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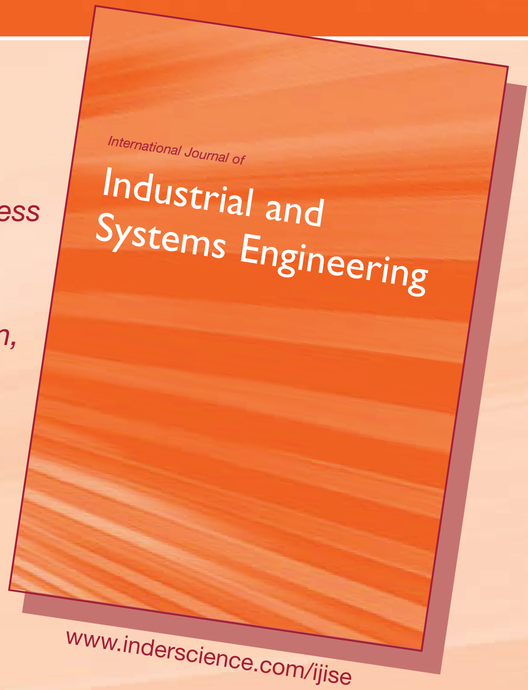

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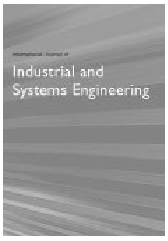

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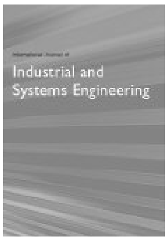

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One vendor-one retailer in vendor managed inventory problem with stochastic demand

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Abstract: One of the basic problems in supply chain operation is lack of information exchanges related to inventory between vendor and retailer. Vendor managed inventory (VMI) provides a good approach to handle this problem. VMI has been proven to reduce cost and improve customer service level. This research aim is to develop a VMI model for the system with one vendor and one retailer to minimise the total system cost. The model is developed for (t, q) policy where the retailer's cycle time is fixed. Due to the complexity nature of the model, simulation-optimisation using genetic algorithm is employed to determine the decision variables which are the retailer's lot size, the vendor's lot size, and the number of replenishments in a vendor cycle. Numerical experiments are conducted to show how the proposed model works. Sensitivity analysis is also conducted to understand the effects of some input parameters.

Keywords: vendor managed inventory; VMI; genetic algorithm; stochastic demand.

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1 Introduction

Vendor managed inventory (VMI) becomes an interesting topic since Wal-Mart and Procter & Gamble successfully implemented VMI in the late 1980. VMI applications have successfully helped to reduce cost and improve customer service level. VMI has also been successfully applied by many USA companies, such as Johnson & Johnson. In another part of the world, Barila, a European company which produces pasta, also employed VMI (Waller et al., 1999).

Some research works have been done related to VMI environment. Research works on VMI have grown from one vendor-one retailer system into one vendor-multiple retailer system. Deterministic and stochastic demands have been considered in various VMI research works. VMI models with deterministic demand have been developed as a preliminary model for developing a VMI model with stochastic demand. The deterministic demand models are important to study the basic interactions between the vendor and the retailer(s), while the stochastic models are developed to meet customer stochastic demands. Furthermore, VMI models with one vendor and one retailer should be extended into VMI models with one vendor and a multiple retailer system. It is needed due to the fact that a lot of suppliers deal with multiple retailers.

Related to VMI models with one vendor and one retailer system, there are some research works focused on this area. Dong and Xu (2002), Yao et al. (2007a, 2007b), Vlist et al. (2007), Pasandideh et al. (2011), Hariga and Al-Ahmari (2013), and Nia et al. (2015) developed various VMI models with one vendor and one retailer system under deterministic demand. On the other hand, Kim (2004), Wang (2009), Xu and Leung (2009), Kiesmuller and Broekmeulen (2010), Lee and Ren (2011), and Lu et al. (2015) proposed various VMI models with one vendor and one retailer system under stochastic demand. There are two fundamental questions in the VMI replenishment decisions. The first question is when to deliver to the downstream member and the second question is how large the product quantity to be delivered in one replenishment.

