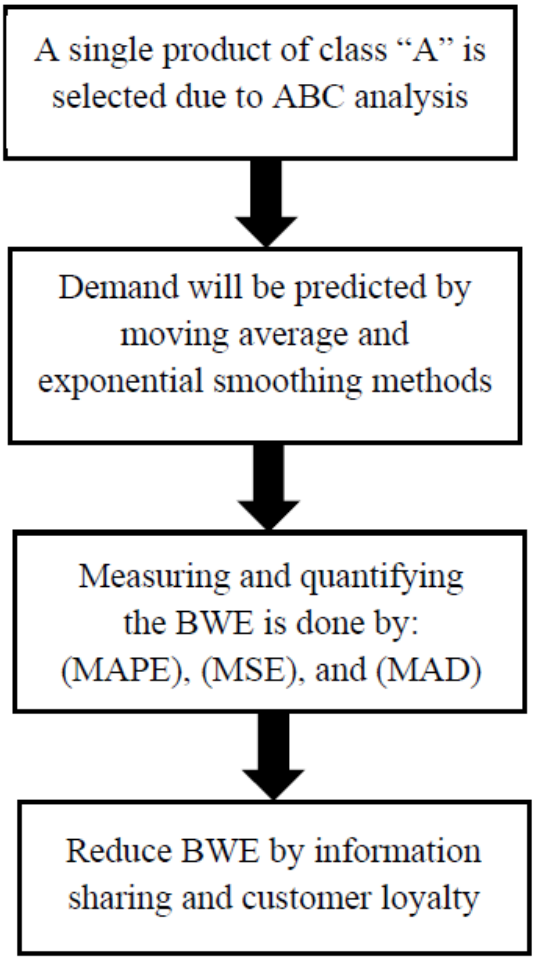


Fig.1. The proposed methodology.

The ABC analysis is used to identify different categories of stock that will require different controls and monitoring. The classifications of ABC analysis:'A' Class – 10-20% of the items accounts for 70-80% of the annual consumption value of the items.'B' Class – 30% of the items accounts for 15-25% of the annual consumption value of the items.'C' Class – 50% of the items accounts for 5% of the annual consumption value of the items.Class "A" products: having the fewest inventory items but the greatest demand values, necessitating greater controls and administration. Because these items are critical to an organization because they have the largest annual consumption, a corporation must select an acceptable order pattern to avoid the Bullwhip Effect (excess capacity). As a result, for bullwhip effect study, we will select the item with the largest yearly consumption, which appears first in "A" Class items.

III. CASE STUDY

The research is based on a data set that represents information about Power-Driven Hand Tools (supply chain # 24). The data set, which can be downloaded online, reveals how practitioners using an inventory optimization tool mimic supply networks in the actual world. These chains show how real-world supply

networks have been modeled by real-world users. The results of applying ABC analysis to the Power-Driven Hand Tools data set are shown in Table 1 and Fig. 2., respectively.

Category	% of items	% of usage
Class A Items	23.81	78.77
Class B Items	28.57	13.61
Class C Items	47.62	7.62

Table 1
ABC classes for the Data.

Item #	class	Item _76	B	Item _63	C
Item _58	A	Item _65	B	Item _64	C
Item _43	A	Item _61	B	Item _55	C
Item _38	A	Item _74	B	Item _75	C
Item _54	A	Item _66	B	Item _41	C
Item _59	A	Item _51	B	Item _67	C
Item _60	A	Item _42	B	Item _48	C
Item _39	A	Item _77	B	Item _50	C
Item _36	A	Item _68	B	Item _69	C
Item _45	A	Item _46	B	Item _49	C
Item _44	A	Item _62	B	Item _72	C
		Item _47	B	Item _40	C
				Item _56	C
				Item _57	C
				Item _53	C
				Item 37	C
				Item _70	C
				Item _71	C
				Item _52	C
				Item _73	C

Based on ABC Analysis, item # 58 will be selected because it has the highest annual consumption compared to the other items, which comes first in class "A" items for bullwhip effect analysis.

