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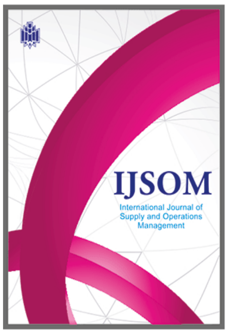

The Bullwhip Effect on the VMI-Supply Chain Management via System Dynamics Approach: The Supply chain with Two Suppliers and One Retail Channel

Alireza Hosseini[a] and Yahia Zare Mehrjerdi[*a]

[a] *Department of Industrial Engineering, Yazd University, Yazd, Iran*

Abstract
This work investigates the effect of different inventory policies of a supply chain model using the system dynamics approach which belongs to the class of Vendor Managed Inventory (VMI), automatic pipeline, inventory and order based production control systems (VMI-APIOBPCS). This work helps management to investigate the effect of different policies such as adding the VMI system or third party logistic (TPL) on the whole cost of the supply chain. To this end, this work applies system dynamics in supply chain with two suppliers and one retail channel which consist of VMI system. Moreover, this work studies the performance of the proposed model via three metrics: Bullwhip effect; satisfaction of the end-customer; the amount of the whole inventory of chain.

Keywords: Supply chain management; Vendor managed inventory; System dynamics; Bullwhip effect; Optimal policy.

[*] Corresponding author email address: mehrjerdyazd@gmail.com

1. Introduction

Recently, there has been considerable attention among supply chain management regarding the effect of different policies of a supply chain management on operations and reducing cost. After designing an integrated policy which led to acceptable results in the whole chain, efficient algorithms can be devised to find the global optimal solution under each policy. We need a tool to easily investigate the necessity of policies such as outsourcing, VMI system, TPL, inventory level among others, in the supply chain. Here we utilize system dynamics as the main tool for investigation. In context of VMI, we can consider two categories for related studies: 1- Investigating the policy of hiring VMI system and its necessity in a specific supply chain. 2- Implementation the policy of hire VMI system and study related optimal solution. According to Darwish and Odah (2010), VMI is an integrated approach for retailer–vendor coordination, according to which the vendor decides on the appropriate inventory levels within bounds that are agreed upon in a contractual agreement between vendor and retailers. Today there are many optimization studies in context of VMI. For example, Disney and Towill (2002) consider the performance of a production or distribution-scheduling algorithm termed Automatic Pipeline Inventory and Order Based Production Control System (APIOBPCS) embedded within a VMI supply chain where the demand changes over time. The Properties of the optimal systems are checked via various metrics: Bullwhip, customer service level and inventory cost metrics.

Also, Darwish and Odah (2010) developed a mathematical model that explicitly incorporated VMI contractual agreement into a multi-retailer supply chain. Moreover, they investigated the effect of vendor order cost, vendor holding cost, over-stock limit and penalty cost on the supply chain. Kristianto et al. (2012) extended the functionality of the VMI model by developing an adaptive fuzzy smoothing constant. The proposed adaptive fuzzy VMI control was successfully applied and Bullwhip effect was investigated. Lee and Ren (2011) analyzed a simple periodic-review stochastic inventory model to examine the benefits of VMI from economies of scale in production/delivery in a global environment characterized by exchange rate uncertainty and large fixed costs of delivery. In particular, they suggest that despite of all the inventory costs transferred from the retailer, the supplier can be better off when his fixed cost of production/delivery is larger than the retailer’s fixed ordering cost.

Yu and et al. (2012) consider a Vendor Managed Inventory (VMI) type supply chain where supplier and vendor decide how to manage their raw material inventory with fast deteriorating rate and their product with slow deteriorating rate which minimizes the whole inventory level of supply chain and related cost. The decision variables are a common replenishment cycle of the product and the replenishment frequency of the raw material. Then the convexity of the cost functions was presented based on which, a golden search algorithm was developed to find the optimal solution of the model. Barrón et al. (2012) develop a heuristic algorithm to solve a system under VMI approach with multi-product and multi-constraint based on EOQ with backorders considering two classical backorders costs: linear and fixed. For this system, the optimization problem is a nonlinear integer programming (NLIP). The authors show that this heuristic algorithm is better than the previous genetic algorithm published based on three aspects: the total cost, the number of evaluations of the total cost function and computational time.