Due to the fact that a lot of suppliers deal with multiple retailers, Darwish and Odah (2010) developed a VMI model with one vendor and multiple retailers system under deterministic demand. In their research, the vendor replenishes retailers at the same time and the product quantities to be delivered to retailers are constant.

In reality, customer demands are stochastic. Hence, there is a need to extend Darwish and Odah (2010) research work by considering stochastic demand. However, it is necessary to develop a VMI model with one vendor and one retailer system under stochastic demand as a basic model for developing a VMI model with one vendor and multiple retailers system under stochastic demand. Therefore, this research proposes a VMI model with one vendor and one retailer system under stochastic demand in which the vendor replenishes the retailer at the same time and the product quantities to be delivered to the retailer are constant. In details, we will develop a VMI model for one vendor-one retailer system under stochastic demand using (t, q) policy in which a fixed amount q will be delivered to the retailer in each retailer's replenishment cycle of length t.

The remaining parts of this paper are arranged as follows. In Section 2, literature review on WMI models for one vendor and one retailer system will be presented. In Section 3, mathematical models will be developed. Section 4 will explain how simulation-optimisation using genetic algorithm is employed to find optimal solutions. Section 5 shows numerical experiments used to illustrate the performance of the proposed model. Sensitivity analysis is conducted in Section 6 to examine the effects of some input parameters on decision variables of the proposed model. Section 7 concludes the research and gives recommendations for future works.

2 Literature review

In the traditional inventory system, a retailer places an order based on their own interest. The vendor will fulfil the retailer order by delivering the product. In VMI, replenishment decision is delegated to the vendor. The vendor, therefore, monitors the retailer's inventory level and makes corresponding replenishment decision. Hence, the vendor will know the real demand and he does not rely on the retailer order which may not be the real demand.

This paper focuses on VMI model with one vendor and one retailer system. Relationship between one vendor and one retailer can be addressed in a deterministic or a stochastic demand environment. Some research works for both situations have been conducted. Therefore, VMI research papers for one vendor and one retailer system under stochastic and deterministic demand are firstly reviewed in this paper.

Related to the research works with one vendor and one retailer system under deterministic demand, Dong and Xu (2002) investigated the impact of VMI implementation on supply chain inventory system performance for short and long terms, and then those performances were compared to full channel coordination. They found that the vendor's and the retailer's profits change by the time and the profit after VMI implementation is always higher than before VMI, even if cost parameters do not change. Yao et al. (2007a, 2007b) examined how benefits distributed among a supplier and a buyer in a supply chain system. Vlist et al. (2007) criticised Yao et al. (2007a) by taking into consideration shipment cost in inventory costs. Wang et al. (2010) resolved Yao et al. (2007a) and Vlist et al. (2007) problems. In another direction, Pasandideh et al. (2011) developed a multi-product EOQ model for one supplier and one retailer system. (R, Q) policy was used in their research and then genetic algorithm was employed to find optimal solutions. Hariga and Al-Ahmari (2013) developed a single product inventory model which was integrated with shelf space arrangement under VMI and consignment stock. Order-up-to-level policy was used in their research and then generalised reduced gradient (GRG), which was available in What's Best add-in from LINDO Systems, was employed to determine optimal solutions of the model. Wee et al. (2011) proposed a model to incorporate VMI policy with a green supply chain for electronic product. Their model considered deteriorating factor of the product. Replenishment number and order quantity were decision variables in their research. Nia et al. (2015) developed an economic order quantity model for single-buyer and single-supplier system and multiple items were considered in their model. They developed the model under green VMI policy. A hybrid genetic algorithm was then employed to find near optimal solutions in their research.