IV. RESULTS AND DISCUSSION

4.1 Predicting the Bullwhip Effect

The impact of demand forecasting on the "bullwhip" effect for a special supply chain consisting two-stages will be predicted using Exponential Smoothing forecast and a Moving Average to estimate the mean and variance of demand. The retailer uses these estimates to form a simple "order-up-to" inventory policy [5].

Exponential Smoothing Forecasting: We assume that the retailer follows a simple order-up-to inventory policy Y_t requires each stage of the supply chain to raise its inventory level up to a given target level in each period.

$$Y_t = \hat{D}^L{}_t + z\hat{\sigma}^L{}_{et} \quad (1)$$

D^L: is an estimate of the mean demand over L periods, σ^L: is an estimate of the standard deviation of the L period forecast error, z: is a constant chosen to meet a desired service level (safety factor).If the retailer uses a simple exponential smoothing forecast with smoothing parameter (α); $0 < \alpha < 1$, then the variance of the orders, q^{EX}, placed by the retailer to the manufacturer, satisfies:

$$\frac{Var(qEX)}{Var(D)} \geq 1 + (2L\,\alpha + \frac{2L^2\alpha^2}{2-\alpha})(\frac{1-\rho}{1-\rho\beta}) \quad (2)$$

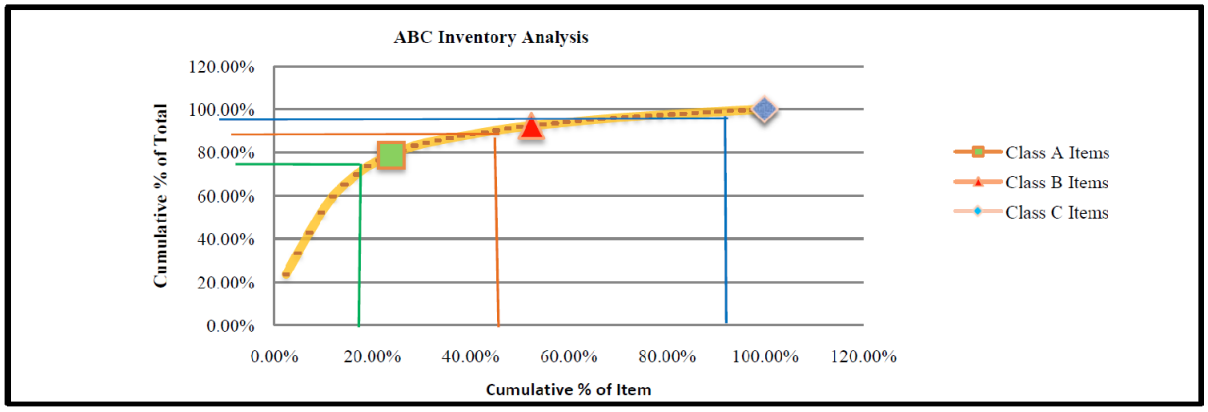


Fig.2. Classes classifications of data.

Lead Time (L)	BWE	Smoothing parameter (α)	BWE	Correlation parameter	BWE
1	1.37	0.2	1.81	-1	2.63
2	1.81	0.4	3.00	-0.8	2.52
3	2.33	0.6	4.71	-0.4	2.27
				0	1.98
4	2.93	0.8	7.22	0.4	1.64
5	3.59	1	11.00	0.8	1.23
				1	1.00

Table 2
The influence of lead time, smoothing parameter, and correlation on BWE.

From Table 2 we can conclude that as a result of using Exponential Smoothing Forecasting, BWE increases as lead time and smoothing parameter increase.

