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THE IMPACT OF A VENDOR-MANAGED INVENTORY POLICY ON THE CASH-BULLWHIP EFFECT

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It is essential to secure a sustainable flow of cash along the supply chain in the modern corporate environment. Due to the growing significance of cash flow, the concept of the cash-flow bullwhip effect has recently drawn academic attention to finding solutions to the cash shortage. The supply chain's response to the bullwhip effect, known as the cash-flow bullwhip effect, causes cash-flow volatility to be amplified from downstream to upstream. A number of research studies have looked into the sources and effects of the cash-flow bullwhip effect, but none have concentrated on solutions. This study investigated for the first time the impacts of the vendor-managed inventory policy as a tool for mitigating the cash-flow bullwhip effect. The findings show that the vendor-managed inventory policy typically shortens the cash-conversion cycle of each supply chain member and can, therefore, be implemented as a policy for mitigating the cash-flow bullwhip effect.

Keywords: Cash-Flow Bullwhip Effect, Cash Flow, Supply Chain Management, and Vendor Inventory Management.

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1. INTRODUCTION

Because strong cooperation and relationships among supply chain (SC) members make the SC more efficient and competitive, several companies have implemented vendor-managed inventory (VMI) into SC management to keep the inventory level as close to the ideal inventory level as feasible (Cai *et al*., 2017). VMI is an integrated coordination mechanism which enables the buyer and supplier to raise the SC's efficiency and competitiveness while allowing the supplier to manage an inventory level through a contractual agreement (Yao and Dresner, 2008). By using VMI throughout the SC, companies are able to reduce the costs of inventory, order, and transportation, as well as to improve demand forecasting, production planning, and service levels (Mateen and Chatterjee, 2015).

Numerous companies are utilizing it to mitigate the bullwhip effect (BWE) by maintaining a proper inventory level from downstream to upstream members after realizing the influence of VMI on SC BWE mitigation (Dong *et al*., 2007). The BWE is the term used to describe the amplifying of inventory level fluctuation, as demand distortion information in the retailer downstream is transmitted to the supplier upstream. For this reason, most VMI research has focused on the BWE incurred by the SC's material movement. However, no study has specifically examined how VMI affects the cash-flow bullwhip effect (CFBWE). Therefore, this study investigated whether VMI decreases the CFBWE of SC participants.

The BWE has been a major focus of research conducted in order to increase the effectiveness and efficiency of SCs while investigating its causes and impacts to identify various mitigation policies. VMI manages the BWE by responding to demand fluctuation through a supplier's replenishment decisions for a buyer. Related studies demonstrate that the BWE in the SC is significantly diminished by the VMI policy (Stranger, 2013). In addition, various studies have been performed to analyze the effects of the VMI on customer satisfaction, service level, and total inventory cost while considering lead times, replenishment cycles, stochastic demands, and penalty costs.

Compared to the importance of the financial flow in a sustainable SC, no research studies have assessed the influence of VMI on the CFBWE, which describes the fluctuation of cash level, as inventory levels are amplified when the BWE becomes strengthened. Consequently, this study developed a mathematical model to evaluate how VMI affects the CFBWE throughout the SC. To fulfill this, it incorporated the VMI mechanism between the distributor, who acts as the buyer and the manufacturer, who acts as the vendor, while the retailer and the supplier function according to traditional SC management. This research demonstrates the potential of the VMI mechanism for reducing both the BWE and the CFBWE.

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2. LITERATURE REVIEW

Because VMI is an effective inventory control mechanism across the SC, numerous research studies have employed a range of modeling approaches to reduce SC costs through various SC contracts and policies. To improve inventory control under the VMI mechanism, Matten *et al*. (2015) examined the impact of VMI under periodic inventory review with an inventory limit for the retailer's penalty policy for vendor oversupply. The findings reveal that trustworthiness plays a key role in the efficiency of the VMI coordination mechanism throughout the SC. Later, Taleizadeh *et al*. (2020) created a VMI model to compare a reorder-point/order-quantity replenishment policy with a periodic review replenishment policy in terms of cost-efficiency under a partial back-ordering condition. The results indicate that the effectiveness of the two replenishment policies varies with different cost parameters and cycle times.

Several studies have adopted the VMI mechanism to reduce the related costs in the SC. For instance, Mateen and Chatterjee (2015) developed an analytical model to compare the production and operating cost reduction in four types of VMI model under different operating conditions. The results reveal that VMI models exhibit generally low total cost when responding to the operating conditions and the replenishment policies. Han *et al*. (2017) considered a decentralized VMI problem with a multiple distributor as third-party logistics to compare the conventional SC operation with the VMI coordination operation in terms of total cost reduction. The results illustrate that VMI coordination improves the effectiveness of the entire SC with incentive and penalty policies through total cost sharing between each SC member.

In addition, Disney and Towill (2003) utilized a VMI simulation model to illustrate the benefits of the VMI mechanism on inventory control in the traditional SC. The findings suggest that VMI noticeably mitigated the BWE occurring from the volatile demand change. Weraikat *et al*. (2019) created an analytical model to analyze the impact of VMI on the pharmaceutical SC. They reported that the safety stock level and capacity control are important factors in reducing the total inventory cost under VMI as they minimize drug wastage. In the same year, Sainathan and Groenevelt (2019) examined five SC contracts to determine the proper contract type for VMI. Because none of the five contracts properly coordinated with VMI, the authors modified quantity flexibility and sales rebate contracts to develop two new SC contract models.

Numerous studies have considered the effects of VMI on the environmental aspects of the SC. For instance, Gharaei *et al*. (2019) created a mathematical model that includes green production and quality control policies to identify the optimal batch-sizing policy under VMI coordination. They found that the optimal batch-sizing policy lowers the overall SC cost under VMI with consignment stock agreement. Using a mathematical model, Bai *et al*. (2019) evaluated the coordination effect of VMI on carbon emission reduction in the SC for deteriorating products. Their findings showed that VMI with a revenue-sharing contract improves the profit and emissions of a decentralized SC coupled with carbon cap-and-trade regulation and green technology investments. In addition, Stellingwerf *et al*. (2019) applied cooperative game theory to investigate the financial and environmental influences of VMI in a supermarket SC. They reported that VMI is an effective mechanism through which to reduce transportation costs and carbon emissions for a supermarket chain.

On the other hand, the game theory technique was also used in a number of additional studies to examine the impact of VMI on SC inventory control. For instance, Yu *et al*. (2009) utilized a Stackelberg game model to ascertain the evolutionary stability between the producer and the buyer under the VMI policy. The results reveal that the trusted partnership reduces the inventory and replenishment costs through information sharing. In another study, Xiao and Xu (2013) applied a Stackelberg game model to analyze the degree of coordination between the pricing and the service level under a VMI mechanism. They found that there is a tradeoff between the pricing and the service level in the SC for deteriorating products. Taleizadeh *et al*. (2015) also employed the Stackelberg game model to identify the optimal values of the retail pricing and the product replenishment frequency in the SC for a deteriorating product.

By contrast, numerous studies have applied the system dynamic approach to look into how VMI affects SC management. For example, Li *et al*. (2013) utilized both the VMI mechanism and third-party logistics to develop a hybrid model of a distribution SC. They found that this model improves the BWE, inventory levels, and service levels compared with a traditional SC model. Similarly, Hossseini and Mehrjerdi (2016) developed a hybrid model which integrates a VMI mechanism into an order-based production control system to determine the proper inventory level while considering three SC metrics – BWE, service level, and total inventory level. The results demonstrate that their hybrid model improves the BWE and inventory level.

In recent years, some researchers have adopted the latest methods to analyze the impacts of these methods on the SC management problem. For instance, Badakhshan and Ball (2023) consider various disruption problems in product and cash flow to decide the proper inventory and cash replenishment policies using a digital twin framework and machine learning approach. The results of the study indicate that the proposed method effectively decreases the SC disruption problems in terms of demand, capacity, and cash flow through the entire SC. In addition, the study of Mohammadi *et al*. (2024) has applied the deep reinforcement learning approach to solve a waste and shortage problem under a VMI mechanism in the blood SC while demonstrating the effectiveness of deep reinforcement learning in the complex inventory allocation problem. As awareness of environmental preservation increases, several researchers have focused on green SC. For example, the study of Astanti *et al*. (2022) utilizes the VMI model under a cap and trade regulation to determine optimal inventory decisions in terms of logistics cost and carbon emission. The study shows that the VMI mechanism reduces the delivery frequency and quantity, which further decreases logistics costs and carbon emissions.

On the other hand, several studies have considered the CFBWE in the SC, as shown in Table 1. After the first identification of the CFBWE in the SC (Tangsucheeva and Prabhu, 2013), many studies have analyzed the causes and impacts of the CFBWE in the various SC environments using a wide range of approaches. While also investigating the impacts of the credit risk of each SC member (Sim and Prabhu, 2023) and the relationships between the CFBWE and the firm-level variable (Patil and Prabhu, 2024) in the SC. The review of the related studies shows that the research studies on the CFBWE have not been extensively conducted. Since the importance of the CFBWE has recently been recognized by several researchers, most related studies have mainly focused on the causes and effects of the CFBWE in the SC. Although the investigation of the causes and impacts of the CFBWE is also important, it is also required to provide mitigation methods to alleviate the CFBWE in the SC. To address this gap, this study has applied one of the mitigation methods for BWE to the CFBWE case. To the best of the author's knowledge, no study has considered the VMI policy as a mitigation method for the CFBWE in the SC. Thus, it is crucial to analyze how the VMI mechanism influences the CFBWE from downstream participants to upstream participants of the SC. The novelty of this study is to present a mitigation method for the CFBWE while assessing whether the mitigation methods for the BWE still have some impacts on the CFBWE in the SC.

