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Abstract

Building on the extensive literature on interorganizational systems (IOS), information sharing, and vendor-managed inventory (VMI), this paper develops an analytical model to examine under which conditions VMI generates positive inventory cost savings and the level of these savings. The results show that in order to gain positive benefits from VMI for a supply chain, as a whole, the ratio of the upstream partner's replenishment leadtime to the downstream partner's should be at least as large as a critical value determined by the ratio of their inventory holding costs (which is always smaller than 1). Furthermore, the paper demonstrates that the higher the replenishment leadtime ratio, the greater the inventory cost savings with VMI

Keywords: Interorganizational system, information sharing, vendor-managed inventory, supply chain coordination

"The goal is to reduce all inventory in the pipeline, not just Amkor's inventory…We has reduced direct and indirect inventory by 50% in 18 months through VMI arrangements with our suppliers " said Gary N. Swinden, director of supply- chain integration at Amkor Technology Inc. (Electronic Buyers' News 1999)

Introduction

Advanced information technologies have brought about tremendous changes to the way businesses operate. Many of these changes are concerned with the way firms interact with others in their supply chains. As a result, supply chain management has rapidly converged with information system management (Challener 2000). With the introduction of interorganizational systems (IOS), enabled by Electronic Data Interchange (EDI) or the Internet, the concept of information sharing has been embedded into many sophisticated supply chain management initiatives, such as Collaborative Planning, Forecasting, and Replenishment (CPFR), Vendor Managed Inventory (VMI) and Efficient Consumer Response (ECR), all of which have become increasingly used in industries (Emigh 1999).

VMI is a supply chain management initiative, as well as a type of IOS, where wholesalers are authorized to manage the inventory of agreed-upon stock-keeping units at retail locations. The potential benefits from VMI are very compelling and can be summarized as reduced inventory costs and improved customer service such as a reduction in order cycle time (Achabal 2000; Waller et al. 1999). These benefits have been realized by successful retail businesses, notable as Wal-Mart (Cetinkaya and Lee 2000).

There has been a rich body of literature examining how the implementation of IOS can benefit adopters through information sharing along supply chain using initiatives such as VMI (Premkumar 2000; Raghunathan 1999; Strader et al. 1999; Lee and Whang 2000; Mukhopadhyay et al. 1995; Yao et al. 2001). However, there has been little literature that has extensively and quantitatively studied the relationship between logistics decision parameters and the benefits of information sharing, specifically from VMI. In this paper, we draw on previous research work from both the areas of IOS and of supply chain management, and then construct a dyadic model to examine how VMI affects supply chain performance. In particular, this paper addresses when,

and by how much a two-level supply chain benefits from those logistics decision parameters, such as leadtime and inventory carrying costs that are affected as a result of VMI.

The paper is organized into 7 sections. The following section reviews the relevant literature; Section 3 presents the modeling framework; Section 4 discusses the proposition development; section 5 presents numeric examples, section 6 discuss the results, and section 7 draws some managerial implications.

Literature Review

It has been well acknowledged that IOS, as linkages between suppliers and buyers, can improve a firm's performance and bring a firm competitive advantages (Cash and Konsynski 1985; Clemons and McFarlan 1986; Palmer and Markus 2000; Sethi, Whang and Pegels 1993; Premkumar and Ramamurthy 1995; Bakos 1991). Specifically, in conjunction with supply chain management, many studies have shown reduced inventory as one of the major benefits resulting from the implementation of IOS, either enabled by EDI or Internet technologies (Premkumar 2000; Raghunathan 1999; Strader et al. 1999; Lee and Whang 2000; Mukhopadhyay et al. 1995). Empirical evidence has also been found that the implementation of IOS results in improved inventory management (Choudhury et al. 1998; Yao et al. 2001; Waller et al. 1999).

There is also another stream of research that has quantitatively studied the value of information sharing in supply chains. The causes and consequences of the bullwhip effect have been studied in depth (The bullwhip effects is the phenomenon that the size of inventory overages and shortages increase, the further a firm is from the final consumer in a supply chain), showing that this effect can be minimized through information sharing (Lee et al. 1997; Chen et al. 2000; Cachon and Fisher 2000; Lee et al. 2000; Gavirneni et al. 1999). Other researchers examining cooperation in supply chains have found such policies, such as VMI, can decrease the bullwhip effect, thereby improving a supply chain's efficiency (Xu et al. 2000; Cachon and Zipkin 1999).

Throughout the whole body of relevant literature, it has been well recognized that inventory reduction can be reached by implementing initiatives such as IOS, information sharing, supply chain coordination, or VMI. This paper contributes to the literature by developing an analytical model to provide a better understanding of the extent of inventory cost savings from VMI, given critical logistic decision making parameters, i.e. replenishment leadtime and inventory carrying costs.

