Journal of Business Economics and Management
ISSN 1611-1699/eISSN 2029-4433
2017 Volume 18(1): 163–179
doi:10.3846/16111699.2016.1266695

EVALUATING VENDOR MANAGED INVENTORY SYSTEMS: HOW INCENTIVES CAN BENEFIT SUPPLY CHAIN PARTNERS

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Received 25 January 2016; accepted 27 November 2016

Abstract. In a vendor managed inventory (VMI) system, the effects of financial incentives on the entire supply chain (SC) and on the individual firms are investigated in this study. To this end, order management, order replenishment and inventory control activities of a two-echelon SC are examined via modeling using discrete event simulation. By determining the appropriate parameters for the incentives with scenario analysis, balanced profit distribution between buyers and a supplier in VMI is established. Simulation outputs of the traditional model, VMI only and VMI with incentives models are compared based on profits with paired comparisons. In VMI with incentives, both buyers, and the supplier experience higher benefits than the traditional system. This study provides a new method which eliminates the unbalanced benefit distribution due to VMI and offers almost equal benefits to the participating firms. With financial incentives, firms are encouraged to share information with each other to work in a coordinated SC.

Keywords: vendor managed inventory, supply chain contracts, distribution network, simulation, modeling, inventory management, incentive systems, performance.

JEL Classification: M11, C15.

Introduction

In contemporary global markets, geographically distant firms still have dependencies to each other. Traditional supply chains (SC) where each firm acts independently may not be beneficial in a setting with distant partners. Vendor managed inventory (VMI) is used as an alternative to the traditional SC system by coordinating firms based on inventory management (Davis-Sramek *et al.* 2009). In a VMI setting, a buyer shares its demand and inventory information with its supplier, and the supplier uses this information to decide when and how much product to be sent to the buyer (Al-Ameri *et al.* 2008; Ryu 2006; Southard, Swenseth 2008; Tanskanen *et al.* 2009). Previous studies show that the VMI system has a positive influence on the SC network performance. When the firm based performance in the SC is considered, previous findings indicate that at least one of the participating firms may not get benefit from VMI (Mishra, Raghunathan 2004; Yao *et al.* 2007; Yu *et al.* 2009). The aim of the coordination mechanisms should not be only to make all the system profitable but also to provide financial benefits for every participating firm. Firms may not be willing to be part of this system if they do not benefit individually (Simatupang, Sridharan 2002). These participating firms could be encouraged by using financial incentives. To the best of our knowledge, using financial incentives to improve VMI benefits for individual firms is missing in the VMI literature.

This study embeds an incentive system in a VMI SC that includes multiple buyers and a supplier. The proposed incentive system is compared with traditional system and the VMI only system. Based on the comparisons, this study discusses the effects of VMI and the incentive system on the SC and the individual firms separately. The proposed SC networks are modeled by discrete event simulation. Parameters of the incentive system used in the simulation runs are selected by a scenario analysis. The goal of the scenario analysis is to make sure that all the participants will benefit and have almost equal profits. The main aim of this study is to construct a VMI system with incentives that produce more profits for the whole SC and the participating firms comparing to a traditional system with assuring balanced benefit distribution for the participating firms.

The remainder of the paper is as follows. Section 1 presents literature review. Section 2 describes the methodology of the study. Section 3 shows the application of the methodologies with a numerical example. Section 4 demonstrates the results of the numerical example. Finally, in the conclusions section, findings are discussed.

1. Literature review

Vendor managed inventory and supply chain contracts have been extensively studied in the literature for the last decades. Govindan (2013) identified six VMI dimensions: inventory, transportation, manufacturing, coordination, general benefits and information sharing. Govindan *et al.* (2013) categorized coordination contracts based on transfer payments, inventory risk allocation, and advance-purchase discount. For a detailed literature review for VMI and SC contracts, studies of Govindan (2013) and Govindan *et al.* (2013) can be referred respectively.

1.1. Vendor managed inventory

In a VMI system, the buyer does not give an order; instead, the supplier decides when and how much to send to the buyer. For this system to work properly, the buyer needs to share demand and the inventory information.

In this study, effects of VMI are considered in two aspects; the whole SC network and the participating firms. Several studies indicate that benefits of VMI on SC include decreased inventory amounts, costs, stock out problems and increased service levels. In a recent study, Choudhary and Shankar (2015) showed that in many cases VMI brings less cost and less inventory than the traditional system under time-varying stochastic demand.

