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VMI and international Supply Chains: A Case of Fastener Industry

Abstract

Vendor Management Inventory (VMI) is one of the most widely discussed partnering initiatives for improving supply chain efficiency. Also known as continuing replenishment or supplier managed inventory, VMI became popular in mid 80's pioneered by the famous case of Wall-Mart and P&G. Through information sharing and procurement collaboration, VMI allows suppliers to manage inventory for their customers, thus streamlining the entire supply chain process and leading to cost reduction for the overall supply chain. VMI suits best for high volume and long product-life-cycle commodities, and fastener falls into this category. VMI was first implemented in the fastener industry in mid 90's in USA, and later was applied in Taiwan by QST International Corp.

Considering the dynamics involved in international fastener supply chain, a case study of focal company, QST was conducted in this article. The purpose is to compare VMI with the traditional international inventory management practice by simulating various scenario designs. Under a preset safety stock level, this study first examined supply chain performances under four different demand patterns, then performances were assessed by a series of surge demand changes, and final simulations were made with different transaction terms that are commonly used in international trade.

In fastener supply chain, obsolescence and line shutdown are the two major risks. Balancing them, obsolescence caused by high inventory and line shutdown from low stock, is always the dilemma in inventory management. Consequently, this article selects inventory carrying cost, inventory turnover rate and order fulfillment rate as the key performance indexes (KPI) for its comparison criteria.

The findings of this study indicate that VMI is superior to the traditional model for the customer as well as for the entire supply chain. This systematic modeling approach provides fastener players with feasible methodology in solving real world VMI problems.

Keywords: vendor managed inventory, fastener supply chain, system dynamics

1. Introduction

Vender Managed Inventory (VMI) was first developed in mid-80's and becomes an emerging operational paradigm (Simchi-Levi D.et al. 2001). By sharing actual sales or usage information with its vendors, a customer can out-source its inventory management responsibility to its vendors. Through information sharing and process collaboration among supply chain parties, inventory allocation can be optimized across the boundaries between enterprises, leading to cost reduction, quick response, higher operational efficiency and customers' satisfaction. Many successful cases have been reported, such as Wall-Mart/P&G/Johnson & Johnson in USA, and Nestle/Carrefour in Taiwan.

Wang(1998) stated that VMI suits most for commodities with the following characteristics; 1) long product life cycle; 2) predictable demand pattern; 3) non-key component/product; 4) standard product. In Taiwan, VMI model has been pioneered by IT industry and then expanded to others. However, wide research has not been made available. Fastener, i.e. nuts, bolts, screws and rivets, etc., is considered as a typical c-class commodity with relatively long product life cycle, and is ideal for VMI application.

The annual output of Taiwan fastener industry is around $2 billions with 85% exported worldwide, which represents over 30% of the global fastener trade and is rated as world number one. During the past few years, Taiwan fastener industry has been under serious competition pressure, driven mainly by impacts from globalization, Internet development and VMI business model. Facing threats imposed by these impacts, fastener industry now is developing strategies towards a business model of global logistics operation to meet the demand from users, especially those led by multi-national OEM customers.

In mid 90's, VMI model was first introduced to US fastener industry. Under global competition, OEM fastener users were obliged to focus on their core business and outsource their non-core activities and operations to gain more effective competence. For their fastener supply, OEM users adopted reduction on the number of vendor and global sourcing strategies to reduce their total acquisition cost. The trend of global sourcing from developed countries did help Taiwan to cross over the geographical barriers of location and supply relationship. However, due to the complicated operations involved in VMI business model, the development of VMI operation, especially an international VMI opeation, is still hindered.

The objective of this study is to build an operational model of VMI, by which Taiwan fastener industry can understand VMI better and then implement international VMI effectively. The model and methodology presented in this research can serve as a decision-supporting tool and upgrade the Taiwan Fastener industry.

2. Literature Review

2.1.Vendor Managed Inventory

Definitions of VMI varied on different usages, and this study lists a few typical definitions in Table 1. There are three major characteristics; (1) VMI manages the inventory of down-steam customer. (2) VMI is a cross-enterprise process. (3) VMI is about real-time information exchange.

Table-1 Definitions of VMI

Definitions of VMI	Scholar
Vendor receives point of sales (POS) or inventory information from retailer and use for its inventory management and replenishment decision.	Betts (1994)
A process, based on the demand information provided by the distributor, vendor generates purchase order for the distributor.	Hall (1998)
Vendor is requested to be responsible for managing product supply and inventory of the retailer.	Yossi (1998)
An inventory management solution, by controlling sales and inventory information, uses for market demand forecast and inventory replenishment.	Chai, (1998)
Buyer shares its inventory level information with its vendor so that the vendor can manage the inventory located at customer's end.	Lin, (2000)
Vendor monitors buyer's inventory level and periodically executes inventory replenishment decisions including order quantity, delivery time, etc.	Waller, Johnson & Davis (2001)

Most of the existing VMI studies apply qualitative approach to describe the general behavior and give direction suggestion for future study. A few research studies indicate VMI can drive cost down with both short and long term benefit. Three major aspects are outlined among all VMI researches in Table 2, (a) Conceptual introduction. (b) Successful case study. (c) Mathematic models.

