Supply chain integration in vendor-managed inventory

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Abstract

This paper develops an analytical model that explores how important supply chain parameters affect the cost savings to be realized from collaborative initiatives such as vendor-managed inventory (VMI). Results from the model show that benefits, in the form of inventory cost reductions, may be generated from integration depending upon the ratio of the order costs of the supplier to the buyer and the ratio of the carrying charges of the supplier to the buyer. Results also show that these benefits are disproportionately distributed between buyers and suppliers.

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1. Introduction

Evidence has shown that vendor-managed inventory (VMI) can improve supply chain performance by decreasing inventory levels and increasing fill rates; as a result, industry use of VMI has grown over time \cite{10}. VMI is a collaborative commerce initiative where suppliers are authorized to manage the buyer's inventory of stock-keeping units. It integrates operations between suppliers and buyers through information sharing and business process reengineering. By using information technologies, such as Electronic Data Interchange (EDI) or Internet-based XML protocols, buyers can share sales and inventory information with suppliers on a real time basis. Suppliers can then use this information to plan production runs, schedule deliveries, and manage order volumes and inventory levels at the buyer's stock-keeping facilities.

The potential benefits from VMI are very compelling and can be summarized as reduced inventory costs for the supplier and buyer and improved customer service levels, such as reduced order cycle times and higher fill rates \cite{1,25}. These benefits have been realized by successful retailers and suppliers, most notably Wal-Mart and key suppliers like Proctor and Gamble \cite{4}. Given that not all supply chains use VMI or related supply chain initiatives (e.g., continuous replenishment) however, under
what conditions does VMI actually produce benefits? Moreover, some industry reports have indicated that VMI merely moves inventories from retailers upstream to wholesalers or manufacturers, so where do the benefits from VMI surface among participating parties? Understanding these issues will provide firms in supply chains with profound insights for decision making and negotiations with trading partners.

There have been a number of papers that have examined the factors affecting the benefits to be derived from VMI or other collaborative supply chain initiatives and the distribution of these benefits between suppliers and buyers. For example, using analytical modeling, an early study revealed that the order release policy in use with VMI influences the level of inventory required at the vendor, thus directly affecting a supplier’s inventory costs [4]. Based on a similar approach, another study found that the value of continuous replenishment programs is affected by characteristics of consumer demand [21]; that is, when the demand variance increases, inventory reductions due to continuous replenishment programs decrease. In an empirical study of just-in-time practices, which are often used in conjunction with VMI, it was found that the benefits from JIT in terms of inventory reductions are most likely to flow to buyers rather than to suppliers [7].

We extend this previous research by first using an analytical model to determine how key logistics parameters, most notably ordering costs and inventory carrying charges, can affect the benefits to be derived from VMI. We then determine how the benefits are likely to be distributed between a buyer and supplier in a supply chain, given these logistics parameters. Finally, we present a numerical example to illustrate our results. Our major findings are (1) that total supply chain benefits are higher if the supplier’s ordering cost is small relative to the buyer’s prior to the implementation of VMI, or large relative to the buyer’s after the implementation of VMI and (2) that the buyer receives more benefits from inventory cost savings while the supplier maintains a higher level of inventory.

These results have managerial ramifications in that they can help demonstrate when and by how much VMI is likely to produce benefits for supplier–buyer dyads in practice. Furthermore, the results provide some important insights as to how the benefits are naturally distributed between participants and as to the factors that influence the distribution of benefits. Together, these results can be conveniently used by practitioners in making decisions about whether VMI alliances should be formed and what side-payment arrangements are appropriate if the benefits are distributed unevenly.

The rest of the paper is structured as follows: in the next section, a review of the literature on information sharing and integration in supply chains is presented. Section 3 presents the framework of our model, while Section 4 uses the framework to analyze cost savings due to VMI and the distribution of these savings between buyers and sellers. Finally, conclusions, limitations, managerial implications, and future research topics are presented.

2. Literature review

The implementation of VMI requires both the sharing of information and the coordination and integration of processes between buyers and suppliers. In general, buyers share demand and inventory status information with their suppliers (information sharing) so that suppliers can take over the inventory control and purchasing function from the buyers (process integration). As a result, we examine literature on both information sharing and supply chain integration.