In the context of investigating the effect of selecting optimal policy in supply chain management performance using the VMI approach, there are few studies in comparison with optimization studies. For example, Chen, et al. (2012) investigates the issues of the vendor's optimal distribution policies as affected by demand uncertainty in the supply chain. They investigate these issues considering a centralized two-echelon supply chain of a short life-cycled product with one vendor and two retailers facing heterogeneous stochastic demand distributions. In a similar study, Arora and et al. (2010) evaluated a supply chain with multi retailers and distributors, with each distributor following a unique policy. The first policy is continuous replenishment process policy where the retailers' inventory is replenished in every time interval by the supplier. In the next three policies, inventory of the retailers is replenished by some definite policy factors. The Vendor Managed Inventory (VMI) system is employed for updating the inventory of the retailers. For updating the inventory of distributors an order-up-to policy (q, Q) is used. Finally, a framework was developed to measure the satisfaction level of customers.

The paper is structured as follows. Section 2 discusses system dynamics background. In section 3, we introduce and design the conceptual model of system dynamics VMI-APIOBPCS model. In section 4 we present the system dynamics VMI-APIOBPCS model of this work. In section 5, we perform simulation analysis and finally we review the research results.

2. System Dynamics Background

System dynamics studies a closed-loop system with feedback. The systematic series of behaviors of a close system are induced by the feedback loop structure contained in it. The dynamic changes of the system behavior are driven by the internal forces and loop interactions. Through time shifting, behaviors are the accumulated results of internal loop structure and interactions within the system, not from exterior factors (Tseng, 1996). The dynamic movement of the system can be caused by a feedback loop, and there are two types of feedback: reinforcing loop and balancing loop. Systems archetype is composed of many circulations formed as a result of all kinds of problems that affect one another in society. Senge and Lannon (1990) classified these circulations into nine major systems archetypes: (1) Delayed balancing process; (2) Limitation to goals; (3) Shifting the burden; (4) Temporary solution; (5) Escalation; (6) Success; (7) Common tragedy; (8) Failure; (9) Growth and underachievement; Fixes that Fail; and (11) Accidental Adversaries. In the section that follows we describe three of these basic system thinking theories.

Ge, et al. (2004) presented a system dynamics approach for the analysis of the demand amplification problem, also known as the bullwhip effect, which has been studied fairly in the literature. The construction of a system dynamics model is reported using a part of a supermarket chain system in the United Kingdom as an example. Suryani et al. (2010) have employed system dynamics for demand scenario analysis and planned capacity expansion. De Marco et al. (2012) used system dynamics to assess the impact of Radio Frequency Identification (RFID) technology on retail operations. Zare Mehrjerdi (2011) employed system thinking approach to demonstrate the role of RFID in supply chain profitability engagement. System dynamics modeling has been applied, to specific management issues such as healthcare work force planning and emergency healthcare providers (Royston et al 1999, Keolling, 2005). Zare Mehrjerdi employed the systems thinking concepts for analyzing the weight related healthcare problem (2013), quality function deployment profitability (2011), system dynamics approach for new product development (2013), library cost control (2012), strategic system selection (2014), and healthcare expense control (2012). These models demonstrate the rich variety of areas in which system dynamics may play a significant role, however.

Sohrabi et al. (2016) examined supplier selection in three echelon supply chain and the VMI under- price dependent demand condition. Poorbagheri and Niaki (2014) discussed a vendor managed inventory model for single vendor, multi retailor and single warehouse supply chain system with stochastic demand. On the VMI modeling of the problem in the supply chain context, some researchers have been get involved: Rasay et al. (2015), Kim and Park (2010), Mohsen Akhbar (2014, 2015), and Mitra Moubed (2016) to mention a few. Moubed et al. (2016) developed a reverse supply chain taking collaboration into concentration. Various supply chain parameters are used to develop the stochastic model of the problem then meta-heuristic approaches are used to solve the problem. Akhbari et al. (2014b) contributes to the debate on the role of VMI-type contracts in supply chains by reviewing published literature during 1998-2011. A total of forty selected referred journal papers are systematically reviewed. Authors have focused on different perspectives including supply chain configuration, demand pattern, number of products and the type of protocols in party’s agreement.

