Managing Bullwhip Effect in Acoustic Guitar Manufacturing: A Case Study Through Vendor Managed Inventory (VMI) Approach

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Abstract. The Bullwhip Effect is a condition where differences arise between the supply and demand numbers within supply chain management. This acoustic guitar manufacturing faces challenges resulting from demand fluctuations, supply chain complexities, and inventory inefficiencies, which often lead to the Bullwhip Effect. The company experiences fluctuations in both demand and supply, consequently leading to inventory accumulation in its warehouses. This study aims to reduce the Bullwhip Effect score in acoustic guitar manufacturing by implementing the Vendor Managed Inventory (VMI) method. VMI acts as a regulatory mechanism during distribution, ensuring better control over dispatched products by incorporating forecasting techniques such as single exponential smoothing, double exponential smoothing, and linear regression. Before implementing VMI, the Bullwhip Effect scores were 1.42 for Retailer 1 and 1.69 for Retailer 2. After the successful implementation of VMI, significant reductions in the Bullwhip Effect scores were observed, with scores of 0.48 and 0.91 recorded for Retailer 1 and Retailer 2, respectively.
Keywords: Bullwhip Effect, Vendor Managed Inventory (VMI), forecasting, inventory

1 Introduction

The supply chain has a function to connect customers with retailers, distributors, manufacturer and suppliers [1-2]. The supply chain can be interpreted as a static system, limited to its surroundings [3], or as a system with stakeholders aiming to fulfil customers' needs [4]. Supply chain management can be defined as the process of managing the network from upstream (suppliers) to downstream (customers), while considering performance factors such as cost, time, quality, and customer requirements. In general, the supply chain comprises several elements, including suppliers, distributors, retailers, logistics, warehousing, and customers. It is crucial to acknowledge that demand in supply chain management is dynamic, meaning it changes over time, intermittently, and cyclically, requiring careful attention to demand management [5]. Moreover, the same author states that the supply chain exhibits high dependency; even a slight change in the downstream can affect the entire process up to the upstream. Throughout this process, there are a lot of information exchanged between the stakeholders in the supply chain that need to be managed.

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This company operates in the guitar manufacturing sector and is one of the largest companies in Bandung, West Java. Currently, the company collaborates with two vendors to fulfil the demand from customers. Acoustic guitars are among the best-selling products, prompting the company to implement a 'make to stock' production system. Consequently, the company has accumulated an excess inventory of acoustic guitars in its warehouse. This surplus inventory has led to warehouse overcapacity issues. For instance, there was an overstock of 97 units at retailer 1 and 83 units at retailer 2 during the period from January 2022 to December 2022. This excess inventory has had negative implications for the company, impacting warehouse capacity, increasing inventory costs, and potentially affecting the quality of the guitars.

This company is grappling with an issue related to overstocked inventory due to inaccuracies in demand prediction and a lack of information flow with its vendors. This discrepancy between the number of orders and actual demand can result in overcapacity, a phenomenon known as the 'bullwhip effect' [6]. This surplus capacity can adversely affect the company. Vendor Managed Inventory (VMI) is a method that can be implemented to efficiently manage the company's inventory by actively involving vendors in inventory control [7]. In this approach, vendors and the company engage in two-way information exchange to facilitate decision-making related to inventory management, with the goal of reducing overstock. Suppliers take on the responsibility of monitoring and delivering the product in the correct quantity and within the specified timeframe to prevent instances of inventory depletion and ensure customer satisfaction. The implementation of VMI aims to reduce overstock and mitigate the negative impacts associated with the bullwhip effect.

2 Methodology

This research applied the Vendor Managed Inventory (VMI) methodology to reduce the bullwhip effect phenomenon in Acoustic Guitar Manufacturing. The first step involves collecting order and demand data from two vendors, followed by calculating the bullwhip effect score for current condition. The next step is implementing Collaborative, Planning, Forecasting, and Replenishment (CPFR) by forecasting the demand and order data using three different methods. The selected forecasting method served as input for the latest Bullwhip effect calculations.