Related to VMI research works for one vendor and one retailer system under stochastic demand, Kim (2004) developed a VMI model with one company A and an outsourcing company B. Company A replenished some materials to company B. Company A used (r, Q) policy to replenish the materials. Company B produced company A's order after a number of orders. A Markov decision model was developed in this research. Yao and Dresner (2008) studied information sharing (IS), continuous replenishment programs (CRP) and VMI. They employed order-up-to-level periodic review (R, S) policy. It has been concluded that VMI and CRP tend to reduce inventory more than IS. Wang (2009) studied a single manufacturer and a single distributor system in which the demand was uncertain and the production yield was random. Wang (2009) found that VMI provided higher expected profits than traditional arrangement if the manufacturer was price-taker and the wholesale price was relatively high. Otherwise, traditional arrangement was better than VMI if the wholesale price was low. Wang (2009) also concluded that if the manufacturer was price-setter, the manufacturer and the supply chain were better under VMI than under traditional arrangement. Xu and Leung (2009) proposed a VMI model to optimise supply chain profit for one retailer-one vendor system. They applied (S, T) policy, where the retailer's stock was increased up to level S every T time units. S and T were decision variables in their research. Kiesmuller and Broekmeulen (2010) proposed an inventory model for one vendor-one retailer system in which multiple products was considered. Their research developed the model by detailing warehouse operations. Lee and Ren (2011) compared VMI and retailer managed inventory, in which the retailer and the vendor faced exchange rate uncertainty and incurred different ordering costs. The exchange rate was modelled using Markovian transition with a known transition probability matrix. They recommended (s, S) policy to be applied at the supplier under VMI. Lu et al. (2015) analysed the impact of an overconfident supplier related to his green manufacturing decision and his possibility to add profits. They compared retail-managed inventory, vendor-managed inventory and integrated supply chain.

Another research work, which was done by Lee and Cho (2014), designed a VMI model with consignment stock for one vendor and one retailer system under both stochastic and deterministic demand. (Q, r) policy was applied in their research. Their research focused on how to share stock out and how to determine the penalty cost due to stock out at retailer site.

In reality, there exists the situation where a supplier dealts with multiple retailers. Darwish et al. (2014) developed two models for VMI with one vendor and multiple retailer system which incorporated quality aspect into the proposed models. In another research, Darwish and Odah (2010) developed a VMI model with one vendor and multiple retailer system. They considered deterministic demand in their research. They proposed a VMI model in which the vendor replenishes the retailers at the same time and the product quantities to be delivered to the retailer are constant. Due to the fact that customer demands are stochastic, there is a need to extend Darwish and Odah (2010) research work by considering stochastic demand. However, it is necessary to develop a VMI model with one vendor and one retailer system under stochastic demand as a basic model for developing a VMI model with one vendor and multiple retailers system under stochastic demand. Therefore, this research proposes a VMI model with one vendor and one retailer system under stochastic demand in which the proposed model settings for replenishment time and the quantity of product to be delivered to the retailer are the same as in the research of Darwish and Odah (2010). (t, q) policy will be used in our proposed model. The developed model will help the vendor to determine the retailer's lot size (q), the number of replenishments in a vendor cycle, and the vendor's lot size. The model aim is to minimise the expected total system cost.

3 Model development

This research focuses on VMI with one retailer and one vendor system. We considers a vendor who places an order to his upstream member periodically and then the vendor delivers the order quantity in multiple lots with smaller size to his downstream member, i.e., the retailer, in one replenishment cycle. The lot sizes delivered to the retailer are equal each replenishment. For details, the system behaviour is described as follows:

1. The system starts with a vendor placing order to his external supplier with ample capacity. The vendor's order lot size is Q units.
2. The vendor delivers q units of product every t units of time to the retailer. The replenishment cycle time of the retailer (t) is fixed.
3. During a vendor cycle time (T), there is n replenishments. Consequently, T equals to the number of replenishments in a vendor cycle multiplied by the length of a retailer cycle (t).

The relations of the retailer's cycle time, the vendor's cycle time, the retailer's lot size, the vendor' lot size and number of replenishment in a vendor cycle are shown as follows:

$$T = n * t \tag{1}$$

$$Q = n * q \tag{2}$$

It is noted that, customer demand at the retailer is stochastic. The retailer inventory position will be reduced gradually due to stochastic demand. This research is conducted for a single non-deteriorating product. Demand observed by the retailer is assumed to follow Poisson distribution. This research assumes that delivery lead time from vendor to retailer is negligible. The inventory policy considers shortage as lost sales. There is a lost sales cost which is incurred to the system when shortages occur.