Table 1. The recent studies on the CFBWE

Reference	Methods	Order Policy	Metric	Contents
Tangsucheeva and Prabhu (2013)	Mathematical model	Order-up-to policy	Cash conversion cycle	The measurements of the CFBWE in the SC
Goodarzi *et al*. (2017)	System dynamics	OUT policy	Cash conversion cycle	The causes of the BWE in the centralized and decentralized SC
Badakhshan *et al*. (2020)	System dynamics	Customized order policy	Cash conversion cycle	The main factors of the CFBWE in the SC
Chen *et al*. (2022)	Forecasting model	Order-up-to policy	Cash conversion cycle	The impacts of the CFBWE in the parallel SC
Sim and Prabhu (2023)	Mathematical model	Order-up-to policy	Accounts receivable turnover Account payable turnover Cash conversion cycle	The impacts of the credit risk of each SC member on the CFBWE in the SC
Patil and Prabhu (2024)	Regression model	-	Cash conversion cycle	Identifying the relationships between the CFBWE and firm-level variables in the SC

3. METHODOLOGY

To investigate the effect of VMI on the CFBWE, this study developed a mathematical model of the VMI policy in a SC, which is composed of one retailer, one distributor, one manufacturer, and one supplier, as shown in Figure 1. This model represents the traditional SC incorporating cash-flow processes such as account receivable and account payable activities under the VMI mechanism. This was then compared with the SC under the VMI policy in terms of financial performance indexes – accounts receivable turnover (ART), accounts payable turnover (APT), debt to equity ratio (DTER), and cash conversion cycle (CCC). Although this study has formulated one mathematical model to investigate the influences of the VMI mechanism, the mathematic model is presented as several sub-models to illustrate how the VMI policy for the manufacturer and the distributor and the non-VMI policy for the supplier and the retailer are differently operated in terms of mathematical formulation.

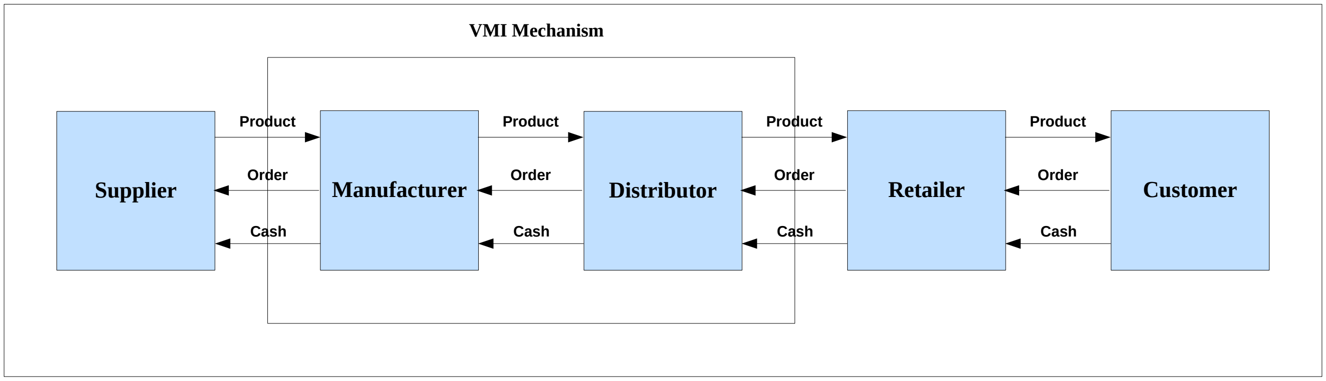

Figure 1. The VMI mechanism

3.1 Vendor-managed Inventory Model

A mathematical model of the CFBWE was developed by incorporating the VMI policy (Disney and Towill, 2003) into the author's previous model (Sim and Prabhu, 2022). This study investigates how the VMI policy reduces the CFBWE of each SC echelon throughout the SC because it is known that the VMI mechanism is one of the mitigation methods for the SC's BWE reduction. In order to achieve effective inventory control, a buyer and a supplier work together to manage a system inventory under the VMI policy. In this study, the VMI policy was only applied to the distributor as a buyer and the manufacturer as the supplier to evaluate the impacts of the VMI policy on the CFBWE.

3.1.1 Retailer and supplier sub-model

Given that the retailer and supplier operate with an order-up-to policy, the mathematical model for retailer and the supplier was developed as follows. The order-up-to policy is an inventory strategy in which a quantity of the product is ordered to satisfy the target inventory level. In the traditional inventory models, under the order-up-to-policy, the target inventory of each SC member is usually calculated based on the sum of the demand during the lead time and the time interval of the order. In this study, the time interval of orders is represented by the order in-transit, which is an order that is on route to the recipient, while the order quantity of each SC member is calculated using Equation (1). The order quantity is decided by deducting the sum of the previous time inventory ($\mathrm{INV_{j,t-1}}$), the order quantity $\left(\mathrm{ORD_{j,t-L}}\right)$ dispatched from the upstream participant in a lead time, and the order in-transit $\left(\mathrm{OINV_{j,t}}\right)$ from the sum of the predicted consumption$\left(\mathrm{FC_{j,t}} \cdot \mathrm{L}\right)$ during lead time, the order $\left(\mathrm{ORD_{j-1,t}}\right)$ dispatched to the downstream participant, and the previous time of back order $\left(\mathrm{BO_{j,t-1}}\right)$ unfulfilled, as formulated in Equation (1). From the retailer's perspective, index j indicates the retailer, index j-1 indicates the downstream member, namely the customer, and index j+1 indicates the upstream member, the distributor.

$$\mathrm{ORD_{j,t}} = \mathrm{FC_{j,t}} \cdot \mathrm{L} - (\mathrm{INV_{j,t-1}} + \mathrm{ORD_{j,t-L}} + \mathrm{OINV_{j,t}} - \mathrm{ORD_{j-1,t}} - \mathrm{BO_{j,t-1}}) \qquad \forall\ \mathrm{i,t} \tag{1}$$

The predicted consumption ($\mathrm{FC_{j,t}}$) is the expected demand during the leader time, which is estimated by summing the previous time of the predicted consumption ($\mathrm{FC_{j,t-1}}$) and deducting the predicted consumption ($\mathrm{FC_{j,t-1}}$) in a previous time from the order ($\mathrm{ORD_{j-1,t}}$) dispatched to the downstream participant divided by one plus the demand rate of smooth time ($\mathrm{T_c}$), as formulated in Equation (2) by Disney and Towill (2003).

$$\mathrm{FC_{j,t}} = \mathrm{FC_{j,t-1}} + (\mathrm{ORD_{j-1,t}} - \mathrm{FC_{j,t-1}})/(1 + \mathrm{T_c}) \qquad \forall\ \mathrm{j,t} \tag{2}$$

The inventory consists of products which are ready to sell to the downstream participant in the SC. The inventory ($\mathrm{INV_{j,t}}$) is determined by deducting the sum of the order ($\mathrm{ORD_{j-1,t}}$) dispatched to the downstream participant and the previous time of back order ($\mathrm{BO_{j,t-1}}$) unfulfilled from the sum of the previous time of the inventory($\mathrm{INV_{j,t-1}}$) and the order ($\mathrm{ORD_{j,t-L}}$) received from the upstream participant in a lead time, as formulated in Equation (3).

$$\mathrm{INV_{j,t}} = \mathrm{INV_{j,t-1}} + \mathrm{ORD_{j,t-L}} - \mathrm{ORD_{j-1,t}} - \mathrm{BO_{j,t-1}} \qquad \forall\ \mathrm{j,t} \tag{3}$$

The order in transit is an order which is on its way to the recipient. The order in-transit $(\mathrm{OINV_{j,t}})$ is determined by summing the order $(\mathrm{ORD_{j,t}})$ dispatched from the upstream participant during a lead time, as formulated in Equation (4).

$$\mathrm{OINV_{j,t}} = \sum_{t}^{t+(L-1)} \mathrm{ORD_{j,t}} \qquad \forall\ j,t \qquad (4)$$

The backorder cannot be fulfilled at the current time due to the lack of inventory. The back order $(\mathrm{BO_{j,t-1}})$ is determined by deducting the current inventory $(\mathrm{INV_{j,t}})$ from the order $(\mathrm{ORD_{j-1,t}})$ dispatched to the downstream participant, as formulated in Equation (5). If the current inventory is larger than the required order dispatched to the downstream participant, the back order is not generated.

$$\mathrm{BO_{j,t-1}} = \mathrm{ORD_{j-1,t}} - \mathrm{INV_{j,t}} \qquad \forall\ j,t \qquad (5)$$

3.1.2 Distributor and manufacturer sub-model

To explore the impacts of the VMI policy on the CFBWE in the SC, the VMI policy was applied to the channel between the distributor as a buyer and the manufacturer as a supplier. The mathematical model of the VMI policy is as follows. The order quantity of the distributor is determined by deducting the reorder point of the distributor $(\mathrm{ROP_{j,t-1}})$ in a previous time from the sum of the order quantity received from the retailer $(\mathrm{ORD_{j-1,t}})$ in a previous time and the reorder point of the distributor $(\mathrm{ROP_{j,t}})$ at the current time, as formulated in Equation (6) by Disney and Towill (2003).

$$\mathrm{ORD_{j,t}} = \mathrm{ORD_{j-1,t}} + \mathrm{ROP_{j,t}} - \mathrm{ROP_{j,t-1}} \qquad \forall\ j,t \qquad (6)$$

The reorder point of the distributor is the specific level of the distributor's inventory, which should be replenished at all times. The reorder point of the distributor $(\mathrm{ROP_{j,t}})$ is estimated by summing the reorder point of the distributor in a previous time $(\mathrm{ROP_{j,t-1}})$ and deducting the reorder point of the distributor in a previous time $(\mathrm{ROP_{j,t-1}})$ from the safety inventory of the distributor at the current time $(\mathrm{SS_{j,t}})$ divided by one plus the delivery lead time of the distributor $(\mathrm{T_q})$, as formulated in Equation (7) by Disney and Towill (2003).

$$\mathrm{ROP_{j,t}} = \mathrm{ROP_{j,t-1}} + (\mathrm{SS_{j,t}} - \mathrm{ROP_{j,t-1}})/(1 + \mathrm{T_q}) \qquad \forall\ j,t \qquad (7)$$

The safety stock refers to the additional inventory required to prevent an out-of-stock situation due to unexpected sales. The safety stock of the distributor $(\mathrm{SS_{j,t}})$ is estimated by multiplying the order of the retailer $(\mathrm{ORD_{j-1,t}})$ by the safety inventory factor $(\mathrm{G_j})$, as formulated in Equation (8).

$$\mathrm{SS_{j,t}} = \mathrm{ORD_{j-1,t}} \times \mathrm{G_j} \qquad \forall\ j,t \qquad (8)$$

The quantity of finished goods in the manufacturer's inventory is determined by deducting the sum of the order $(\mathrm{ORD_{j-1,t}})$ dispatched to the distributor and back-order $(\mathrm{BO_{j+1,t-1}})$ in a previous time from the sum of the inventory in a previous time $(\mathrm{INV_{j+1,t-1}})$ and the WIP order $(\mathrm{ORD_{j+1,t-LP}})$ received in a production lead time, as formulated in Equation (9). In addition, the distributor's inventory level is determined using Equation (3), while the backorder quantities of the distributor and the manufacturer are estimated as shown in Equation (5).

