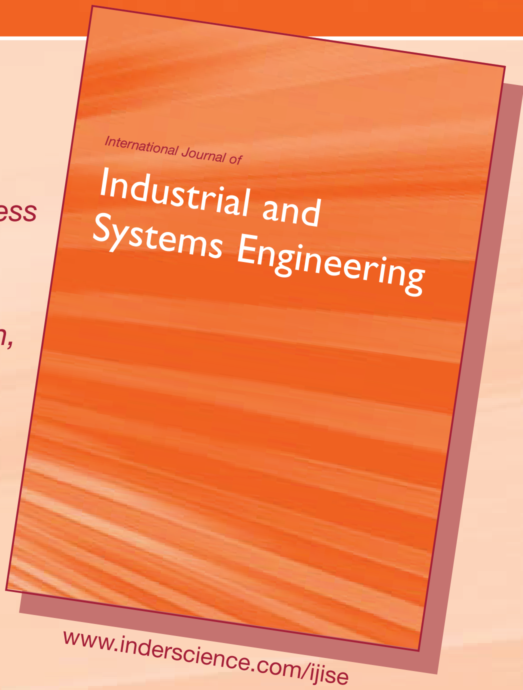
International Journal of

Industrial and Systems Engineering

Editor-in-Chief:
Prof. Angappa Gunasekaran

Scope of the Journal

ISSN: 1748-5037 (Print), ISSN: 1748-5045 (Online)



www.inderscience.com/ijise

In today's global economy, the most successful engineering managers rely on a combination of technical skills and business principles. Industrial and systems engineering (ISE) aims at imparting fundamental knowledge to develop the ability to address complex industrial issues, highlighting how to design, run, control and optimise production systems. IJISE addresses the development of ISE principles, tools, systems and methods with special emphasis on the applications of ISE techniques and tools in improving organisational productivity and competitiveness in global markets.

Topics covered include:

- Engineering economic analysis
- Computer methods for engineering
- Engineering experimental design
- CIMS, robotics and automation
- Quality engineering, environment risk analysis
- Systems reliability engineering, maintenance analysis
- Human factors/ergonomics in design
- Simulation modelling/analysis
- System design and control systems, concurrent engineering
- Production systems analysis/design
- Facilities layout/design
- Financial/investment engineering
- Information systems, ICT, AI/expert systems design
- Project management, decision support systems
- Technology management/transfer

Not sure if this title is the one for you?

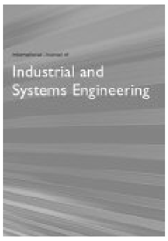
Visit the journal homepage at **www.inderscience.com/ijise** where you can:

- View sample articles in full text HTML or PDF format
- Sign up for our free table of contents new issue alerts via e-mail or RSS
- View editorial board details
- Find out about how to submit your papers
- Find out about subscription options, in print, online or as part of a journals collection

You can order online at **www.inderscienceonline.com** or download an order form from **www.inderscience.com/subform**.

This title is part of the Science, Engineering and Technology Collection (see **www.inderscience.com/set**). For library collection subscriptions or for a free institutional online trial, please contact **subs@inderscience.com.**

INDERSCIENCE PUBLISHERS
Linking academia, business and industry through research



International Journal of Industrial and Systems Engineering

2019 Vol.31 No.1

Pages	Title and author(s)
1-14	**Robust integral backstepping control with extended Kalman filter of permanent magnet synchronous motor** Ibtissem Bakhti; Souad Chaouch; Abdessalam Makouf; Tarek Douadi **DOI**: 10.1504/IJISE.2019.096883
15-37	**Exploring the relationship of discrete components of inventory with financial performance in Indian automotive industry** Tanuj Nandan; Vikas Kumar Choubey **DOI**: 10.1504/IJISE.2019.096884
38-69	**Statistical study on the use of the measurement techniques in predictive maintenance taking Moroccan companies as an example** Amal Boukili; Mohammed El Hammoumi; Said Haouache **DOI**: 10.1504/IJISE.2019.096885
70-94	**Assessing software upgradation attributes and optimal release planning using DEMATEL and MAUT** Rana Majumdar; P.K. Kapur; Sunil Kumar Khatri **DOI**: 10.1504/IJISE.2019.096886
95-112	**Reliability evaluation and improvement of manufacturing helicopter in an aircraft manufacturing company - case study: skid types helicopter landing gear** Mohammad Farahmand; Maliheh Ganji; Seyed Mojtaba Sajadi **DOI**: 10.1504/IJISE.2019.096887
113-136	**One vendor and multiple retailers system in vendor managed inventory problem with stochastic demand** Cahyono Sigit Pramudyo; Huynh Trung Luong **DOI**: 10.1504/IJISE.2019.096888

International Journal of Industrial and Systems Engineering

This journal also publishes Open Access articles

Editor in Chief
Prof. Angappa Gunasekaran

ISSN online
1748-5045

ISSN print
1748-5037

12 issues per year
Subscription price

Scopus

In today's global economy, the most successful engineering managers rely on a combination of technical skills and business principles. Industrial and systems engineering (ISE) aims at imparting fundamental knowledge to develop the ability to address complex industrial issues, highlighting how to design, run, control and optimise production systems. *IJISE* addresses the development of ISE principles, tools, systems and methods with special emphasis on the applications of ISE techniques and tools in improving organisational productivity and competitiveness in global markets.

About this journal | Editorial board | Submitting articles

Sign up for new issue alerts
Subscribe/buy articles/issues
View sample issue
Latest issue contents as RSS feed
Forthcoming articles
Journal information in easy print format (PDF)

Publishing with Inderscience: ethical guidelines (PDF)
View all calls for papers
Recommend to a librarian (PDF)
Feedback to Editor

Find related journals

Keep up-to-date
Our Blog
Follow us on Twitter
Visit us on Facebook
Our Newsletter (subscribe for free)
RSS Feeds
New issue alerts

One vendor and multiple retailers system in vendor managed inventory problem with stochastic demand

Cahyono Sigit Pramudyo*

Department of Industrial Engineering,
Faculty of Science and Technology,
State Islamic University 'Sunan Kalijaga',
Yogyakarta, Indonesia
Email: cahyono.pramudyo@uin-suka.ac.id
and
Industrial and Manufacturing Engineering Field of Study,
Department of Industrial Systems Engineering,
School of Engineering and Technology,
Asian Institute of Technology,
P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand
Email: cahyono.sigit.pramudyo@ait.ac.th
*Corresponding author

Huynh Trung Luong

Industrial and Manufacturing Engineering Field of Study,
Department of Industrial Systems Engineering,
School of Engineering and Technology,
Asian Institute of Technology,
P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand
Email: luong@ait.ac.th

Abstract: In many supply networks, the retailers are reluctant to share information about demand and inventory level to the vendor. This might lead to many difficulties for the vendor in establishing his own order/production plan. Vendor managed inventory (VMI) policy can help to solve that problem. By applying VMI, information sharing is not really a problem for the vendor anymore and this policy have been proven to help reduce total inventory cost as well as improve customer service level in the supply network. In this research, a VMI model for the system with one vendor and multiple retailers will be developed. The main target of the model is to determine the retailer's lot size, the vendor's lot size, the retailer cycle time, and the number of replenishments in a vendor cycle so as to minimise the total system cost. For solution purpose, simulation-optimisation technique using genetic algorithm is employed to help find optimal solutions for the decision variables. Numerical experiments are conducted to show the applicability of the proposed model. Sensitivity analysis is also conducted to examine the effects of some input parameters on the optimal solution.

Keywords: vendor managed inventory; VMI; simulation-optimisation; genetic algorithm.