The following notations will be used throughout this paper:

Q	vendor's order lot size
q	retailer's lot size
T	vendor cycle time
t	retailer cycle time
n	number of replenishments in a vendor cycle
AVO	average vendor order cost (VOC) per time unit
VOC	vendor order cost per order

C_{VH}	unit holding cost at the vendor site ($/unit/unit time)
AT_V	average vendor holding cost per time unit
D_c	delivery cost per time unit
C_d	delivery cost per delivery
BIP_i	retailer beginning inventory position for cycle i
EIP_i	retailer ending inventory position for cycle i
D_i	customer demand for cycle i
RHC_i	the retailer holding cost per unit time in cycle i
t_1	time when the inventory position equals to 0
HR	unit holding cost at retailer site ($/unit/unit time)
ERHC	expected retailer holding cost per unit time
RLC_i	retailer lost sales cost for cycle i
LS	unit cost of lost sales ($/unit)
ERLC	expected retailer lost sales cost per unit time
D	average retailer demand per unit of time
SU_i	shortage amount for cycle i

3.1 System modelling

This research focuses on development of a VMI model for one vendor and one retailer supply chain system to minimise the expected of the total system cost. The system consists of a vendor and a retailer. Consequently, there are costs incurred at both vendor side and retailer side.

The vendor costs consist of VOC, vendor holding cost and delivery cost. On the other hand, the retailer costs consist of holding cost and lost sales cost. At the system level, total system cost is the sum of the vendor costs and the retailer costs. It is noted that all system costs are paid by the vendor.

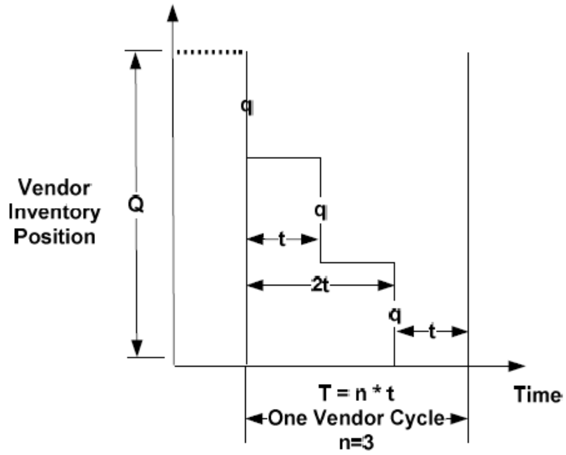
3.2 Vendor costs

VOC is incurred one time in a vendor cycle. The average VOC per time unit (AVO) is calculated as VOC divided by the length of a vendor cycle (T).

$$AVO = \frac{VOC}{T} = \frac{VOC}{n * t} \tag{3}$$

The vendor inventory position is reduced due to the delivery of product from the vendor to the retailer. An illustration of vendor inventory position is presented in Figure 1 for the case when the number of replenishments equals to three.

Figure 1 Vendor inventory position



The total vendor holding cost in a vendor cycle (T_V) is calculated as follows:

$$T_V = C_{VH} * \{t*(Q-q) + t*(Q-2q) + \cdots + t(Q-(n-1)q)\}$$
$$T_V = C_{VH} * t * q * n\left(\frac{(n-1)}{2}\right) \tag{4}$$

From the above expression, the average total vendor holding cost per time unit (AT_V) can be determined as follows:

$$AT_V = \frac{T_V}{T} = \frac{C_{VH} * t * q * n * \left(\frac{(n-1)}{2}\right)}{n * t} = \frac{C_{VH} * q}{2}(n-1) \tag{5}$$

Delivery cost is incurred one time per delivery. So the delivery cost per time unit (D_c) will be delivery cost per delivery (C_d) divided by retailer cycle time (t).

$$D_c = \frac{C_d}{t} \tag{6}$$

3.3 Retailer costs

For retailer costs calculation, the simulation model developed in this research will observe some data.

1 Retailer beginning inventory position for cycle i (BIP_i). BIP_i is defined as the retailer inventory position right after a replenishment in cycle i.

2 Retailer ending inventory position for cycle i (EIP_i). EIP_i is defined as the retailer inventory position right before a replenishment in cycle i.