2.1 The Bullwhip Effect

The bullwhip effect is a phenomenon characterized by a variance between the number of demand and orders. This phenomenon exerts a profoundly negative impact on supply chain performance, affecting from upstream (suppliers) to downstream (customers) aspects, including costs, machine capacity, and excess inventory [8]. Demand variability, or the difference between supply and demand become one of the primary causes of the bullwhip effect [9]. Other factors that creating the bullwhip effect phenomenon include order batching, price fluctuation, inflation and discounts [2]. According to the same author, the bullwhip effect can be mitigated through the implementation of information sharing. Supply chain management heavily relies on the seamless flow of information to interconnect its system components through data exchange [10-11]. It is important for businesses to have access to real-time and accurate information to support the decision-making process to improve their performance. For instance, many companies utilize the data and information they receive to manage demand and control inventory.

Calculating The Bullwhip Effect Score:

$$\mu \text{ (Demand)} = \frac{\text{Total Demand}}{\text{Period}} \quad (1)$$

$$\mu \text{ (Order)} = \frac{\text{Total Order}}{\text{Period}} \quad (2)$$

$$\sigma \text{ (Demand)} = \sqrt{\frac{\sum_{i=1}^{n}(Xi-X)}{n-1}} \quad (3)$$

$$\sigma \text{ (Order)} = \sqrt{\frac{\sum_{i=1}^{n}(Xi-X)}{n-1}} \quad (4)$$

$$\text{CV (Order)} = \frac{\sigma\ (Order)}{\mu\ (Order)} \quad (5)$$

$$\text{CV (Demand)} = \frac{\sigma\ (Demand)}{\mu\ (Demand)} \quad (6)$$

$$\text{BE Score} = \frac{CV\ (Order)}{CV\ (Demand)} \quad (7)$$

Where:

μ (Demand) : Average Demand
μ (Order) : Average Order
σ (Demand) : Deviation Standard of Demand
σ (Order) : Deviation Standard of order
CV (Demand) : Coefficient of Variance of Demand
CV (Order) : Coefficient of Variance of Order
BE Score : The Bullwhip Effect Score

2.2 Vendor Managed Inventory (VMI)

The Vendor-Managed Inventory (VMI) approach is a condition where vendors or suppliers are directly involved and responsible for making decisions related to inventory management [12]. Vendors have several roles in VMI, such as managing on-hand inventory, forecasting and regarding inventory replenishment. Vendors must closely monitor the changes in customer demand to make decisions in inventory replenishment. VMI provides companies with several advantages including a reduction in warehouse inventory, cost savings within the supply chain and the elimination of safety stock [13]. To achieve the optimal inventory level, the collaboration between VMI and the Collaborative, Planning, Forecasting, and Replenishment (CPFR) strategy is an effective approach for implementation in companies. CPFR is a tool that provides accurate demand calculation [14]. In this research, three different forecasting methods utilized, including Single Exponential Smoothing, Double Exponential Smoothing, and Linear Regression with Time. The forecasting methods with the lowest Mean Squared Error (MSE) value were chosen.

- The Single Exponential Smoothing Calculation:

$$F_{t+1} = \alpha X_t + (1-\alpha)F_t \quad (8)$$

Where :
F_t : Forecast result for period t
F_{t+1} : Forecast result for period t+1
α : Smoothing Parameter
X_t : The Actual value on Period t

- The Double Exponential Smoothing Calculation:

$$S_t = \alpha X_t+(1-\alpha)(S_{t-1}+ b_{t-1}) \quad (9)$$

$$b_t = \gamma(S_t - S_{t-1})+(1-\gamma)b_{t-1} \quad (10)$$
$$F_{t+m} = S_t + b_t.m \quad (11)$$

Where:
X_t : The Actual value on Period t
St : Intercept value for period t
St-1 : Intercept value for period t-1
Bt : Slope value for period t
bt- 1 : Slope value for period t-1
α, γ : Smoothing Parameter
Ft+k : Forecast result for period t+k

- The Linear Regression with Time Calculation:

$$Ft = a + b.t \quad (12)$$
$$b = \frac{n\sum X_{t.}t - \sum X_t \sum t}{n\sum t^2 - (\sum t)^2} \quad (13)$$
$$a = X_t - b.t = \frac{\sum X_t}{n} - b\frac{\sum_t}{n} \quad (14)$$

Where:
X_t : The Actual value on Period t
n = Total number of observations
b = Slope Value
a = Intercept Value
F_t : Forecast result for period t

3 Results and Discussion

This acoustic guitar manufacturer working with 2 different vendors to fulfill order from customers. However, from the previous data it can be seen in the Figure 1 and Figure 2 that there was variance between the order and the demand, which resulted disruption in its inventory.