Moving Average Forecasting: Moving average forecasting method is used under up-to-order inventory policy to estimate standard deviation and mean of customer demand by retailer. In every period the retailer estimates the mean lead time demand as $\hat{\mu}_t^L = L\,\hat{\mu}_t$. Where $\hat{\mu}_t$ is an average of demand observations (p).

$$\hat{\mu}_t = \frac{\sum_{i=1}^{p}(Dt-i)}{p} \quad (3)$$

if order-up-to inventory policy is used, and simple moving average method is used by retailer, then the variance of the order q^{MA} placed by the retailer to the manufacturer, satisfies:

$$\frac{Var(qM\,A)}{Var(D)} \geq [1 + (\frac{2L}{p} + \frac{2L2}{p2})(1 - \rho^{p})] \quad (4)$$

Where Var(D) is the variance of customer demand. The bound is tight when z = 0.

More than one observation can be noted from Equation (4). First of all, the amplification of variability from the retailer to the manufacturer is a function in terms of three parameters, (1) p, the number of observations, (2) L, the lead time from the retailer to the manufacturer, and (3) ρ, the correlation parameter. As number of observation (p) decrease and lead time increase (L), the variability increase. Here, the three parameters of moving average forecasting method (ρ, L, p) are analyzed to see their effect on bullwhip effect. See Table 3 below.

Lead Time (L)	BWE	Smoothing parameter (α)	BWE	Correlation parameter	BWE
1	1.2468	0.2	1.5432	-1	2.0864
2	1.5432	0.4	2.4976	-0.8	1.6161
3	1.8889	0.6	4.1153	-0.4	1.5433
				0	1.5432
4	2.2839	0.8	6.6657	0.4	1.5430
5	2.7288	1	10.600	0.8	1.4703
				1	1.0000

Table 3
The Influence of Lead Time, SmoothingParameter, and Correlation on BWE.

From Table 3 we can conclude that as a result of using Moving Average Forecasting technique, BWE decreases as the correlation parameter increases. BWE decreases as lead time increases

4.2. Quantifying and Measuring the BWE

The size of the increase in variability is determined by the forecasting method used. Demand forecasting can generate the bullwhip effect. Furthermore, the extent of the increase in unpredictability is clearly dependent on the forecasting approach. We arrived at this conclusion by comparing the extent of variability increase for the two forecasting systems (Moving average and Exponential smoothing),for i.i.d demands and $z = 0$ [4].So, We choose the parameters **P** *(*Number of Observations*)* and **α** (Smoothing Parameter), such that both forecasts have the same variance of the forecast errors, design the forecasts[4].
When equating the standard deviation of both moving average and exponential smoothing method, this result will be obtained:

$$\frac{Var(qEX)}{\sigma^2} = 1 + \frac{4L}{p+1} + \frac{4L^2}{P(P+1)} = 1 + \frac{2P}{P+1}(\frac{2L}{P} + \frac{2L^2}{P^2}) \quad (5)$$

As a result, the variability of Exponential smoothing is larger than moving average by a factor.The bullwhip effect will be greater for a retailer using an exponential smoothing forecast than for a retailer using a moving average forecast [4].

4.3Accuracy of Forecasting Methods

In this section, we will compare the previously discussed forecasting methods: exponential smoothing and moving average. However, in order to select the most accurate forecasting approach, several factors must be considered: Mean Square Error (MSE), Mean Absolute Deviation (MAD), and Mean Absolute Percent Error (MAPE). Values of (MSE, MAD and MAPE) are obtained and they are compared to select the best forecasting method which gives accurate demand forecasting for the Product.By the following relationship, different values of (α) and (p) are obtained in different trials to forecast the demand with exponential smoothing and moving average methods. It is applied in a supply chain data that represents "Power-Driven Hand tools information". Table 4 demonstrates different values of (α) and (p)obtained using equation 6 in different trials that will be used to forecast the demand with exponential smoothing and moving average methods.

$$\alpha = \frac{2}{P+1} \quad (6)$$

Trial	Number of observations (P)	Smoothing parameter (α)
#1	7	0.25
#2	5	0.33
#3	3	0.5
#4	1	1

Table 4
All experienced trials.