2.1. Information sharing

A stream of research has quantitatively studied the value of information sharing in supply chains, especially the causes and consequences of the bullwhip effect. The bullwhip effect is the phenomenon whereby the size of inventory overages and shortages increases the further a firm is from final consumer demand in a supply chain. Much of this literature has shown that the bullwhip effect can be minimized through information sharing in the supply chain [2,5,13,15,16]. The result of a decrease in the bullwhip effect is an improvement in supply chain performance (e.g., the lowering of inventory levels and the reduction in cycle times) [3,26].

A number of research papers have specifically studied the value of information sharing through
VMI or similar programs. An early study developed economic-lot-size models for cooperative inter-organizational relationships and found that cooperative relationships can improve the total cost performance of the buying firm and its supplier when information is exchanged [14]. Another paper presented an analytical model for coordinating inventory and transportation decisions in VMI systems and found that the vendor’s actual inventory requirement is partly determined by the parameters of the shipment-release policy in use [4]. This result holds because vendors have the autonomy to retain orders until an agreeable dispatch time is reached, with the expectation that an economical consolidated dispatch quantity will accumulate before an order is dispatched. Other researchers also analytically examined the impact of continuous replenishment programs (CRP, a practice similar to VMI) on the relationship between a manufacturer and its retailers [21]. They found that the value of CRP in terms of inventory reductions is affected by demand characteristics such as the variance of demand; that is, when demand variability is relatively high, inventory reductions achieved through CRP are low.

2.2. Supply chain integration

It was predicted that information technologies would allow for closer integration of adjacent firms in the supply chain through the development of electronic linkages (e.g., electronic data interchange) [17]. The ability to smooth supply and demand, and thus reduce the possibility of inventory overages or shortages, has been suggested as a key benefit of systems like VMI, CRP, JIT, quick response, and efficient consumer response that integrate the operations of supply chain members [12].

Based on data from the specialty retail clothing industry, an early paper found significant performance improvements for firms using quick response systems [19]. Using data from three different industry classifications, separate research determined that just-in-time systems lowered the logistics costs (inventory, transportation, purchasing, and/or production) of purchasers and could, through process re-engineering at supplier locations, lower upstream logistics costs, too [9]. It has also been empirically shown that one of the most important reasons for the competitiveness of Japanese producers was the nature of Japanese subcontracting, which emphasized synergistic relations between supply chain members [18].

However, a number of studies have found that supply chain integration does not necessarily result in benefits for both suppliers and buyers. A buyer’s inventory costs may be reduced only because costs are transferred to the supplier [8,11,22,27]. In particular, a theoretical study found that suppliers benefit from JIT only if they have high holding costs and low ordering costs relative to their customers [7].

In the next section, we extend the previous research work to develop conditions under which there are likely to be net benefits from the implementation of a VMI system. We then determine how benefits may be distributed between buyers and suppliers given various levels of ordering and carrying charges.

3. Modeling framework

In order to derive the benefits and distribution of benefits from VMI, we construct a two-level supply chain consisting of a single supplier and a single buyer and examine inventory management practices before and after the implementation of VMI. A simple supply chain is used for computational ease, though many of the results can be generalized to more complex supply chains. We assume that a single stock-keeping unit is transacted between the supplier and the buyer and that the buyer faces external demand from consumers. In a supply chain without VMI, the supplier observes consumer demand only indirectly through the buyer’s ordering policy. With VMI, the supplier’s information system directly receives consumer demand data. Consumer demand is assumed to be deterministic and known to the buyer under normal (non-VMI) operating procedures and known to both the buyer and supplier under VMI. The supplier’s and buyer’s inventory carrying charges per unit are denoted as $H$ and $h$, respectively (throughout the paper, parameters in upper case and lower case are associated with the supplier and buyer, respectively). The supplier’s cost of placing an order are denoted as $C$, $c$ (without VMI), and $c'$ (with VMI)—there is no need to define $C'$ since it is assumed that VMI does...
not change the supplier’s order cost. Without loss of generality, we assume that order lead times, the time between when an order is placed and when the shipment is received, are negligible for both the supplier and the buyer. That is, once a replenishment order is placed by either the supplier or the buyer, the replenishment shipment is received instantaneously.