$$\mathrm{INV_{j+1,t}} = \mathrm{INV_{j+1,t-1}} + \mathrm{ORD_{j+1,t-LP}} - \mathrm{ORD_{j-1,t}} - \mathrm{BO_{j+1,t-1}} \qquad \forall\ j,t \qquad (9)$$

The order quantity of the manufacturer $(\mathrm{ORD_{j+1,t}})$ is estimated by the sum of the predicted consumption of the manufacturer $(\mathrm{VC_{j+1,t}})$, system inventory deviation adjustment factor $(\mathrm{DSINV_t})$, WIP inventory deviation adjustment factor $(\mathrm{DWINV_{j+1,t}})$, and the previous time of back order $(\mathrm{BO_{j+1,t-1}})$ unfulfilled, as formulated in Equation (10) by Disney and Towill (2003).

$$\mathrm{ORD_{j+1,t}} = \mathrm{VC_{j+1,t}} + \mathrm{DSINV_t} + \mathrm{DWINV_{j+1,t}} + \mathrm{BO_{j+1,t-1}} \qquad \forall\ j,t \qquad (10)$$

The predicted consumption of the manufacturer ($VC_{j+1,t}$) denotes the expected demand of the manufacturer, which is determined by summing the predicted consumption of the manufacturer ($VC_{j+1,t-1}$) in a previous time and deducting the predicted consumption of the manufacturer ($VC_{j+1,t-1}$) in a previous time from the order ($ORD_{j,t}$) received from the supplier, which is then divided by one plus the demand rate of the manufacturer's smooth time (T_m), as formulated in Equation (11) by Disney and Towill (2003).

$$VC_{j+1,t} = VC_{j+1,t-1} + (ORD_{j,t} - VC_{j+1,t-1})/(1 + T_m) \qquad \forall \ j,t \qquad (11)$$

The system inventory deviation adjustment factor is a correction factor used to adjust the difference between the target system inventory level and the actual system inventory level. The system inventory deviation adjustment factor ($DSINV_t$) is determined by deducting the actual system inventory ($SINV_t$) from the target system inventory ($TSINV_t$) which is then divided by the system inventory deviation adjustment time (T_i), as formulated in Equation (12).

$$DSINV_t = (TSINV_t - SINV_t)/T_i \qquad \forall \ t \qquad (12)$$

Similarly, the WIP inventory deviation adjustment factor is a correction factor used to correct the difference between the target WIP level and the actual WIP level. The WIP inventory deviation adjustment factor ($DWINV_{j+1,t}$) is estimated by deducting the actual WIP inventory ($WINV_{j+1,t}$)from the target WIP inventory ($TWINV_{j+1,t}$) which is then divided by the WIP inventory deviation adjustment time (T_w) as formulated in Equation (13).

$$DWINV_{j+1,t} = (TWINV_{j+1,t} - WINV_{j+1,t})/T_w \qquad \forall \ j,t \qquad (13)$$

The WIP inventory refers to the partially completed material awaiting to become a finished product. The WIP inventory ($WIP_{j+1,t}$) is determined by deducting the order quantity of the manufacturer ($ORD_{j+1,t-L}$) in a lead time from the sum of the WIP inventory ($WINV_{j+1,t-1}$) in a previous time and the order quantity of the manufacturer ($ORD_{j+1,t-L-LP}$) in a lead time and production lead time, as formulated in Equation (14). In this study, it is assumed that the sum of the lead time and the production lead time (LP) cannot be greater than the current time.

$$WINV_{j+1,t} = WINV_{j+1,t-1} + ORD_{j+1,t-L} - ORD_{j+1,t-L-LP} \qquad \forall \ j,t \qquad (14)$$

The system inventory is the total inventory level of the distributor and the manufacturer under a VMI policy. The system inventory ($SINV_t$) is estimated by adding the inventory level of the distributor ($INV_{j,t}$) and the inventory of the manufacturer ($INV_{j+1,t}$), as formulated in Equation (15).

$$SINV_t = INV_{j,t} + INV_{j+1,t} \qquad \forall \ j,t \qquad (15)$$

The target system inventory is the quantity of system inventory that will be retained at all times as a safety buffer for both the distributor and the manufacturer. The target system inventory ($TSINV_t$) is determined by multiplying the predicted consumption of the manufacturer ($VC_{j+1,t}$) by the production lead time (T_p), as formulated in Equation (16).

$$TSINV_t = VC_{j+1,t} \cdot T_p \qquad \forall \ j,t \qquad (16)$$

Similarly, the target WIP inventory is the quantity of WIP inventory the manufacturer will maintain at all times as a safety buffer. The target WIP inventory ($TWINV_{j+1,t}$) is determined by multiplying the predicted consumption of the manufacturer ($VC_{j+1,t}$) by the WIP inventory deviation adjustment time (T_w), as formulated in Equation (17).

$$TWINV_{j+1,t} = VC_{j+1,t} \cdot T_w \qquad \forall \ j,t \qquad (17)$$

3.1.3 Cash flow sub-model

The accounts receivable of each participant ($AR_{j,t}$) denotes the payments from credit sales, which are estimated by summing the accounts receivable not paid in a previous time ($AR_{j-1,t}$) and the new invoice generated at the current time, the latter of which is determined by deducting the payment collected at the current time ($ARC_{j,t}$) from multiplying the finished product price (P_j) with the order rate from its buyer at the current time ($OAR_{j-1,t}$), as formulated in Equation (18).

$$AR_{j,t} = AR_{j,t-1} + P_j \cdot OAR_{j-1,t} - ARC_{j,t} \qquad \forall\ j,t \qquad (18)$$

The account payable of each participant ($AP_{j,t}$) refers to the liability from credit purchases, which is estimated by summing the account payable not fulfilled in a previous time ($AP_{j,t-1}$) and the new payment made at the current time, the latter of which is determined by deducting the payment made at the current time ($APG_{j,t}$) from multiplying the finished product price of its supplier (P_{j+1}) with the order rate of its supplier at the current time ($OAR_{j,t}$), as formulated in Equation (19).

$$AP_{j,t} = AP_{j,t-1} + P_{j+1} \cdot OAR_{j,t} - APG_{j,t} \qquad \forall\ j,t \qquad (19)$$

The cash level is the cash quantity of each participant, which is estimated by deducting the summation of account payable quantity at the current time ($AP_{j,t}$), the cost of goods sold ($COGS_{j,t}$) at the current time, and the inventory holding cost ($IHC_{j,t}$) at the current time from the sum of the cash level in a previous time ($CASH_{j,t-1}$) and the account receivable quantity at the current time ($AR_{j,t}$), as formulated in Equation (20).

$$CASH_{j,t} = CASH_{j,t-1} + AR_{j,t} - AP_{j,t} - COGS_{j,t} - IHC_{j,t} \qquad \forall\ j,t \qquad (20)$$

3.2 Financial Performance Index

To explore the effect of the VMI policy on the CFBWE, this study utilized four financial performance indicators – ART, APT, DTER and CCC, along with the inventory levels and cash levels of each SC participant. The ART is an efficient indicator which indicates how frequently a business collects its unpaid invoices over a specific time frame. A high turnover rate for accounts receivable indicates that the business successfully collects its receivable which indicates the high proportion of quality customers of the business. On the other hand, the APT is an efficient ratio that indicates how frequently a business settles its unpaid debts over a specific time frame. A high turnover of account payable indicates that the business swiftly pays off its payable which represents the cash it has available to pay its current liabilities.

A leverage ratio called the DTER assesses how heavily a corporation relies on debt to fulfill its debt obligations. A high DTER, which is determined by dividing a business's total liabilities by its total equity, reveals that the business operates with debt financing rather than its own financing resources. Conversely, the CCC, also referred to as the net operating cycle, indicates the average length of time that passes from inventory purchase to convert it to cash, as formulated in Equation (21). A low CCC indicates how fast the company converts the inventory into cash, revealing its financial health in terms of liquidity.

$$\text{Cash conversion cycle} = \frac{\text{Average inventory}}{\text{Cost of goods sold}/365} + \frac{\text{Average account receivable}}{\text{Revenue}/365} - \frac{\text{Average account payable}}{\text{Cost of goods sold}/365} \qquad (21)$$

4 RESULTS AND DISCUSSION

To analyze the VMI mechanism's effects on the CFBWE, a CFBWE model was developed with a VMI policy for the SC channel between the distributor and the manufacturer. This study compared the differences between the traditional and VMI SCs to measure the CFBWE phenomena while using five indicators – the order, the inventory, the account receivable, the account payable, and the cash level, as well as four financial indicators – the ART, the APT, DTER, and the CCC. In this study, the main parameter available in the input dataset is only the customer order amount. Other input parameters are the delivery lead time (L), the manufacturing lead time (PL), the safety inventory factor (G_j), the demand rate of smooth time (T_c), the system inventory deviation adjustment time (T_i), the demand rate of the manufacturer's smooth time (T_m), the WIP inventory deviation adjustment time (T_w), the production lead time (T_p), and the delivery lead time of the distributor (T_q). In addition, the relationships between the parameters are illustrated in Figure C.1 in the Appendix.

4.1 Cash-flow Bullwhip Effect

The SC phenomenon known as the CFBWE describes how small fluctuations of demand in a downstream level amplify a CCC in an upstream level throughout the entire SC. This study uses the customer demand data from Tangsucheeva and Prabhu (2013) to observe the CFBWE. There was no difference in the retailer's order quantity because both the VMI policy case and the non-VMI policy case used the same customer demand data. Using the mathematical model developed, this study first examined the order quantity of each participant – a retailer, a distributor, a manufacturer, and the supplier – through the SC, as shown in Figure 2.

Under the VMI policy, the order quantities placed by the retailer, the distributor, the manufacturer and the supplier decreased by 0.24%, 1.84%, 4.41%, and 6.41%, respectively, compared with the conventional SC. The fact that the order quantities from the manufacturer and distributor dropped in comparison with a non-VMI policy, thereby indicating that the VMI policy impacts the order quantity of the distributor, which is controlled by the manufacturer as a vendor, as illustrated in Figure 2. Under the non-VMI policy, the conventional SC case is denoted as (a), while in the VMI policy case it is denoted as (b) in all figures throughout this paper.