Reference to this paper should be made as follows: Pramudyo, C.S. and Luong, H.T. (2019) 'One vendor and multiple retailers system in vendor managed inventory problem with stochastic demand', *Int. J. Industrial and Systems Engineering*, Vol. 31, No. 1, pp.113–136.

Biographical notes: Cahyono Sigit Pramudyo received his Master of Industrial Engineering and Management from Institut Teknologi Bandung Indonesia. He received his Bachelor of Industrial Engineering from Universitas Gadjah Mada Indonesia. He received his Doctoral degree from Industrial and Manufacturing Engineering at Asian Institute of Technology Thailand. He is a Lecturer in the Department of Industrial Engineering at the State Islamic University 'Sunan Kalijaga', Yogyakarta, Indonesia. His research interests are vendor managed inventory, decision support system, and simulation.

Huynh Trung Luong is an Associate Professor of Industrial and Manufacturing Engineering field of study at Asian Institute of Technology in Thailand. He received his Doctoral and Master degrees from Industrial Systems Engineering Program in Asian Institute of Technology. He holds a Bachelor degree from Ho Chi Minh City University of Technology, Vietnam. His research interest is developing analytical models which aim at deriving exact optimal or near optimal solutions for operational problems in industries including emergency inventory policy, inventory policies for perishable product, supply chain design and measures of bullwhip effect in supply chains, availability-based and reliability-based maintenance, fuzzy quality control charts, statistical design of experiments and network flow-related problems.

1 Introduction

In a supply chain with asymmetric information system, vendor does not know inventory level at retailer. In such a supply chain, supply chain members have their own inventory control policies and they do not share their inventory information (Lee and Billington, 1992).

To overcome this pitfall, vendor managed inventory (VMI) can be seen as a way to help optimise inventory control in supply chain system. VMI becomes an interesting topic since Wal-Mart and Procter and Gamble successfully implemented VMI in the late 1980. VMI applications have successfully helped to reduce cost and to improve customer service level. VMI has also been successfully applied by many US 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 retailers 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 VMI models 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. The VMI models with one vendor and one retailer should be extended into VMI models with one vendor and multiple retailers. 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 that have been conducted in 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 related to 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.

Related to VMI models with one vendor and multiple retailers system, Lu (1995), Viswanathan and Piplani (2001), Woo et al. (2001), Zhang et al. (2007), Nachiappan and Jawahar (2007), Yu et al. (2009a, 2009b), Zavanella and Zanoni (2009), Sadeghi et al. (2014a), Darwis and Odah (2010), Almehdawe and Mantin (2010), Chen et al. (2010), Shao et al. (2011), Sue-Ann et al. (2012), Yu et al. (2012), Hariga et al. (2013, 2014), Pasandideh et al. (2014), and Mateen and Chatterjee (2015) developed various VMI models with one vendor and multiple retailers system under deterministic demand. Also, Banerjee and Banerjee (1994), Cachon (2001), Egri and Váncza (2013), Mutlu and Cetinkaya (2010), Wong et al. (2009), Zhao et al. (2010), Rad et al. (2014), Choudhary and Shankar (2015), and Mateen et al. (2015) proposed various VMI models with one vendor and multiple retailers system under stochastic demand.

In Darwish and Odah (2010) research work, the authors 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. Therefore, this research proposes a VMI model with one vendor and multiple retailers under stochastic demand in which the vendor replenishes the retailer at the same time and the product quantities to be delivered to the retailers are constant. In details, we will develop a VMI model for one vendor and multiple retailers 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. This research is an extension of the research conducted by Pramudyo and Luong (2015, In Press) which dealt with the one vendor – one retailer system.

The remaining parts of this paper are arranged as follows. In Section 2, literature review on VMI models for one vendor-multiple retailers system will be presented. In Section 3, mathematical models will be developed. Section 4 will explain how simulation-optimisation technique using genetic algorithm is employed to find optimal solutions. Section 5 presents numerical experiments to illustrate the applicability 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 results.

2 Literature review

In modern supply chain networks, VMI has become an interesting topic in inventory decision-making. VMI differs with the traditional inventory system. 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.

Some research works related to VMI system have been conducted. The research works on VMI can be classified as one vendor-one retailer system and one vendor-multiple retailers system. The demand pattern can be considered as deterministic or stochastic. Research works on VMI have grown from one vendor-one retailer system into one vendor – multiple retailer system and from deterministic demand into stochastic demands. This paper focuses on VMI models with one vendor and multiple retailers system under stochastic demand. Therefore, VMI research papers for one vendor and multiple retailers system under stochastic and deterministic demand are reviewed in this paper.