Mateen and Chatterjee (2016) demonstrated that VMI does not only decreased costs but also reduced Greenhouse Gas Emissions. De Toni and Zamolo (2005) indicated in their study that VMI decreased the total inventory amount in the electrical appliances chain. Bertazzi *et al.* (2005) showed that VMI decreased the average costs compared to the traditional system. Sari (2007) also found that VMI decreased inventory levels and costs in the SC. Gronalt and Rauch (2008) demonstrated that VMI decreased the average raw material inventory in the system and increased service levels. Southard and Swenseth (2008) indicated that VMI decreased distribution costs in an agricultural simulation study. Disney and Towill (2003) found that VMI decreased bullwhip effect as opposed to the traditional system.

Niknamfar (2015) used VMI to integrate production-distribution planning while managing bullwhip effect and concluded that VMI revealed more efficient SC than the traditional system. Govindan (2015) compared VMI and the traditional system under stochastic demand with low and high variability. Their VMI system under Silver–Meal heuristic with safety stock revealed the least SC cost.

How VMI offers firm-based benefits is also a matter of interest in the literature. Choudhary and Shankar (2015) showed that in most of the cases, buyers' inventory levels and suppliers' inventory levels decreased due to VMI.

Dong and Xu (2002) indicated in their studies that, in the short term the buyer had an increased profit from VMI, but the supplier's profit decreased. Supplier only experienced benefits from VMI in the long run at certain inventory cost values. Mishra and Raghunathan (2004) found that the supplier's inventory was much more in VMI than in the traditional system and retailers had increased profits. Yao *et al.* (2007) showed that VMI increased the inventory of the supplier. In Yu *et al.* (2009) study, the buyer's inventory costs decreased, and the supplier's inventory costs increased in the short term. In the long term, all the members benefit from VMI.

Chakraborty *et al.* (2015) proposed a setting with VMI in which vendor pays a penalty cost when the buyer's stock exceeds a predetermined limit. The authors investigated an appropriate stock limit and penalty cost levels in which both buyer and the vendor are better off. This study is similar to ours in finding appropriate parameters in which both parties benefit. Different from our study, Chakraborty *et al.* (2015) used penalty cost based on stock limits while cost and incentive parameters are based on backorders and lead time in our study.

As a summary, Table 1 presents which participating partner benefits from VMI as indicated in the previous research. Studies in the past literature mostly indicate that one party benefits from VMI system and this benefiting party is usually the buyer. Only one study using cost-sharing mechanisms showed that both buyers and the supplier benefited from VMI (Chakraborty *et al.* 2015) but did not state which part benefited more. What is missing in the literature is the proposition of a method that eliminates the unbalanced benefit distribution due to VMI by providing almost equal benefits to the participating firms. To fill this gap in the literature, this study explores how benefits from VMI can be distributed evenly among partners while identifying the most appropriate incentive parameters.

1.2. Incentive systems in the SC

Incentive contracts in SCs are mostly used to distribute risks and benefits due to coordination of the chain members (Giannoccaro, Pontrandolfo 2004). The most popular incentives in the literature are wholesale contracts (Gerchak, Wang 2004; Wang *et al.* 2013), buy-back (Ding, Chen 2008), revenue sharing (Gerchak, Wang 2004; Giannoccaro, Pontrandolfo 2004; Palsule-Desai 2013; Zhou, Yang 2008), quantity flexibility (Tsay 1999), sales rebate (Taylor 2002; Wong *et al.* 2009) and quantity discounts (Klastorin *et al.* 2002; Li, Liu 2006).

Among all incentive systems, penalty costs and bonus payments are newer ones in the literature. Zimmer (2002) used penalty costs and bonus payments as incentive systems in his study. The penalty cost per item is paid by a supplier to a retailer when an order is not completely delivered. In response, the retailer pays a bonus to the supplier when the order is delivered on time and in full amount. Zimmer (2002) found that the incentive system works as effectively as a central SC. Chiadamrong and Prasertwattana (2006) developed a system, which adds quantity discounts to penalty and bonus payments of Zimmer (2002). They showed that the model with all three incentives resulted in improving service level.

Table 1. Studies showing who benefits from VMI

Study	Main finding showing if the participant benefit from VMI	
	Buyer/retailer	Supplier
Choudhary and Shankar (2015)	No – Inventory levels increased	Yes – Inventory levels decreased
Dong and Xu (2002)	Yes – Profits increased in short-term	No – Profits decreased in the short term
Mishra and Raghunathan (2004)	Yes – Profits increased	No – Holding costs increased
Yao *et al.* (2007)	Yes – Holding cost decreased	No – Holding cost increased
Yu *et al.* (2009)	Yes – Inventory costs decreased in short term	No – Inventory costs increased in short-term
Chakraborty *et al.* (2015)	Yes – Costs may decrease with incentives	Yes – Costs may decrease with incentives

Yin and Ma (2015) showed in their studies that both parties obtained improved profits and service levels with the bonus contract based coordination. In a recent study, Lee *et al.* (2016) showed that VMI with stockout penalty cost performed as good as the integrated system where the supplier's minimum cost under the contract is less than or equal to the total cost of the SC in the integrated system. The incentive system offering a penalty cost when there is a stockout is similar to our study, however, Lee *et al.* (2016) have not studied how to balance VMI benefits among the partners.