By applying system dynamics to supply chain optimization, maximized performance can be achieved by accessing all the key information among the supply chain members and deriving a systematic solution among the parties. In order to design optimal policy for implementation of VMI in a specific supply chain management, we need a tool which can check the necessity of VMI for our chain and also captures its effect on different parts of the chain. Here we use the system dynamics approach as the main tool for this purpose. The system dynamics approach is one of the best methodologies in solving system problems with dynamic complexity (W. Forrester, 1958). It leads to a systematic view and obtains desirable policies.

For the VMI service provider, a systematic tool can be used to plan and prepare the solution against the odds of uncertainty. Li and et al. (2013) applied a system dynamics approach for VMI in supply chain management. They also add TPL to supply chain and consider one supplier and two retailers under system dynamics approach. Finally, they used some metrics to show the validation of the study such as inventory level in different levels of chain. In this study, we introduce a novel system dynamics approach for VMI in supply chain management. This study is easily utilized for designing different policies in SCM. Management can easily change different parameters of chain and observe the results. For example, one can add VMI system in supply chain and check its suitability for different levels of the chain such as inventory level or satisfaction metric. Also management can check the effect of safety stock on the chain by varying it during a time interval and capturing the results dynamically. After developing the model, we need some metrics to check the effect of VMI system on the whole of supply chain. For this purpose, we identify three basic metrics which are frequently utilized: Bullwhip effect, satisfaction of end-customer and the amount of the whole inventory of the chain, See table 1.

Table1. Used performance metric of VMI in literature

Studies in VMI context	**Performance assessment metrics**		
	Reduce total inventory of supply chain	**Improvement Bull Whip effect**	**Improvement satisfaction of end customer**
(Disney and Towill, 2002)	✓	✓	✓
(Kim and Park, 2010)	✓		
(Yao and et al. 2010)	✓		
(Kristianto and et al.2012)	✓	✓	
(Lee and Ren, 2011)	✓		
(Yu and et al. 2012)	✓		
(Arora and et al. 2010)	✓		✓
(Li and et al. 2013)	✓		✓

3. Conceptual model of system dynamics VMI-APIOBPCS model

In order to minimize supply chain cost, including production cost and inventory cost, (Disney and Towill,2002) introduce a VMI-APIOBPCS model. The purpose of this system design is to find a proper target inventory level and design three optimal control mechanisms (demand forecasting mechanism, inventory deviation adjustment, and WIP inventory deviation adjustment mechanism). Fig.1 shows the conceptual model of the traditional supply chain and Fig.2 shows conceptual model of VMI supply chain (Disney and Towill, 2002).

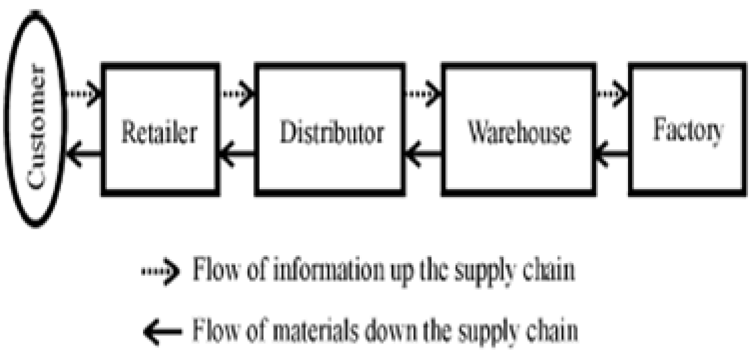

Figure1. The traditional supply chain

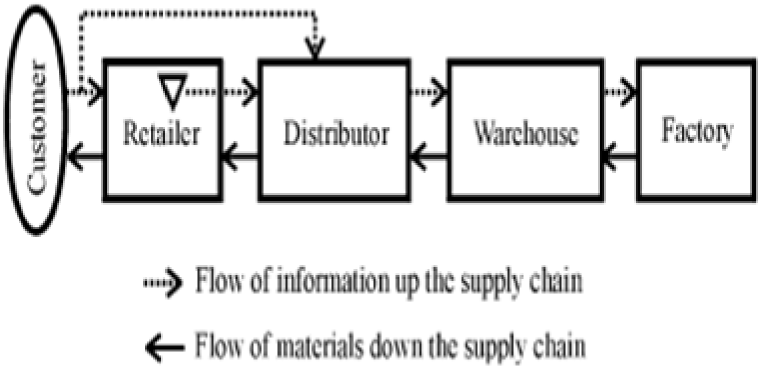

Figure2. A VMI supply chian

Using the typical model when a distributor needs product, model places an order with a manufacturer. The distributor is in total control of the timing and size of the order being placed and maintains the inventory plan. However, using the VMI model, the manufacturer receives data which inform him about the distributors' sales and stock levels. The manufacturer can capture each item which the distributor carriers as well as the true point of sale data and he is responsible for creating and maintaining the inventory plan. Based on the VMI model, the manufacturer generates the order, not the distributor. VMI does not change the "ownership" of inventory. It remains as it did prior to VMI. In order to design a VMI-system dynamic model, first we need a conceptual model of VMI. Figure 3 and Figure 4 show the conceptual model of the traditional system dynamic supply chain and the VMI system dynamic supply chain respectively.