The type of supply chain described above approximates those in a number of industries like automobiles where the buyer’s demand is reasonably stable and predictable. Toyota, for example, faces fairly predictable demand, at least in the short-to-medium run, for many of its models. Certain consumer goods (e.g., staples such as sugar, flour, and canned soups) may also face fairly stable and predictable demands.

The ordering process considered is an inventory review system where orders are placed at predetermined reorder points. Since demands are known, the main cost minimization parameter available to the buyer in a non-VMI system is its order size. In other words, the buyer must determine its order quantity. Once the buyer reaches its reorder point, a replenishment request is passed to the supplier, and the order quantity is immediately shipped to the buyer. The supplier then reviews its inventory and plans its own ordering or production processes. The major difference between not using and using VMI is that the buyer’s order quantity is determined by the supplier in a VMI system. Fig. 1 presents the modeling framework.

4. Analysis of inventory costs

4.1. Without VMI

Prior to implementing VMI, our model is the same as the classic economic order quantity (EOQ) model in inventory management. Therefore, the optimal order quantity and total inventory cost for the buyer can be easily obtained. The EOQ and total inventory cost are calculated as follows:

\[ q^* = \sqrt{\frac{2cr}{h}}; \quad tc^* =hq^* = \sqrt{2crh} \]  

(1)

where \( r \) is the annual demand in units; \( c \) is the cost of placing a single order; \( h \) is the carrying charge per unit per year; \( q \) is the lot size or order quantity in units; \( tc \) is the total inventory cost; and * indicates the optimal value.

Similar to the buyer’s, the supplier’s decision is to determine the economic order quantity that minimizes its total inventory costs. Therefore, we have:

\[ Q^* = \sqrt{\frac{2CR}{H}}; \quad TC^* = HQ^* = \sqrt{2CRH}. \]  

(2)

Since it is assumed that all product shipped from the supplier to the buyer is eventually sold to consumers, annual demand for the supplier and buyer is the same \( (R=r) \). Therefore, total inventory cost for the supply chain without VMI is:

\[ TC_{\text{no VMI}} = TC^* + tc^* = \sqrt{2CRH} + \sqrt{2crh} \]

\[ = \sqrt{2R} \cdot \left( \sqrt{CH} + \sqrt{ch} \right). \]  

(3)

4.2. With VMI

Now consider the case where the supplier and buyer have agreed to use VMI. The consequence is that the supplier has full knowledge of demand and is responsible for managing the inventory for both parties. In a serial supply chain, the order quantity for the supplier is likely to be an integer multiple of the buyer’s replenishment quantity \( Q=k_{\text{VMI}}q \), where \( k_{\text{VMI}} \) is a positive integer [23]. In other words, \( k_{\text{VMI}} \) may be viewed as the replenishment frequency between the supplier and the buyer. Hence, the objective is to find the optimal order quantities \( (Q \) and \( q) and
replenishment frequency \((k_{\text{VMI}})\) that minimize the costs of the integrated supplier–buyer system.

As the order quantity is \(q\), the average inventory level for the buyer is \(q/2\). The average inventory level for the supplier is determined by \(Q, q,\) and \(k_{\text{VMI}}\) since there are \(k_{\text{VMI}}\) replenishments of quantity \(q\) during each supplier’s inventory cycle (i.e., the time between successive replenishments of the supplier’s inventory). Once a shipment of \(q\) units to the buyer reduces the supplier’s inventory to 0, the supplier instantaneously receives a replenishment that brings it back up to \(Q\). The supplier’s inventory stays at level \(Q\) after the second shipment of \(q\) to the buyer reduces the supplier’s inventory cycle (i.e., the time between successive replenishments of the supplier’s inventory). Therefore, we can write the supplier’s average inventory to the buyer is the last one during the supplier’s supply chain system under VMI:

\[
I_s = \frac{1}{k_{\text{VMI}}} \sum_{i=1}^{k_{\text{VMI}}} [Q - (i - 1)q],
\]

which can be further simplified to

\[
I_s = Q - \frac{k_{\text{VMI}} - 1}{2} q.
\]