Mateen *et al.* (2015) assumed a stock limit in retailers and penalty cost for the vendors for exceeding the limit in a stochastic demand environment. They explored the effects of various levels of cost parameters on total costs with sensitivity analysis. However, they did not seek the effects of the coordination for retailers and the vendor separately. To the best of our knowledge, previous studies using penalty and bonus payments with VMI has not aimed to balance the benefits of the SC partners. Our study is different in the way that penalty and bonus payments are embedded in a VMI system and are used to balance benefits among SC members. Additionally, previous studies did not compare the performance of the VMI only and the VMI with incentives system. This study makes this comparison because observing the effects of using more than one coordination mechanism will be supportive in making better managerial decisions.

2. Methodology

Discrete-event simulation is used to create the proposed distribution networks. The simulation software used is Arena 13.5 developed by Rockwell Software, Wisconsin, USA (Arena 2013). Simulation was chosen as the modeling tool because the proposed models include several stochastic variables such as demand, time between demands and lead times. This study investigates a two-echelon SC including ten identical buyers and a supplier. Three different SC models are offered. The first and the base model is a traditional distribution network in which no coordination mechanism is used. A resemblance of the traditional system and the flow structure of the traditional system is shown in Figure 1 and 2 respectively. In the traditional system, there is no information flow between buyers and supplier other than the order placement. The second model is a VMI system in which the supplier decides when and how much to send to their buyers. To make such decisions, the supplier should have consumer demand information and the buyer's inventory information. In VMI, the supplier also uses total consumer demand information to calculate their order amount. Despite the supplier makes decisions about the buyer's inventory, the buyers carry their inventory costs. The supplier only carries the buyer's order costs. A resemblance of a VMI system can be seen in Figure 3.