The Modeling Framework

In this paper, we construct a simple two-level supply chain that consists of a single wholesaler and a single retailer. A simple supply chain is constructed to ease computation, although many of the results can be generalized to more complex supply chains. We assume only one item is transacted between the wholesaler and the retailer. The retailer faces external demand from end consumers. In a supply chain without VMI, the wholesaler observes the consumer demand through the retailer's ordering policy. With the implementation of VMI, the wholesaler's information system receives direct input, i.e. consumer demand. Consumer demand assumed to be deterministic, and known to the retailer under the normal (non-VMI) operating procedures and to both the retailer and wholesaler under VMI. Replenishment leadtimes are assumed to be known with certainty. Replenishment leadtime is the time period between when an order is placed and when shipment is received by the retailer or wholesaler. The wholesaler and retailers' replenishment leadtimes are denoted as L and l, respectively. (Throughout this paper, parameters represented in upper case and lower cases are designated for the wholesaler and the retailer, respectively.)

The ordering process is an inventory review system where orders are placed at pre-determined reorder points. (This is different from periodic ordering system where orders are placed at each periodic review, regardless of inventory level.) Since demand and leadtime are known, the only parameter to be considered by the retailer in minimizing its logistics costs is order size. Once the retailer decides order size, the information is passed on to the wholesaler, and the requested quantity is shipped to the retailer immediately. According to the retailer's order quantity, the wholesaler will review its inventory level, and plan its own ordering process, which is similar to the retailer's.

Analysis of Inventory Cost Savings in VMI

Without Implementing VMI

The retailer's decision to place an order is made when the inventory level reaches a pre-determined reorder point. The only decision the retailer has to make is what quantity to order. This model is the same as the classical economic order quantity (EOQ)

model in inventory management. Therefore, we can easily obtain the optimal order quantity and total inventory costs[1] for the retailer. Note that we intentionally drop the term of purchase cost for computation convenience, since it has no effects on our results.

$$q* = \sqrt{\frac{2cr}{h}} \; ; \quad tc^* = hq^* = \sqrt{2crh} \tag{1}$$

Where r is annual demand in units; c is ordering cost per order; h is holding cost per unit per year; q is lot size or order quantity in units; tc is total inventory costs; and * indicates optimal amount.

The wholesaler's decision is similar to the retailer's to determine the economic order quantity (EOQ) that minimizes total inventory costs. Therefore, we have:

$$TC^* = HQ* = \sqrt{2CRH} \tag{2}$$

Annual demand for the wholesaler and retailer is the same (R=r). We further assume that ordering cost is the same for the wholesaler and retailer. Therefore, total inventory cost for the supply chain, including both the wholesaler and retailer, is:

$$TC^*_{without} = TC^* + tc^* = \sqrt{2CRH} + \sqrt{2crh} = \sqrt{2CR} \cdot (\sqrt{H} + \sqrt{h}) \tag{3}$$

With Implementing VMI

We now consider the case where the wholesaler and the retailer have agreed to engage in the practice of VMI to facilitate information sharing. The consequence is that the wholesaler has full knowledge of demand and will be responsible for managing the inventory for both parties. Hence, the objective is to optimize the integrated wholesaler-retailer system. Note, ordering activities are no longer needed between the wholesaler and the retailer, that is, the ordering cost for the retailer falls to zero. Therefore, we use the upper case for computation convenience and obtain the expression for total costs:

$$TC_{with} = \frac{CR}{kq} + \frac{(h + Hk)q}{2} \tag{4}$$

k is the ratio of the wholesaler's replenishment leadtime to the retailer's (k=L/l). We assume that the replenishment leadtime equals the inventory cycle time. This is the case for many business situations. For example, inventory of soft drinks at retail location is replenished regularly by suppliers, which the replenishment leadtime equals the inventory cycle time. Hence, the average inventory level is proportional to the replenishment leadtime, and since the average inventory level for the retailer is just q/2, we then can obtain the average inventory level for the wholesaler, which is *kq/2*.[2]

Taking the first derivative of expression (4) with regard to order quantity, we obtain the optimal order quantity and total inventory cost at optimal quantity:

$$q^* = \sqrt{\frac{2CR}{k(h + Hk)}} \tag{5}$$

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[1]Note that the total inventory cost includes two components: inventory holding cost and ordering cost.