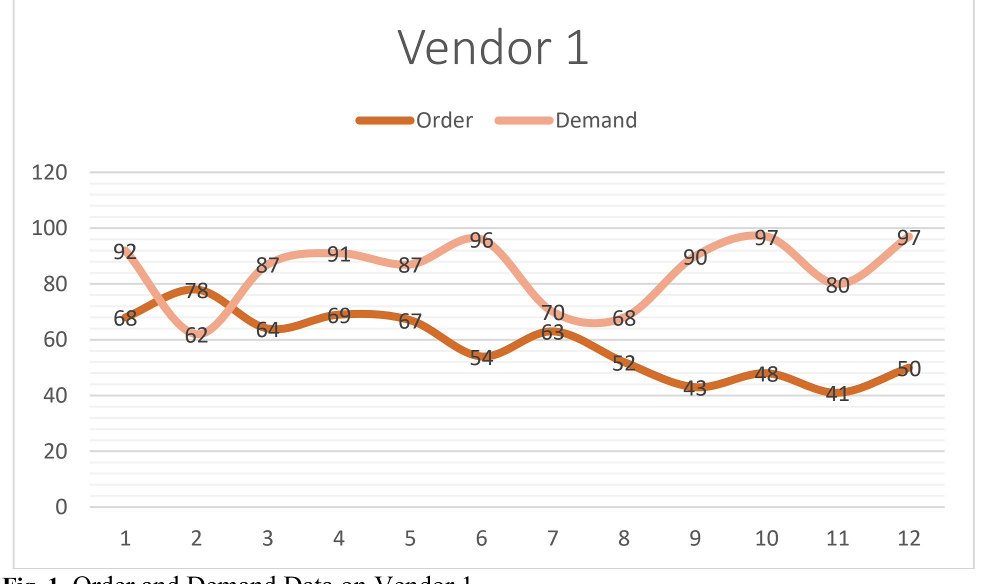

Fig. 1. Order and Demand Data on Vendor 1

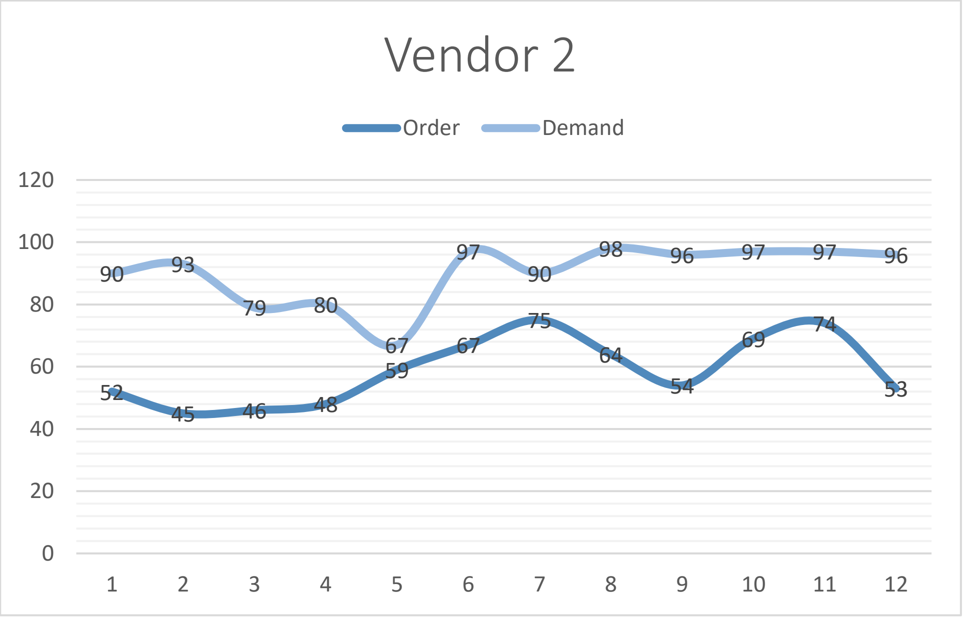

Fig. 2. Order and Demand Data on Vendor 2

These figures represent the disparity between demand and orders in the acoustic guitar manufacturing process. Consequently, the next step involved calculating the Bullwhip Effect for the current situation.