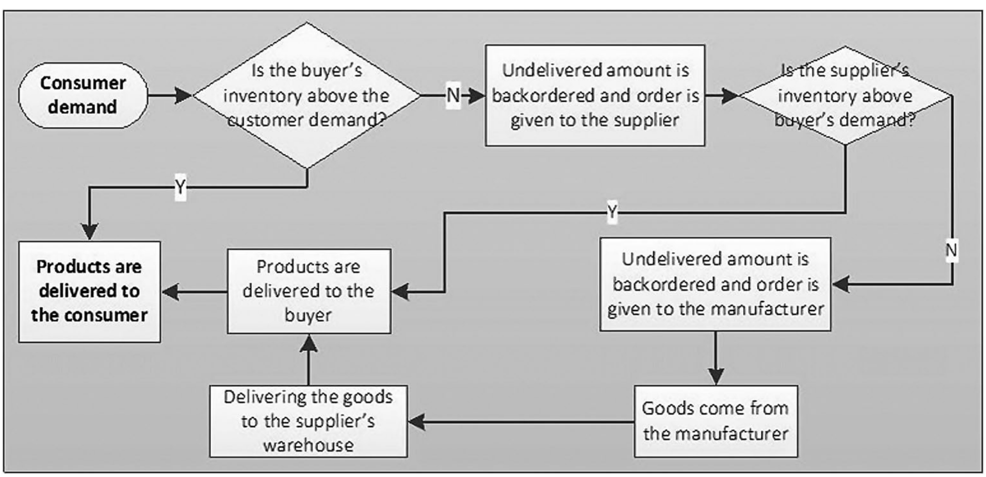

Fig. 1. Flow diagram for the traditional system

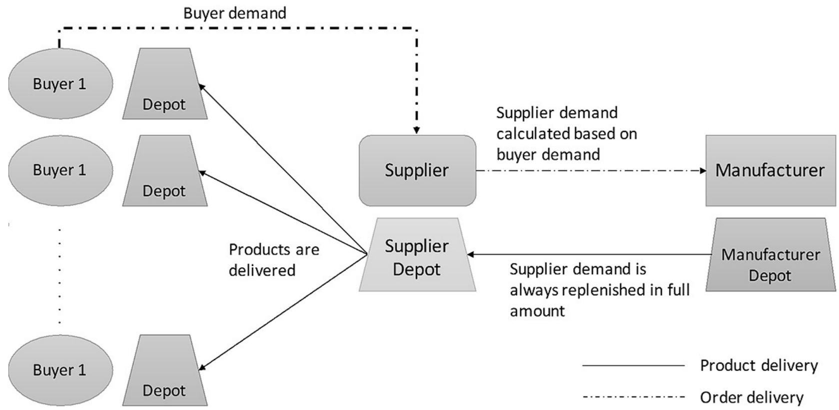

Fig. 2. Resemblance of the traditional system

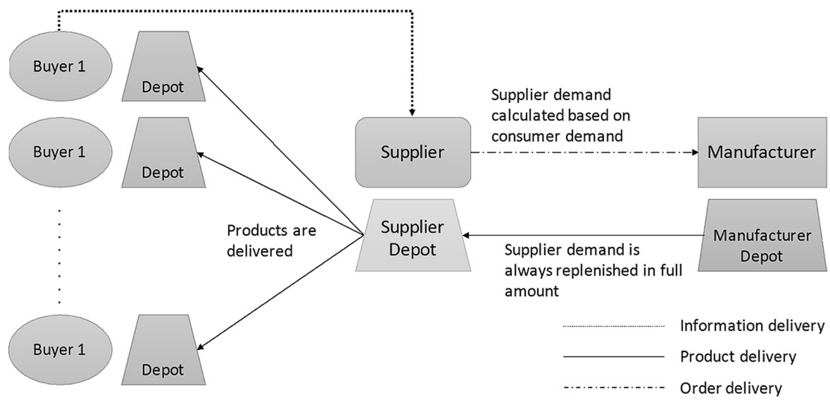

Fig. 3. Resemblance of the VMI system

The third model used in this study is the VMI system with incentives, which focuses on lead times to improve the profits. Incentives have the following conditions: if the delivery time from a supplier to a buyer is below a predefined threshold with a full amount, the buyer pays a bonus to the supplier. If the delivery is below the exact order amount, undelivered items are backordered. The supplier pays a penalty cost for each backordered item.

Incentive payments aim to increase the performance of the VMI. In all models, manufacturer replenishes supplier orders in full amount and fixed time. The traditional system, VMI only and VMI with incentives are compared in terms of performance.

3. Mathematical modeling

Mathematical modeling in this study consists of two parts. In the first part, the estimation of the performance indicators is explained in detail. The second part shows the calculation of inventory parameters used in the models.

3.1. Performance indicators

Performance indicators used for the comparisons are total SC profit, buyer's total profit, and supplier's profit. Since this study is focused on the benefits for SC members, profit is the main performance indicator in this study. The notations that will be used in performance indicator calculations are as the following:

TC_i = total cost,
k_i = order cost per order,
h_i = holding cost per item,
b_i = backorder cost per item,
p_i = purchase cost per item,
f = selling price of the product for the buyer,
r_i = reorder point,
Inv_i = average inventory in the system,
$Back_i$ = average backorder quantity,
Pur_i = total amount of purchased products,
Ord_i = total order amount (every order counts),
Sal_i = Total number of sold products,
$Q_j(t)$ = order quantity of jth buyer on time t,
$Q_s(t)$ = order quantity of supplier on time t,
$I_i(t)$ = on hand inventory on time t,
$OI_i(t)$ = amount of inventory on order on time t,
$PI_i(t)$ = inventory position on time t (if this value drops to r_i or below $Q_i(t)$ amount of order is given, $PI_i(t) = I_i(t) + OI_i(t) - BM_i(t)$),
$D_i(t)$ = customer demand on time t,
$BM_i(t)$ = backorder amount on time t,
$i = j, s$ (j = buyer, s = supplier),
$j = 1,2, \ldots, n$,
$t = 0,1,2, \ldots, n$.

Total costs for all the SC members are calculated as the sum of the holding cost, order cost, and backorder cost. Total costs are calculated for the SC and each chain member separately. To calculate the average inventory amount and the average backorder amount, time persistent averages calculated by the simulation software are used. This way, all the inventory and backorder amounts on all t times are considered. For all chain members, total cost and total revenue calculations are shown in Equations 1–5:

$$TC_i = k_i * Ord_i + h_i * Inv_i + b_i * Back_i + Pur_i * p_i; \quad (1)$$

$$Inv_i = \frac{\int_{t=0}^{n} I_i(t)}{n}; \quad (2)$$

$$BM_i(t) = \begin{cases} D_i(t) > I_i(t), & BM_i(t-1) + (D_i(t) - I_i(t)) \\ D_i(t) \le I_i(t), & BM_i(t-1) \end{cases}; \tag{3}$$

$$Back_i = \frac{\int_{t=0}^{n} BM_i(t)}{n}; \tag{4}$$

$$Total\ Revenue_i = TR_i = f \text{ or } p_j * sal_i, \tag{5}$$

where: $t = 0, 1, 2, \ldots, n$; $i = j, s$; $j = 1, 2, \ldots, n$.