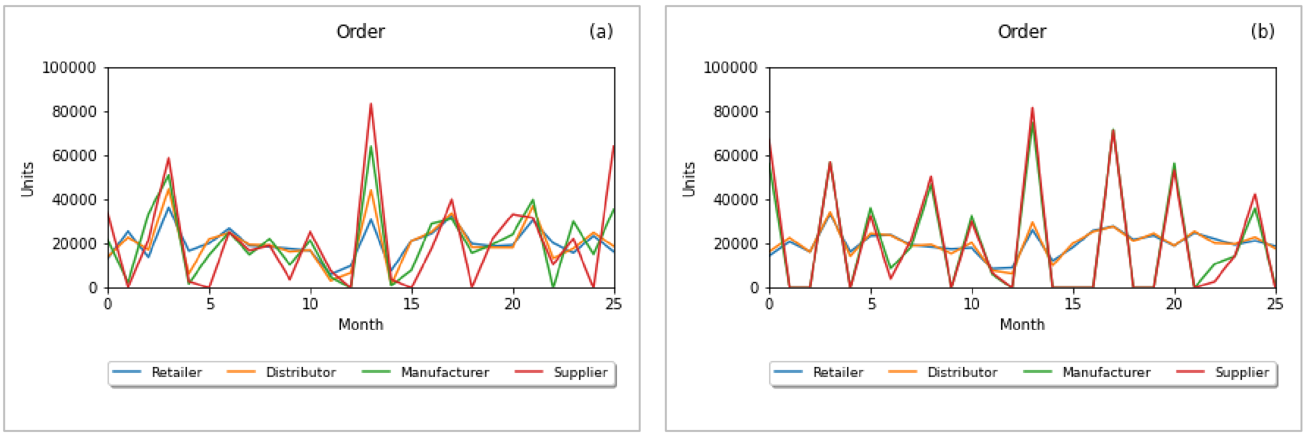

Figure 2. Comparison of order quantity

Because the VMI policy is known to be a method for mitigating the BWE, this study investigated how each SC participant's inventory level changes under a VMI policy. As indicated in Figure 3, except for the manufacturer, the average inventory levels of each participant in a VMI policy case decrease to 85.18% for the retailer, 87.43% for the distributor, and 40.99% for the supplier compared to a non-VMI policy case. As a vendor of the VMI policy, the manufacturer's inventory level increased to 98.34% (as expected). As the overall quantity of the inventory level under a VMI policy is smaller than that under a non-VMI policy, the results indicate that the VMI policy influences each participant's inventory reduction, which further reduces their overall inventory holding cost across the SC.

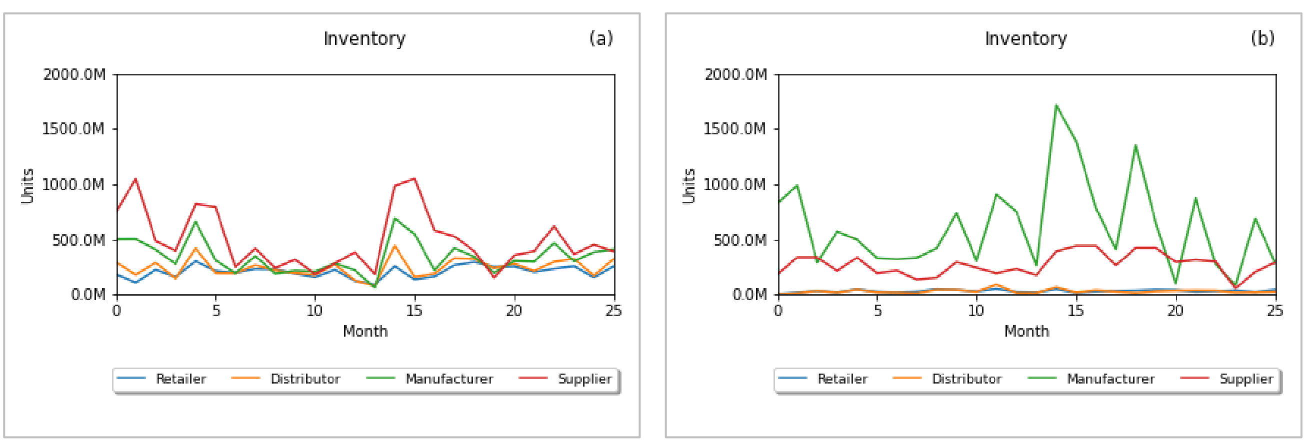

Figure 3. Comparison of inventory levels

Because the BWE can lead to excess inventory and create a cash-flow shortfall, this study investigated how both non-VMI and VMI policies affect each participant's cash level in the SC. The findings show that the excess inventory lengthens the CCC from material purchase to product sales and reduces each participant's cash level, while the lengthy CCC grows the CFBWE from downstream participants to upstream participants across the entire SC. As illustrated in Figure 4, under a VMI policy, the retailer's cash level rises by 8.78%, the distributor's by 17.23%, and the supplier's by 11.94% for each participant. However, the manufacturer's cash level fell by 23.65% compared to a non-VMI policy. Because the manufacturer controls the total inventory quantity of the distributor and the manufacturer under the VMI policy, it is reasonable to have a large quantity of inventory which reduces the cash level of the manufacturer. The result reveals that the VMI policy partially mitigates the CFBWE by avoiding each participant's cash-flow shortfall.

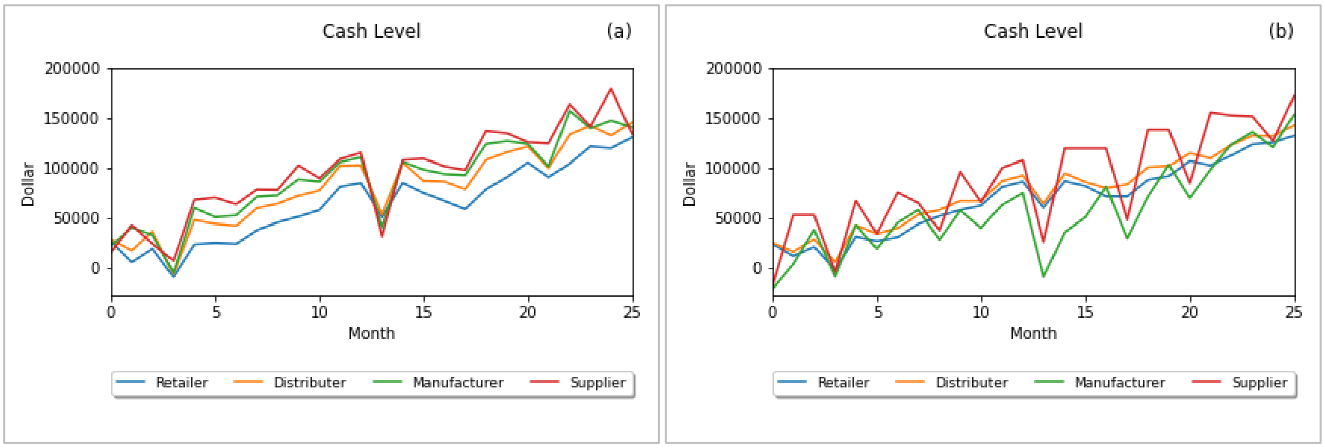

Figure 4. Comparison of cash levels

It is crucial to handle the accounts receivable and the accounts payable efficiently to maintain sustainable cash flow in the SC. For these reasons, this study analyzed two important account ledgers in the accounting process. Under the VMI policy, the distributor's, manufacturer's, and supplier's respective accounts receivable amounts declined by 0.24%, 1.84%, and 4.41%, while the retailer's accounts receivable amounts are largely similar to those under the non-VMI policy, as shown in Figure 5. Because the low number of accounts receivable indicates that the seller collects its payments from the purchaser, the VMI policy partially improves the cash flow of the distributor as a purchaser and the manufacturer as a supplier.

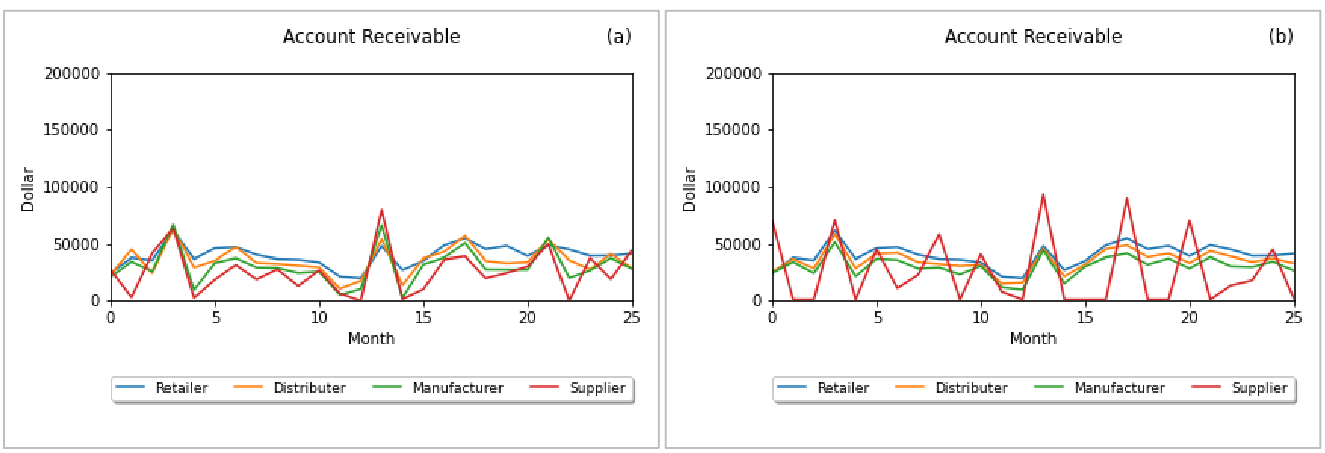

Figure 5. Comparison of accounts receivable quantities

Similarly, the accounts payable amounts of each SC participant were investigated, as illustrated in Figure 6. Under the VMI policy, the retailer's and distributor's respective accounts payable amounts declined by 0.24% and 1.84%, while the manufacturer's and supplier's respective accounts payable amounts declined by 4.41% and 6.41%, compared to the non-VMI policy. Because the low number of accounts payable indicates that the purchasers make quick payments to the seller, the VMI policy leads to a partial improvement of each SC participant's cash flow. As a result, the CFBWE is diminished, as all SC participants are reduced under the VMI policy.