Related to the VMI research works with one vendor and multiple retailers system under deterministic demand, Lu (1995) focused on minimising the vendor's total annual cost. The objective is subject to the maximum cost that the buyer may be prepared to pay. Viswanathan and Piplani (2001) introduced the benefit of common replenishment epochs in coordinating supply chain inventories. This research work concluded that below a given threshold value of the vendor's order processing costs, common replenishment strategy actually led to the increase of vendor's and total system costs. Woo et al. (2001) analysed an inventory system of one vendor and multi retailers where the single vendor is a manufacturer. The vendor and the buyers planned to establish new ordering systems (e.g., EDI-based ordering systems) between them to reduce the ordering cost. The authors mentioned that the vendor and all buyers could share substantial cost savings from this ordering cost reduction investment. Zhang et al. (2007) expanded the work of Woo et al. (2001). They developed a model in which the cycle times for all buyers/retailers and the vendor were not the same. Compared to Woo et al. (2001), the proposed model can help to reach smaller joint total cost. Nachiappan and Jawahar (2007) formulated mathematical model to maximise the system profit and find the optimal contract price between the vendor and buyers. A genetic algorithm was proposed to find the optimal solution of the model and LINGO was used to find optimal sales quantity. The results showed that VMI helps to increase the supply chain profit. Yu et al. (2009a) focused on how the vendor can take advantage of market and inventory information for increasing his own profit by using a Stackelberg game in a VMI model. The Stackelberg equilibrium was utilised to maximise the vendor's and the retailer's profits. They concluded that the vendor and the retailer can increase their profits by the cooperative contract. Yu et al. (2009b) analysed the interaction between a manufacturer and his retailers to optimise their individual net profits by considering advertising, pricing, and inventory factors. A Stackelberg game has also been used to find the Stackelberg equilibrium. An analysis was conducted to examine what actions should be taken if the prices of raw materials or holding costs increase. Zavanella and Zanoni (2009) studied consignment stock (CS) policy for a single-vendor and multiple-buyer to determine the replenishment decisions. In this research work, the system cycle is defined as the period from when the vendor incurs one setup activity until when the vendor produces enough to satisfy all the demand. This research considered two scenarios, i.e., order emission cost for each buyer was more than set up cost incurred by the vendor and the contrary scenarios. An analytical model was derived to help solve the problem. Sadeghi et al. (2014a) proposed a VMI model which is an extension of Zavanella and Zanoni (2009) work by including optimisation of route delivery and total production system reliability. This research proposed a VMI model for one vendor and multiple retailers so as to minimise the total supply chain costs and to maximise the production system reliability using the approach of redundancy allocation problem (RAP). Genetic algorithm is used to find the optimal solution and simulated annealing is employed to speed up the searching process. In another research work, Sadeghi et al. (2014b) also proposed a VMI model as the extension of Zavanella and Zanoni (2009) research work. The objective was to minimise total inventory and transportation cost. Particle swarm optimisation (PSO) was used to find the optimal solution. Also, genetic algorithms (GA) and local search were used to speed up the searching process. Darwish and Odah (2010) focused on the operating policies for the vendor and retailers with the objective of minimising the total cost of supply chain. The research developed a model for a single-vendor multi-retailer supply chain under VMI where VMI contractual was explicitly included. The authors found that the vendor tends to replenish the retailer more frequently if the vendor ordering cost increases. On the other hand, if the vendor holding cost increases, the shipment size first increases and then decreases. An efficient algorithm was developed to find the global optimal solution. Almehdawe and Mantin (2010) also analysed one manufacturer and multiple retailers system under VMI. A Stackelberg game was used to model the problem. Two scenarios were examined in which the first scenario is the case where the manufacturer is the leader, and the second scenario is the case where one retailer is a dominant player. The objective was to maximise each player profits. The results showed that the existence of a dominance retailer will help to increase supply chain efficiency when the lowest market scale among retailers occurs and the manufacturer always prefer to be the leader due to higher profits. Chen et al. (2010) proposed VMI models for profit maximisation problem. Equilibrium analysis was conducted for cooperative and non-cooperative settings. Three conditions were compared. They are wholesale price-only, VMI, and VMI-consignment. A Stackelberg game was also used to model the problems. It has been found that non-cooperative settings tend to increase prices, less stock and lower profits. Shao et al. (2011) proposed a VMI model for non-cooperative supply chain with one vendor and several retailers. The profit maximisation was analysed by determining wholesale price, marketing cost, replenishment cycle, and backorder quantity. Sue-Ann et al. (2012) dealt with one vendor and many buyers under VMI policy. PSO and a hybrid of genetic algorithm-artificial immune system (GA-AIS) were used to find the optimal sales quantity, sales price and contract price in order to maximise the supply chain profit. It has been conducted through numerical experiments that PSO performs better than GA-AIS. Yu et al. (2012) studied how to manage the system-wide inventories of fast deteriorating raw material and slow deteriorating product. This research work developed an integrated model to analyse the total inventory and deterioration cost for such a system. A golden search algorithm was developed to help find the optimal solution of the model. The authors found that the deteriorating rate of the product affects the total cost while the deteriorating rate of raw material has less impact on the total cost. Hariga et al. (2013) proposed a model for a single vendor and multiple retailers system. The authors proposed a cost efficient heuristic to solve the problem. It was concluded that the heuristic algorithm gained greater cost savings. Pasandideh et al. (2014) designed a fair contract used to optimise the profit of the manufacturer and retailers. GAMS software was used to determine the optimal solution of the model. Hariga et al. (2014) proposed a VMI model for one vendor and multiple retailers which consider upper stock limits at retailers and overstock cost for exceeding these upper limits. Heuristic procedure was developed to generate the delivery schedules. Equal size shipment was considered in this research with the objective is to determine the optimal vendor cycle time and the number of replenishments to each retailer. Both common and various replenishment retailer cycles were compared in this paper. The results showed that VMI performs better than non-VMI. Mateen and Chatterjee (2015) also proposed VMI models for one vendor and multiple retailers to analyse different policies, i.e., equal size shipment with various retailer cycle times, equal size shipment with the same retailer cycle time, maintaining the same retailer inventory level by the vendor synchronising system, and increasing batch size shipment with the same retailer cycle time. Analytical technique was used to solve the models. The results showed that the benefit of VMI depends on the operating condition, the replenishment policy is an important factor for optimising the system, and the benefits due to VMI are not distributed same for all members in the system. Darwish et al. (2015) proposed VMI models which incorporated quality aspect into the proposed models. Decentralised and centralised model were developed. The results showed that the supply chain with centralised system performs better than decentralised system in term of profit.

Related to the VMI research works with one vendor and multiple retailers system under stochastic demand, Banerjee and Banerjee (1994) investigated a model for one vendor and multiple buyers/retailers under stochastic demand and lead time. Cachon (2001) investigated the competitive and cooperation behaviour in the supply chain inventory game. The objective was to minimise backorder penalty cost and inventory carrying cost. Egri and Váncza (2013) focused on asymmetric private information of demand and cost. This paper described the general mechanism in which inventory planning was done according to the newsvendor model. The results showed that the coordination protocol needs no independent decision maker for guaranteeing truthfulness and efficiency of the network. Mutlu and Cetinkaya (2010) proposed a VMI model for one vendor and multiple retailers which focus on integrated models for inventory and transportation policy. The challenge in this research was to balance transportation scale economies and penalty of delaying order shipments because of shipment consolidation. Wong et al. (2009) dealt with a VMI model for one supplier and multiple retailers system with a sales rebate contract. Retailers were considered independent with demand function sensitive only to their own price and depend on all retailers' prices. It has been observed that the supplier gains more profit with competing retailers. Zhao et al. (2010) proposed a VMI model to integrate ordering and delivering decisions for a coal delivery problem. Markov decision process was used to develop the model and modified policy iteration was used to find the optimal solution. Rad et al. (2014) compared the retailer managed inventory (RMI) and VMI. The models are developed for one vendor and two retailers system. The vendor costs consist of vendor raw material order costs, and production costs. Algorithms were developed to find optimal solutions. The results showed that VMI led to a greater reduction of total system costs than RMI. Choudhary and Shankar (2015) analysed the value of changing from information sharing to VMI under non-stationary stochastic demand. (R, S) policy was examined and the results showed that the benefits of

VMI depended on the order issuing efficiency. When the order issuing efficiency is high, the benefits of VMI were maximised. Mateen et al. (2015) proposed a VMI model for one vendor and multiple retailers under stochastic demand to minimise expected total system costs. (s, S) policy was applied in the proposed model. Approximation and simulation were used to find the optimal solutions. Shortages were considered in the proposed model by delivering based on equal stock out probability.

In this research, we extend Darwish and Odah (2010) research work. In that research, the authors developed a VMI model with one vendor and multiple retailer system. They considered deterministic demand in their research and analysed 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. Therefore, this research proposes a VMI model for one vendor and multiple retailers 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, the retailer's cycle time (t) 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 for one vendor and multiple retailers 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 members, i.e., retailers, in one replenishment cycle.

It is noted that demands at all retailers are stochastic and all retailer's demands are assumed to follow Poisson distribution. The retailer's inventory position will be reduced gradually due to stochastic demand. For all retailers, equal cycle time is applied for inventory replenishment mechanism.

This research is conducted for a single non-deteriorating product. We assume that delivery lead time from vendor to all retailers is negligible. The inventory policy considers shortage as lost sales and there is a lost sales cost which is incurred to the system when shortages occur.

The objective of this research is to find the optimal value of some interested decision variables so as to minimise the expected total system cost by use of simulation-optimisation technique. The variables are as follows.

1. lot size of each retailer (q_j)
2. the vendor's order lot size (Q)
3. the number of replenishments in a vendor cycle (n)
4. the retailer cycle time (t)

For details, the system behaviour is described as follows.

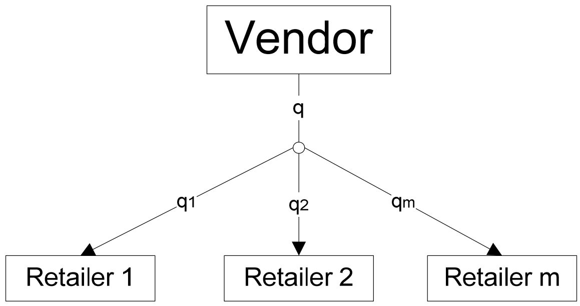
1 The system starts with a vendor placing order to his external supplier with ample capacity every (T) time units. The vendor's order lot size is Q units.

2 There are a number of replenishments to the retailers in a vendor cycle. The vendor delivers q units of product every t time units to all retailers. The retailer's lot sizes (q_j) are proportional to their average demand.

3 There are m retailers in the system.

The system is described in Figure 1.