The supplier uses (r, Q) inventory control system with a continuous review. When the inventory drops to r or below, Q amount is ordered. In the traditional SC, for the supplier to calculate the parameters of this system, the buyers' orders are considered. In the VMI system, the buyer will not place an order and buyers' r and Q parameters are calculated by the supplier. That is why the r and Q parameters of the traditional system cannot be used in the VMI system. In the VMI system to calculate the right amount of order quantity (Q) and the reorder point (r) a systematic inventory control using total consumer demand information should be applied by the supplier.

3.2. Inventory parameters in the VMI system

In the VMI system, the supplier has the buyer's customer demand and inventory information. With this information, the supplier continuously reviews the buyer's inventory. To decide when and how much of a product to send to the buyer, consumer demand and the buyer's inventory amount are considered in an (r, Q) inventory model with stochastic demand and stochastic lead time. According to this system, the supplier sends Q amount of products to the buyer when the buyer's inventory level drops to r.

It is assumed that products coming to the supplier from the manufacturer are in full amount. The supplier also uses the r, Q system with a stochastic demand as the order policy. To calculate the parameters of this system, consumer demand to the buyers is used as the demand information for the supplier. This is the most important difference between the traditional and the VMI system for the inventory control parameter calculation. In the traditional system, for the supplier, while r, Q is calculated, the buyer's demand information is used. In the VMI system, for suppliers, while r, Q is calculated, the consumer demand information is used. In other words, in the VMI system, D_s for the supplier is the consumer demand.

For both the buyer and the supplier, r, Q values that give the minimum total cost is calculated. Calculated values are used in simulation models. Calculations are performed, as shown in Winston (2003), based on Economic Order Quantity (EOQ) model with stochastic demand. Assumptions of this model are as the following:

1. Demand is backordered;
2. Continuous review is used;
3. Orders can be given at any time.

In calculations, as used in Winston (2003), it is assumed that $PI_j(t) = I_j(t)$ for initial values. During simulation runs, these values may be different from each other. For VMI, the total cost of the chain members will be as the following:

$TC_j\ (Q_j, r_j)$ = Expected holding cost + expected backorder cost,

$TC_s\ (Q_s, r_s)$ = Expected holding cost + expected backorder cost + expected order cost + expected buyers' holding cost.

As used in Winston (2003), Q_i value that minimizes total cost function is very close to EOQ. For this reason, in this study Q_i is used as EOQ value and calculated as given in Equation 6:

$$Q_i^* = \left(\frac{2k_i * \mu(D_i)}{h_i} \right)^{1/2}. \quad (6)$$

For a certain Q_i value, r_i value which minimizes the $TC_i\ (Q_i, r_i)$ equation can be found by marginal analysis. Firstly, probability of stockout during lead time is calculated as shown in Equation 7 (Winston, 2003):

$$P(X_i \geq r_i^*) = \frac{h_i * Q_i^*}{b_i * \mu(D_i)} \quad if\ \frac{h_i * Q_i^*}{b_i * \mu(D_i)} < 1. \quad (7)$$

With the assumption that during lead time demand is normally distributed with a mean of $\mu(X_i)$ and a standard deviation of $\sigma(X_i)$, non-stockout probability during lead time is calculated by subtracting the probability of stockout from 1. Then r_i would be as calculated in Equation 8:

$$r_i^* = z * \sigma(X_i) + \mu(X_i). \quad (8)$$

Total revenue and the total cost is calculated as shown in Equations 9 and 10:

$$Total\ revenue\ (buyer) = TR_j = f * Sal_j; \quad (9)$$

$$Total\ revenue\ (supplier) = TR_s = p_j * Sal_s. \quad (10)$$

For the incentive system, the bonus is added to the total cost of the buyers and the penalty is added to the total cost of the suppliers. Bonus, penalty, cost, and revenue are calculated as demonstrated in Equations 11 and 12 for the incentive system:

$$Bonus(t) = \begin{cases} bonus * Q_j(t), & late\ delivery\ time \leq 0\ and\ Q_j(t) - I_s(t) \leq 0 \\ 0, & otherwise \end{cases}; \quad (11)$$

$$Penalty(t) = \begin{cases} penalty * (backorder), & Q_j(t) - I_s(t) > 0 \\ 0, & Q_j(t) - I_s(t) \leq 0 \end{cases}. \quad (12)$$