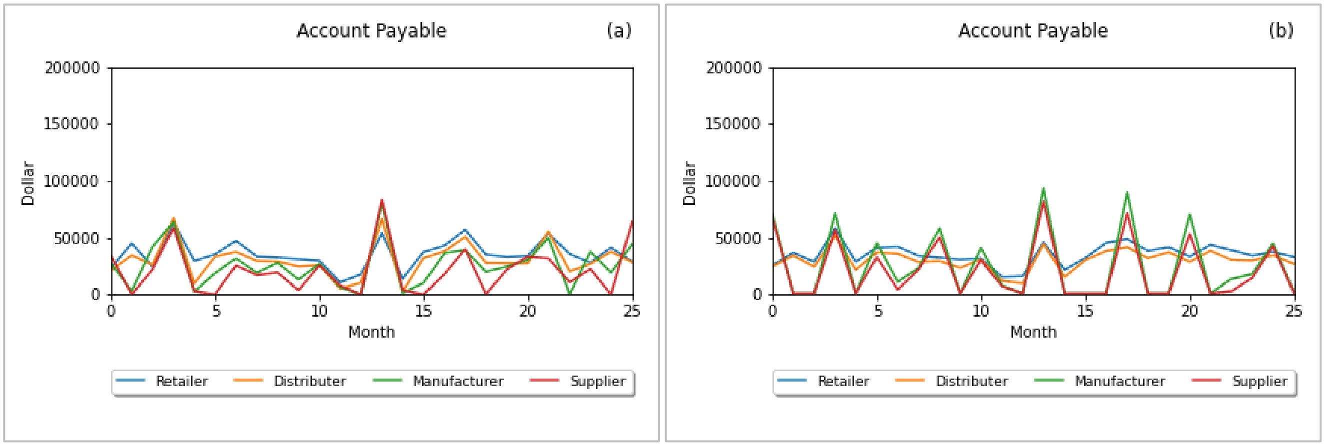

Figure 6. Comparison of accounts payable quantities

As one of the primary sources of the CFBWE, this study examined the influences of the VMI policy on the BWE, which characterizes the fluctuations of demand as it passes through the SC from the downstream to the upstream. The standard representation of BWE is Var(I)/Var(D) which denotes the variance of each SC participant's inventory and demand, respectively. The BWE generally increases from the retailer to the supplier as the lead time for delivery lengthens. However, its effectiveness in mitigating the BWE demonstrates the expected influence of the VMI policy, as depicted in Figure 7.

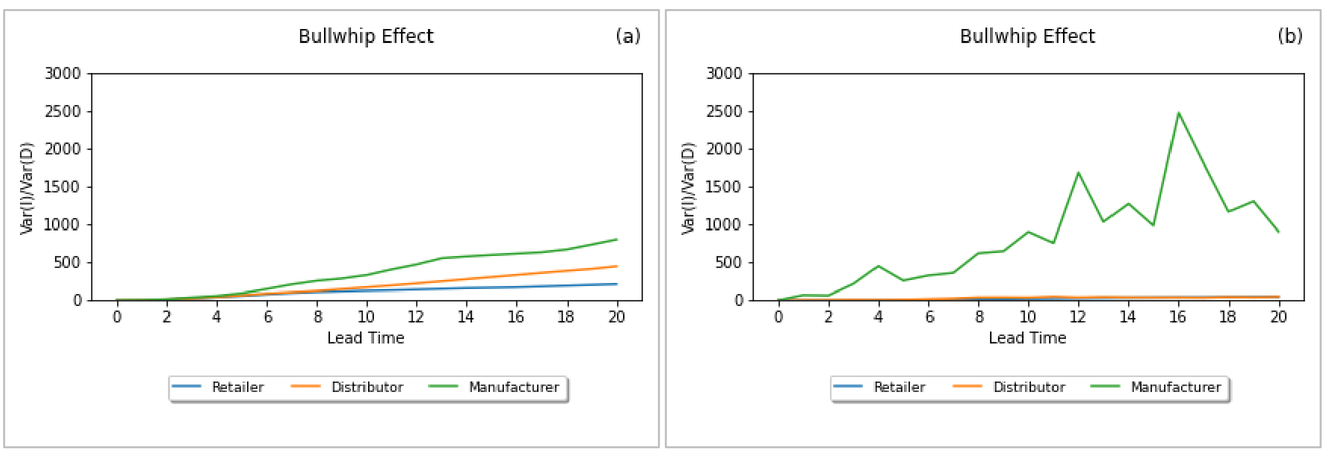

Figure 7. Comparison of bullwhip effects

For instance, compared with the non-VMI policy, under the VMI policy, the retailer's and the distributor's respective BWE declined by 80.70% and 85.21%, while the manufacturer's BWE raised by 130.85%. Given that the manufacturer controls the system inventory of the manufacturer and the distributor, it is natural for the manufacturer's BWE to grow under the VMI policy. Because the VMI policy lessens the BWE, this study further investigated its influence on the CFBWE. The standard representation of CFBWE is Var(CCC)/Var(D), which denotes the variance of each SC participant's CCC and demand, respectively, as depicted in Figure 8. In response to changes in the delivery lead time, the retailer's and the distributor's respective CFBWE declined by 91.75% and 95.89%, while the manufacturer's CFBWE also declined by 40.75% compared to the non-VMI policy. The decreased ratio of CFBWE implies that the VMI policy works to lessen the BWE in order to ameliorate the CFBWE.

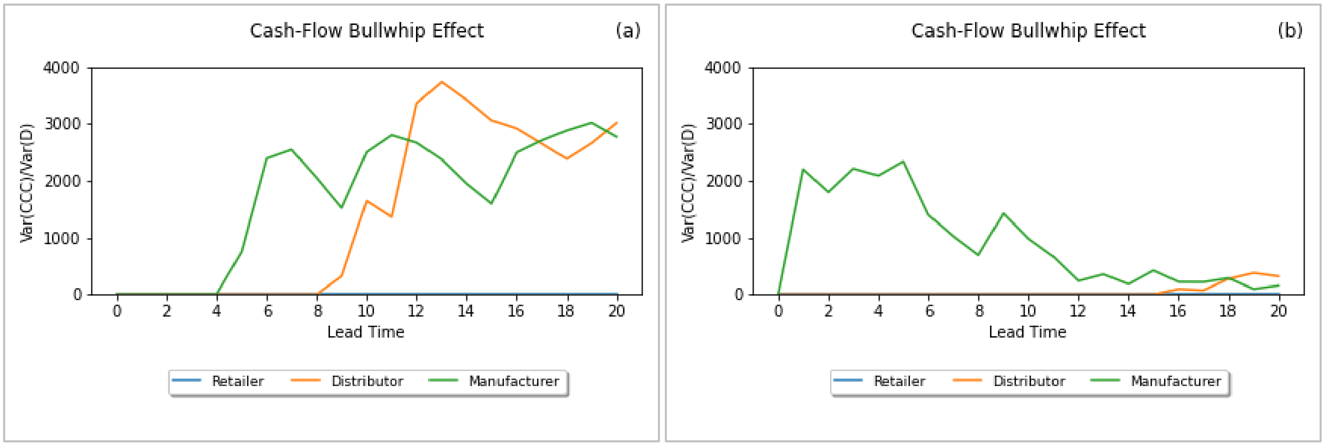

Figure 8. Comparison of cash-flow bullwhip effects

4.2 Financial Performance

Four financial measures – ART, APT, DTER, and CCC – were utilized to examine the impacts of the VMI policy on the CFBWE. The ART identifies how successfully each SC participant collects all of its receivables during a specific time frame. In general, a high ratio of the ART denotes an efficient collection of its dues from the purchaser. As illustrated in Figure 9, under the VMI policy, the retailer's ratio declined by 0.02%, the distributor's by 1.44%, and the manufacturer's by 15.68% for each participant compared to a non-VMI policy. Because the low ratio is considered a good indicator of payment collection, the results imply that the VMI policy lessens the CFBWE across the entire SC.

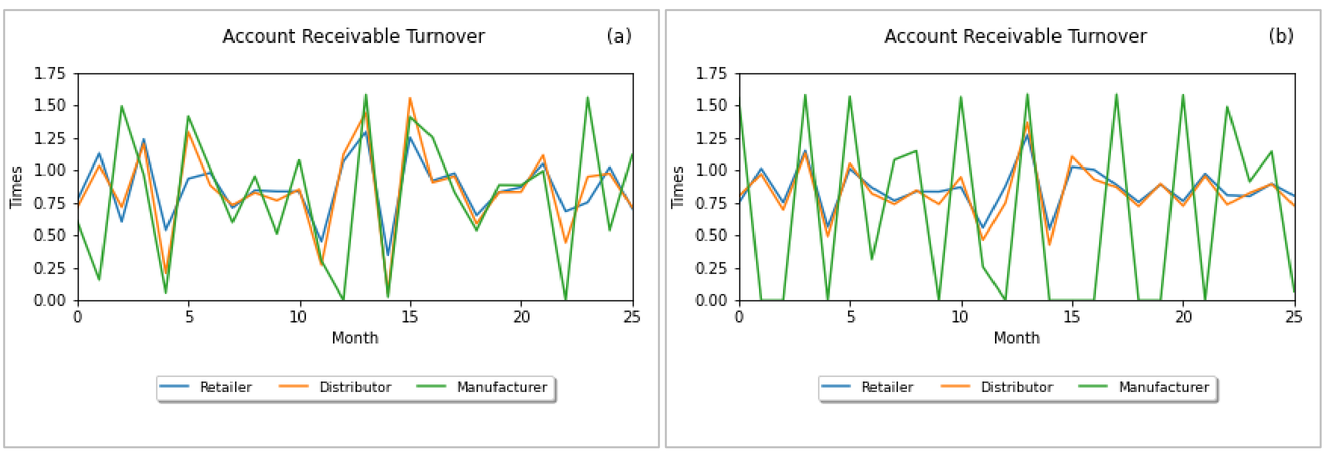

Figure 9. Comparison of ART

In addition, this study considered the APT which describes whether each SC participant efficiently pays its total payable over a particular period. Similar to an ART, a high ratio of the APT indicates timely payment being made to the supplier. In the case of the VMI policy, the APT ratios of the retailer and the manufacturer decreased by 2.02% and 25.07% compared with the non-VMI policy, as illustrated in Figure 10. However, the APT ratio of the distributor increases by 3.54 times that of the manufacturer under the non-VMI policy. The results indicate that the VMI policy increases both the retailer's and the manufacturer's ability to pay their short-term obligations and the control over cash flow for all business opportunities. Given that the distributor's APT ratio in the VMI policy is relatively higher than that of the distributor in the non-VMI policy, the result indicates that the VMI policy does not effectively improve the distributor's CFBWE in terms of the APT.