Table-2 VMI Research Summary

Research Method	Research Subject	Research Source
Conceptual Introduction	Introducing concepts, key success factors (KSF's), limitations, and operational processes of VMI. Wang, Y.W. (1998) summarized those KSF's of VMI implementation.	Chai, (1998), Wang, (1998), Stratman(1997), Lamb(1997), Cottrill(1998), Williams(2000)
Successful Case Study	Introducing actual VMI application and evaluate performance of focal enterprises. McCrea (2002) presented a case study in fastener industry and gives its 6 KSF's.	Nolan(1997), Nolan(1998), Holmstrom(1998), Haavik(2000), Yen, (2001), McCrea(2002)
Mathematic Model	Constructing mathatical models to illustrate the cost reductions conveyed by VMI. Disney (2002) simulated the entire supply chain operations and interactions among them.	Waller(1999), Chou, (2001), Chaouch(2001), CHENG, (2000), Dong(2001), Disney(2002)

Disney (2002), by integrating the APIOBPCS [1] theory and VMI model, successfully constructed a generic simulation system for all VMI applications (Figure 1). It illustrates the scenarios of the entire supply chain and provides a clear picture of why the organizational performance is improved. By comparing each inventory level with the respective target level, the VMI mechanism can make a series of production and replenishment decisions to achieve smooth, uninterrupted streamlined material flow over the entire supply chain.

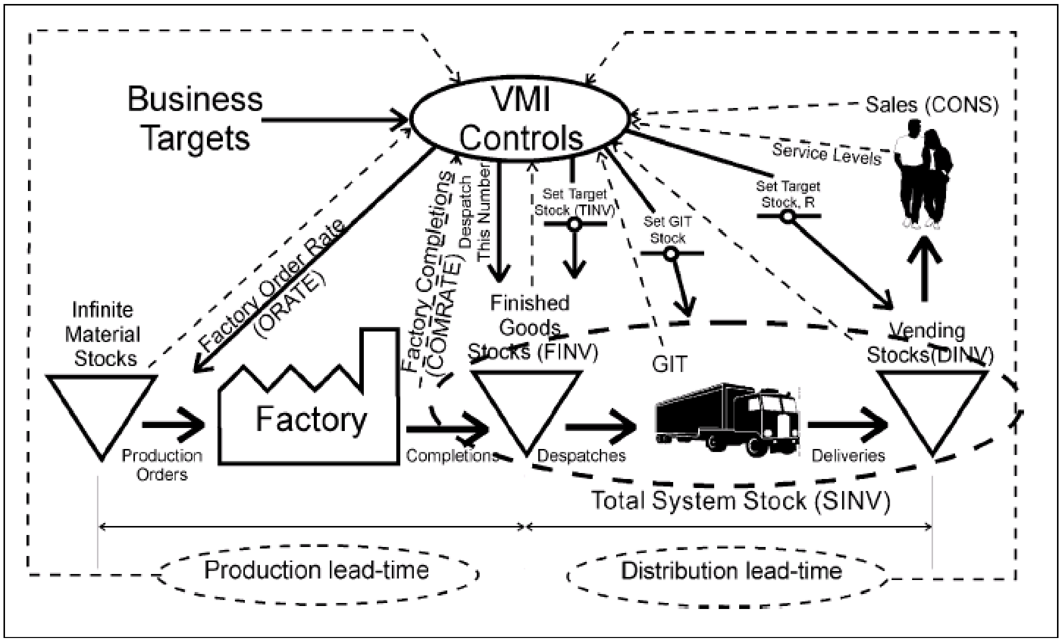

Figure-1: VMI Scenarios (Disney, 2002)

The scope and services of VMI vary from different location and application in the international supply chain in practice. An overseas vendor usually offers remote VMI services and a local vendor provides on-site VMI services. From a global logistics point of view, to optimize its service to the OEM fastener end user, on-site VMI provider should locate its service as close as possible to the user's point of assembly (POA), and remote VMI provider (overseas vendor) should manage to reduce (optimize) total supply chain inventory, provide just-in-time delivery and streamline the material flow.

Though different practices on different segments, the fundamental principle behind various form of VMI operation is still the same concept of information sharing and process collaboration. Only by integrating both the on-site and remote VMI together, pumping materials through the overseas vendors to the end user's assembly lines, an end-to-end seamless and complete logistics service will then be available for the end user. The mission of "serving the end customer" will then be possible.

[1] APIOBPCS: Automatic Pipeline Inventory and Order Based Production Control System Naim & Towill (1995). A mathematic methodology designed for production and distribution scheduling.

2.2. Supply Chain Performance Measurement

This study adopted quantitative indicators in measuring supply chain performance. These indicators are selected based on performance among different segments in supply chain. Performance measures of Total Logistics Cost (TLC), customer satisfaction and supply chain flexibility are chosen and measured respectively on supply chain parties, i.e. customer, distributor, manufacturer and total supply chain.

Total Logistics Cost has always been the key performance indicators of a supply chain. It consists of inventory-carrying cost, transportation cost, production cost, storage cost, ordering cost and information handling cost, etc. Among these costs, storage, transportation and inventory carrying cost have the slack for cost reduction, and inventory carrying cost is most promising candidate for further cost reduction (Barr, 1995).

From Stock & Lambert (2001), customer satisfaction is composed of on-time delivery, claim response time, advanced delivery notice, product quality and pricing, etc. Regardless of the industry type, on-time delivery is always the most important indicator for customer satisfaction.