In the incentive systems, total cost for buyers and suppliers, and total revenue for buyers and suppliers were calculated as in Equations 13, 14, 15 and 16 respectively:

$$TC_j = \sum_{t=0}^{n} Bonus(t) + k_j * Ord_j + h_j * Inv_j + b_j * Back_j + Pur_j * p_j; \quad (13)$$

$$TC_s = \sum_{t=0}^{n} Penalty(t) + k_s * Ord_s + h_s * Inv_s + b_s * Back_s + Pur_s * p_s; \quad (14)$$

$$TR_j = f * Sal_j + \sum_{t=0}^{n} Penalty(t); \quad (15)$$

$$TR_s = p_j * Sal_s + \sum_{t=0}^{n} Bonus(t). \quad (16)$$

Finally, total profit is calculated by subtracting total cost from total revenue as displayed in Equations 17 and 18:

$$Profit_j = TR_j - TC_j; \quad (17)$$

$$Profit_s = TR_s - TC_s. \quad (18)$$

4. Numerical example

To apply the proposed models, inventory and order data of a heating equipment retailer firm in Manisa, Turkey is used. Several data were obtained from the retailer which are as follows: consumer demand amounts for 18 months, time between consumer demands for 18 months, demand from buyer to the supplier during 18 months, lead time, reorder point, buying and selling price of the product. The 18 month data of consumer demand, time between consumer demands and demand from buyer to the supplier were observed from June 2012 to December 2014. Based on the data obtained, stochastic variables of the consumer demands, the time between consumer demands and lead time were calculated as 5+ gamm (0.667, 4.36) units per arrival, 0.5 + weib (3.98, 0.991) days time between arrivals and norm (12, 3.38) days respectively. Any variance in the data is expected to be represented in the calculated stochastic variables. The manager of the retailer firm reported that there are several similar buyers of the same supplier around the close territory. For this reason, it is assumed that there are ten identical buyers. For all the buyers, consumer demand, time between consumer demands, and demand from buyer to supplier is assumed to be the same. Cost values, lead time parameters, and consumer demand variables as obtained from the retailer can be seen in Table 2.

Table 2. Cost and lead time parameters used in the models

Variable	Value
Buyer holding cost (h_j)	20% of p_j (Waters 2003) = 21/year, 1.75/month
Buyer backorder cost (b_j)	Profit loss per unit: 30/year, 2.5/month
Buyer order cost (k_j)	50/order
Buyer purchase cost (p_j)	105/unit
Supplier holding cost (h_s)	20% of p_s =16.4/year, 1.36/month
Supplier backorder cost (b_s)	Profit loss per unit = 23/year, 1.916/month
Supplier order cost (k_s)	50/order
Supplier purchase cost (p_s)	82/unit (profit margin 28.5%)
Lead time between supplier and buyer	Norm (12, 3.38) days
Lead time to supplier	6 days
Time between consumer arrivals	0.5 + weib (3.98, 0.991) days
Consumer demand	5 + gamm (0.667, 4.36) units per arrival

Since obtained data is for 18 months, for EOQ calculations the planning period is used as a month. Also, for lead time the demand planning period is considered as a month. *r; Q* parameters for the VMI simulation are calculated based on the equations in Section 3. *r; Q* parameters for the traditional system are used as obtained from the buyer. For the Traditional (TRD), VMI and VMI incentive (VMIINV) systems, three simulation models are established. Warm up period is identified by detecting the time when the profit values for the traditional model start to become steady. After the 24th month, profit in the traditional system become steady. Table 3 shows the simulation parameters used in the models.

Table 3. Simulation parameters

Parameters	Values
Total running time	7920
Warmup period	720
Total time to obtain data	7200
Replication number	60
Time unit	day

Incentive mechanisms are based on three parameters; bonus, penalty for backorders and lead time threshold. Lead time threshold is the value used to decide whether to pay a bonus to the supplier. If the supplier brings products below the threshold time, then the buyer pays a bonus to the supplier. To find the most appropriate values of these variables, simulated scenario analyses are performed. For the scenario analysis, all the combinations of the three variables between a certain range are used. For bonus and the penalty cost, the range is identified as 1 to 20 per product. For the threshold, the range is used as 6 to 11 days. The aim of the simulation experiments is to find the best parameter combination in which the supplier and the buyers gain higher profits than the traditional system in a more balanced way compared to the other available combinations. The selected combination is used in the simulation runs.

A scenario analysis is performed for the VMIINV model since it is the only model that includes incentive parameters. Process analyzer from Rockwell Arena Software from Wisconsin, USA is used for the scenario analysis. Since there are too many combinations of the incentive variables in the defined ranges, only results from the selected combinations are given here. Profit for the buyers, the supplier, the system and profit differences compared to the traditional system for selected parameter combinations can be seen in Table 4.