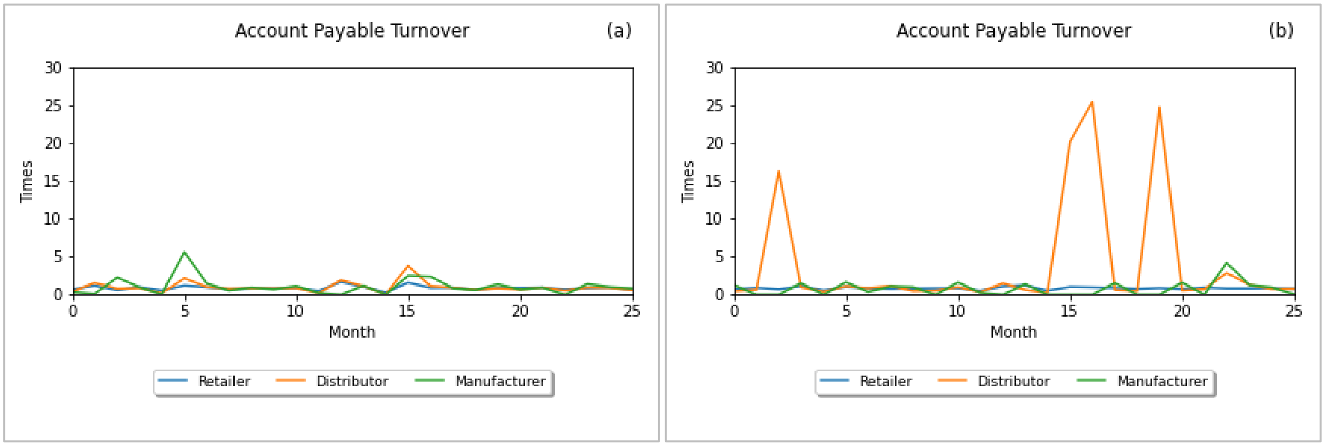

Figure 10. Comparison of APT

The ability to meet financing obligations is indicated by the DTER, which is also known as the leverage ratio. A solid financial situation is typically characterized by a DTER of less than two. Since the accounts receivable is a current asset and the accounts payable is a short-term liability on the balance sheet, this study extensively assumes the accounts payable to be a debt and the accounts receivable an equity in the DTER over a short-term period. As depicted in Figure 11, compared with the non-VMI policy case, the retailer's DTER declined by 5.18%, the distributor's by 19.23%, and the supplier's by 76.28%. However, in the VMI policy, the manufacturer's DTER is 4.21 times larger than it is in the non-VMI policy. The findings show that, aside from the manufacturer, the VMI policy ensures that every participant of the SC maintains a suitable level of inventory and further reduces the risk of investing in excess inventory. While the partial VMI policy between the distributor and the manufacturer is included into the SC, there are restrictions on the manufacturer's ability to improve the CFBWE.

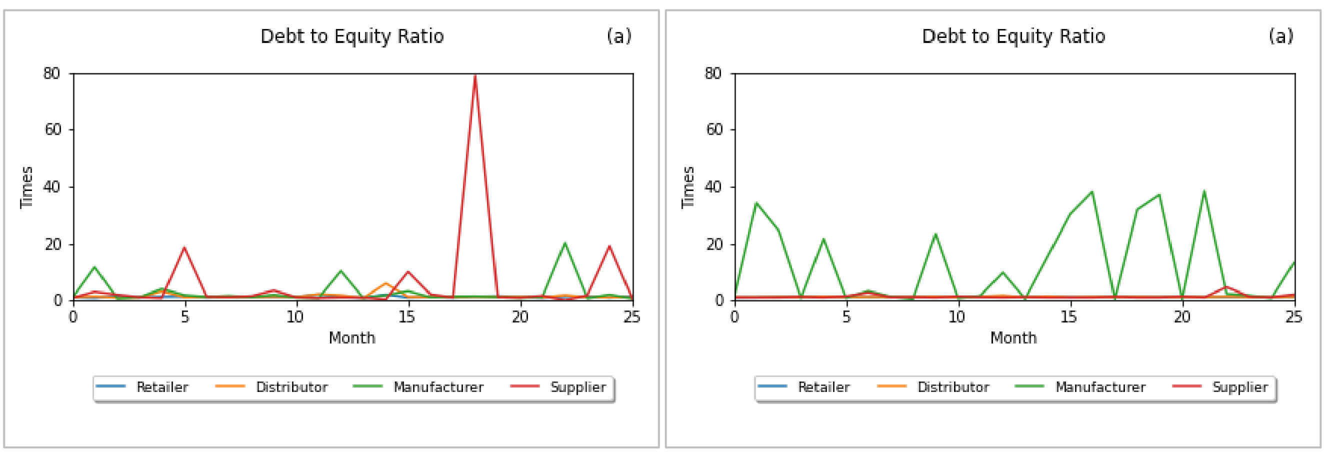

Figure 11. Comparison of DTER

Since the CFBWE in the SC can be measured using a popular financial ratio called the CCC, its effects on minimizing the CFBWE were assessed using the VMI policy. The period needed to turn inventory investments into cash following sales is known as the CCC. A low ratio demonstrates proper cash flow management in relation to net profit and efficient resource utilization by the SC participant. As indicated in Figure 12, under the VMI policy, the retailer's cash level declined by 9.01%, the distributor's by 26.45%, the manufacturer's by 8.75% and the supplier's by 71.21% compared with the non-VMI policy. As a common financial ratio of the CFBWE, these findings suggest that the VMI policy can be utilized as a technique for reducing the CFBWE in the SC.

As shown in Table 2, this study uses four financial measures to find which measure is a proper indicator of the CFBWE under the VMI scheme. Compared with the non-VMI policy case, the results indicate that the CCC and ART are proper financial indicators under the VMI mechanism in the SC, while the APT and DTER do not properly represent the reduction of the distributor and the manufacturer.

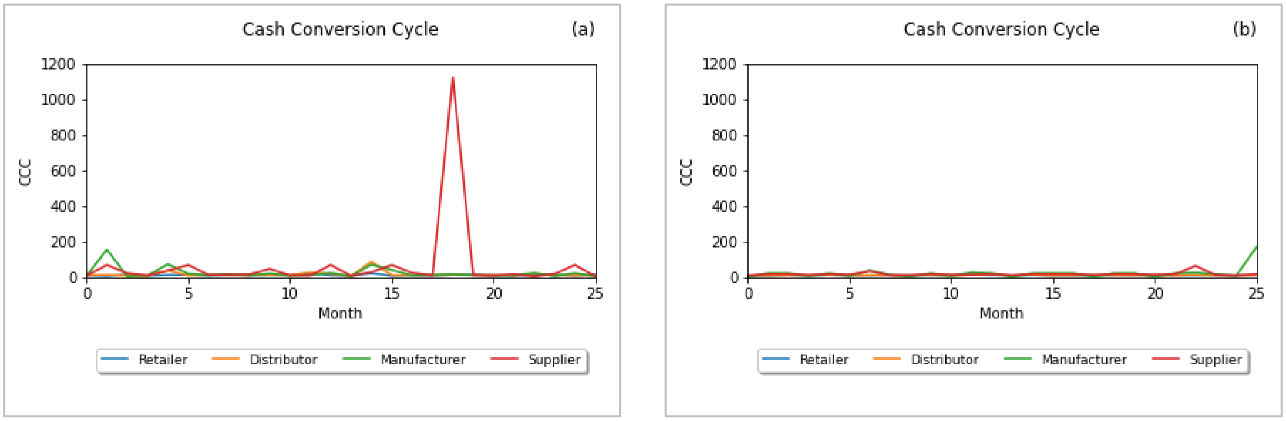

Figure 12. Comparison of CCC

Table 2. The results of financial measures (%)

Measure	Retailer	Distributor	Manufacturer
ART	-0.02	-1.44	-15.68
APT	-2.02	+353.77	-25.07
DTER	-5.18	-19.23	+421.14
CCC	-9.01	-26.45	-8.75

4.3 Sensitivity Analysis

Since the lead time is well known as a critical factor causing the BWE in the SC, most studies have analyzed the impacts of the delivery lead time on the BWE in the SC. Due to this reason, this study employed a sensitivity analysis to look at the influences of the manufacturing lead time on the CFBWE, while changing the manufacturing lead time from 10 days to 15 days. This study employed a sensitivity analysis to look at the influences of the manufacturing lead time on the CFBWE, while changing the manufacturing lead time from 10 days to 15 days. In the case of the non-VMI policy, the rise in the manufacturing lead time causes a fluctuation in the CFBWE, as depicted in Figure 13. Conversely, the VMI policy causes the CFBWE for the retailer and distributor to fluctuate as a result of the lengthening of the production lead time. However, the CFBWE for the manufacturer was reduced by 59.09% and 77.97% in 10 days and 15 days, respectively, of the manufacturing lead time. Because the CFBWE is amplified for the retailer and distributor but not for the manufacturer as a result of the longer manufacturing lead times, the results suggest that the manufacturing lead time may be one of the factors contributing to the CFBWE in the SC. Conversely, the findings also suggest that one of the manufacturer's options as a vendor under the VMI policy for reducing the CFBWE can be an increase in the manufacturing lead time.