Supply chain flexibility represents the capability to respond and adapt to uncertainties in the supply chain environment. For an international supply chain as this study focused, geographical distance and duration of supply chain create many unexpected incidents and uncertainties, especially those created by country boundaries crossing, long transaction processing and information delay make flexibility even more important in measuring an international supply chain.

Table-3 Supply Chain Key Performance Indicators (KPI)

KPI's	Customer	Distributor	Manufacturer	Total Supply Chain
Logistics Costs	Finished Product, WIP	Material Handling, Distribution Cost, Inventory Turns	Production Cost	Order Processing, Sales Cost, Return handling
Customer Satisfactio	Customer Satisfaction, Quality of Order Handling	On-time Delivery	Product Quality	
Flexibility	Demand Responsiveness	Distribution Flexibility	Production Flexibility	Quick Response to Market Demands
Others	Order Processing Time	Material Procurement Time	Manufacturing Lead Time, Manufacturing Technology	Time-to-cash, Sales Growth, Market Share, ROI

Sources	Ghalayini et al (1997), Beamon (1998), Etrovic et al.(1998), Tan et al.(1998), Beamon (1999), Brewer & Speh (2000), Sabri & Beamon (2000), Lambert & Pohlen (2001), TaiWeb (2001), SCC (2002), Tan (2002)

2.3. System Dynamics

Due to isolated information and decision made with limited sources, most of the decision made among parties in the supply chain are only beneficial to one or a few, not optimal to the whole supply chain. In addition to the poor information sharing causing the deficiency of decision making, the existing forecasting and management techniques usually deal with the complexity of business operation only, not the dynamics of the whole supply chain system. Failing to incorporating the dynamics of system behavior into decision making processes will not resolve the supply chain management problem thoroughly（Senge, 1990）.

In 1956, Jay W. Forrester (at Slone, MIT) first marriage the concept of information feedback with business administration systems and develop the System Dynamics, which is one of the best methodologies in solving system problems with dynamic complexity. It leads us to view our world in a systematic way and reach for a better decision.

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 itself. 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).

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. For VMI service provider, a systematic tool can be used to plan and prepare the solution against the odds of uncertainty.

2.4. Summary

Past research on VMI and supply chain management have not deeply explored into the dynamic behaviors between supply chain parties, key performance drivers and related quantitative analysis. For fastener industry, little study has been made available for VMI implementation, especially for a remote VMI service provided from Taiwan.

Among all the research methodologies, System Dynamics is a mature tool integrated theories of control, system, information, decision-making and computer simulation, and is ideal for the study of complicated non-linear system with multi-variables and time-varying phases. This system dynamics approach can reveal the structure and behaviors of VMI and also provide a common ground for VMI policy design through simulation experiments.

When it comes to supply chain performance measurement, key performance indicators (KPI) shall be selected based on the specific emphasis of the focal industry.

For fastener supply chain inventory management, the two major risks are obsolescence and line shut down, and performance is judged by minimizing both risks at the same time. High safety stock policy is commonly adopted in fastener industry to eliminate the risk of line shut down caused by stock-out. However, high inventory policy induces automatically the risk of obsolescence, especially in the case of a short product life cycle or frequent engineering change, which are all part of current product design trend. This study selects inventory carrying cost and inventory turnover as the KPI's in measuring the performance of inventory control, and order fulfillment ratio is chosen to reflect the performance in customer satisfaction.

The KPI's and supply chain parties measured in this study are shown in Table 4. Where, manufacturer implies the fastener maker located overseas (Taiwan), vendor means the remote VMI provider in Taiwan (in this study – QST) and customer is either a local fastener end user (purchase fastener for its own product assembly lines) or a local fastener re-seller (purchase fastener and re-sell to an end user). Total supply chain means the aggregate of all the three parties mentioned above.

Table-4 Selected KPI's of International Fastener Supply Chain

<table>
<tr><th rowspan="2">Performance Aspects</th><th rowspan="2">Key Performance Indicators (KPI's)</th><th colspan="4">Supply Chain Parties Measured</th></tr>
<tr><th>Manufacturer</th><th>Vendor</th><th>Customer</th><th>Total Supply Chain</th></tr>
<tr><td rowspan="2">Inventory Control</td><td>Inventory Carrying Cost</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Inventory Turnover</td><td>●</td><td>●</td><td>●</td><td>●</td></tr>
<tr><td>Customer Satisfaction</td><td>Order Fulfillment Ratio</td><td></td><td></td><td colspan="2">●</td></tr>
</table>

3. Modelling

Started with a briefing of the focal company and its actual operation of remote VMI, both of the conventional customer managed inventory (CMI) model and the VMI model are then introduced. Through the construction of system dynamics models, the system structure and dynamic behaviors of both CMI and VMI models are studied and compared.

3.1. The focal company – QST, Taiwan

QST International Corporation (QST) is the largest fastener service company in Taiwan focused on OEM quality fastener export and related services. In response to the demand of the market, QST has been providing remote VMI programs to its overseas customers since 1997. QST's remote VMI is outlined as follows,

- Multi-countries: Remote VMI is served for customers located in USA and France.
- Multi-customers: Total 7 customers are served with remote VMI.
- Multi-warehouses: Total 10 overseas warehouses are involved.
- Multi-manufactures: Total 25 manufacturers (located in Taiwan) are involved.
- Multi-parts: A total of 600 SKU’s are covered in QST’s remote VMI program.
- Business Scale: Annual VMI sales is 5 millions US Dollars (2002).