Figure 1 Vendor-retailers system



The relations between the retailer's cycle time (t), the vendor's cycle time (T), the total retailer's lot size (q), the vendor's lot size (Q) and number of replenishments in a vendor cycle (n) are shown as follows.

$$T = n * t \quad (1)$$

$$Q = n * q \quad (2)$$

Demand of all retailers follows Poisson distribution with D as the average total demand of all retailers per time unit. Due to retailer's lot sizes are proportional to their average demands (D_j), the relation between the total retailer's lot size (q) and each retailer's lot size (q_j) are shown as follows.

$$q = \sum_{j=1}^{m} q_j \quad (3)$$

$$\frac{q}{q_j} = \frac{D}{D_j} \quad (4)$$

The following notations will be used throughout this research:

Q vendor's order lot size

q total retailer's lot size

q_j lot size of retailer j

T vendor cycle time

t retailer cycle time

n	number of replenishments in a vendor cycle
m	number of retailers in the system
AVO	average vendor order cost (VOC) per time unit
VOC	VOC per order
C_{VH}	unit holding cost at the vendor site ($/unit/time unit)
T_V	vendor holding cost in a vendor cycle
AT_V	average vendor holding cost per time unit
D_c	delivery cost to all retailers per time unit
C_d	delivery cost to all retailers per delivery
BIP_{ij}	retailer j's beginning inventory position in cycle i
EIP_{ij}	retailer j's ending inventory position in cycle i
D_{ij}	demand of retailer j for cycle i
RHC_{ij}	the holding cost of retailer j per time unit in cycle i
t_{1ij}	time at which the inventory position of retailer j in cycle i equals to 0, if happen
HR	unit holding cost at retailer site ($/unit/time unit)
$ERHC_j$	expected holding cost of retailer j per time unit
$ERHC$	expected holding cost of all retailers per time unit
RLC_{ij}	lost sales cost of retailer j per time unit in cycle i
LS	unit cost of lost sales ($/unit)
$ERLC$	expected lost sales cost of all retailers per time unit
$ERLC_j$	expected lost sales cost of retailer j per time unit
D	average demand of all retailers per time unit
D_j	average demand of retailer j per time unit
SU_{ij}	shortage amount of retailer j in cycle i
u_j	maximum allocated space limit of retailer j on inventory level (unit)
CP	unit penalty cost of violating the maximum allocated space limit at retailers ($/unit)
RPC_{ij}	penalty cost of violating the maximum allocated space limit at retailer j per time unit in cycle i
$ERPC_j$	expected penalty cost at retailer j per time unit
$ERPC$	total expected penalty cost per time unit.

3.1 System modelling

This research focuses on development of a VMI model for one vendor and multiple retailers system to help minimise the expected total system cost. The total system cost consists of costs at vendor and costs at retailers. At vendor, the total cost includes VOC, vendor holding cost, and delivery cost. At retailers, the total cost includes holding cost, lost sales cost and penalty cost. It is noted that all system costs are paid by the vendor. Therefore, the penalty cost at retailer is the additional expense that the retailer will charge the vendor to temporarily allocate additional space if the beginning inventory level at a retailer cycle exceeds the pre-allocated space.

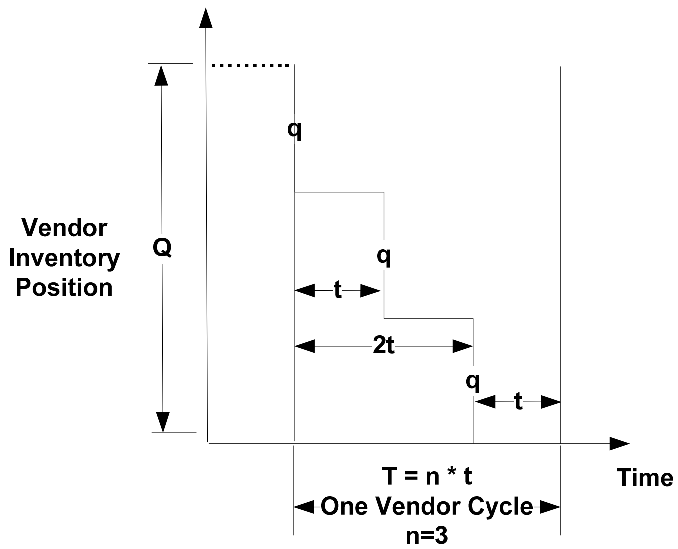
3.2 Costs at vendor

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

$$AVO = \frac{VOC}{T} = \frac{VOC}{n * t} \tag{5}$$

The vendor inventory position is gradually reduced due to the delivery of product from the vendor to retailers as illustrated in Figure 2 when the number of replenishments equals to three.

Figure 2 Vendor inventory position



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

$$\begin{aligned} T_V &= C_{VH} * \{t * (Q - q) + t * (Q - 2q) + \cdots + t(Q - (n-1)q)\} \\ T_V &= C_{VH} * t * q * n * \left(\frac{(n-1)}{2}\right) \end{aligned} \tag{6}$$

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

$$AT_V = \frac{T_V}{T} = \frac{C_{VH} * t * q * n * \left(\frac{(n-1)}{2}\right)}{n * t} = \frac{C_{VH} * q}{2}(n-1) \tag{7}$$

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

$$D_c = \frac{C_d}{t} \tag{8}$$

3.3 Costs at retailer

For determination of costs at retailers, the simulation model developed in this research will observe some data.

1. Retailer j's beginning inventory position in cycle i (BIP_{ij}). BIP_{ij} is defined as the retailer j's inventory position right after a replenishment at the beginning of cycle i.
2. Retailer j's ending inventory position in cycle i (EIP_{ij}). EIP_{ij} is defined as the retailer j inventory position just before replenishment at the end of cycle i.
3. Demand of retailer j for cycle i (D_{ij}). D_{ij} is the stochastic demand at retailer j in cycle i and its value will be generated through simulation process.

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

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

$$BIP_{1j} = q_j \tag{9}$$

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

$$BIP_{ij} = EIP_{(i-1)j} + q_j \tag{10}$$

b. Demand of the retailer j in cycle i (D_{ij}) follows Poison distribution with parameter $D_j * t$. D_j is the average demand of retailer j per unit of time.

c. Ending retailer j's inventory position in cycle i (EIP_{ij}) is determined as follows.

$$EIP_{ij} = Max\{0, BIP_{ij} - D_{ij}\} \tag{11}$$

d. Shortage amount of retailer j at the end of cycle i, SU_{ij}, is determined as follows.

$$SU_{ij} = Max\{0, D_{ij} - BIP_{ij}\} \tag{12}$$

e. Repeat step a to d for 40 cycles. However, the first 10 cycles are considered as warm up period, only the results of the last 30 cycles are used for data collection purpose.

For analysing costs at retailer, this research employed the expected path approach (Hadley and Whiten, 1963; Moinzadeh and Nahmias, 1998) by considering all possible cases that are likely to occur in a replenishment cycle. Follow that approach, if the expected retailer's inventory position at the end of a cycle is considered, there are two possible scenarios related to the ending inventory position in a retailer cycle (EIP_{ij}).

a the first scenario is the case when 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.

The above scenarios can be described in Figures 3 and 4.