[2]Since the retailer's average inventory level is *q/2*, and the total quantity shipped by the wholesaler should equal to the total quantity the retailer received. Therefore, we have $\frac{q}{2} \cdot \frac{1}{l} = I_m \cdot \frac{1}{L}$, where I_m is the wholesaler's average inventory. By collecting terms, we get $I_m = kq/2$.

$$TC^*_{VMI} = \sqrt{2CR} \cdot \sqrt{\frac{(h + Hk)}{k}} \qquad (6)$$

Benefit Comparison With and Without VMI

To examine the inventory cost differences with and without implementation of VMI, we calculate the total inventory cost changes in percentage (V):

$$V = \frac{TC^*_{without} - TC^*_{with}}{TC^*_{without}} = \frac{\sqrt{h} + \sqrt{H} - \sqrt{\frac{h + Hk}{k}}}{\sqrt{h} + \sqrt{H}} = \frac{1 + \sqrt{d} - \sqrt{\frac{1 + dk}{k}}}{1 + \sqrt{d}} \qquad (7)$$

Where d is the ratio of inventory holding cost of the wholesaler's to retailer's.

Proposition 1[3]: *The percentage of total inventory cost savings with implementation of VMI between the wholesaler and the retailer (V) increases in the replenishment leadtime ratio of the wholesaler's to the retailer's (k).*

Proposition 1 indicates that total inventory cost savings monotonically increase in k regardless of the value of ratio d. This demonstrates that, the larger the differences in the replenishment leadtime between the wholesaler and the retailer, the greater the total inventory cost savings. This makes sense in the notion that implementation of VMI helps save more on inventory costs when the ratio k is larger because the larger the ratio k, the longer the wholesaler's replenishment leadtime as to the retailer's and the greater the wholesaler's average inventory level. It does not, however, provide any indication whether the total inventory cost savings is positive or negative, which leads to our second proposition:

Proposition 2a[4]: *The percentage of total inventory cost savings with implementation of VMI between the wholesaler and the retailer (V) is positive in the case of $k \geq$.*

Proposition 2b: The percentage of total inventory cost savings with implementation of VMI between the wholesaler and the retailer (V) is dependent on the value of d in the case of k<1:

$$V \geq 0 \text{ while } k \geq \frac{1}{1 + 2\sqrt{d}} ; \quad (2) \text{ V} < 0 \text{ while } k < \frac{1}{1 + 2\sqrt{d}} .$$

Proposition 2a indicates that implementation of VMI between the wholesaler and the retailer creates positive inventory cost savings in the case that the wholesaler's replenishment leadtime is equal or greater than the retailer's regardless of the value of ratio d. Proposition 2b shows that whether implementation of VMI generates positive inventory cost savings is dependent on the value of ratio d in the case of $k<1$. This is the case in the sense that implementation of VMI saves less on the inventory costs when

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[3]Proof of proposition 1: Take partial derivative of (7) with regard to k, we get: $\partial V / \partial k = \frac{1}{1 + \sqrt{d}} \cdot \frac{1}{2k^2} \cdot \sqrt{\frac{k}{1 + dk}} > 0$. Q.E.D.

[4]Proof of proposition 2a & 2b: If we set V=0, we will get the relationship between k and d as: $\frac{1}{1 + 2\sqrt{d}}$. Since d>0, k<1. From the proof of proposition 1, we have learned that V monotonically increases in k. Hence, V will be always equal or greater than 0 in the case of k>=1. In the case of $k<1$, V is determined by $\frac{1}{1 + 2\sqrt{d}}$.

the retailer's average inventory level goes up as its replenishment leadtime increases, i.e. *k* decreases, till a level that the total inventory cost savings is no longer positive.

Numeric Examples

This section presents numeric examples that help to better understand the relationship between the extent of inventory cost savings and ratio *d* and *k*.

Table 1 shows inventory cost savings in percentage given various values of the ratio *k* and *d*. It can be seen that it is not always true that VMI is associated with positive benefits. While the ratio *k* is smaller than 1 and the ratio *d* is smaller than a critical value, implementation of VMI can generate negative benefits. For example, the inventory cost savings are negative while *k*=.25 and *d*<=2. However, it is always true that benefits are positive if the ratio *k* is greater than 1. It is also worth noting that the absolute value of inventory cost savings for a symmetric ratio pair of *k*, e.g. .25 and 4, is not symmetric. Higher value of the ratio tends to have higher absolute value of inventory cost savings. For example, in the case of *d*=1, inventory cost savings are –11.80% and 44.10% for *k*=.25 and *k*=4, respectively.