Under QST’s remote VMI program, inventory located in those 10 overseas warehouses can be divided into two categories of different ownership;

A. Consignment Stock: Inventory ownership belongs to and managed by QST. Based on consignment transaction terms, ownership is transferred to the customer only upon inventory is drawn by the customer from the warehouse.

B. Non-consignment Stock: Ownership belongs to the customer but managed by QST. Under common international transaction terms (FOB, C&F, CIF), product ownership is transferd from QST to the customer on the preset terms. Even QST does not take the ownership, customers delegate inventory management responsibility to QST under a preset VMI agreement.

With several years successful implementation of remote VMI, QST faced a bottleneck in expanding this model. There are three major barriers;

A. QST’s supply base is composed of 300 vendors, mostly small scale, located in Taiwan and China. Most of the vendors lack in inventory management resources and capability to support QST’s remote VMI operation.

B. To govern the complicated collaborations and responsibilities between supply chain parties, a VMI agreement/contract is commonly used. Without a ready simulation tool to evaluate VMI performance and risk before launching, it is difficult and not effective in the processes of agreement negotiating and decision-making.

C. Frequent, or real-time, data exchange between supply chain parties and replenishment calculations are required for VMI operation. The model cannot be properly expanded without the support of automated software system, which is not commercially available in Taiwan.

In addition to the development of VMI application software for process automation, a simple simulation model is required to illustrate and promote VMI business model, to evaluate the risk and performance before deployment. This study therefore constructed system dynamics models for both CMI and VMI systems and performance evaluating subsystems respectively to measure and compare the behavior of the two models.

3.2. Conventional Customer Managed Inventory (CMI) Model

Conventional inventory management model is described in Figure 2. The Stock and Flow Map simulate the physical material flow and inventory management decision (information flow) model of a conventional international business transaction – the customer purchases fastener from an overseas (Taiwan) vendor.

The CMI model comprises two warehouses, the first one is actually a virtual warehouse containing the aggregated inventory of all the un-delivered orders placed with the vendor, including back orders, raw material, WIP, finished product and product in-transit. The aggregated inventory (Order_In_Process_CMI) increases with customer purchase (Customer_Order_Rate) and decreases with customer order receipt (Receiving_Rate_CMI). The second warehouse is the physical warehouse located at the customer site. The customer inventory (Customer_Inventory_CMI) increases with customer order receipt and decreases with customer shipment (Customer_Shipment_Rate) to its assembly line or its customer.

The actions of customer shipment depend on its usage rate (Usage_Rate) as well as inventory availability at customer warehouse. When customer inventory is less than the usage, the customer shipment upper limit equals to quantity of customer inventory. The Order Fulfillment Ratio (Order_Fulfillment_Ratio_CMI), the ratio of actual shipment over required usage, is commonly used as the indicator for measuring customer satisfaction.

(Inventory_Adjustment_CMI) represents the difference between the actual and desired inventory at customer warehouse. This inventory adjustment plus the estimated usage becomes the desired production quantity (Desired_Production_CMI).

The desired production quantity deducts not-delivered orders quantity gives the data of customer’s desired order rate (Desired_Order_Rate_CMI). To meet the common practice of economical ordering quantity required by international purchasing and periodic batch ordering in fastener industry, this study modified the desired order rate over a fixed ordering period (Order_Period_CMI) into periodic ordering rate (Customer_Order_Rate).

In short, customers dominate the entire inventory management process (customer managed inventory), they calculate replenishment quantity based on current inventory levels and estimated usage, then place order with their overseas vendors on a periodic basis.