Figure 3 The first scenario

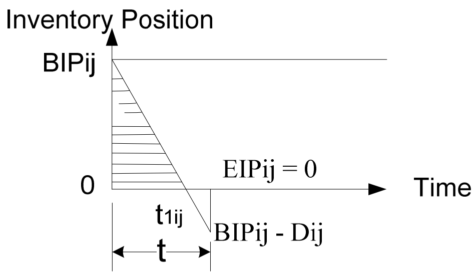
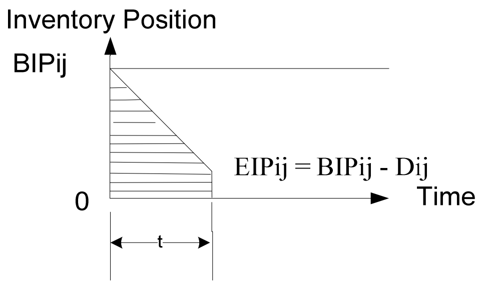


Figure 4 The second scenario



For the first scenario, the holding cost of retailer *j* per time unit in cycle *i* (RHC_{ij}) is calculated as follows.

$$RHC_{ij} = HR * \frac{BIP_{ij} * t_{1ij}}{2t} \quad (13)$$

where

$$\frac{BIP_{ij}}{D_{ij} - BIP_{ij}} = \frac{t_{1ij}}{t - t_{1ij}} \Leftrightarrow t_{1ij} = \frac{BIP_{ij} * t}{D_{ij}} \quad (14)$$

So,

$$RHC_{ij} = HR * \frac{BIP_{ij}^2 * t}{2 * t * D_{ij}} = HR * \frac{BIP_{ij}^2}{2D_{ij}} \quad (15)$$

For the second scenario, the holding cost of retailer *j* per time unit in cycle *i* (RHC_{ij}) is calculated as follows.

$$RHC_{ij} = HR * \frac{\frac{2BIP_{ij} - D_{ij}}{2} * t}{t} \tag{16}$$

$$RHC_{ij} = HR * \frac{2BIP_{ij} - D_{ij}}{2} \tag{17}$$

For both scenarios, the general formula for the holding cost of retailer *j* per time unit in cycle *i* (RHC_{ij}) is expressed as follows.

$$RHC_{ij} = HR * \left(\frac{BIP_{ij} + Max\{0, (BIP_{ij} - D_{ij})\}}{2\left[1 - \frac{Min(0, (BIP_{ij} - D_{ij}))}{BIP_{ij}}\right]} \right) \tag{18}$$

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

Hence, the expected holding cost of retailer *j* per time unit ($ERHC_j$) and the total expected holding cost of all retailers per time unit (*ERHC*) is calculated as follows.

$$ERHC_j = \frac{\sum_{i=11}^{40} RHC_{ij}}{30} \tag{19}$$

$$ERHC = \sum_{j=1}^{m} ERHC_j \tag{20}$$

The lost sales cost of retailer *j* for cycle *i* (RLC_{ij}) is calculated as the accumulated shortage amount at the end of the cycle multiplied by unit cost of lost sales. Therefore, lost sales cost of retailer *j* per time unit for cycle *i* (RLC_{ij}) and expected lost sales cost of retailer *j* per time unit ($ERLC_{ij}$) are calculated as follows.

$$RLC_{ij} = LS * \frac{Max\{0, (D_{ij} - BIP_{ij})\}}{t} \tag{21}$$

$$ERLC_j = \frac{\sum_{i=11}^{40} RLC_{ij}}{30} \tag{22}$$

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

Hence, expected lost sales cost of all retailers per time unit (ERLC) is calculated as follows.

$$ERLC = \sum_{j=1}^{m} ERLC_j \tag{23}$$

The penalty cost at retailer *j* in cycle *i* (RPC_{ij}) is charged when the retailer's beginning inventory position is over the maximum allocated space. There are two possible scenarios that may occur for the beginning inventory position of retailer *j* in cycle *i* (BIP_{ij}), i.e.

a The first scenario is when the beginning inventory position is less than the maximum allocated space limit at retailer *j* ($BIP_{ij} < u_j$). There will be no penalty cost.

b The second scenario is when the retailer beginning inventory position is greater than the maximum allocated space limit at retailer *j* ($BIP_{ij} > u_j$). In this case, penalty cost will be charged.

Therefore, the penalty cost at retailer *j* per time unit in cycle *i* (RPC_{ij}) and expected penalty cost at retailer *j* per time unit ($ERPC_j$) are calculated as follows.

$$RPC_{ij} = CP * \frac{Max\{0, (BIP_{ij} - u_j)\}}{t} \tag{24}$$

$$ERPC_j = \frac{\sum_{i=11}^{40} RPC_{ij}}{30} \tag{25}$$

where CP is unit cost of penalty ($/unit).

Hence, total expected penalty cost at retailers per time unit ($ERPC$) is calculated as follows.

$$ERPC = \sum_{j=1}^{m} ERPC_j \tag{26}$$

3.4 Total system cost

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

$$\text{Total system cost} = AVO + AT_V + D_c + ERHC + ERLC + ERPC \tag{27}$$

3.5 Model implementation

In the model, the decision variables that need to be determined are as follows.

1 Number of replenishments in a vendor cycle (n).

2 Total retailer's lot size (q).

Based on value of q, we can determine the lot size of each retailer *j*, which is proportional to the average demand of retailer *j*.

3 Another decision variable is the retailer cycle time (t).

4 Model optimisation

This research develops a VMI model for one vendor and multiple retailers system under stochastic demand using (t, q) inventory policy in which a constant amount q will be delivered to the retailers in each retailer replenishment cycle of length t. The retailer's lot sizes (q_j) are proportional to the average demands. The objective of this research is to find the optimal value of the retailer's lot size, the vendor's order lot size, the retailer cycle time and the number of replenishments in a vendor cycle so as to minimise the expected total system cost. Due to the complicated nature of the mathematical model representing the problem as seen before, analytical solution cannot be derived, and therefore, simulation-optimisation technique using genetic algorithm is employed to help find optimal solutions. In this research, @RISK and @RISKOptimizer, which are parts of Palisade Decision Tools Suite developed by Palisade Corporation, 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.

For more details, the simulation-optimisation procedure is performed as follows:

a 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).

b Determine parameters for solution: initial solutions and solution ranges (for number of replenishment cycles in a vendor cycle, retailer cycle time, and retailer's lot size).

c Apply genetic algorithm: in this process, genetic algorithm will be employed to help search for the optimal solutions. Firstly, genetic algorithm generates an initial population of feasible solutions in form of chromosomes. The fitness of each chromosome will be evaluated by simulation. Then, the fittest chromosomes will be selected. Next, 'offspring' chromosomes will be created through crossover and mutation processes. The least-fit chromosomes of the population will then be replaced with better offspring chromosomes.

d Evaluate the fitness of each chromosome generated by genetic algorithm using Monte Carlo simulation with Latin Hypercube sampling technique. A simulation run consists of many iterations. An iteration is started by generating the random demand for 40 retailer cycles. Some outputs are collected for each iteration. They are beginning inventory position of retailer j for cycle i (BIP_{ij}), customer demand of retailer j for cycle i (D_{ij}), ending inventory position of retailer j for cycle i (EIP_{ij}), shortage amount of retailer j for cycle i (SU_{ij}), the holding cost at retailer j for cycle i (RHC_{ij}), the lost sales cost at retailer j for cycle i (RLC_i) and the penalty cost at retailer j for cycle i (RPC_{ij}). Based on the observed data, the expected total system cost for the current simulation can be determined for the last 30 cycles. It is noted that this research simulates 40 cycles per iteration. However, the first 10 cycles are considered as warm up period, only the results of the last 30 cycles are used for data collection purpose.

e The simulation process repeats until the maximum number of iterations has been reached. The statistics related to the distribution of the total system cost are collected and expected total system cost is determined. Another simulation will then be conducted if the stopping criterion is not met.

f 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 (e.g., minimum improvement for continuing the simulation process is 0.01% in the last 500 simulations). Statistics for all simulations and optimal solutions are determined at the end of the simulation process.