Therefore, considering \(q = Q/k_{\text{VMI}}\), we can obtain the expression for total inventory cost for the integrated supply chain system under VMI:

\[
TC_{\text{VMI}} = \frac{CR}{Q} + H \cdot I_s + \frac{c' R}{q} + \frac{hq}{2} = \frac{CR}{Q} + H \left( Q - \frac{k_{\text{VMI}} - 1}{2} q \right) + \frac{c' R_{\text{VMI}}}{Q} \frac{hQ}{2k_{\text{VMI}}}.
\]  

\[\text{(4)}\]

Note that the first term in Eq. (4) is the supplier’s total ordering cost, the second term is the supplier’s total inventory holding cost, the third term is the buyer’s total ordering cost, and the last term is the buyer’s total inventory holding cost. Although the buyer does not need to place orders with the supplier under VMI, some order costs, like information processing costs and bookkeeping costs, may still be incurred. Therefore, it is reasonable to assume non-zero, but smaller, order costs for the buyer \((c' < c)\), since the buyer’s ordering process has been simplified after implementing VMI.

Since \(Q\) and \(k_{\text{VMI}}\) are independent, replacing \(q\) by \(Q/k_{\text{VMI}}\) and taking the first partial derivative of expression (4) with regard to \(Q\) and \(k_{\text{VMI}}\), respectively, leads to the optimal order quantity and the optimal replenishment frequency. (Note, since \(k_{\text{VMI}}\) is an integer, previous work [23] offers a method for computing its value associated with minimum total costs. The method treats \(k_{\text{VMI}}\) as a continuous variable and finds the value for \(k_{\text{VMI}}\) that minimizes total cost. Two values for total cost are then computed using the two integers that surround the optimal value for \(k_{\text{VMI}}\). The integer that yields the lower total cost is the “optimal” integer. In our case, as we do not intend to compute the actual value of the optimal \(k_{\text{VMI}}\), but instead its relationship with other parameters, we treat \(k_{\text{VMI}}\) as a continuous variable.)

\[
Q^* = \sqrt{\frac{2k_{\text{VMI}}(CR + c' R'_{\text{VMI}})}{(k_{\text{VMI}} + 1)H + h}}
\]

\[\text{(5)}\]

and

\[
k_{\text{VMI}}^* = \sqrt{\frac{(H + h)Q^2}{2c' R}}.
\]

\[\text{(6)}\]

Taking the second derivative of expression (4) with regard to order quantity and replenishment frequency, respectively, we obtain: \(\frac{\partial^2 TC_{\text{VMI}}}{\partial Q^2} = (2CR + 2c' R_{\text{VMI}})/Q^3 > 0\) and \(\frac{\partial^2 TC_{\text{VMI}}}{\partial k_{\text{VMI}}^2} = [(HQ + hQ/k_{\text{VMI}}^2)] > 0\). Thus, total inventory cost is minimized at \(Q^*\) and \(k_{\text{VMI}}^*\).

From (5) and (6), we can further write:

\[
k_{\text{VMI}}^* = \sqrt{\frac{C(H + h)}{c' H}},
\]

\[\text{(7)}\]

\[
Q^* = \sqrt{\frac{2CR}{H}},
\]

\[\text{(8)}\]

and

\[
q^* = \sqrt{\frac{2c' R}{H + h}}.
\]

\[\text{(9)}\]

Inserting (7), (8), and (9) into (4), we obtain the total inventory cost at the optimal order quantity and replenishment frequency:

\[
TC_{\text{VMI}}^* = \sqrt{2R \cdot \left( \sqrt{CH} + \sqrt{c'(H + h)} \right)}.
\]

\[\text{(10)}\]
Therefore, in order to minimize total inventory cost in the integrated VMI system, the supplier will be ordering each \( \sqrt{\frac{2h}{r}} \) time it places an order from its own upstream supplier. This is the same order quantity for the supplier as in the non-VMI scenario. The supplier will replenish the buyer’s inventory with orders of \( \sqrt{\frac{2h}{r}} \), an order quantity smaller than the quantity without VMI.