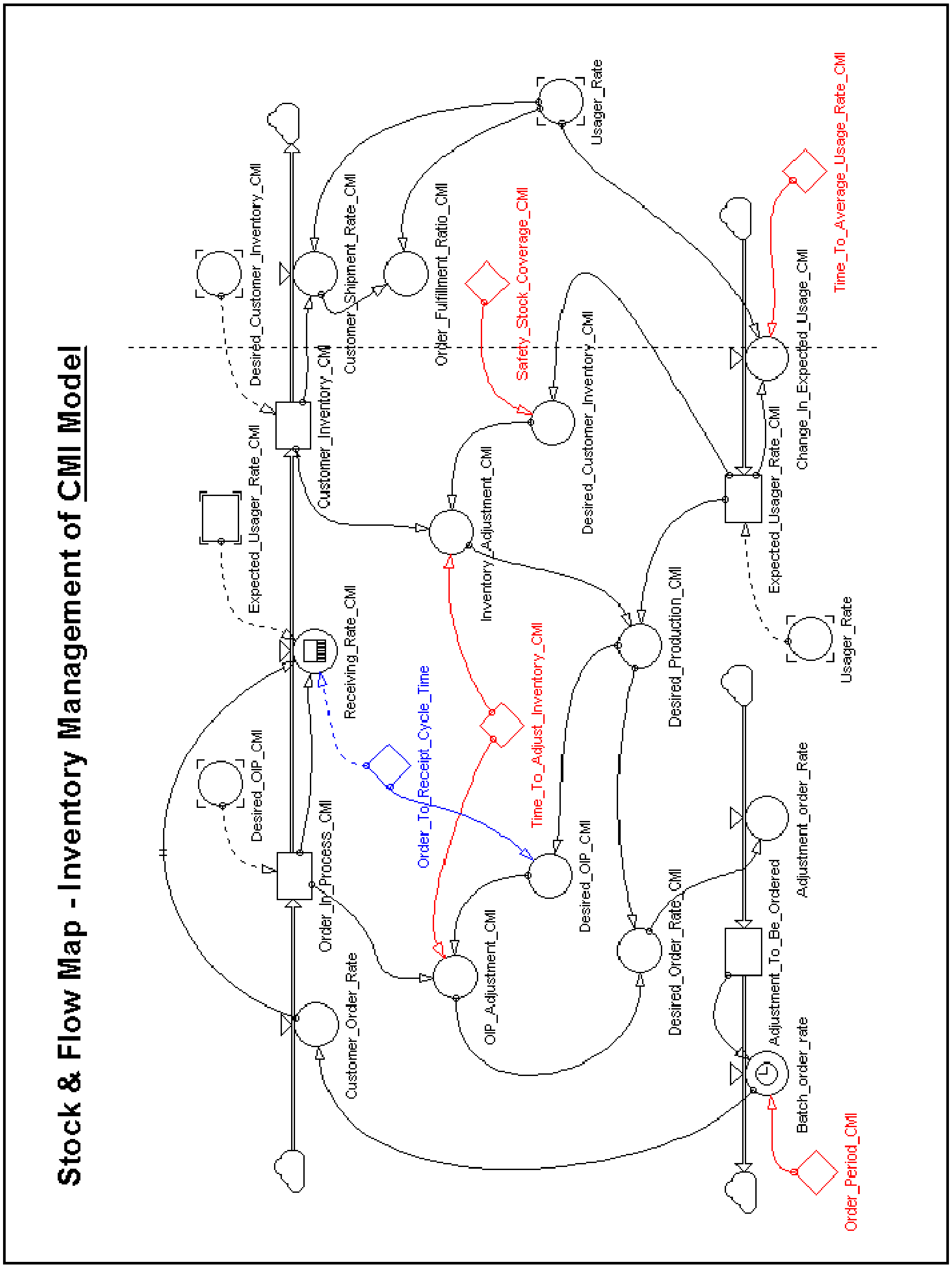

Figure-2 Stock and Flow Map of CMI Inventory Management Model

3.3. Vendor Managed Inventory (VMI) Model

Figure 3 illustrates the inventory management system of VMI model. It simulates the remote VMI operations; the customer provides its estimated annual usage and delegates the inventory management responsibility to its overseas vendor by signing a long term VMI agreement specifying targeted inventory levels and related replenishment details.

Under the VMI model, the aggregated un-delivered inventory as described in CMI model has been detached into its three original components; i.e. order in-process inventory located at the manufacturer (Order_In_Process_VMI), finished inventory located at the vendor (Vendor_Inventory_VMI) and shipment in-transit (Transit_Inventory_VMI). Order in-process inventory also includes back orders, raw material and WIP; vendor inventory indicates the finished stock kept by the vendor (VMI provider); transit inventory includes all the shipments in-transit, on the water and in-land transportation, between the vendor and the customer.

In light of physical and virtual warehouse concept, these three inventories are then converted into three warehouses; manufacturing, vendor and in-transit warehouse. By adding customer warehouse, VMI model is composed of four warehouses comparing with two in CMI model.

Along with the increase of warehouse number from two to four, gates number increases from three to five under VMI model. The first additional gate is the out-flow from the manufacturing warehouse (Production_Rate_VMI) defined as the third order material delay of (Order_Rate) to reflect real world production output delay. The second additional gate between vendor inventory and shipment in-transit is the out-flow from the vendor warehouse (Vendor_Shipment_Rate_VMI).

Besides the differences in warehouse and gate, the Stock and Flow Map of VMI model is same as that of CMI model. In summary, through information exchange, the vendor receives customer shipment rate and estimated usage rate information from its customer. By comparing the actual and desired aggregated inventory quantity located in transit and customer warehouse, replenishment decisions can be made accordingly. Acting as an intermediation in the supply chain, the vendor warehouse provides a material flow adjustment mechanism, striking a balance in which the flow rate difference between the manufacturing rate and usage rate is reduced.