In step d., it should be noted that when we start running the simulation, we must assume a specific beginning inventory level for the first cycle, and hence, this first cycle and some later cycles should be ignored to ensure the randomness of the simulation model. However, there is no clear rule to set the length of the warm-up period. In principle, the longer the warm-up period, the more accurate result received from simulation model but the simulation time will be prolonged. In fact, we have conducted pilot test with various values of warm-up period and we found that the warm-up period of 10 cycles is good enough because there is no significant differences (statistically) between this settings with the other settings where warm-up period is more than 10 cycles.

5 Numerical example

In this section, we consider a one vendor and three retailers system. The input data are presented in Tables 1, 2 and 3.

Table 1 Cost data

Cost name	*Value*	*Dimension*
Vendor order cost (*VOC*)	2,000	USD per order
Vendor holding cost (C_{VH})	4	USD per unit per time unit
Delivery cost (C_d)	200	USD per delivery
Retailer holding cost (*HR*)	4	USD per unit per time unit
Retailer lost sales cost (*LS*)	10	USD per unit
Penalty cost (*CP*)	1	USD per unit

Table 2 Average demands of retailers

j	*Value*	*Dimension*
1	50	Units per time unit
2	100	Units per time unit
3	150	Units per time unit
Total	300	Units per time unit

Table 3 Maximum allocated space limits of retailers

j	*Allocated limit*	*Dimension*
1	60	Units
2	120	Units
3	180	Units

With the above input data, the maximum number of simulations is set to be 10,000 simulations and the number of iterations is set to be 1,000 iterations per simulation. Those parameters have been selected after conducting pilot test and we see that setting higher values for these numbers will not help to improve the solution at all.

Due to the fact that genetic algorithm is employed, the range of decision variables should be provided for @RISKOPTIMIZER to start. These ranges are firstly set to be wide, and then, through pilot tests, the ranges will be narrowed down so that it can be expected that the optimal solutions are located within the ranges. After that, the simulation program will be run at full scale to determine the more precise optimal solutions. However, when the solution of any decision variable comes from simulation is at the lower bound or upper bound of the corresponding range, that range will be expanded and the simulation program will be run again. Solutions are acceptable only when located within the pre-specified ranges. For the problem under consideration, the initial solution for the number of replenishments (n) is set to be 1 with the range from 1 to 5, the initial solution for the total retailer's lot size (q) is set at the total average demand of all retailers per time unit with the range from 1 to 1,000, and the initial solution for the retailer cycle time (t) is set to be 1 with the range for from 1 to 5.

Related to parameters of genetic algorithm, we use crossover rate of 0.5 and mutation rate of 0.1. These values are the recommended values for general purpose use in @RISKOPTIMIZER. In fact, we have tested with other combinations of crossover rate and mutation rate, but we do not see any advantage in comparison with the recommended values for these two parameters. Related to the size of initial population, we also tested with different values and then select 100 which give good performance in terms of convergence rate of genetic algorithm and simulation time.

Related to stopping criterion for the simulation process, the simulation process will be stopped when the maximum number of simulations, i.e., 10,000, is reached or when the improvement is less than 0.01% in the last 500 simulations, whichever occurs first.

With the above settings, the results received from the developed simulation – optimisation model for the problem under consideration are as follows: the optimal number of replenishments is 1, i.e., delivering one time in a vendor cycle; the optimal vendor's lot size is 532 units; the optimal retailer cycle time is 2-time units; and retailer's lot sizes are 89, 177, 266 units for retailers 1, 2 and 3, respectively. The minimum expected total system cost is 2501.39 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 in a vendor cycle (n), each retailer's lot size (q_j), the vendor's lot size (Q), and the retailer cycle time (t). The parameters of interest are *VOC*, unit holding cost at the vendor site (C_{VH}), unit holding cost at retailer site (*HR*), unit cost of lost sales (*LS*), and unit cost of penalty (*CP*).

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 500 to 4,000 USD per vendor order. The results are summarised in Table 4.

Table 4 Sensitivity analysis w.r.t. VOC

Vendor order cost	*Vendor order lot size*	*Number of replenishments*	*Retailer cycle time*	*Total retailer lot size*	*Lot size of each retailer*		
VOC	*Q**	*n**	*t**	*q*	*q*1	*q*2	*q*3
500	284	1	1	284	47	95	142
1,000	285	1	1	285	48	95	143
1,500	528	1	2	528	88	176	264
2,00	532	1	2	532	89	177	266
3,000	664	1	3	664	111	221	332

From Table 4, it can be seen that when the VOC increases, the vendor's lot size increases. In addition, the retailer cycle time increases when the vendor delivers more. The above trend looks reasonable because when VOC increases the vendor should reduce his order frequency. This leads to the fact that the vendor's order lot size should increase to fulfil the demand in each order cycle. As a consequence, the total retailer's lot size and the retailer cycle time should be increased if the number of replenishments remains unchanged. It also means that each retailer's lot size should increase as the VOC increases.

6.2 *Effect of* C_{VH}

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 4 USD per unit per time unit. The results are summarised in Table 5.

Table 5 Sensitivity analysis w.r.t. C_{VH}

Vendor holding cost	*Vendor order lot size*	*Number of replenishments*	*Retailer cycle time*	*Total retailer lot size*	*Lot size of each retailer*		
C_{VH}	*Q**	*n**	*t**	*q*	*q*1	*q*2	*q*3
0.5	1,410	5	1	282	47	94	141
1	1,124	4	1	281	47	94	141
2	843	3	1	281	47	94	141
3	568	2	1	284	47	95	142
4	532	1	2	532	89	177	266

From Table 5, it can be seen that when the vendor holding cost increases, the vendor's order lot size and the number of replenishments 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 retailers in one vendor cycle should be reduced. In addition, the retailer cycle time increases when the vendor starts to deliver more than total retailer average demand per time unit, i.e., the vendor delivers more than 300 units per retailer cycle. This trend is understandable because when the total retailer's lot size is more than the average demand of all retailers, the retailer cycle time should be increased to avoid overstock in a retailer cycle.

It is noted that for the vendor holding cost equals to 0.5 USD per unit per time unit, the simulation was run by extending the range of number of replenishments to [1, 10] instead of [1, 5]. It is done because the solution reaches the maximum value in the initial range of the number of replenishments in a vendor cycle.

6.3 *Effect of 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 6.

Table 6 Sensitivity analysis w.r.t. HR

Retailer holding cost	*Vendor order lot size*	*Number of replenishments*	*Retailer cycle time*	*Total retailer lot size*	*Lot size of each retailer*		
HR	*Q**	*n**	*t**	*q*	*q*1	*q*2	*q*3
1	573	1	2	573	96	191	287
2	566	1	2	556	94	189	283
3	550	1	2	550	92	183	275
4	532	1	2	532	89	177	266
5	499	1	2	499	83	166	250

From Table 6, it can be seen that when the retailer holding cost increases, the retailer's and vendor's lot sizes decrease. This trend is understandable because when the retailer holding cost increases, the total retailer's lot size should be reduced. This also means each retailer's lot size decreases. Consequently, the vendor's order lot size decreases if the number of replenishments and the retailer cycle time remain unchanged.

6.4 *Effect of retailer LS cost*

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 9 to 11 USD per unit. The results are summarised in Table 7.