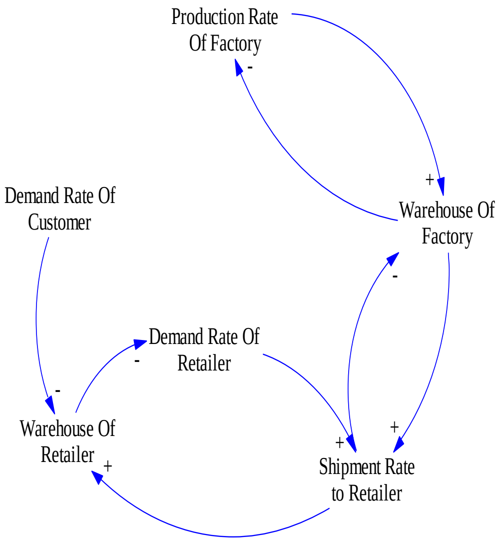

Figure3. The conceptual model of traditional system dynamics supply chain

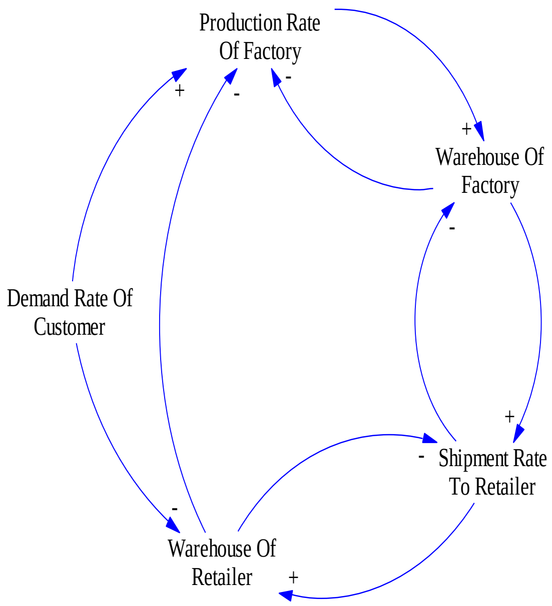

Figure4. The conceptual model of VMI system dynamics supply chain

In the above figures the difference between the traditional supply chain and the VMI supply chain in production rate of factory are depicted. Information from the warehouse of the retailer and the demand flow toward suppliers and production rate directly depends on the real demand of the end-customer.

4. System dynamics VMI-APIOBPCS model

After identify the conceptual system dynamics VMI-APIOBPCS model, we introduce a real VMI supply chain model with two suppliers and one retail channel. Table 2 shows the definition of the variables and parameters:

Table2. Variables and parameters of system dynamics VMI-APIOBPCS model

Variables and Parameters	
Tp	Production Lead-time
Ta	Demand rate of suppliers smooth time
Ti	Time to adjust inventory
Tw	Time to adjust WIP
G	Safety stock gain
ETQ	Economic transport quantity
VCON	Virtual consumption
VINV	Supplier inventory levels
WIP	Work-in-process inventory level
EINV	Inventory deviation

Table2. Continued

Variables and Parameters	
ORT	Order rate of supplier
AEWIP	Work-in-process inventory deviation regulation factor
AEINV	Deviation adjustment rate of system inventory
AVCON	Manufacturers forecasted consumption
TINV	System target inventory level
VCON	Virtual consumption
VINV	Supplier inventory levels
WIP	Work-in-process inventory level
EINV	Inventory deviation
ORT	Order rate of supplier
AEWIP	Work-in-process inventory deviation regulation factor
AEINV	Deviation adjustment rate of system inventory
AVCON	Manufacturers forecasted consumption
TINV	System target inventory level
TWIP	Target work-in-process inventory level
EWIP	Deviation of work-in-process inventory
CRT	Supplier completion rate
RINP	Inventory level of retailers
SRT	Delivering rate to retailers
DSS	Net changes in the distributors re order point
GIT	Goods in transit between echelons
RINV	Actual inventory level of retailers
L	Transportation time from suppliers to retailers
ACON	Demand rate of retailers after forecasting
SS	Safety inventory level
ART	Order arrival rate
ROP	Reorder-point of distributors
SHIP	Shipment rate to end consumer
Service level	Ratio between retailer inventory and customer demand