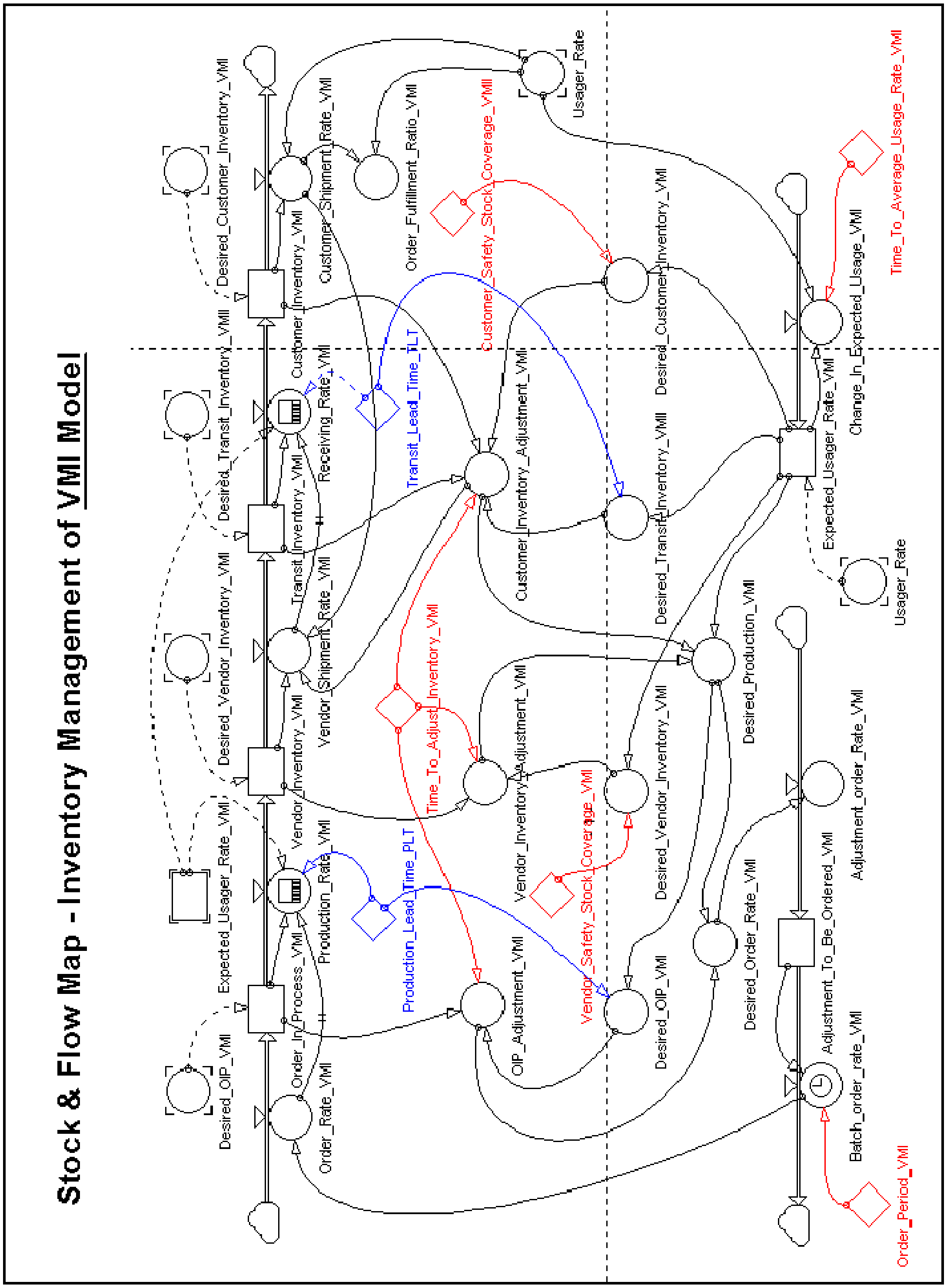

Figure-3 Stock and Flow Map of VMI Inventory Management Model

3.4. Supply Chain Performance Measurement

After models being built, the next step is to measure the performances of both CMI and VMI inventory systems. Among the three KPI's selected, Order Fulfillment Ratio can be measured directly from the inventory models. However, in order to derive the inventory turnover and carrying cost indicators, subsystems for performance evaluation must be further developed. Formulas used in the subsystems for the three KPI's are outlined as below;

- Inventory Carrying Cost = Inventory Cost * Carrying Cost Factor
  = (Inventory Quantity * Acquired Price) * Carrying Cost Factor
- Inventory Turnover = Inventory Cost / Sales
- Order Fulfillment Ratio = (Shipment Quantity / Customer Order Quantity) * 100%

For the performance evaluating subsystems, the major difference between CMI and VMI models is in the vendor inventory. In CMI model, the vendor carries no inventory other than shipment in-transit under a C&F or CIF international trading terms. In the case of VMI, the vendor's assignment is to build up an intermediate material flow adjusting mechanism; hence vender inventory is a must.

4. Model Simulation and Discussion

Common practices and terms in the international fastener supply chain operation are considered and key business dynamics are selected and organized for scenario design. Dynamic simulations are applied to those constructed models under a series of designed scenarios so that performance of both CMI and VMI models can be evaluated and compared.

4.1. Scenario Design

As illustrated in Figure 4, the greater of the demand fluctuation implies the greater risk of shut down. From the aspect of transactional terms, risk of obsolescence varies between different terms and conditions.

To compare the performances of CMI and VMI models and to search for optimum inventory under VMI model, three scenarios are designed for further simulations under these key business dynamics.