Table 1. Total Inventory Cost Savings for Various Values of Replenishment Leadtime Ratio (k)
and Inventory Holding Cost Ratio (d) (In Percentage)

d \ k	.25	.5	1	2	4
.25	-37.44	.00	25.46	42.26	52.86
.5	-24.26	7.38	28.26	41.42	49.27
1	-11.80	13.40	29.29	38.76	44.10
2	-1.46	17.16	28.26	34.51	37.87
4	5.72	18.35	25.46	29.29	31.28

k: Replenishment Leadtime Ratio
d: Inventory Holding Cost Ratio

Figure 1 presents the effects of ratio *k* on inventory cost savings for three scenarios of ratio *d*, .5, 1 and 2. It can be seen that ratio *k* has positive effects on inventory cost savings with diminishing returns. The values at which inventory cost savings equal zero are always smaller than 1. It is also interesting to see that higher value of the ratio *d* has a larger rate of diminishing return. For example, the curve with *d*=2 becomes the lowest from the highest while the ratio *k* increases.

Figure 1. Effects of Replenishment Leadtime Ratio (k) on Total Inventory Cost Savings in Percentage

Discussion

The results of this paper are consistent with previous research work. Previous research conducted by Prekumar (2000) with IOS and Extranets, Raghunathan (1999) with Collaborative Forecasting and Replenishment (CFAR), Strader et al. (1999) with Extranet, and Choudhury et al. (1998) with electronic markets has shown that implementation of IOS can benefit the supply chain through reducing costs such as inventory costs. Our study provides further evidence that inventory cost reduction can be achieved through implementation of IOS such as VMI.

Lee et al (2000) and Xu (2000) concluded positive inventory cost savings resulting from information sharing in a supply chain. Their approaches are focused on how the information sharing can reduce forecasted demand variation, i.e. the bullwhip effect,
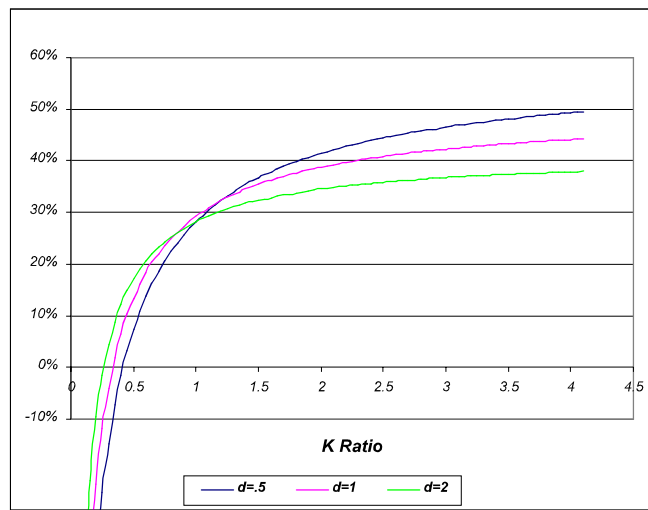
thereby achieve better supply chain coordination. Cachon and Zipkin (1999) demonstrated a cooperative inventory policy is better than a competitive one, using game theory model in a two-stage supply chain. Our results, derived from a model with known demand and leadtime, also demonstrate the conditions under which positive inventory cost savings can be achieved through information sharing in VMI.

Waller et al. (1999) empirically studied VMI and concluded that most of inventory reduction achieved with VMI can be attributed to more frequent inventory reviews, order intervals, and deliveries. Our results show that EOQ between the wholesaler and the retailer after VMI is smaller than that before VMI,[5] which implies more frequent inventory reviews, order intervals and deliveries.

Although our model is representative of many actual supply chains, we recognize our results are limited due to the settings we assumed in the model. In particular, the demand and replenishment leadtime were assumed known; ordering costs per order were considered the same for both the wholesaler and the retailer; ordering costs were assumed zero between the wholesaler and the retailer with VMI. Future research may be done to examine the robustness of results with releasing some or all of the assumptions.

The derivation of the relationship between the ratio of the inventory holding costs and the cost savings of the VMI results in very complicated expressions and the properties are difficult to be determined. Future research will be done to keep exploring the relationship.

Managerial Implications

One of the major contributions of this paper is that it provides practitioners not only strong managerial implications but also a convenient and useful tool for making decisions. Two of the ratios studied in this paper, replenishment leadtime ratio and inventory holding cost ratio, can be easily observed and controlled by companies. If the replenishment leadtime ratio k is greater than 1, companies know that they would always enjoys positive inventory cost savings from implementation of VMI with their partners. In the case that k is not greater than 1, they should study the inventory holding cost ratio before they make decisions to implement VMI with their partners.

Moreover, the extent of inventory cost savings can also be estimated using our results. The potential inventory cost savings can be used to evaluate the costs of implementing an IOS to enable VMI. The implementation should be carried out if the potential inventory cost savings are greater than the costs of implementing the IOS.

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[5]This conclusion can be obtained from inequity of $q^*_{with} = \sqrt{\dfrac{2CR}{k(h+Hk)}} < q^*_{without} = \sqrt{\dfrac{2CR}{h}}$ while K>=1.

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