Table 7 Sensitivity analysis w.r.t. LS cost

Retailer lost cost	*Vendor order lot size*	*Number of replenishments*	*Retailer cycle time*	*Total retailer lot size*	*Lot size of each retailer*		
LS	*Q**	*n**	*t**	*q*	*q*1	*q*2	*q*3
9	516	1	2	516	86	172	258
9.5	527	1	2	527	86	176	264
10	532	1	2	532	89	177	266
10.5	534	1	2	534	89	178	267
11	540	1	2	540	90	180	270

From Table 7, it can be seen that the total retailer's lot size and the vendor's lot size increase when the retailer lost sales cost increases. This also means that each retailer's lot size increases. This trend is understandable because when the lost sales cost increases, the total retailer's lot size and each retailer's lot size should be increased to avoid lost sales cost due to shortages. Consequently, the vendor should increase his order lot size if the number of replenishments and the retailer cycle time remain unchanged.

6.5 *Effect of CP*

To study the effect of the penalty cost, this research conducts some experiments for selected values of the penalty cost ranging from 0.25 to 1.5 USD per unit. The results are summarised in Table 8.

Table 8 Sensitivity analysis w.r.t. *CP*

Penalty cost	*Vendor order lot size*	*Number of replenishments*	*Retailer cycle time*	*Total retailer lot size*	*Lot size of each retailer*		
PC	Q^*	n^*	t^*	q	$q1$	$q2$	$q3$
0.25	541	1	2	541	90	180	271
0.5	538	1	2	538	90	179	269
0.75	537	1	2	537	90	179	269
1	532	1	2	532	89	177	266
1.25	527	1	2	527	88	176	264
1.5	525	1	2	525	88	175	263

From Table 8, it can be seen that the total retailer's lot size and the vendor's lot size decrease when the penalty cost increases. This also means that each retailer's lot size decreases. This trend is understandable because when the penalty cost increases, the retailer's lot size and each retailer's lot size should be reduced to avoid penalty cost due to product overstock. As a consequence, the vendor should reduce his order lot size if the number of replenishments and the retailer cycle time remain unchanged.

7 Conclusions

This research developed a VMI model for one vendor and multiple retailers system under stochastic demand in which the vendor monitors the retailer's inventory position and makes corresponding replenishment decision. (t, q) policy is used in our proposed model. The main targets of this research is to determine the number of replenishments in a vendor cycle, each retailer's lot size, the retailer cycle time, and the vendor's lot size in order to minimise the expected total system cost. For solution purpose, this research employs simulation-optimisation technique using genetic algorithm to find optimal solutions. Sensitivity analyses are also conducted to examine the effects of some input parameters on the optimal solutions.

There are some observations from the results of this research. Firstly, the vendor should increase his lot size and reduce his order frequency when the VOC increase. Secondly, the vendor order lot size and the number of replenishments should be reduced when the vendor holding cost increases. In addition, the retailer cycle time increases when the vendor starts to deliver more than total retailer average demand per time unit. Thirdly, the retailer's and vendor's lot sizes should be reduced when the retailer holding cost increases. Fourthly, the retailer's lot size and the vendor's lot size should be increased when the retailer lost sales cost increases in order to avoid lost sales cost due to shortages. At last, the retailer's lot size and the vendor's lot size should be decreased when the retailer penalty increases to avoid penalty cost due to product overstock.

For future research, this research can be extended in some ways. Firstly, the proposed model was designed for one vendor and multiple retailers systems. The future research may consider multiple vendors and multiple retailers system as an extension of the proposed model. On the other hand, the delivery and holding cost are same for all retailers in the current research. This cost may be differed for each retailer in the future research. Furthermore, the delivery/transportation cost may be incorporated in the total cost function. Another issue that needs to be addressed is the allocation of delivery amount in a retailer replenishment cycle to each retailer. In the current research, we assumed that this amount is allocated proportionally based on the average demand of each retailer. Other allocation schemes should be considered. The model can also be expanded to consider different replenishment cycles for different retailers in one vendor cycle.

Acknowledgements

The authors are thankful for the comments of the anonymous reviewers. The authors also would like to thank the Ministry of Religious Affairs – Republic of Indonesia for the doctoral scholarship fund.

References

Almehdawe, E. and Mantin, B. (2010) 'Vendor managed inventory with a capacitated manufacturer and multiple retailers: retailer versus manufacturer leadership', *Int. J. Production Economics*, Vol. 128, No. 1, pp.292–302.

Banerjee, A. and Banerjee, S. (1994) 'A coordinated order-up-to inventory control policy for a single supplier and multiple buyers using electronic data interchange', *Int. J. Production Economics*, Vol. 35, Nos. 1–3, pp.85–91.

Cachon, G.P. (2001) 'Stock wars: inventory competition in a two-echelon supply chain with multiple retailers', *Operations Research*, Vol. 49, No. 5, pp.658–674.

Chen, J-M., Lin, I-C. and Cheng, H-L. (2010) 'Channel coordination under consignment and vendor-managed inventory in a distribution system', *Transportation Research Part E*, Vol. 46, No. 6, pp.831–843.

Choudhary, D. and Shankar, R. (2015) 'The value of VMI beyond information sharing in a single supplier multiple retailers supply chain under a non-stationary (Rn, Sn) policy', *Omega*, Vol. 51, pp.59–70.

Darwish, M.A. and Odah, O.M. (2010) 'Vendor managed inventory model for single-vendor multi-retailer supply chains', *European Journal of Operational Research*, Vol. 204, No. 3, pp.473–484.

Darwish, M.A., Odah, O.M. and Goyal, S.K. (2015) 'Vendor managed inventory models for single-vendor multi-retailer supply chains with quality consideration', *International Journal of Industrial and Systems Engineering*, Vol. 20, No. 1, pp.22–57.

Dong, Y. and Xu, K. (2002) 'A supply chain model of vendor managed inventory', *Transportation Research Part E*, Vol. 38, No. 2, pp.75–95.

Egri, P. and Vanca, J. (2013) 'A distributed coordination mechanism for supply networks with asymmetric information', *European Journal of Operational Research*, Vol. 226, No. 3, pp.452–460.

Hadley, G. and Whiten, T.M. (1963) 'An inventory-transportation model with N locations', *Multistage Inventory Modelsand Techniques*, pp.116–142, Stanford University Press, Stanford, California.

Hariga, M., Gumus, M. and Daghfous, A. (2014) 'Storage constrained vendor managed inventory models with unequal shipment frequencies', *Omega*, Vol. 48, pp.94–106.

Hariga, M., Gumus, M., Daghfous, A. and Goyal, S.K. (2013) 'A vendor managed inventory under contractual storage agreement', *Computers and Operations Research*, Vol. 40, No. 8, pp.2138–2144.

Hariga, M.A. and Al-Ahmari, A. (2013) 'An integrated retail space allocation and lot sizing models under vendor managed inventory and consignment stock arrangements', *Computers and Industrial Engineering*, Vol. 64, No. 1, pp.45–55.

Kiesmuller, G.P. and Broekmeulen, R. (2010) 'The benefit of VMI strategies in a stochastic multi-product serial two echelon system', *Computers and Operations Research*, Vol. 37, No. 2, pp.406–416.

Kim, E. (2004) 'Stochastic vendor managed replenishment with demand dependent shipment', *European Journal of Operational Research*, Vol. 152, No. 3, pp.723–744.

Lee, H. and Billington, C. (1992) 'Managing supply chain inventory: pitfalls and opportunities', *Sloan Management Review*, Vol. 33, No. 3, pp.65–73.

Lee, J-Y. and Ren, L. (2011) 'Vendor-managed inventory in a global environment with exchange rate uncertainty', *International Journal of Production Economics*, Vol. 130, No. 2, pp.169–174.

Lu, L. (1995) 'Theory and methodology: a one-vendor multi-buyer integrated inventory model', *European Journal of Operational Research*, Vol. 81, No. 2, pp.312–323.

Lu, X., Shang, J.Y., Wu, S., Hegde, G.G., Vargas, L. and Zhao, D. (2015) 'Impacts of supplier hubris on inventory decisions and green manufacturing endeavors', *European Journal of Operational Research*, Vol. 245, No. 1, pp.121–132.