Exponential Smoothing Forecasting Method:
In this method value of forecast can be obtained by equation:

$$F_{t+1} = \alpha\,(\text{Actual demand}_t) + (1-\alpha)\,(\text{Forecasted demand}_t) \quad (7)$$

Moving average forecasting method:
In this method value of forecast can be obtained by this equation:

$$\hat{Y}_{t+1} = (Y_t + Y_{t-1} + \ldots + Y_{t-m+1}) / (m) \quad (8)$$

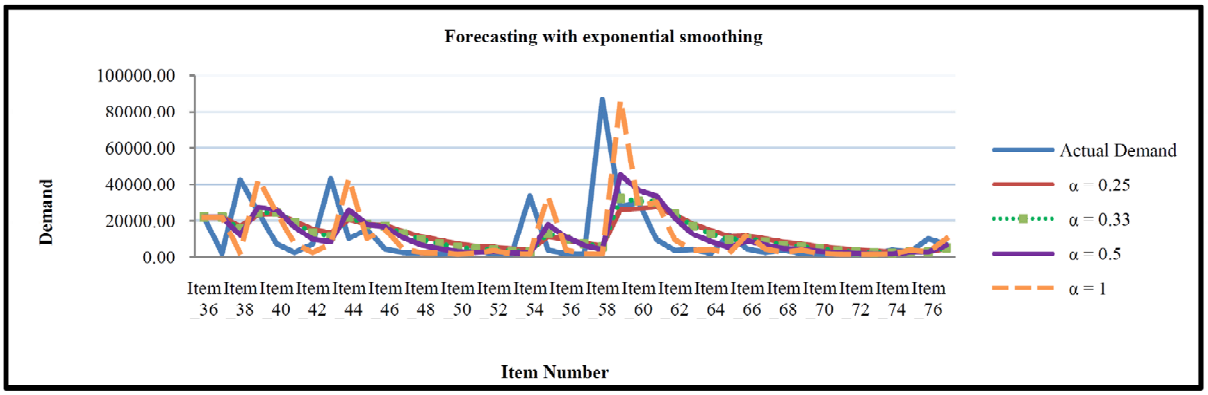


Fig. 3. Forecasting with exponential smoothing method.

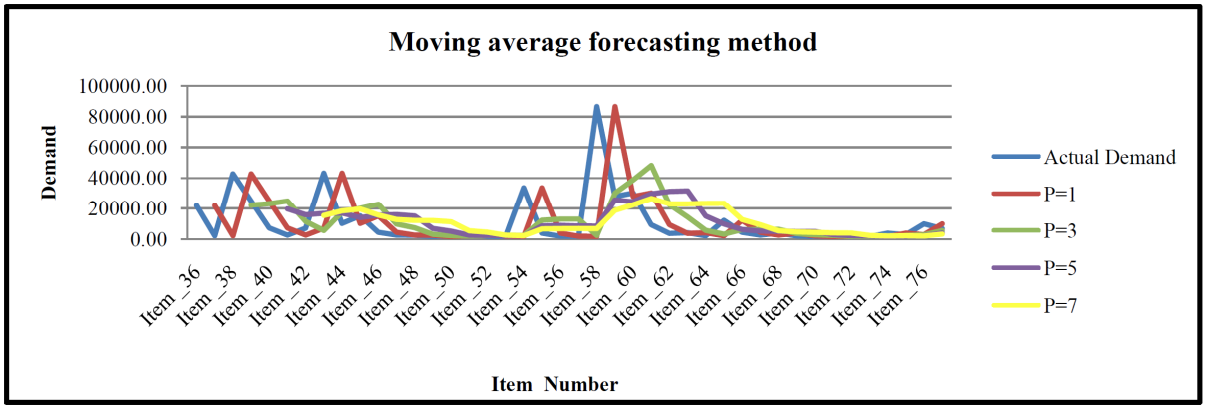


Fig.4. Forecasting with moving average method.

As shown in Fig.3. and Fig.4., in the moving average approach, trial #4 is the most accurate because the anticipated demand is near to the actual demand when compared to the other trials. It also provides predictability in demand estimates. On the other hand, in the exponential smoothing method, trial #4 is likewise the most accurate because the anticipated demand is near to the actual demand when compared to other trials. Moving average smoothing is generally more accurate than exponential smoothing. This is plainly demonstrated in Table (5), where the moving average has the lowest number of errors.