Table 1. The Bullwhip Effect Score for Current Situation

Vendor	µ (Demand)	µ (Order)	σ (Demand)	σ (Order)	CV (Demand)	CV (Order)	Bullwhip Effect Score
1	84.75	58.08	12.04	11.65	0.14	0.20	1.41
2	90.00	58.83	9.73	10.73	0.11	0.18	1.69

The results presented in Table 1 indicate that the bullwhip effect scores for the current Vendor 1 and Vendor 2 are 1.41 and 1.69, respectively. These scores represent fluctuation in the number of demand and orders, leading to distortions in the inventory management of acoustic guitar manufacturing. It is essential for this acoustic guitar manufacturing to reduce the bullwhip effect score as it significantly impacts inventory costs and product quality produced. The VMI (Vendor-Managed Inventory) method is implemented to reduce the bullwhip effect score by utilizing the CPFR (Collaborative Planning, Forecasting, and Replenishment) concept. In the forecasting phase, three specific methods are employed, namely single exponential smoothing, double exponential smoothing, and linear regression with time. For the forecasting process, WinQSB software is employed, and the chosen forecasting method is the one that produces the smallest Mean Squared Error (MSE) value.

Table 2. The MSE Values

Forecasting	MSE	
	Vendor 1	Vendor 2
Single Exponential Smoothing	184,6498	94,7272
Double Exponential Smoothing	184,7804	94,7272
Linear Regression with Time	127,0848	64,2173

According to Table 2, linear regression with time was selected based on its lower MSE values compared to the other forecasting methods. The forecasting results using linear regression with time are presented in Table 3.

Table 3. The Forecasting Result

Month	Vendor 1	Vendor 2
13	89.27	98.96
14	89.97	100.33
15	90.66	101.71
16	91.36	103.09
17	92.06	104.47
18	92.75	105.84
19	93.44	107.22
20	94.14	108.6
21	94.84	109.98
22	95.53	111.35
23	96.23	112.73
24	96.93	114.11

Forecasting was conducted for the upcoming 12 months, revealing a slightly increasing data trend. These forecasting results were used as an input for calculating the bullwhip effect score following the implementation of VMI, which can be seen at Table 4.

Table 4. The Bullwhip Effect Score after Implementing VMI

Vendor	μ (Demand)	μ (Order)	σ (Demand)	σ (Order)	CV (Demand)	CV (Order)	Bullwhip Effect Score
1	93.01	84.75	2.51	2.51	0.03	0.03	1.10
2	106.53	90.00	4.97	4.97	0.05	0.06	1.18

The results of the bullwhip effect score based on Table 4, as observed after the implementation of VMI, reveal a noticeable reduction when compared to the bullwhip effect score under current conditions. This reduction signifies the success of the VMI method in mitigating the bullwhip effect phenomenon that typically arises in the acoustic guitar manufacturing process. It is also indicating that the adoption of VMI has led to improved inventory management and reduced fluctuations in demand and orders, contributing to more efficient operations.

4 Conclusions

The acoustic guitar manufacturing process exhibits the bullwhip effect, reflecting a disparity between demand and orders, resulting in inventory overstock. The implementation of VMI in this acoustic guitar manufacturing has demonstrated positive result. Adopting a forecasting technique, specifically choosing linear regression with time series analysis with the lowest error value making it an optimal choice for enhancing the efficiency and effectiveness of inventory management in the guitar manufacturing industry. This method results in more accurate demand forecasting for the company to manage and will lead to improved inventory control. This is indicated by reduction of the Bullwhip effect scores from 1.41 to 1.10 for Vendor 1 and from 1.69 to 1.18 for Vendor 2. These reduced scores approach a value of 1, indicating a diminishing gap between orders and demand. In conclusion, VMI proves effective in mitigating the bullwhip effect phenomenon within the acoustic guitar manufacturing context. This case study demonstrates the potential of implementing VMI in other industries, especially for industries that face challenges in demand fluctuations and inventory management.

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