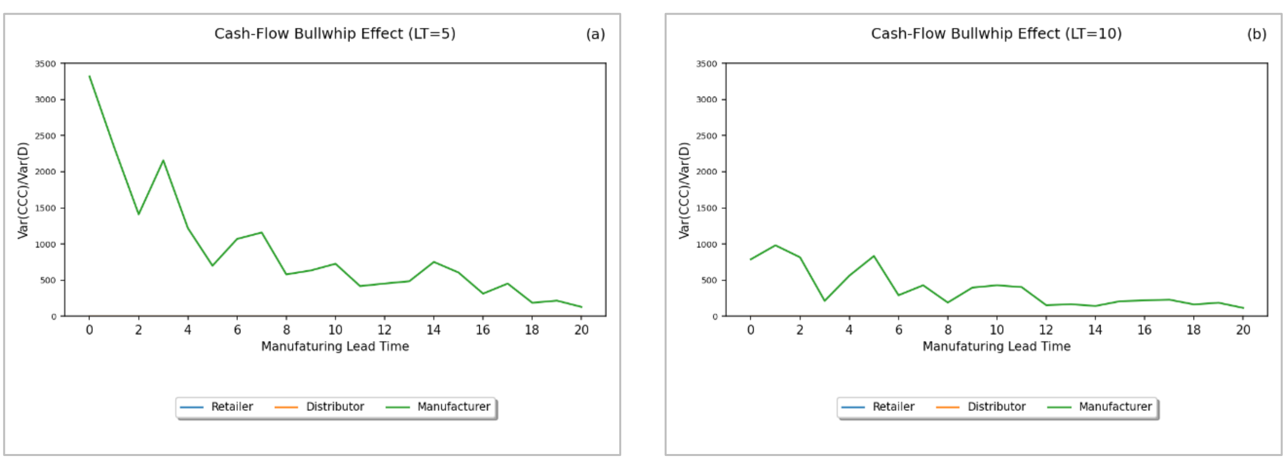

Figure 13. The impacts of manufacturing lead time on the CFBWE

5. CONCLUSIONS

The CFBWE, which results in a chain of cash-flow shortages among all SC participants, must be adequately countered by the company because it is one of the key markers of a company's financial health in the SC. Despite the fact that numerous studies have highlighted the significance of the CFBWE for sustainable SC operations, they have mostly concentrated on its causes and impacts at various points along the SC. No research has offered a solution for reducing the CFBWE. To fulfill this gap, this study has applied one of the mitigation methods for BWE to the CFBWE case while assessing the first-time effects of the VMI policy on the channel between the distributor as the buyer and the manufacturer as the vendor on the CFBWE across the SC.

The outcomes show that one of the typical bullwhip impact mitigation strategies actually lessens the CFBWE. In comparison to a non-VMI policy, the VMI policy improves the CFBWE issue in terms of accounts receivable, accounts payable, and cash level when it operates the supply channel between the distributor and the manufacturer. The results show that the VMI policy lessens the CFBWE for each SC participant in terms of the working capital metric, the CCC. The CFBWE of the manufacturer (as the controller of the system inventory under the VMI policy) also lessens with respect to the CFBWE 's coefficient of variation. The findings show that the VMI policy generally lessens the SC's exposure to the CFBWE. In addition, the sensitivity analysis of the manufacturing lead time demonstrates that a suitable lead time can also reduce the manufacturer's CFBWE under the VMI policy.

This study shows that the VMI policy helps to reduce the CFBWE, but it has a drawback in that the results were only applicable to the customer demand data that was adopted. To verify the effects of the VMI policy on the CFBWE, multiple scenarios must be applied to the created mathematical model. Additionally, the VMI policy between the distributor as a buyer and the manufacturer as a supplier was the only topic of this study. The developed model has to expand the VMI policy to include all SC participants in order to examine its impact on the CFBWE. However, the fact that one of the BWE mitigation strategies lessens the CFBWE provides an excellent opportunity for subsequent studies to evaluate the influences of other BWE mitigation strategies.

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REFERENCES

Astanti, R. D., Daryanto, Y., and Dewa, P. K. (2022). Low-Carbon Supply Chain Model Under A Vendor-Managed Inventory Partnership and Carbon Cap-And-Trade Policy. *Journal of Open Innovations: Technology, Market, and Complexity*, 8(1):30

Badakhshan, E., and Ball, P. (2023). Applying Digital Twins for Inventory and Cash Management in Supply Chains Under Physical and Financial Disruptions. *International Journal of Production Research*, 61(15):5094-5116.

Badakhshan, E., Humphreys, P., Maguire, L., and Mcivor, R. (2020). Using Simulation-Based System Dynamics and Genetic Algorithms to Reduce The Cash Flow Bullwhip in The Supply Chain. *International Journal of Production Research*, 58 (17): 5253–5279.

Bai, Q., Gong, Y., Jin, M., and Xu, X. (2019). Effects of Carbon Emission Reduction on Supply Chain Coordination with Vendor-Managed Deteriorating Production Inventory. *International Journal of Production Economics*, 208:83-99.

Cai, J., Tadikamalla, P. R., Shang, J., and Huang, G. (2017). Optimal Inventory Decisions Under Vendor Managed Inventory: Substitution Effects and Replenishment Tactics. *Applied Mathematical Modeling*, 43:611-629.

Chen, X., Zeng, J., and Yuan, X. (2022). The Impact of Bullwhip Effect on The Cash Flow in Two- Parallel Supply Chain Systems with The Competition Effect. *Discrete Dynamics in Nature and Society*, 2022:1–21.

Disney, S. M., and Towill, D. R. (2003). The Effect of Vendor Managed Inventory (VMI) Dynamics on The Bullwhip Effect in Supply Chains. *International Journal of Production Economics*, 85:199-215.

Dong, Y., Xu, K., and Dresner, M. (2007). Environmental Determinants of VMI Adoption: An Exploratory Analysis. Transportation Research Part E: *Logistics and Transportation Review*, 43(4):355-369.

Han, J., Lu, J., and Zhang, G. (2017). Tri-Level Decision Making for Decentralized Vendor-Managed Inventory. *Information Sciences*, 421:85-103.

Hosseini, A., and Mehrjerdi, Y. Z. (2016). The Bullwhip Effect on The VMI-Supply Chain Management Vis System Dynamics Approach: The Supply Chain with Two Supplier and One Retailer Channel. *International Journal of Supply and Operations Management*, 3(2):1301-1317.

Gharaei, A., Karimi, M., Ashkan, S., and Shekarabi, H. (2019). An Integrated Multi-Product, Multi-Buyer Supply Chain Under Penalty, Green, and Quality Control Policies and A Vendor Managed Inventory with Consignment Stock Agreement: The Outer Approximation with Equity Relaxation and Augmented Penalty Algorithm. *Applied Mathematical Modeling*, 69:223-254.

Goodarzi, M., Makvandi, P., Saen, R.F., and Sagheb, M.D. (2017). What Are Causes of Cash Flow Bullwhip Effect in Centralized and Decentralized Supply Chains?. *Applied Mathematical Model*, 44:640–654.

Li, G., Wang, X., and Wang, Z. (2013). System Dynamics Model for VMI&TPL Integrated Supply Chains. *Discrete Dynamics in Natural and Society*, 2013:17-33.

Mateen, A., and Chatterjee, A. K. (2015). Vendor Managed Inventory for Single-Vendor Multi-Retailer Supply Chains. *Decision Support Systems*, 70:31-41.

Mateen, A., Chatterjee, A. K., and Mitra, S. (2015). VMI for Single-Vendor Multi-Retailer Supply Chains Under Stochastic Demand. *Computers & Industrial Engineering*, 79:95-102.

Mohamadi, N., Niaki, T. A. S., Taher, M., and Shavandi, A. (2024). An Application of Deep Learning and Vendor-Managed Inventory in Perishable Supply Chain Management. *Engineering Applications of Artificial Intelligence*, 127:107403.

Patil, C., and Prabhu, V. (2024). Supply Chain Cash-Flow Bullwhip Effect: An Empirical Investigation. *International Journal of Production Economics*, 267:109065.

Sainathan, A., and Groenevelt, H. (2019). Vendor Managed Inventory Contracts – Coordinating The Supply Chain While Looking from The Vendor's Perspective. *European Journal of Operational Research*, 272:249-260.

Sim, J. and Prabhu, V. V. (2022). The Impact of Credit Risk on Cash-Bullwhip Effect in Supply Chain. *The Engineering Economist*, 67(4):266-287.

Stellingwerf, H. M., Kanellopoulos, A., Cruijssen, F. C. A. M., and Bloemhof, J. M. (2019). Fair Gain Allocation in Eco-Efficient Vendor-Managed Inventory. *Journal of Cleaner Production*, 231:746-755.

Taleizadeh, A. A., Noori-Daryan, M., and Cardenas-Barron, L. E. (2015). Joint Optimization of Price, Replenishment Frequency, Replenishment Cycle and Production Rate in Vendor Managed Inventory System with Deteriorating Items. *International Journal of Production Economics*, 159:285-295.

Taleizadeh, A. A., Shokr, I., Konstantaras, I., and Vafaeinejad, M. (2020). Stock Replenishment Policies for A Vendor-Managed Inventory in A Retailing System. *Journal of Retailing and Consumer Services*, 55:102137.

Tangsucheeva, R., and Prabhu, V. (2013). Modeling and Analysis of Cash-Flow Bullwhip in Supply Chain. *International Journal of Production Economics*, 145:431-447.

Weraikat, D., Zanjani, M. K., and Lehoux, N. (2019). Improving Sustainability in A Two-Level Pharmaceutical Supply Chain Through Vendor-Managed Inventory System. *Operations Research for Health Care*, 21:44-55.

Xiao, T., and Xu, T. (2013). Coordination Price and Service Level Decisions for A Supply Chain with Deteriorating Item Under Vendor Managed Inventory. *International Journal of Production Economics*, 145:743-752.

Yao, Y., and Dresner, M. (2008). The Inventory Value of Information Sharing, Continuous Replenishment, and Vendor-Managed Inventory. *Transportation Research Part E: Logistics and Transportation Review*, 44(3):361-378.

Yu, Y., Chu, F., and Chen, H. (2009). A Stackelberg Game and Its Improvement in A VMI System with A Manufacturing Vendor. *European Journal of Operations Research*, 192 (3):929-948.

APPENDIX A

A.1 Nomenclature

$AP_{j,t}$: The account payable of supply chain member j at time t
$APG_{j,t}$: The payment made by supply chain member j at time t
$AR_{j,t}$: The account receivable of supply chain member j at time t
$ARC_{j,t}$: The payment collected by supply chain member j at time t
$BO_{j,t}$: The back order of supply chain member j at time t
$CASH_{j,t}$: The cash level of supply chain member j at time t
$COGS_{j,t}$: The cost of goods sold of supply chain member j at time t
$DSINV_{t}$: The system inventory deviation adjustment factor at time t
$DWINV_{j,t}$: The WIP-inventory deviation adjustment factor of the manufacturer at time t
$FC_{j,t}$: The predicted order demand of supply chain member j at time t
$IHC_{j,t}$: The inventory holding cost of supply chain member j at time t
$INV_{j,t}$: The inventory of supply chain member j at time t
G_{j}: The safety inventory factor
$OAR_{j,t}$: The order rate of supply chain member j at time t
$OINV_{j,t}$: The in-transit-inventory of supply chain member j at time t
$ORD_{j,t}$: The order amount from supply chain member j at time t
P_{j}: The finished product price of supply chain member j
$ROP_{j,t}$: The reorder point of supply chain member j at time t
$SINV_{t}$: The actual system inventory at time t
$SS_{j,t}$: The safety inventory of supply chain member j at time t
$TSINV_{t}$: The target system inventory at time t
$TWINV_{j,t}$: The target WIP-inventory of the manufacturer at time t
T_{c}: The demand rate of smooth time
T_{i}: The system inventory deviation adjustment time
T_{m}: The demand rate of the manufacturer’s smooth time
T_{w}: The WIP inventory deviation adjustment time
T_{p}: The production lead time
T_{q}: The delivery lead time of the distributor
$VC_{j,t}$: The predicted consumption of the manufacturer at time t
$WINV_{j,t}$: The actual WIP-inventory of the manufacturer at time t

APPENDIX B

B.1 Results under the VMI mechanism

In this section, R, D, M, and S stand for the retailer, the distributor, the manufacturer, and the supplier, respectively.