In Table 4, the integer combination of 19, 2, 11 for bonus, penalty and threshold, respectively provide the most balanced profit distribution among the buyers and the supplier. In this combination, the profit increase for the buyers is close to the profit increase for the supplier but the buyers' total profit increase is still more than the supplier's increase. To reduce this difference, the scenario analysis continues with decimal increases to penalty cost. Among the tested combinations, 19, 2.126, 11 is chosen to be the one that provides the most balanced profit distribution between the buyers and the supplier. Therefore, 19, 2.126, 11 values for bonus, penalty and threshold, respectively, is chosen to be used in simulation runs as incentive parameters for VMIINV model.

Table 4. Chosen values in scenario analysis for VMIINV

Model	Bonus	Penalty	Threshold	Profit Ret	Profit Sup	Profit Sys	Profit increase retailers	Profit increase supplier	Difference between profit increases
vmiinv	19	4	11	9623.8	11405.4	21029.1	923.27	–326.59	1249.86
vmiinv	19	2	11	9020.1	12009	21029.1	319.57	277.01	42.56
vmiinv	20	2	10	9370.1	11659	21029.1	669.57	–72.99	742.56
vmiinv	18	1	9	9506.4	11522.7	21029.1	805.87	–209.29	1015.16
vmiinv	19	2.1	11	9050.3	11978.8	21029.1	348.4	364.0	–15.59
vmiinv	19	2.11	11	9053.3	11975.8	21029.1	351.4	361.0	–9.56
vmiinv	19	2.12	11	9056.3	11972.8	21029.1	354.4	357.9	–3.52
vmiinv	19	2.125	11	9057.9	11971.3	21029.1	355.9	356.4	–0.50
vmiinv	19	2.126	11	9058.2	11971.0	21029.1	356.2	356.1	0.10
vmiinv	19	2.127	11	9058.5	11970.7	21029.1	356.5	355.8	0.71

5. Results

In this study, paired comparisons in profits based on simulation outputs is used to compare the models. Paired comparisons are commonly used to compare simulation output measures in the literature (Kamalapurkar 2011; Southard 2001; Southard, Swenseth 2008). Before the comparison results, mean and standard deviation of the performance measures of the proposed models is presented in Table 5.

In this study for $\alpha_0 = 0.05$, confidence interval of 95% is used. Since more than two systems are compared, confidence interval numbers are calculated as $c = c = k\,(k–1)/2$. Then comparisons for alpha is $\alpha = \alpha_0/c$ (Kamalapurkar 2011; Rossetti 2010). In this study, there are three models – TRD, VMI, VMIINV – for paired comparisons. The number of paired comparisons is found $c = 3*(3–1)/2 = 3$, and alpha (α) for paired comparisons is calculated as $\alpha = 0.05/3 = 0.0482$.

The first performance indicator is total system profit. Paired comparison results for total profit is given in Table 6. Our results show that both the VMIINV and the VMI systems produce more profit than the traditional system. The VMIINV and VMI systems are found to have no difference in system profit. Systematic inventory control with VMI, an

Table 5. Profit values of simulation models

		ProfitRet*		ProfitSup**		Profit Sys***	
Model	N	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev.
TRD	60	8700.5	267.4	43687.7	1086.7	20432.5	534.6
VMIINV	60	9058.2	267.1	44954.1	1084.9	21029.1	580.7
VMI	60	9880.2	288.3	44309.0	1071.2	21032.5	579.2

Notes: *ProfitRet is used for profit for the retailers; **ProfitSup is used for profit for the supplier; ***ProfitSys is used for the profit for the system.

appropriate amount of product delivery on time, and supplier's inventory control based on consumer demand induce an increase in total SC profit.

The second performance indicator is buyers' total profit. Paired comparison results for retailers' profit can be seen in Table 7. Results show that the VMIINV and VMI models provide more profit for buyers than the traditional model ($p < 0.0482$). Due to the inventory control handled by the supplier in VMI, buyers have balanced order amounts. Because of the balanced order amounts and order costs carried by the supplier using VMI systems have brought more profit for buyers.

Another result of our analysis is that the VMIINV result in less profit for buyers than the VMI model. The reason for this finding is that in the VMIINV model, the buyers compensate bonus payments to the supplier that increases their costs. Besides that, buyers still have more profit in the VMIINV compared to the traditional model. With incentives, the profit of buyers decreased but the amount of the profit is still more than the traditional system. This condition is an indication of buyers sharing some of their benefits from the VMI with the supplier to form a balanced distribution.

The last analysis is about how VMI and incentives affected the supplier's performance. As shown in Table 8, the VMIINV model significantly increased the supplier's profit when compared to the traditional model ($p < 0.0482$). VMI only model decreased the profit of the supplier. To increase the whole SC performance, one of the chain members may have to sacrifice their benefit (Ryu 2006). In our study, in the VMI only case, the member that sacrifices its profit is the supplier. Supplier's profit merely increased in the case when the incentive system is used with the VMI. Buyers also have more profit with VMIINV as compared to the traditional system. These results indicate that to make the supplier gain profit from the VMI, financial incentives should be used.