We can further describe the properties of the optimal replenishment frequency with VMI, and its relationship to the optimal replenishment frequency without VMI (using the following proposition. Assume \( d \) is the ratio of the supplier’s order cost to the buyer’s order cost to the buyer’s (\( d = H/h \)), \( g \) is the ratio of the supplier’s ordering cost to the buyer’s without VMI (\( g = C/c \)), and \( g' \) is the ratio of the supplier’s order cost to the buyer’s with VMI (\( g' = C/c' \)).

**Proposition 1.** The optimal replenishment frequency (\( k_{VMI}^* \)) with VMI is greater than the replenishment frequency without VMI (\( k_{noVMI}^* \)). In addition, the optimal replenishment frequency increases in \( g' \) but decreases in \( d \).

**Proof.** Eq. (7) can be re-written as: \( k_{VMI}^* = \sqrt{\frac{g'(d+1)}{d}} \). From (1) and (2), we obtain the replenishment frequency: \( k_{noVMI}^* = \sqrt{\frac{g'}{d}} = \sqrt{\frac{g'}{2}} \). Since \( c' < c \), \( g' > g \). So, \( k_{noVMI}^* = \sqrt{\frac{g'}{d}} = \sqrt{\frac{g'}{2}} < \sqrt{\frac{g'(d+1)}{d}} = k_{VMI}^* \). It is easy to see that \( k_{VMI}^* \) increases in \( g' \) and decreases in \( d \).

Proposition 1 provides an analytical result that supports the conventional wisdom with respect to VMI; that is, implementing VMI leads to higher replenishment frequencies with smaller replenishment quantities between the supplier and the buyer. The optimal replenishment frequency tends to be higher when the difference between the supplier’s order cost (\( C \)) and buyer’s order cost with VMI (\( c' \)) is larger. Since the supplier’s order cost does not change when VMI is implemented, the more the buyer’s order cost is reduced, the higher the optimal replenishment frequency. In addition, the optimal replenishment frequency tends to be higher when the buyer’s carrying charge relative to the supplier’s carrying charge is high. This makes sense in that the supplier should replenish the buyer’s inventory with smaller quantities more often to minimize the average inventory levels at the buyer’s location due to the relatively high carrying charge.

### 4.3. Benefits of VMI

To examine the inventory cost differences following the implementation of VMI, we calculate the change in total inventory cost in percentage terms (\( V \)):

\[
V = \frac{TC_{noVMI} - TC_{VMI}^*}{TC_{noVMI}}
\]

\[
= 1 - \frac{\sqrt{CH} + \sqrt{c'(H + h)}}{\sqrt{ch} + \sqrt{CH}}
\]

\[
= 1 - \frac{1}{g'} \cdot \frac{1 + d}{d} \quad \text{for } g' = \frac{C}{c}
\]

The larger the \( V \), the greater the benefits generated from VMI.

Next, we introduce a number of propositions that demonstrate the relationships between the total inventory costs and the logistics parameters.

**Proposition 2a.** The percentage of total inventory cost savings with the implementation of VMI between the supplier and the buyer (\( V \)) decreases in the order cost ratio of supplier to buyer in the absence of VMI (\( g \)).

**Proposition 2b.** The percentage of total inventory cost savings with the implementation of VMI (\( V \)) increases in the order cost ratio of the supplier to the buyer with VMI (\( g' \)).

**Proof.** It can be shown that:

\[
\frac{\partial V}{\partial g'} = - \frac{1}{2} \cdot \left( 1 + \sqrt{\frac{1}{g'}} \cdot \frac{1 + d}{d} \right) \cdot \frac{1}{\sqrt{d}} \cdot g'^{-3/2} < 0
\]