Based on (Disney and Towill, 2002) VMI-APIOBPCS model, Figure 5 introduces a system dynamics model to the supply chain with two suppliers and one retail channel.

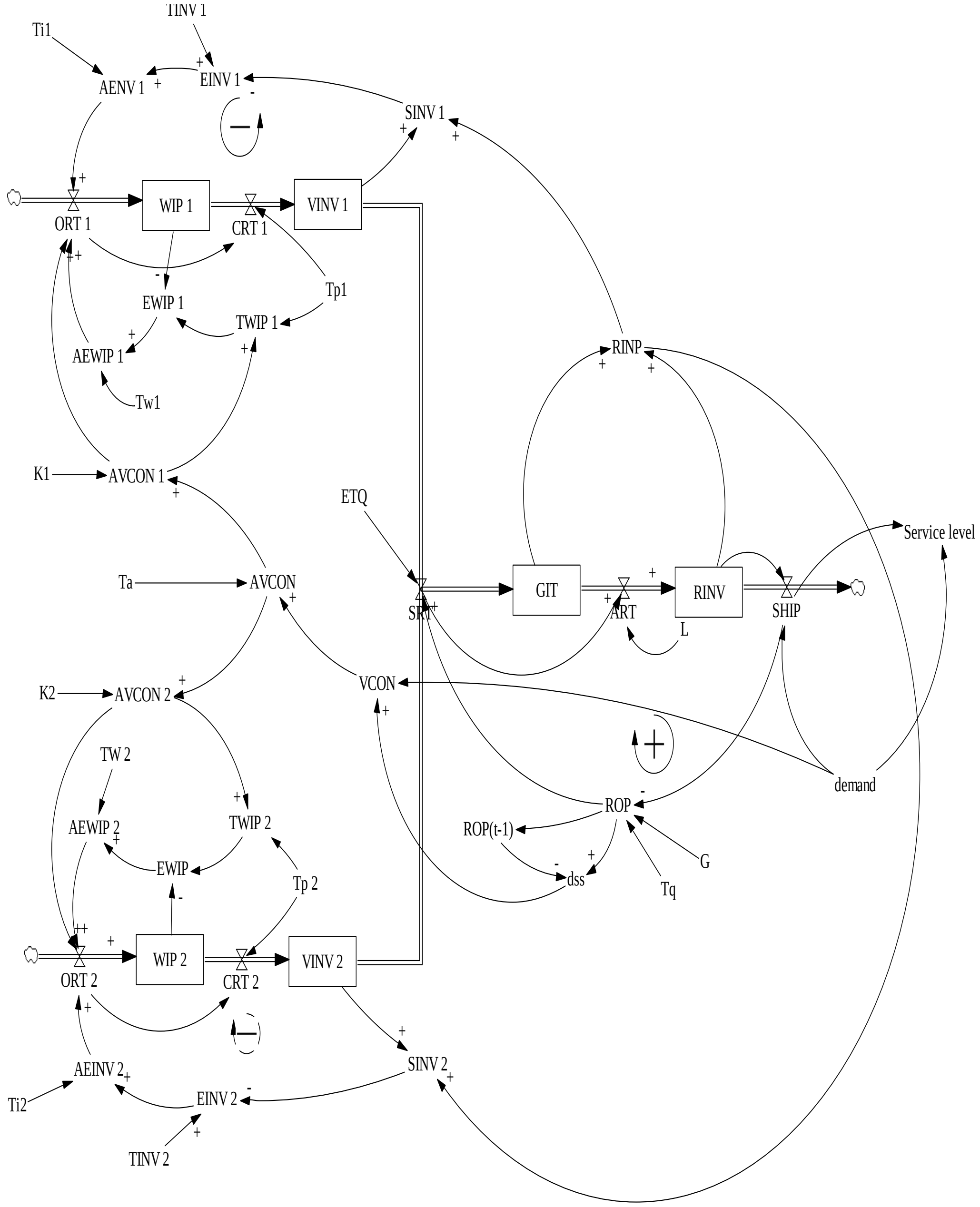

Figure5. VMI-APIOBPCS system dynamics model with two supplier and one retail channel