Mateen, A. and Chatterjee, A. (2015) 'Vendor managed inventory for single-vendor multi-retailer supply chains', *Decision Support Systems*, Vol. 70, No. 1, pp.31–41.

Mateen, A., Chatterjee, A. and Mitra, S. (2015) 'VMI for single-vendor multi-retailer supply chains under stochastic demand', *Computers and Industrial Engineering*, Vol. 79, No. 1, pp.95–102.

Moinzadeh, K. and Nahmias, S. (1988) 'A continuous review model for an inventory system with two supply modes', *Management Science*, Vol. 34, No. 6, pp.761–773.

Mutlu, F. and Cetinkaya, S. (2010) 'An integrated model for stock replenishment and shipment scheduling under common carrier dispatch costs', *Transportation Research Part E*, Vol. 46, No. 6, pp.844–854.

Nachiappan, S. and Jawahar, N. (2007) 'A genetic algorithm for optimal operating parameters of VMI system in a two-echelon supply chain', *European Journal of Operational Research*, Vol. 182, No. 3, pp.1433–1452.

Nia, A.R., Far, M.H. and Niaki, S.T. (2015) 'A hybrid genetic and imperialist competitive algorithm for green vendor managed inventory of multi-item multi-constraint EOQ model under shortage', *Applied Soft Computing*, Vol. 30, pp.353–364.

Pasandideh, S.H., Niaki, S.T. and Nia, A.R. (2011) 'A genetic algorithm for vendor managed inventory control system of multi-product multi-constraint economic order quantity model', *Expert Systems with Applications*, Vol. 38, No.3, pp.2708–2716.

Pasandideh, S.H., Niaki, S.T. and Niknamfar, A.H. (2014) 'Lexicographic max-min approach for an integrated vendor-managed inventory problem', *Knowledge-Based Systems*, Vol. 59, No. 1, pp.58–65.

Pramudyo, C.S. and Luong, H.T. (2015) 'One vendor -one retailer in vendor managed inventory problem with stochastic demand', *International Journal of Industrial and Systems Engineering*, In Press.

Rad, R., Razmi, J., Sangari, M. and Ebrahimi, Z. (2014) 'Optimizing an integrated vendor-managed inventory system for a single-vendor two-buyer supply chain with determining weighting factor for vendor's ordering cost', *Int. J. Production Economics*, Vol. 153, pp.295–308.

Sadeghi, J., Sadeghi, S. and Niaki, S.T. (2014a) 'A hybrid vendor managed inventory and redundancy allocation optimization problem in supply chain management: an NSGA-II with tuned parameters', *Computers and Operations Research*, Vol. 41, No. 1, pp.53–64.

Sadeghi, J., Sadeghi, S. and Niaki, S. (2014b) 'Optimizing a hybrid vendor-managed inventory and transportation problem with fuzzy demand: an improved particle swarm optimization algorithm', *Information Sciences*, Vol. 272, pp.126–144.

Shao, H., Li, Y. and Zhao, D. (2011) 'An optimal decisional model in two-echelon supply chain', *Procedia Engineering*, Vol. 15, pp.4282–4286.

Sue-Ann, G., Ponnambalam, S. and Jawahar, N. (2012) 'Evolutionary algorithms for optimal operating parameters of vendor managed inventory systems in a two-echelon supply chain', *Advances in Engineering Software*, Vol. 52, pp.47–54.

Viswanathan, S. and Piplani, R. (2001) 'Coordinating supply chain inventories through common replenishment epochs', *European Journal of Operational Research*, Vol. 129, No.2, pp.277–286.

Vlist, P.V., Kuik, R. and Verheijen, B. (2007) 'Note on supply chain integration in vendor-managed inventory', *Decision Support Systems*, Vol. 44, No.1, pp.360–365.

Waller, M., Johnson, M.E. and Davis, T. (1999) 'Vendor-managed inventory in the retailer supply chain', *Journal of Business Logistics*, Vol. 20, No. 1, pp.183–203.

Wang, C. (2009) 'Random yield and uncertain demand in decentralised supply chains under the traditional and VMI arrangements', *International Journal of Production Research*, Vol. 47, No.7, pp.1955–1968.

Wong, W., Qi, J. and Leung, S. (2009) 'Coordinating supply chains with sales rebate contracts and vendor-managed inventory', *Int. J. Production Economics*, Vol. 120, No. 1, pp.151–161.

Woo, Y., Hsu, S. and Wu, S. (2001) 'An integrated inventory model for a single vendor and multiple buyers with ordering cost reduction', *Int. J. Production Economics*, Vol. 73, No.3, pp.203–215.

Xu, K. and Leung, M.T. (2009) 'Stocking policy in a two-party vendor managed channel with space restrictions', *International Journal of Production Economics*, Vol. 117, No.2, pp.271–285.

Yao, Y., Evers, P. and Dresner, M. (2007b) 'Response to 'note on supply chain integration in vendor managed inventory', *Decision Support Systems*, Vol. 44, No.1, pp.366–367.

Yao, Y., Evers, P.T. and Dresner, M. (2007a) 'Supply chain integration in vendor-managed inventory', *Decision Support Systems*, Vol. 43, No.2, pp.663–674.

Yu, Y., Chu, F. and Chen, H. (2009a) 'A Stackelberg game and its improvement in a VMI system with a manufacturing vendor', *European Journal of Operational Research*, Vol. 192, No.3, pp.929–948.

Yu, Y., Huang, G. and Liang, L. (2009b) 'Stackelberg game-theoretic model for optimizing advertising, pricing and inventory policies in vendor managed inventory (VMI) production supply chains', *Computers and Industrial Engineering*, Vol. 57, No.1, pp.368–382.

Yu, Y., Wang, Z. and Liang, L. (2012) 'A vendor managed inventory supply chain with deteriorating raw materials and products', *International Journal Production Economics*, Vol. 136, No.2, pp.266–274.

Zavanella, L. and Zanoni, S. (2009) 'A one-vendor multi-buyer integrated production-inventory model: the 'consignment stock' case', *Int. J. Production Economics*, Vol. 118, No.1, pp.225–232.

Zhang, T., Lianga, L., Yua, Y. and Yua, Y. (2007) 'An integrated vendor-managed inventory model for a two-echelon system with order cost reduction', *Int. J. Production Economics*, Vol. 109, Nos. 1–2,, pp.241–253.

Zhao, Q., Chen, S., Leung, S. and Lai, K. (2010) 'Integration of inventory and transportation decisions in a logistics system', *Transportation Research Part E*, Vol. 46, No. 6, pp.913–925.

Scopus Preview

Sources

Title

Enter title

Find sources

Title: International Journal Of Industrial And Systems Engineering ×

i

CiteScore metrics for journals and serials

CiteScore metrics from Scopus are:
- Comprehensive
- Transparent
- Current and free

Use this page to find a source and view associated metrics. Use qualitative as well as quantitative metrics when presenting your research impact. Always use more than one quantitative metric. Learn more about CiteScore.

1 result

Export to Excel Download Scopus Source List

View metrics for year: 2018

Source title	CiteScore	Highest percentile	Citations 2018	Documents 2015-17	% Cited	SNIP	SJR	Publisher
International Journal of Industrial and Systems Engineering	0.82	49% 164/323 Industrial and Manufacturing Engineering	200	245	44	0.551	0.296	Inderscience

^ Top of page

About Scopus

What is Scopus
Content coverage
Scopus blog
Scopus API
Privacy matters

Language

日本語に切り替える
切换到简体中文
切換到繁體中文
Русский язык

Customer Service

Help
Contact us