Scenario #1 : Model Behavior under Fixed Safety Stock

Scenario #2 : Inventory Optimization under Step Pattern Demand

Scenario #3 : Obsolescence Minimization under Transaction Dynamics

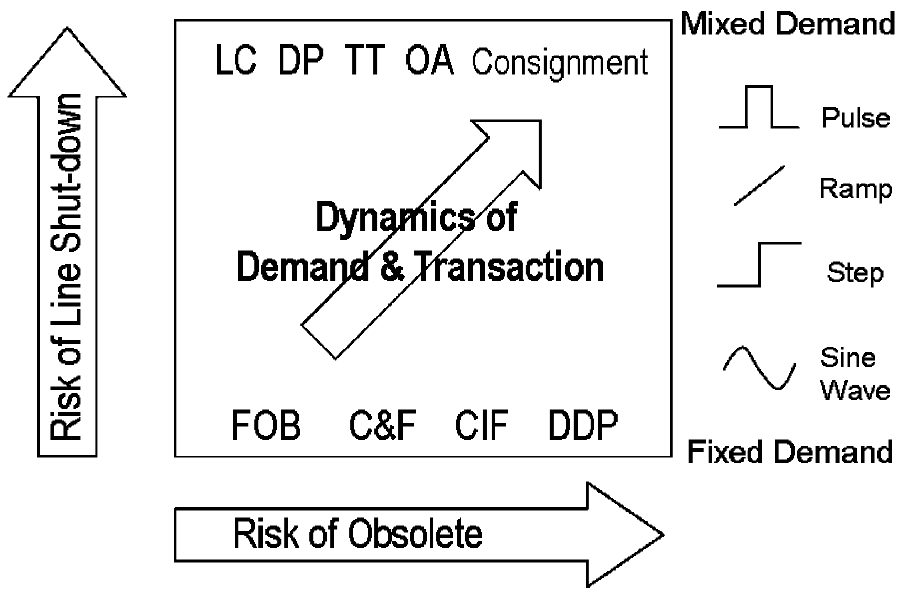

Figure-4 Business Dynamics of International Fastener Supply Chain

1. **Model Behavior under Fixed Safety Stock:** In this scenario, both CMI and VMI models operate under a preset fixed safety stock level and a variety of demand patterns are then applied to both models to measure and record the dynamic responses and system behaviors of each supply chain party.

2. **Inventory Optimization under Step Pattern Demand:** Among various demand patterns, a step increase of demand creates the most impact to inventory management, also can test both the demand level following and response time characteristics of the dynamic system. Thus, this scenario is designed to focus on inventory optimization under a sequence of demand step increases from 20% to 50% for both CMI and VMI models.

3. **Obsolescence Minimization under Transaction Dynamics:** Risk of obsolescence depends heavily on the inventory ownership, which is governed by the transaction terms between the supply chain parties. For an overseas VMI provider, consignment term represents the highest degree of ownership for the inventory. All other common transactional terms, FOB, C&F and CIF, etc., are classified as non-consignment terms. This scenario is designed to study obsolescence minimization, for the overseas vendor, under consignment and non-consignment terms for both CMI and VMI models.

4.2. Simulation Results

The simulation results of the scenarios are as follows;

4.2.1 Scenario #1 (Model Behavior under Fixed Safety Stock)

The performance of the international fastener supply chain parties, the customer, vendor and manufacturer (MFGR), in both CMI and VMI models are measured respectively and compared. A total of four different demand patterns are applied to simulate real world demand dynamics.

- Fixed Demand Pattern: Usage is a fixed constant, stable demand.
- Sin Wave Demand Pattern: Usage goes up and down periodically simulating a seasonal demand variation.
- Ramp Demand Pattern: Usage increases at a fixed ramping slope simulating a growing demand.
- Pulse Demand Pattern: Usage surges for a short period and then falls back simulating a burst of demand like Christmas and new year holidays.

Table-5 Simulation Results under Fixed Safety Stock Scenario

Supply Chain Parties	Key Performance Indicators	Demand Patterns							
		Fixed		Sin Wave		Ramp		Pulse	
		CMI	VMI	CMI	VMI	CMI	VMI	CMI	VMI
Customer	Order Fulfillment Ratio (%)	100	100	97.7	100	100	100	100	100
	Inventory-Carrying Cost (NT$)	954	480	1026	431	1239	638	970	486
	Inventory Turnover (%)	10.6	20.8	19.2	24.3	12.3	23.4	11.2	21.3
Vendor	Inventory-Carrying Cost (NT$)	272	674	273	736	426	908	276	686
	Inventory Turnover (%)	29.5	11.9	36.4	13.1	29.0	13.6	29.8	12.1
MFGR	Inventory-Carrying Cost (NT$)	272	272	273	274	426	427	276	276
	Inventory Turnover (%)	25.1	25.2	31	27.2	24.7	25	25.3	25.3
Total Supply Chain	Order Fulfillment Ratio (%)	100	100	97.7	100	100	100	100	100
	Inventory-Carrying Cost (NT$)	1498	1426	1572	1441	2096	1974	1522	1448
	Inventory Turnover (%)	17.4	17.4	16.8	18.1	19.1	19.2	17.5	17.5

As listed in Table 5, with the fixed safety stock scenario designed, the performances of VMI model is superior to that of CMI. Customer inventory can be reduced by 50%, however, the vendor is paying the price by carrying much higher stock and inventory management responsibility. This can be offset by further inventory optimization plus negotiating a gain-sharing VMI agreement with the customer.

Besides, throughout the simulation process, much smoother and quicker responses were observed on VMI model. It indicates that by adding an intermediate material flow adjusting mechanism and reallocating safety stock towards the up-steam of the supply chain is going to improve the inventory management performances.

4.2.2. Scenario #2 (Inventory Optimization under Step Demand Pattern)

Meeting the goal of 100% order fulfillment, no stock out, optimized inventory for both CMI and VMI models were simulated with a series of demand step increase from 20% to 50%. Simulation results are listed below.