According to the assumptions of this model a common replenishment cycle is assumed for retailer. Under the VMI policy, the vendor makes decisions based on the inventory level, probabilistic demand, and other supply chain information. Also all products received by the retailer are transferred to the customers. The vendor is responsible for the ordering cost of the retailer and determines his/her economic order quantities. Therefore shortage in this system is possible. Retailer shares the inventory information and sales information with two suppliers dynamically and determines the customer service level. According to the fixed customer service level, suppliers choose quantity-based delivering model, which means that vehicle's shipping way is chosen in order to guarantee the economic efficiency of the transportation when the total inventory level is lower than the reorder-point. In general, inventory dynamic fluctuation is measured by the inventory rising time, adjustment time and overshoot. The productivity dynamic change is analyzed by the frequency response method. Below we illustrate the various parts of the model. The relational formulas in VMI-system dynamics model are based on (Disney and Towill, 2002) as given below:

- Manufacturers forecasted consumption:

$$\mathrm{AVCON}_t = \mathrm{AVCON}_{t-1} + \frac{\mathrm{VCON}_t - \mathrm{AVCON}_{t-1}}{1 + T_a}.$$

- Target work-in-process inventory level:

$$\mathrm{TWIP}_t = \mathrm{AVCON}_t \times T_P.$$

- Supplier actual WIP:

$$\mathrm{WIP}_t = \mathrm{WIP}_{t-1} + \mathrm{ORT}_t - \mathrm{CRT}_t.$$

- Manufacturers inventory levels:

$$\mathrm{VINV}_t = \mathrm{VINV}_{t-1} + \mathrm{CRT}_t - \mathrm{SRT}_t.$$

- Target inventory level:

$$\mathrm{TINV}_t = \mathrm{AVCON}_t \times T_s.$$

- System inventory level:

$$\mathrm{SINV}_t = \mathrm{VINV}_t + \mathrm{RINV}_t.$$

- Supplier completion rate:

$$\mathrm{CRT}_t = \mathrm{delay}\left\{\mathrm{ORT}_t, T_P\right\}.$$

- Order rate of supplier:

$$\mathrm{ORT}_t = \mathrm{AVCON}_t + \mathrm{AEINV}_t + \mathrm{AEWIP}_t.$$

▪ Work in process inventory deviation adjustment rate:

$$\mathrm{AEINV}_t = \frac{\mathrm{TINV}_t - \mathrm{SINV}_t}{T_i}.$$

▪ Suppliers can get customers' demand in time and obtain the actual total customer demand downstream through terminal customer data, including the terminal customer demand and changes of reorder-points of retailer:

$$\mathrm{ROP}_t = \mathrm{ROP}_{t-1} + \frac{\mathrm{SS}_t - \mathrm{ROP}_{t-1}}{1 + T_q}.$$

▪ Inventory levels of retailer

$$\mathrm{RINP}_t = \mathrm{RINV}_t + \mathrm{GIT}_t.$$

▪ Order arrival rate:

$$\mathrm{ART}_t = \mathrm{delay}\left\{\mathrm{SRT}_t, L\right\}.$$

▪ Net changes in the distributors re-order point:

$$\mathrm{dSS}_t = R_t - R_{t-1}$$

▪ Safety inventory setting of retailers:

$\mathrm{SS}_t = \mathrm{SHIP}_t \times \mathrm{G}$

▪ Virtual consumption:

$\mathrm{VCON}_t = \mathrm{SHIP}_t + \mathrm{dSS}_t$

▪ Suppliers can check the inventory level of retailer so that they can get the total supply chain inventory level which can optimize the total system inventory level:

$$\mathrm{SINV}_t = \mathrm{RINP}_t + \mathrm{VINV}_t.$$

5. Simulation Analysis

According to the designed VMI-APIOBPC system dynamics model, two different conditions consisting of before and after the use of VMI in the supply chain are investigated. We use Vensim-ple package, and run the test for 100 units of time (month) for this work. We consider a production subsystem parameters settings consisting of T_i, T_W, T_a, T_P and the detail simulation assumption referring to (Disney and Towill, 2002). Other parameters come from real data of the supply chain. Also for capturing the Bullwhip effect of supply chain we consider demand as the RANDOM NORMAL (0, 10, 5, 20, 1) (Figure 6). We set the initial value of inventory level, WIP and service level to zero.