Table 6. Paired comparisons for total system profit

	Up	Down	t	sd	p
VMIINV – TRD	469.3	955.4	9.583	59	0.0000
VMI – TRD	513.5	917.8	11.575	59	0.0000
VMIINV – VMI	–212.1	205.5	–0.052	59	0.9587

Table 7. Paired comparisons for total retailers' profit

	Up	Down	t	sd	p
VMIINV – TRD	235.93	476.53	9.682	59	0.000
VMI – TRD	1066.63	1289.89	34.510	59	0.000
VMIINV – VMI	–929.70	–714.36	–24.963	59	0.000

Table 8. Paired comparisons for the profit of the supplier

	Up	Down	t	sd	p
VMIINV – TRD	223.5	488.7	8.783	59	0.0000
VMI – TRD	–578.0	–347.2	–13.107	59	0.0000
VMIINV – VMI	729.2	908.3	29.890	59	0.0000

The current study explored how members of the SC benefited from VMI usage. Both the VMI and the VMIINV systems increase buyers' profits comparing to the traditional system. This increase is more in the VMI system than in the VMIINV system. From the supplier's perspective, only VMIINV increased the supplier's profit while VMI without incentives decreased the supplier's profit when it was compared to the traditional system. These findings support studies that show VMI provides benefits for buyers, but cause a loss for suppliers (Dong, Xu 2002; Mishra, Raghunathan 2004; Yao *et al.* 2007; Yu *et al.* 2009). Reduced benefits for suppliers with VMI indicate that carrying the buyers' order costs and managing their inventory increased the costs and reduced the supplier's profit. The supplier's rearrangement of their inventory parameters based on consumer demands did not compensate for the profit loss. For the supplier, merely VMI usage does not seem advantageous. To overcome the loss suffered from VMI, financial incentives are needed.

Conclusions

This study demonstrates that the incentive utilization in VMI distributes profits in a balanced way between buyers and the supplier. In the VMI only system, most of the profits of the entire SC is accumulated in the buyers. With incentives, the profit of the buyers is less than the VMI system without incentives but is still higher than the traditional system. These findings indicate, with incentives the benefit gained in the total system is shared between buyers and the supplier. The balanced distribution is based on appropriate incentive parameters. To choose the proper parameters for the incentives, a scenario analysis is used. The scenario analysis reveals incentive parameters that provide balanced profit distribution between buyers and the supplier. Among the proposed models, the VMIINV is chosen as the best model since it increases total system profit, the buyers' profit and the supplier's profit comparison to the raditional system.

While offering a VMI system with incentives, this study provides several contributions to the literature. Firstly, as the performance indicator, this study did not only choose total system performance. The buyers' and the supplier's performance enhancement is also considered while choosing the best model. The second contribution is that the supplier could also gain benefit from VMI by embedding an incentive system. In this study, it was observed that to participate in VMI and to increase system performance the suppliers lose some portion of their profit. Using incentives with VMI eliminated this loss.

The third contribution is from a managerial aspect. A supplier firm can be unwilling to participate in a VMI system considering that it will carry the buyer's costs. If managers try to convince suppliers by stating that they will also increase their profits by sharing the loss and the profits with some incentives, suppliers may feel more secure participating in the VMI system. This study has proposed a way that firms are encouraged to coordinate and share information with each other. Another contribution of this study is to propose simulation models and the inventory parameter calculation methodology which can be used for further studies. The conceptual model can also be used to develop new SC models.

This study has some limitations and however offers possible future research topics. For further studies, longer ranges for incentive parameter may be used to improve flexibility and accuracy. In a longer range, parameters can be searched by using different methods.

This study may have some implementations on bullwhip effect in the SCs. Bullwhip effect occurs due to increased demand variations in the upper streams of the SCs. In this study, supplier demands in the two VMI systems are calculated based on consumer demands instead of buyer demands meaning one echelon is eliminated. This probably result in less variation in supplier demands. However, this is only an intuition and should be measured quantitatively in future studies.

Another limitation of this study is that it is assumed that the buyers are identical to each other. A system that includes diverse buyers can reveal various insights about VMI and incentive systems. The proposed systems can also be explored for more complex SCs, including three or more echelons. A final limitation of this study is due to the simulation methodology. Modeling stochastic variables with simulation consists random elements, and values of these random elements change in every simulation run. Randomness may result in some uncontrollable variation and error in the results. Although this certain situation is tried to be eliminated by excluding warm-up period from the analysis, the simulation may still have some undesired variation.

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