3 Customer demand for cycle i (D_i). D_i is defined as a stochastic demand and its value will be generated through simulation process.

This research simulates 40 cycles of retailer. The following procedure is used in this research.

a For the first cycle, the beginning inventory position equals to retailer's lot size.

$$BIP_1 = q \tag{7}$$

For the next cycles, the beginning inventory position of cycle i equals the ending inventory position of cycle (i–1) plus retailer's lot size.

$$BIP_i = EIP_{i-1} + q \tag{8}$$

b Demand for cycle i (D_i) follows Poison distribution with parameter lambda. Lambda is average retailer demand per unit of time.

c Ending inventory position of cycle i (EIP_i) is determined as follows:

$$EIP_i = \text{Max}\{0, BIP_i - D_i\} \tag{9}$$

d Shortage amount at the end of cycle i, SU_i, is determined as follows:

$$SU_i = \text{Max}\{0, D_i - BIP_i\} \tag{10}$$

e Repeat step a to d for 40 cycles. However, the first ten cycles are considered as warm up period, only the results of the last 30 cycles are used for data collection purpose.

For analysing retailer's costs, this research considers retailer inventory positions at the beginning and at the ending of a retailer cycle. There are two possible scenarios that may occur for the ending inventory position in a retailer cycle (EIP_i).

a The first scenario is the ending inventory position equals to 0, due to shortages are not backlogged.

b The second scenario is the ending inventory position is more than 0.

Above scenarios can be described in Figures 2 and 3.

Figure 2 The first scenario

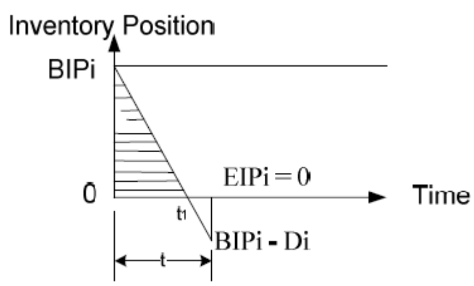
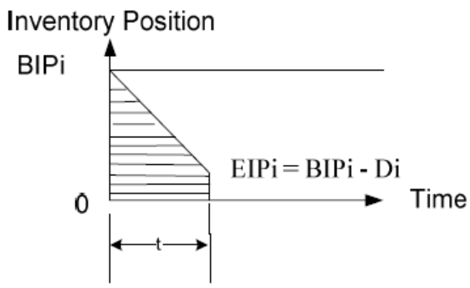


Figure 3 The second scenario



For the first scenario, the retailer holding cost per unit time in cycle i (RHC_i) is calculated as follows:

$$RHC_i = HR * \frac{BIP_i * t_1}{2t} \tag{11}$$

where

$$\frac{BIP_i}{D_i - BIP_i} = \frac{t_1}{t - t_1} \Leftrightarrow t_1 = \frac{BIP_i * t}{D_i} \tag{12}$$

So,

$$RHC_i = HR * \frac{BIP_i^2 * t}{2 * t * D_i} = HR * \frac{BIP_i^2}{2D_i} \tag{13}$$

For the second scenario, the retailer holding cost per unit time in cycle i (RHC_i) is calculated as follows:

$$RHC_i = HR * \frac{\frac{2BIP_i - D_i}{2} * t}{t} \tag{14}$$

$$RHC_i = HR * \frac{2BIP_i - D_i}{2} \tag{15}$$

For both scenarios, the general formula for the retailer holding cost per unit time in cycle i (RHC_i) is expressed as follows:

$$RHC_i = HR * \left(\frac{BIP_i + Max\{0, (BIP_i - D_i)\}}{2\left[1 - \frac{Min\{0, (BIP_i - D_i)\}}{BIP_i}\right]} \right) \tag{16}$$

where HR is unit cost of holding retailer stock ($/unit/time unit).