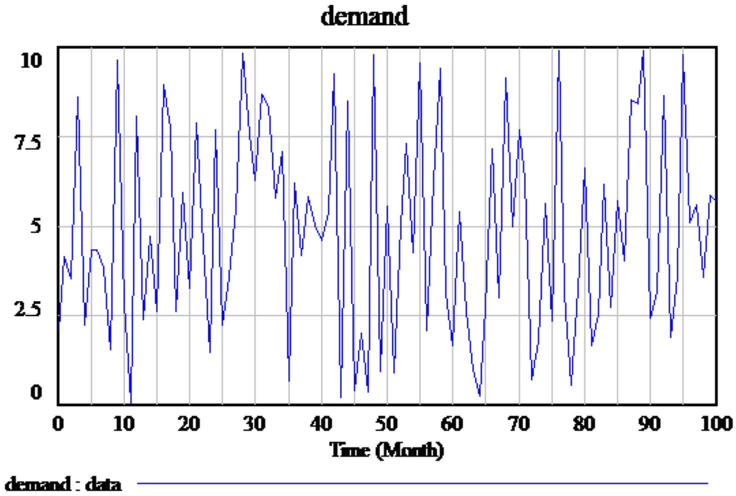

Figure6. Random demand of end-customer

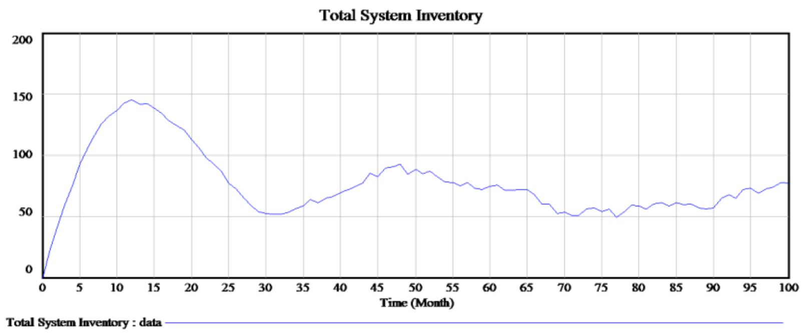

Figure7. Total system inventory of the VMI-APIOBPCS system dynamics model

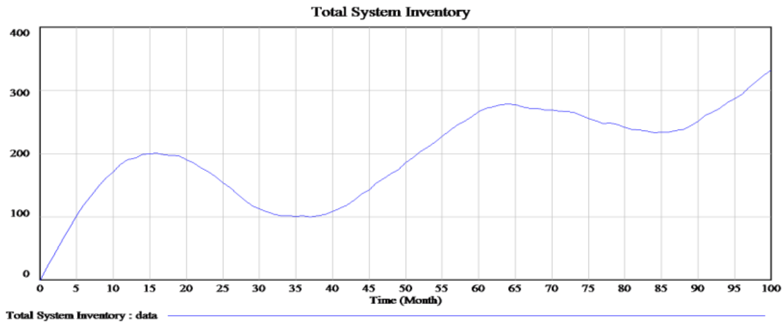

Figure8. Total system inventory of the traditional supply chain

As shown in Figure 7 and Figure 8, when VMI is introduced into the supply chain, the Bullwhip effect becomes smoother and the variance in Figure 7 is less than Figure 8. Also inventory level and fluctuations of total inventory level is reduced. Here we don't need to calculate inventory cost. We compare models with respect to their inventory level. This is because usually less fluctuation in inventory level leads to reducing inventory cost in supply chain.