and

\[
\frac{\partial V}{\partial g} = \frac{1 + d}{d} \cdot g'^{-2} \cdot \left( 1 + \sqrt{\frac{1}{g'd}} \right) > 0
\]
Proposition 2a indicates that total inventory cost savings monotonically decreases in $g$. This demonstrates that the larger the order cost for the supplier relative to the buyer before implementing VMI, the smaller the total inventory cost savings from implementation. The implementation of VMI reduces inventory costs by a greater amount when the order cost ratio is small, because the smaller the $g$, the larger the buyer’s order cost before implementing VMI compared to the supplier’s, and the greater the savings given the buyer need not place orders after implementing VMI. For example, $g=2$ would imply that the supplier’s order cost is twice the buyer’s before VMI, while $g=1$ implies equal order costs. Assume for Dyad A, $g=2$ and for Dyad B, $g=1$. If the order costs for the suppliers under the two dyads are identical, then the buyer in Dyad B would have an order cost twice as large as the buyer in Dyad A would have, and would save more than its counterpart when their order costs were both reduced to the same level ($c’$). Therefore, in terms of order cost reductions from VMI, the buyer in Dyad B has more to gain than does the buyer in Dyad A.

Proposition 2b indicates that total inventory cost savings monotonically increases in $g’$. This demonstrates that the larger the order cost for the supplier, compared to that of the buyer after implementing VMI, the greater the total inventory cost savings from the implementation. This makes intuitive sense because the greater the $g’$, the greater the savings that may be realized by the buyer through order cost reduction and higher replenishment frequency (as stated in Proposition 1).

Considering both Propositions 2a and 2b, we can introduce the following corollary:

**Corollary.** The percentage of total inventory cost savings with the implementation of VMI ($V$) increases in the ratio of the buyer’s order cost without VMI to the buyer’s order cost with VMI ($c/c$).

This corollary shows that the magnitude of total inventory cost savings from VMI is dependent on the reduction of the buyer’s cost of placing an order. Since the buyer is no longer planning and placing the orders with the supplier under VMI, the buyer’s order cost can be substantially reduced. The more it is reduced the greater the total inventory cost savings from VMI.

### 4.4. Benefits distribution

Having demonstrated the properties for total inventory cost savings from VMI, we now examine how the benefits are distributed between the supplier and buyer. We consider only the distribution of inventory holding cost savings, not order cost saving, as we assumed earlier that the buyer bears the cost for orders from the buyer to the supplier. Although this assumption is arbitrary, it is often the case that order costs depend on negotiations between the supplier and buyer and their relative power, both of which are beyond the scope of this research. Therefore, to keep the research within scope, we only study the distribution of holding cost savings. Table 1 presents total inventory holding costs with and without VMI.

<table>
<thead>
<tr>
<th>Total inventory holding costs</th>
<th>Supplier</th>
<th>Buyer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without VMI</td>
<td>$\frac{1}{2} \cdot \sqrt{2R \cdot \sqrt{CH}}$</td>
<td>$\frac{1}{2} \cdot \sqrt{2R \cdot \sqrt{c}}$</td>
</tr>
<tr>
<td>With VMI</td>
<td>$\frac{1}{2} \cdot \sqrt{2R \cdot \sqrt{CH}} \left[ 1 + \sqrt{\frac{d}{g’(d + 1)}} \right]$</td>
<td>$\frac{1}{2} \cdot \sqrt{2R \cdot \sqrt{c}} \frac{1}{\sqrt{d + 1}}$</td>
</tr>
</tbody>
</table>

To illustrate how inventory holding cost savings are distributed between the supplier and buyer, we calculate the percent changes in the supplier’s ($S$) and the buyer’s ($s$) total inventory holding costs (IHC) after introducing VMI. Hence, we have:

$$S = \frac{IHC_{VMI} - IHC_{noVMI}}{IHC_{noVMI}} = \sqrt{\frac{d}{g’(d + 1)}} > 0, \quad (12)$$

and

$$s = \frac{IHC_{VMI} - IHC_{noVMI}}{IHC_{noVMI}} = \sqrt{\frac{g}{g’(d + 1)}} - 1 < 0. \quad (13)$$
We introduce the following propositions that depict the holding cost distributions between the supplier and the buyer.

**Proposition 3a.** The supplier’s total inventory holding cost increases with the implementation of VMI at a decreasing rate in \( g \) and an increasing rate in \( d \).

**Proposition 3b.** The buyer’s total inventory holding cost decreases with the implementation of VMI at a decreasing rate in \( g \) and an increasing rate in \( g' \) and \( d \).