Hence, the expected retailer holding cost per unit time (ERHC) is calculated as follows:

$$ERHC = \frac{\sum_{i=11}^{40} RHC_i}{30} \tag{17}$$

Retailer lost sales cost for cycle i (RLC_i) is calculated as the accumulated shortage amount at the end of the cycle multiplied by unit cost of lost sales. Therefore, retailer lost sales cost per unit time in cycle i (RLC_i) and expected retailer lost sales cost per unit time (ERLC) are calculated as follows:

$$RLC_i = LS * \frac{Max\{0, (D_i - BIP_i)\}}{t} \tag{18}$$

where LS is unit cost of lost sales ($/unit).

Expected retailer lost sales cost per time unit (ERLC) is calculated as follows:

$$ERLC = \frac{\sum_{i=11}^{40} RLC_i}{30} \tag{19}$$

3.4 *System cost*

From the above analysis, we can determine the total system cost per time unit as follows:

$$\text{Total system cost} = AVO + AT_V + D_c + ERHC + ERLC \tag{20}$$

3.5 *Model implementation*

The model implementation consists of three sections.

1 Input data

The input data consists of some data that must be provided to the simulation model. These are VOC, unit holding cost of product at vendor side (CVH), delivery cost per delivery (Cd), unit holding cost of retailer stock (HR), unit cost of lost sales (LS), and average retailer demand per unit of time (D).

2 Retailer cost

In the retailer side analysis, this research observes beginning inventory position for cycle i (BIP_i), customer demand for cycle i (D_i), ending inventory position for cycle i (EIP_i), and shortage amount for cycle i (SU_i). From the observed data, retailer holding cost for cycle i (RHC_i) and retailer lost sales cost for cycle i (RLC_i) will be determined. It is noted that the first cycle beginning inventory position (BIP_1) is set equal to the retailer's lot size.

A simulation consists of some iterations. This research simulates 40 replenishment cycles of retailer in one iteration. However, the first ten cycles are considered as warm up period, only the results of the last 30 cycles are used for data collection purpose. The expected retailer holding cost and lost sales cost are calculated based on the formulas which are discussed in the previous section.

3 Total system cost calculation

The operational decision variables in the model are number of replenishments (n) and the retailer's lot size (q). The research objective is to minimise the expected total system cost.

4 Model optimisation

This research will develop a VMI model for one vendor-one retailer system under stochastic demand using (t, q) policy in which a fixed amount q will be delivered to the retailer in each retailer's replenishment cycle of length t. The objective of this research is to find the optimal value of the retailer's lot size, the vendor order lot size, and the number of replenishments in a vendor cycle to minimise the expected total system cost. Due to the nature of the problem, simulation-optimisation using genetic algorithm is employed to find optimal solutions. In this research, @RISK and @RISKOptimizer, which are parts of Palisade Decision Tools Suite developed by Palisade Corporation (2010), will be used for simulation model development and optimisation, respectively. It should be noted that genetic algorithm, which is embedded in @RISKOptimizer, will be used for finding optimal solutions of decision variables.

In this research, the simulation-optimisation procedure is performed as follows:

1. Determine simulation parameters: maximum number of simulations, stopping criteria based on improvement, number of iterations in one simulation, genetic algorithm parameters (crossover rate and mutation rate).
2. Determining solution parameters: initial solutions and solution range (number of replenishments and retailer's lot size).
3. Run genetic algorithm process. In this process, genetic algorithm is searching for the optimal solutions of the proposed model. Firstly, genetic algorithm generates an initial population of solution in form of chromosomes, (each chromosome contains feasible solution with two variables). Each chromosome will be evaluated in simulation model. Then, the fittest chromosomes will be selected. Next, 'offspring' chromosomes will be created using crossover rate and mutation rate. The least-fit chromosomes of the population will be replaced with better offspring chromosomes.
4. Run a simulation model for each chromosome using Monte Carlo simulation with Latin hypercube sampling. A simulation model consists of iterations. An iteration is started by generating the random demand for 40 retailer cycles. Some outputs are observed for generated demands. They are beginning inventory position for cycle i (BIP_i), customer demand for cycle i (D_i), ending inventory position for cycle i (EIP_i), shortage amount for cycle i (SU_i), the retailer holding cost for cycle i (RHC_i) and the retailer lost sales cost for cycle i (RLC_i). Based on the observed data, the expected total system cost for the current simulation can be calculated for the last 30 cycles. It is noted that this research simulates 40 cycles per iteration. However, the first ten cycles are considered as warm up period, only the results of the last 30 cycles are used for data collection purpose.