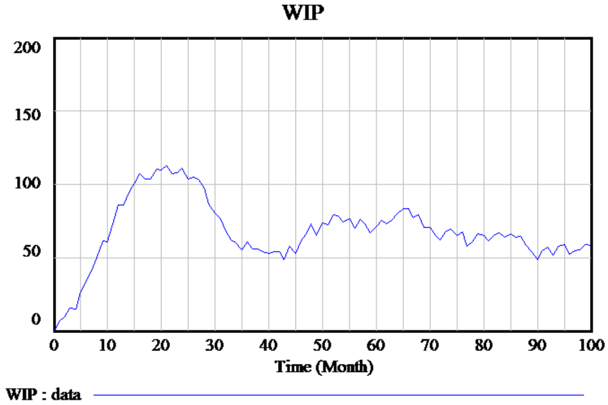

Figure9. WIP of the VMI-APIOBPCS system dynamics model

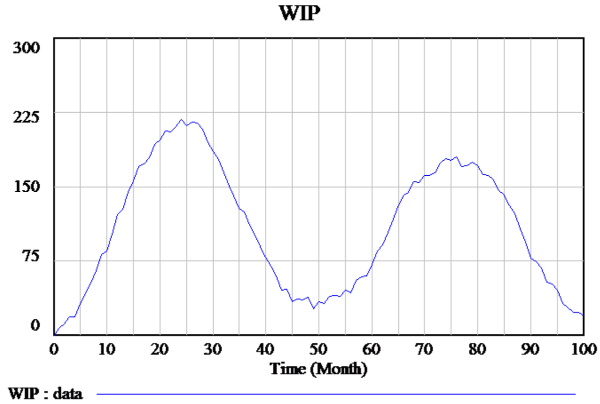

Figure10. WIP of the traditional supply chain

After introducing VMI, the work in process of suppliers is effectively smoothed and reduced (Figure 9 and Figure 10).

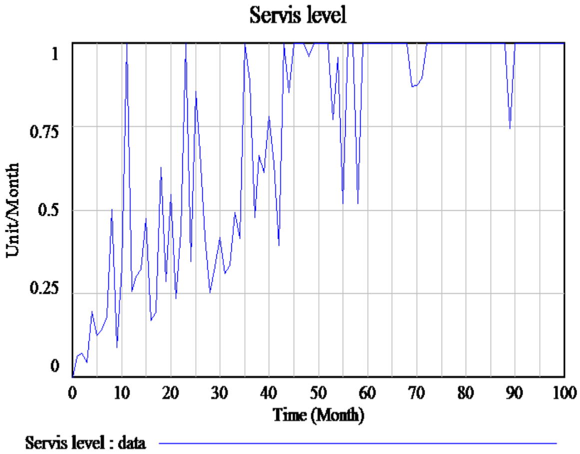

Figure11. Service level of the VMI-APIOBPCS system dynamics model

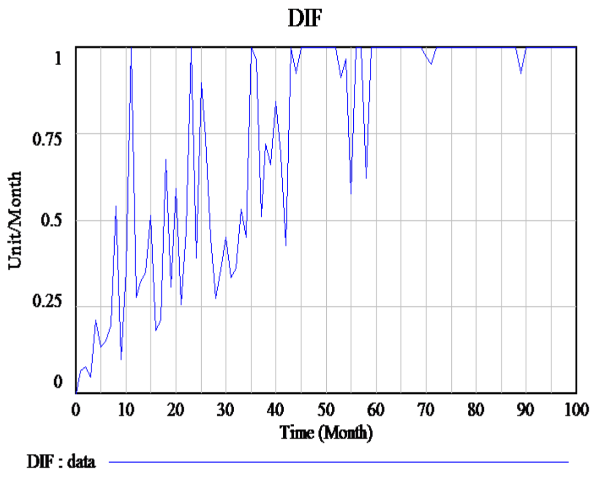

Figure12. Service level of the traditional supply

Service level of the retailer is defined as the ratio between the retailers' inventory level and customers demand. The high fluctuations in the beginning of the simulation in both figures are related to warming up of the system. As Figure 11 and Figure 12 show, after the warm-up, both systems service level fluctuations become smoother. The service level in the VMI system is slightly less than the traditional system (because of the huge level of inventory in traditional system). The average service level in the traditional system is 56%, which is less than the level in the VMI system with 52%.

6. Conclusion

This work introduced a VMI system in the supply chain under the system dynamics approach based on VMI-APIOBPCS model. The system performance of the VMI integrated supply chain under random demand was considered. The simulation studies investigated three basic metrics: Bullwhip effect, total inventory amount and end-customer service level. The simulations show that the Bullwhip effect became smoother and WIP and total inventory significantly reduced under new system. However, the service level of VMI system became slightly less than the traditional supply chain (56% versus 52%). This work can be used in supply chain management to easily select the optimal policy and capture the effect of the fluctuations of the downstream on the upstream and vice versa.

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