Propositions 3a and 3b indicate that the supplier’s holding cost increases after implementing VMI, whereas the buyer’s holding cost decreases after implementing VMI. These results suggest that VMI may shift inventory from the buyer’s site to the supplier’s site when the integrated system is optimized. The greater the ratio of the supplier’s ordering cost to the buyer’s in the absence of VMI \((g)\), the smaller the decrease in buyer inventory. The greater the ratio of the supplier’s ordering cost to the buyer’s with VMI \((g')\), the larger the reduction in buyer inventory and the smaller the increase in supplier inventory. And finally, the greater the ratio of the supplier’s carrying charge to the buyer’s \((d)\), the larger the reduction in buyer inventory, but the larger the increase in supplier inventory.

### 4.5. Numerical example

This section presents a numerical example to better illustrate the relationship between the extent and distribution of inventory cost savings from using VMI and the ratios \( d \), \( g \), and \( g' \). Table 2 shows inventory cost savings in percentage terms given various values of the ratios \( g' \) and \( d \) when \( g = 1 \). It can be seen that inventory cost savings increase in the ratio \( g' \) and decrease in the ratio \( d \). It can also be seen that VMI is not always associated with positive benefits. For example, when the supplier and the buyer have the same carrying charge \((d = 1)\) and the buyer’s post-VMI order cost is reduced by half \((g' = 2)\), no benefits arise from VMI implementation.

![Fig. 2. Effects of ordering cost ratio \((g')\) and inventory carrying charge ratio \((d)\) on replenishment quantity.](image)

Table 2

<table>
<thead>
<tr>
<th>( d )</th>
<th>( g' )</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>.2</td>
<td>15.57%</td>
<td>31.25%</td>
<td>38.20%</td>
<td>42.34%</td>
<td>45.16%</td>
<td></td>
</tr>
<tr>
<td>.4</td>
<td>10.01%</td>
<td>25.02%</td>
<td>31.67%</td>
<td>35.63%</td>
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<td></td>
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<tr>
<td>.8</td>
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<td>23.87%</td>
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<td>30.39%</td>
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<td>21.13%</td>
<td>25.00%</td>
<td>27.64%</td>
<td></td>
</tr>
</tbody>
</table>

The greater the ratio of the supplier’s ordering cost to the buyer’s with VMI \((g')\), the larger the reduction in buyer inventory and the smaller the increase in supplier inventory. And finally, the greater the ratio of the supplier’s carrying charge to the buyer’s \((d)\), the larger the reduction in buyer inventory, but the larger the increase in supplier inventory.
is reduced after implementing VMI (i.e., increased replenishment frequency). It can be seen that increasing values of \( g' \) have a negative effect on replenishment quantities, with diminishing returns. In addition, higher values of \( d \) always correspond to smaller replenishment quantities for a given \( g' \), suggesting that the higher the value of \( d \) the greater the replenishment quantity reduced after VMI.

Fig. 3 indicates how the ratio \( d \) can affect the distribution of benefits (i.e., inventory cost savings) between the buyer and supplier. The figure shows that the buyer always enjoys positive benefits in terms of reduced inventory, whereas the supplier’s inventory increases after implementing VMI. The larger the ratio \( d \) (i.e., the lower the supplier’s carrying charge relative to the buyer’s), the more the supplier’s inventory is increased and the more the buyer’s inventory is reduced. For example, in the case of \( d=0.3 \), the buyer’s inventory is reduced by 38%, and the supplier’s inventory is increased by 34%. This result suggests that VMI shifts inventory from the buyer to the supplier to take advantage of the lower carrying charge at the supplier’s site.

5. Conclusions and implications

5.1. Conclusions

It has been well documented that inventory reductions and cost savings can be reached by implementing collaborative initiatives such as vendor managed inventory, continuous replenishment, and just-in-time purchasing that allow for information sharing and integration among firms in the supply chain. This paper contributes to the literature by developing an analytical model that helps to provide a better understanding of how important supply chain parameters, namely ordering costs and carrying charges, affect the inventory cost savings to be realized from VMI and the distribution of these savings between buyers and suppliers.