5 The simulation process repeats until the maximum number of iterations has been reached. The statistics for the distribution of the target cell (total system cost) is generated at the end of each simulation.

6 The simulation process will be stopped when the maximum number of simulations is reached or when the improvement is less than a pre specified value, i.e., minimum improvement for continuing the simulation process is 0.01% in the last 100 simulations. Statistics for all simulations and optimal solutions are determined at the end of simulation process.

5 Numerical example

This section describes an example to show how the optimisation program works. The program requires input data, initial solution settings and simulation settings.

The model is developed to determine the number of replenishments in a vendor cycle, the retailer's lot size, and the vendor's lot size. The input data are shown in Table 1.

Table 1 The input data

Variable name	*Value*	*Dimension*
Vendor order cost (VOC)	1,500	USD per order
Vendor holding cost (C_{VH})	0.75	USD per unit per time unit
Delivery cost (Cd)	40	USD per delivery
Retailer holding cost (HR)	2	USD per unit per time unit
Retailer lost sales cost (LS)	4	USD per unit
Average retailer demand (D)	300	Units/time unit
Retailer cycle (t)	1	Time unit

For the above input data, the maximum number of simulations is set to be 1,000 simulations and the number of iterations is set to be 500 iterations per simulation.

The initial solution for the first decision variable, i.e., the number of replenishments is 1. The solution range for number of replenishments (n*) is set in the range from 1 to 100. For finding the optimal retailer's lot size (q*), the initial solution for the second variable is set at the average demand per time unit. The range of the retailer's lot size is 1 to 600. The vendor's lot size can then be determined based on the optimal retailer's lot size and the number of replenishments in a vendor cycle.

The other simulation settings are defined as follows. The sampling type is Latin hypercube. For generating the feasible solutions, the genetic algorithm parameters are set at 0.1 for mutation rate and 0.5 for crossover rate. The simulation process will be stopped when the maximum number of simulations, i.e., 1,000, is reached or when the improvement is less than 0.01% in the last 100 simulations, whichever occurs first.

From the simulation results, we conclude that the optimal number of replenishments to minimise the mean of total system cost is 4, i.e., delivering four times. The optimal vendor's lot size is 1,067 units. The expected total system cost is 1,086.27 USD per time unit.

6 Sensitivity analysis

In this section, sensitivity analysis is conducted to examine the effects of input parameters on decision variables. The decision variables are the number of replenishments, the retailer's lot size and the vendor's lot size. The parameters of interest are VOC, unit holding at the vendor site (C_{VH}), unit holding cost at retailer site (HR), and unit cost of lost sales (LS). The optimisation program will be run to find the optimal solution.

6.1 Effect of VOC

To study the effect of the VOC, this research conducts some experiments for selected values of the VOC ranging from 1,000 to 4,000 USD per vendor order. The results are summarised in Table 2.

Table 2 VOC sensitivity analysis

Vendor order cost	*Result*	*Number of replenishment n**	*The retailer's lot size q**	*The vendor's lot size Q**
1,000	934	3	274	823
1,500	1,086	4	267	1,067
2,000	1,198	4	285	1,141
2,500	1,305	5	283	1,413
3,000	1,410	6	273	1,637
3,500	1,494	6	272	1,629
4,000	1,576	6	277	1,663

From the above results, it can be seen that when the VOC increases, the number of replenishments and the vendor's lot size increase, i.e., the vendor tends to deliver more often and increases his order lot size. The above trends look reasonable because when VOC increases the vendor should reduce his order frequency. This leads to the fact that his order lot size should be increased to fulfil the demand in each order cycle. Also, in order to control the holding cost at retailer, the number of replenishments to the retailer in one cycle should also be increased.

6.2 Effect of vendor holding cost (CVH)

To study the effect of the vendor holding cost, this research conducts some experiments for selected values of the vendor holding cost ranging from 0.5 to 2.5 USD per unit per time unit. The results are summarised in Table 3.