Table-6 Simulation Results under Step Demand Pattern Scenario

Key Performance Indicators	**Demand Step Increase**	**Customer**		**Vendor**		**Manufacturer**		**Supply Chain**	
		CMI	**VMI**	**CMI**	**VMI**	**CMI**	**VMI**	**CMI**	**VMI**
Inventory Carrying Cost (NT$)	**20%**	609	170	314	579	314	314	1238	1063
	30%	841	221	336	713	336	335	1513	1269
	40%	1095	277	358	855	358	357	1810	1488
	50%	1369	337	380	1005	380	379	2129	1720
Inventory Turnover (%)	**20%**	21.4	69.8	29.5	16.8	25.1	25.3	25.0	27.1
	30%	16.8	58.1	29.5	14.1	25.1	25.3	21.6	24.2
	40%	14.0	50.2	29.5	12.6	25.0	25.2	19.1	22.0
	50%	12.1	44.4	29.5	11.4	25.0	25.2	17.1	20.2

From Table-6, after adjusting safety stocks to the optimum values, VMI model demonstrated a similar finding as the previous scenario simulation, but the inventory reduction is much more significant. Total supply chain inventory is reduced up to 19%; customer inventory is reduced up to 75%; manufacturer inventory stays the same. And again, the vendor alone contributes the entire performance improvement; vendor inventory of VMI model is doubled than that of CMI.

4.2.3. Scenario #3 (Obsolescence Minimization under Transactional Dynamics)

Maximum risk of obsolescence equals to high ownership of inventory. Under consignment term, supply chain inventories located in the vendor warehouse, in-transit and customer warehouse(s) are all managed and carried by the overseas vendor. In fastener industry, to minimize inventory management cost, the common practice is to set up a fixed safety stock level, say 3 months, for each line item. From the study in section 4.2.2 above, optimum safety stock levels for expected demand patterns can be derived. Vendor’s inventory of maximum obsolescence under both fixed and optimum safety stock policies is simulated by applying a series of step demand increase to both CMI and VMI models. The result is shown in Table 7. Equivalent inventory month is listed alongside for easy comparison.

Table-7 Vendor Obsolescence Risk under Consignment Term

Condition of Safety Inventory	Fixed Safety Stock		Optimum Safety Stock	
	(A) CMI	(B)VMI	(C)CMI	(D) VMI
Demand Step Increase = +20%	$8,549 (5.3months)	$8,198 (5.1months)	$8,090 (4.3months)	$6,070 (3.8months)
Demand Step Increase = +30%			$8,970 (4.8months)	$6,682 (4.2months)
Demand Step Increase = +40%			$9,850 (5.2months)	$7,284 (4.6months)
Demand Step Increase = +50%	out of stock		$10,730 (5.7months)	$7,875 (4.9months)

*Unit: NT$ Thousands

From Table 7, among the four models studied, minimum obsolescence risk is observed under Model (D): VMI model with optimum safety stock policy. It also reveals that obsolescence risk grows with the increase of the demand fluctuations. In model (A), with the preset fixed safety stock, stock-out is observed when a 50% demand step increase is applied.

Under non-consignment term, inventory ownership of the overseas vendors does not include the customer inventory, hence less risk of obsolescence. Simulation result is shown in Table 8. Minimum obsolescence risk is observed under Model (E) and (G); the CMI model. Apparently, the vendor obsolescence risk increases under VMI model.

Table-8 Vendor Obsolescence Risk under Non-consignment term

Condition of Safety Inventory	Fixed Safety Stock		Optimum Safety Stock	
	(E)CMI	(F) VMI	(G) CMI	(H) VMI
Demand Step Increase = +20%	$4,940 (3.1Month)	$6,158 (3.8Month)	$4,940 (3.1Month)	$5,389 (3.4Month)
Demand Step Increase = +30%				$5,832 (3.6Month)
Demand Step Increase = +40%				$6,264 (3.9Month)
Demand Step Increase = +50%	Out of Stock			$6,685 (4.2Month)

*Unit: NT$ Thousands

Under non-consignment term, an overseas VMI provider shall negotiate with its customer for a higher, than the optimum, safety stock policy at the customer warehouse to balance its increased risk of obsolescence.

4.3. Summary

From the above simulations, the performance of VMI model is higher than that of CMI's, especially on customer inventory. Under fixed safety stock policy, customer inventory carrying cost can be reduced by 50%. By adopting the optimum safety stock policy derived from this study, it can be further reduced up to 75%.

5. Conclusion

Being focused on VMI dynamics, both transactional and demand aspects in the international fastener supply chain, this study has constructed a dynamic model and presented quantitative simulation approach for the inventory allocation optimization and obsolescence risk minimization. The methodology provides a tool of performance evaluation of supply chain for further performance improvement, also serves as an excellent tool for illustration and understanding of VMI model and promotion activities.

This study validates that VMI model, with information sharing and operation collaboration between supply chain parties, improves the performance of the whole supply chain. VMI’s superior performance encourages all members of supply chain to share information and collaborate more extensively. Besides reducing the inventory cost for customer, VMI helps vendors to have tighter link with customers, build up long-term partnership, also help manufacturers to achieve better resource planning and efficient production scheduling. Each party can focus on their core business and competence and excel.

To deal with the dynamic behavior inherently built in VMI business operation, System Dynamic (SD) approach make the most out of its systematic modeling and simulation capability to solve and estimate the behavior of VMI system, also provides the necessary observation data and build up the system model for systematic study of the system behavior. The simulation result form the model can not only help determining policies and parameters of the VMI contract but also smoothen out the obstacles of implementation of VMI program.

This study has been constrained from limited resources and tight schedule, several future research topics should be continued after this, including:

(1)Include Cash flow, manpower flow and resource flow into the model, the interaction model will be more realistic and complete.

(2)Extend VMI Model upstream to include manufacturer and material suppliers.

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