Results from the analytical model and numerical examples show that benefits may be generated from VMI as long as the ratio of the order costs of the supplier to the buyer and the ratio of the carrying charges of the supplier to the buyer are “favorable”. In particular, total benefits will be greater when the supplier’s order cost prior to the introduction of VMI is large relative to the buyer’s post-VMI order cost. Similarly, total benefits will also be greater when the supplier’s order cost before the introduction of VMI is small relative to the buyer’s pre-VMI order cost. From this, it can be deduced that changes in the buyer’s order cost due to the introduction of VMI affect the total benefits: the greater the reduction in the buyer’s order cost, the higher the total benefits. It also demonstrates in the numerical examples that greater total benefits are associated with smaller inventory cost ratios; that is, the buyer’s carrying charge is large relative to the supplier’s. Indeed, at some extremes, the total benefits of VMI may be negative.
Results from the analytical model and numerical examples also show that benefits from inventory reductions due to VMI are not equally distributed between buyers and suppliers, and that one party (the buyer) receives all of the benefits while the other (the supplier) bears additional costs. This result confirms suspicions in industry that VMI may move inventories upstream from retailers to wholesalers or even manufacturers. For example, a large retailer may be able to mandate that its suppliers participate in a VMI program through which the retailer’s inventory may be reduced but its suppliers’ inventories increased. The fact that total logistics costs are likely to be unevenly reduced suggests that side-payment arrangements between the retailer and its suppliers may be necessary for healthy, long-term supply chain relationships.

The results of this paper are consistent with previous work [6,20,24]. These previous studies have shown that the implementation of supply chain initiatives, such as VMI, can benefit firms by reducing costs such as inventory costs. By outlining the conditions under which inventory cost reductions can be achieved through VMI, our study provides further evidence to support these earlier papers.

Our research also presents a general model illustrating the benefits to buyers and suppliers from the implementation of VMI. In an early study, simulations were used to show the magnitude of benefits from adopting VMI realized by changing order intervals from 4 weeks to 2 weeks and to 1 week [25]. Our research constructs an analytical model that captures the magnitude of benefits from VMI at any given order frequency. Furthermore, our model also uncovers the factors that affect the optimal order frequency and order quantities.

5.2. Model limitations

Although our model is representative of certain supply chains, we recognize our results are limited due to the assumptions made. In particular, demand is assumed to be known with certainty and the supplier’s order cost is assumed to be unchanged after implementing VMI. Although these limitations affect the magnitude of cost savings to be realized from VMI, we anticipate that the direction of the results should remain unchanged when these assumptions are relaxed.

5.3. Managerial implications

This research provides practitioners with a convenient and useful tool for making decisions with respect to supply chain integration programs. In a business setting, the three supplier/buyer ratios in our model—order costs without VMI, order costs with VMI, and carrying charges—can often be relatively easily observed. Therefore, buyers and suppliers should be able to obtain at least some idea as to whether a program such as VMI is likely to produce firm and supply chain inventory cost reductions, and by how much. Our model indicates, for example, that inventory cost savings are likely to be higher if the buyer’s order cost is significantly reduced by implementing VMI. The potential inventory cost savings can then be compared to the cost of implementing a VMI program (e.g., the technology and labor costs associated with establishing a system), with VMI implementation undertaken when the potential inventory cost savings are thought to be greater than the costs of implementation. The finding of disproportionate benefit distributions, then, provides the supplier and buyer with a better understanding and an important benchmark in their negotiations for proper side-payment arrangements should they be required.

5.4. Future research

This paper presents an analytical model for analyzing inventory benefits from VMI. An empirical model with industry data from VMI programs could provide further evidence to support our results. Future research could also be centered on examining the strategic behavior of firms. For example, it might be beneficial for a supplier to enter into a VMI arrangement with a buyer even if costs outweigh benefits in order to preempt a competitor. Side payments from suppliers to buyers, or vice versa, could also provide incentives to participate in programs such as VMI. Future modeling could examine how these payments can be used to encourage supply chain partners to adopt these programs. Finally, partnership programs, such as VMI, often produce incentives for one firm or the other to engage in self-interested behavior. For example, after taking over inventory management at the buyer’s location, the supplier could attempt to tilt the supply chain benefits in its own direction. Future research
could examine the control procedures that could be established to guard against these types of behaviors.

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