Table B.1. The changes of order quantities (Units)

Month	R	D	M	S	Month	R	D	M	S
1	14,530	16,382	56,228	67,077	13	9,145	6,482	0	0
2	21,006	22,783	0	0	14	26,221	29,642	74,777	81,649
3	16,373	16,290	0	0	15	12,305	10,184	0	0
4	33,415	34,327	56,900	56,882	16	18,336	20,147	0	0
5	16,364	14,392	0	0	17	25,947	25,459	0	0
6	23,574	24,664	36,106	32,675	18	27,880	27,764	71,775	71,238
7	24,066	23,888	8,847	4,203	19	21,933	21,239	0	0
8	19,429	18,995	18,385	21,516	20	23,740	24,747	0	0
9	18,511	19,566	46,759	50,327	21	19,016	19,065	56,379	53,294
10	17,582	15,570	0	0	22	24,984	25,612	0	0
11	18,135	20,531	32,726	30,119	23	22,261	20,254	10,809	2,917
12	8,710	7,945	6,261	6,983	24	19,498	19,864	14,343	14,522

Table B.2. The changes of inventory levels (Units)

Month	R	D	M	S	Month	R	D	M	S
1	3,990	1,740	825,604	184,010	13	22,633	14,046	750,998	234,304
2	17,342	11,745	989,956	336,314	14	18,673	13,629	262,083	176,334
3	31,765	33,929	288,758	336,314	15	47,410	66,715	1,716,284	391,881
4	19,260	16,043	572,116	214,233	16	15,546	18,748	1,390,667	440,484
5	45,707	44,930	496,843	335,789	17	27,384	38,722	781,846	440,484
6	25,059	19,714	330,939	194,370	18	32,599	25,623	409,106	265,313
7	18,044	16,056	320,751	217,670	19	35,171	13,162	1,351,205	423,828
8	25,339	11,094	333,431	136,668	20	43,300	28,745	651,595	423,828
9	47,754	42,967	419,520	154,768	21	40,168	35,305	98,578	294,660
10	40,756	42,016	736,695	294,184	22	24,500	37,303	872,946	315,950
11	27,614	24,369	305,603	243,254	23	30,404	36,010	275,090	298,901
12	50,627	90,574	906,826	193,248	24	37,297	16,876	86,415	56,696

Table B.3. The changes of cash levels (Dollars)

Month	R	D	M	S	Month	R	D	M	S
1	24,573	25,428	-20,285	-17,077	13	86,602	92,742	75,234	107,983
2	12,314	16,680	4,287	53,208	14	60,589	64,283	-8,514	26,334
3	21,534	29,004	38,462	53,208	15	87,097	94,894	35,949	119,805
4	-1,417	6,165	-8,227	-3,674	16	82,185	86,207	51,225	119,805
5	31,725	43,054	43,264	67,451	17	71,839	80,106	81,445	119,805
6	27,147	34,696	19,719	34,776	18	71,827	83,869	29,915	48,567

Month	R	D	M	S	Month	R	D	M	S
7	31,244	40,118	45,655	75,705	19	88,336	100,799	71,561	138,286
8	44,379	53,742	58,506	65,248	20	92,130	102,061	103,419	138,286
9	52,364	58,393	28,549	37,903	21	107,089	115,009	70,065	84,992
10	58,308	67,433	57,898	96,352	22	102,659	109,869	98,663	155,466
11	62,724	67,405	40,346	66,233	23	112,711	123,211	123,569	152,549
12	81,316	87,223	63,317	100,158	24	123,611	132,372	136,022	151,538

Table B.4. The changes of accounts receivable quantities (Dollars)

Month	R	D	M	S	Month	R	D	M	S
1	24,501	25,427	24,572	70,285	13	19,873	16,004	9,723	0
2	37,873	36,760	34,175	0	14	48,042	45,886	44,463	93,471
3	35,525	28,652	24,435	0	15	27,176	21,533	15,276	0
4	61,779	58,477	51,491	71,125	16	35,062	32,088	30,220	0
5	36,676	28,637	21,588	0	17	48,778	45,408	38,189	0
6	46,214	41,254	36,995	45,133	18	54,891	48,789	41,645	89,719
7	47,135	42,116	35,832	11,059	19	45,339	38,382	31,858	0
8	40,379	34,000	28,492	22,982	20	48,238	41,546	37,120	0
9	36,713	32,395	29,349	58,449	21	39,292	33,278	28,597	70,474
10	36,151	30,769	23,355	0	22	49,010	43,723	38,418	0
11	33,834	31,735	30,797	40,907	23	45,022	38,957	30,381	13,511
12	21,290	15,242	11,917	7,826	24	39,472	34,122	29,796	17,928

Table B.5. The changes of accounts payable quantities (Dollars)

Month	R	D	M	S	Month	R	D	M	S
1	25,427	24,572	70,285	67,077	13	16,004	9,723	0	0
2	36,760	34,175	0	0	14	45,886	44,463	93,471	81,649
3	28,652	24,435	0	0	15	21,533	15,276	0	0
4	58,477	51,491	71,125	56,882	16	32,088	30,220	0	0
5	28,637	21,588	0	0	17	45,408	38,189	0	0
6	41,254	36,995	45,133	32,675	18	48,789	41,645	89,719	71,238
7	42,116	35,832	11,059	4,203	19	38,382	31,858	0	0
8	34,000	28,492	22,982	21,516	20	41,546	37,120	0	0
9	32,395	29,349	58,449	50,327	21	33,278	28,597	70,474	53,294
10	30,769	23,355	0	0	22	43,723	38,418	0	0
11	31,735	30,797	40,907	30,119	23	38,957	30,381	13,511	2,917
12	15,242	11,917	7,826	6,983	24	34,122	29,796	17,928	14,522

APPENDIX C

C.1. The relationships between the parameters

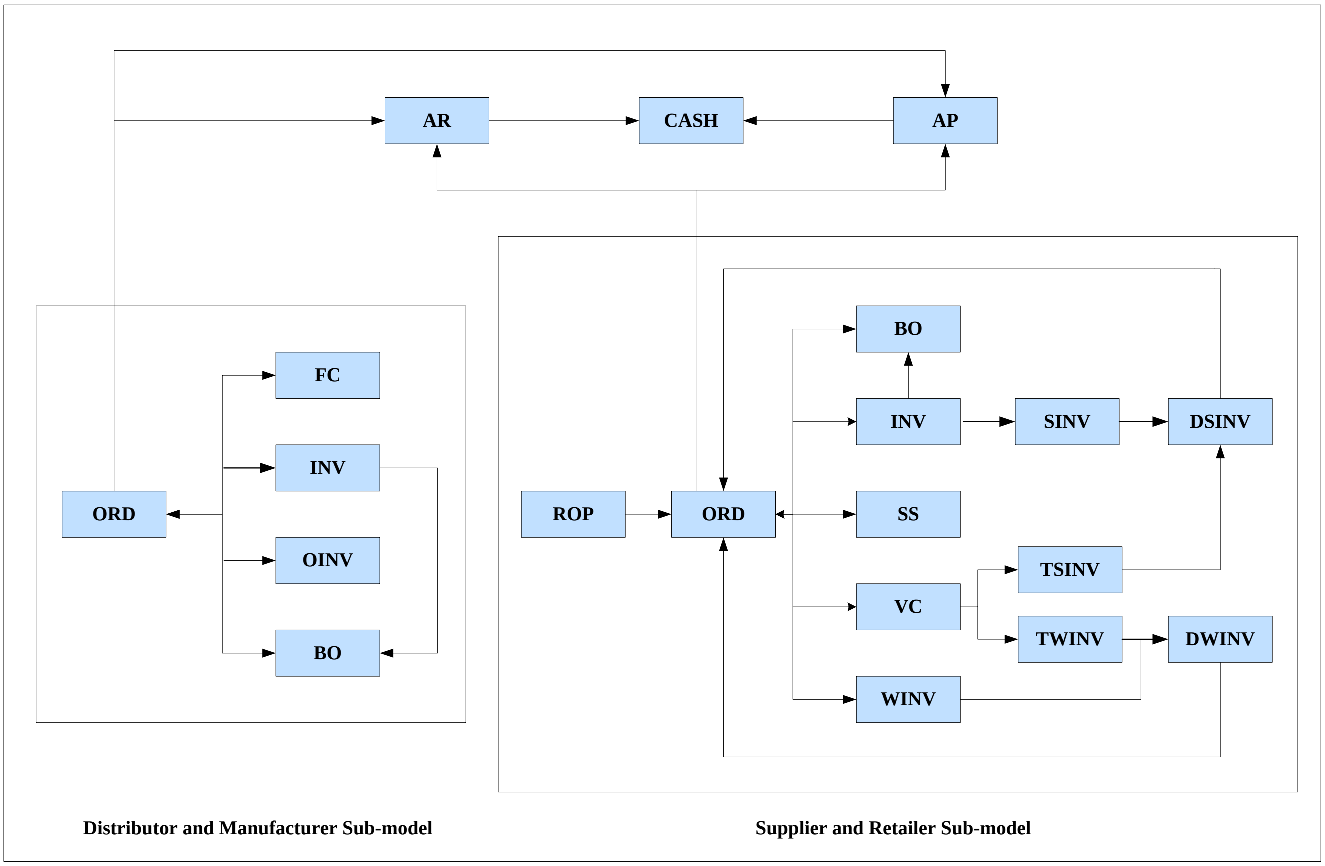

Figure C.1. The relationships between parameters