From the results, it can be seen that when the vendor holding cost increases, the number of replenishments and the vendor's lot size decrease, i.e., the vendor tends to reduce the number of replenishments in a vendor cycle. This trend is understandable because when the vendor holding cost increases, the vendor should reduce his order lot size, and as a result, the number of replenishments to the retailer in one vendor cycle should be reduced.

Table 3 Vendor holding cost sensitivity analysis

Vendor holding cost	*Result*	*Number of replenishment n**	*The retailer's lot size q**	*The vendor's lot size Q**
0.5	962.580	5	284	1,422
0.75	1,086.265	4	267	1,067
1	1,163.335	3	289	866
1.5	1,304.560	3	282	846
2	1,413.158	2	288	577
2.5	1,485.162	2	279	559

6.3 Effect of retailer holding cost (HR)

To study the effect of the retailer holding cost, this research conducts some experiments for selected values of the retailer holding cost ranging from 1 to 5 USD per unit per time unit. The results are summarised in Table 4.

Table 4 Retailer holding cost-sensitivity analysis

Retailer holding cost	*Result*	*Number of replenishment n**	*The retailer's lot size q**	*The vendor's lot size Q**
1	928.08	4	292	1,167
2	1,086.27	4	267	1,067
3	1,205.85	4	264	1,058
4	1,306.40	5	187	935
5	1,353.12	5	149	747

From the results, it can be seen that when the retailer holding cost increases, the retailer's and vendor's lot sizes decrease, but the number of replenishments increases. This trend is understandable because when the retailer holding cost increases, the retailer's lot size should be reduced. Consequently, the number of replenishments should be increased to fulfil the demand in a vendor cycle. Also, in order to reduce the holding cost at the vendor site, the vendor should reduce his order lot size.

6.4 Effect of retailer lost sales cost (LS)

To study the effect of the retailer lost sales cost, this research conducts some experiments for selected values of the retailer lost sales cost ranging from 3 to 8 USD per unit. The results are summarised in Table 5.

From the results, it can be seen that when the retailer lost sales cost increases, the number of replenishments is not affected, but the retailer's lot size and the vendor's lot size increase. This trend is understandable because when the lost sales cost increases, the retailer's lot size should be increased to avoid lost sales cost due to product shortages. Consequently, the vendor should increase his order lot size.

Table 5 Lost sales cost-sensitivity analysis

Retailer lost sales cost	*Result*	*Number of replenishment n**	*The retailer's lot size q**	*The vendor's lot size Q**
3	1,079.48	4	190	760
4	1,086.27	4	267	1,067
5	1,085.75	4	289	1,155
6	1,095.92	4	291	1,163
7	1,104.69	4	292	1,168
8	1,112.44	4	293	1,171

7 Conclusions and future research

This research developed a VMI model for one vendor and one retailer system under stochastic demand in which the vendor monitors the retailer's inventory position and makes corresponding replenishment decision. The unique contribution of this paper is the development of a VMI model for one vendor and one retailer under stochastic demand. The main targets of this research are to determine the number of replenishments in a vendor cycle, the retailer's lot size and the vendor's lot size to help minimise the expected total system cost. This research employed simulation-optimisation technique using genetic algorithm to find optimal solutions. Sensitivity analysis is conducted to examine the effects of some input parameters on the optimal solutions.

Related to managerial implication, there are some observations in this research. Firstly, the vendor should reduce his order frequency while VOC increases. Secondly, the vendor should reduce his order lot size and the number of replenishments to the retailer in one cycle when vendor holding cost increases. Next, the retailer's lot size should be reduced and the number of replenishments should be increased when the retailer holding cost increases. Related to retailer lost sales cost, the retailer's lot size should be increased when the lost sales cost increases.

This research paper considered one vendor and one retailer system with stochastic demand. For future research directions, this research can be extended in some ways. For example, the future research may consider one vendor and multiple retailer system as an extension of the proposed model. Furthermore, the retailer's limited space can be included as a constraint to cope with the fact that the retailer space is usually limited.

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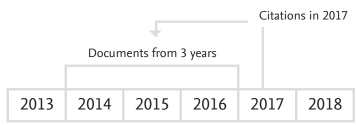

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^ Top of page