Forecast Error	α =1 & P=1		α =0.5 & P=3		α =0.33 & P=5		α =0.25 & P=7	
	E.S	M.A	E.S	M.A	E.S	M.A	E.S	M.A
MAD	11519.8	11519.8	10375.3	10028.3	10224.5	9811.2	10546.3	10512.2
MSE	451534308.2	451534308.2	321692757.4	340404924.3	299403601.5	298443840.7	292686386.1	307269944.1
MAPE	1.24%	1.24%	1.62%	1.61%	1.93%	1.92%	2.17%	2.05%

Table 5
Summary of accuracy of forecasting methods.

4.4 Reduction of BWE

We have illustrated that the bullwhip effect may increase when the demand forecast is not accurate also when lead time is large. In fact, most of the errors that cause increase in BWE are done by humans, whether they were customers or retailers in our supply chain structure. When they are retailer, they might fail in forecasting customers demand by using inaccurate forecasting methods. On the other hand, when they are customers, lack of sincerity and loyalty could cause distortion in demand which lead to high variance between actual demands and orders. Information sharing is one of the used methods to reduce bullwhip effect and increase efficiency of the supply chain in less cost manner. Information sharing has many types: inventory, sales, demand forecast, order status, and production schedule information. Inventory and sales are the two main types of information sharing that will be discussed [15].

Inventory information: in our supply chain structure; consider that the retailer and manufacturer do independently their inventories management without

sharing their inventories status information. They might end up with stock outs or excess in safety stock. In fact, sharing of inventory information is done in different ways. In typical CRP form (Continuous Replenishment Programs) the buyer shares its inventory status with the vendor and ask for managing his inventory [15]. Sales information: consider that the retailer uses exponential smoothing or moving average method to read and forecast market trend, a larger sale could be resulted by retailer which will obligate him to adjust the forecast upward, so orders could be placed are amplified upstream the supply chain. To avoid this distortion in demand (double or triple forecasting), actual sales data should be shared from some retail store.

4.5 Impact of Customer Loyalty in Mitigating the BWE

Customer loyalty is a good effect of being consistent and honest with customers, which makes them feel content, delighted, and the product or service's perceived worth is increased. [16]. Bullwhip effects the customer satisfaction and the cost of supply chain. This effect will cause the competition between companies to be more difficult. A vital competitive tool for companies in CRM is obtaining customer attention to be loyal customers. Hence, cost of retaining customers is less than wining new one [17]. Customer loyalty divided into two categories: behavior loyalty and attitude loyalty. The first one indicates a non-stop purchase and behavior of recommendations. The second one means the tolerance to cost. This could be classified into three categories: 1) re-purchase and recommendation willing. 2) Tolerance to price adjustment. 3) consumption frequency. If the company succeeds in haunting the customer also in retaining him, demand will be somewhat stable. In other words, the fluctuation in demand will be decreased, because the customer will not be influenced by other competitors. Indeed, bullwhip effect will be mitigated.

V. CONCLUSIONS AND FUTURE WORK

In this paper, the bullwhip effect is predicted and quantified using a particular two-stage supply chain comprising one manufacturer and one retailer. In ABC analysis, a single product is assumed. We considered that the store is unaware of the exact distribution of demand. As a result, we estimate the mean and variance of demand using moving average and exponential smoothing forecasting methods. As a consequence, a bullwhip effect ratio metric was provided. Furthermore, the impact of the number of observations, smoothing constant, and lead-time on the bullwhip effect values has been studied. The results suggest that a retailer employing an exponential smoothing prediction will have a bigger bullwhip effect than a retailer using a moving average forecast. Furthermore, knowledge sharing and customer loyalty are regarded as two methods of mitigating the bullwhip impact. This study could be expanded by employing other forecasting approaches, such as time series analysis, to anticipate lead-time demand.

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