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Vendor Managed Inventory (VMI): From Theory to Practical Implementation A Literature Review

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***Abstract* -This review paper considers a supply chain collaborative initiative which is "Vendor Managed Inventory" or "VMI". VMI systems have received significant attention in the last two decades from researches worldwide due to its proved capability in effectively coordinating various parties in the supply chain through information sharing and exchange .In simple terms VMI allows suppliers to manage their retailers' inventories and to decide on replenishment policies for their retailers. Generally contributions to literature of VMI are divided in to (1) Modeling of VMI systems (2)Practical implementation of VMI .This paper aims to analyze the various research aspects of VMI based on extensive literature search and to generate a classification scheme from which students, researches and practitioners can benefit. We could identify that there exists three different angles of research on VMI: (1) General (2) Modeling (3) Case studies. We further breakdown the classification to obtain the following classification scheme (1) Modeling (Mathematical/Simulation) (2) Case studies (3) Benefits (4) Challenges & success factors. Under Mathematical model we have three subsections (1) Optimal replenishment & dispatching policies (2) Pricing under VMI (3) VMI and contractual agreements.**

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1. Introduction

Vendor managed inventory or supplier managed inventory is a supply chain initiative that encourages partnership and integration among parties of the supply chain [1]. VMI was first adapted as a pilot study in 1980s by Wal-Mart and Procter & Gamble and the benefits associated with the implementation were very promising Benefits such as lower inventory levels, fewer stock-outs, and increased sales were generated [2]. Similarly the implementation was successful in other organization for example Campbell Soup Company , Barilla , Intel and Shell Chemical [3].

Vendor managed inventory is considered an example of virtual integration among partners in which no merge is required like in vertical integration. The virtual integration implies that independency of each firm is maintained while decisions are coordinated [3]

1.1. Traditional Supply Chain vs. Vendor Managed Inventory Supply Chain

The difference between traditional supply chain and vendor managed inventory lies in way decisions are made in each firm. [34] differentiated between traditional supply chain and VMI supply chain as the following. (1) In Traditional supply chain or serially linked supply chain each firm acts independently and makes its own decisions regarding inventory stocking and replenishments to optimize its own profit. The interaction among the different firms is limited to flow of material and product from supplier to buyer (downstream) and a flow in terms of cash and orders from buyer to supplier (upstream).The traditional supply chain structure consequently suffers from long lead times, multi decisions points and poor synchronization. (2) On the other hand VMI encourages information sharing and allows upstream supplier to access demand information and make replenishment decisions for the retailer based on agreed upon limits of inventories at the retailer location and ensures customer service levels set by the retailer are maintained. In other words the retailer inventory management responsibility is shifted upstream while downstream buyer shares demand information and leaves the stoking decision to the upstream supplier. In this type of structures, the order processing from the buyer are no longer exists.For this type of structure to be successful a significant amount of information are to be transferred among partners specifically data on sales and inventory levels at the buyer location. Nowadays the availability of accurate data transfer means and the reduction of costs of telecommunication has made it easier for VMI system to be successfully implemented. Benefits from VMI adaptation are substantial .They include reduction of distortion of demand information (known as bullwhip effect) transferred from the downstream supply-chain member [2], [34] to the upstream member , less stock outs [2] and improved product availability and customer service levels [34],[55], synchronized inventory and transportation decisions [2] and long run increase in profits for both the supplier and buyer [18]. One section of this paper is devoted to summarize that benefits generated from VMI.

1.2. Previous Literature review papers on VMI

Three reviewed papers presented a literature review on VMI [4-6]. In their paper [4] presented a literature review on the concept of VMI. They have indicated that generally three types of contributions can be found in literature (1) General papers (2) Models (3) Case studies. In their particular research on the concept of VMI, they have divided their paper based on the following logical scheme (1) The objective of VMI (2) VMI determinates (3) Modeling contribution (4) case studies contribution and the associated success and failure factors and the information exchange. They have also proposed a VMI macro-process that summarizes both operational and collaborative elements of VMI. [5] develops a very rich review paper on VMI. He has considered 138 papers in his research and has propsed three classification scheme (1) Classifaction based on dimensions (2) Classification based on case studies (3) Classification based on VMI structure level. For the dimensions based classification ,the author has identified six dimensions : (1) inventory, (2) transportation(3) manufacturing (4) general benefits (5) coordination/collaboration, and (6) information sharing.As a part of their research [6] has provided a review on simulation/modeling research on VMI and provided a summary of empirical studies that consists of summarizing sevel case studies approaches and key findings.

In this paper we develop our own classifcation scheme for VMI studied work and research. Similar to the previous review papers on VMI we could find that in general three types of reseach papers present on VMI which are general ,Modeling and Case studies. We based our priliminary classification on these three parts of VMI research. We then noticed that a huge portion of papers are dedicated to modeling of VMI (More than 60%) of . So we further breakdown the modeling part in to analytical models and simulation models. Again analytical models are found to receive huge attention from reseaches ,so we further breakdowm analytical models in to sub sections. Also we preferred to dedicate a section for benefits of VMI and anther section for challenges and success factors. The difference between our review paper and other review papers [4-6] is that we present a logical and simple classification that is shown to be very easy to follow and understand. In analytical modeling part we start by stating the basic VMI models with basic assumptions ,then we provide extensions of the basic assumptions of the model. To our knowledge no review paper has presented the basic model and its extenstions. We tried to balance between covering as much as number of studies on VMI and to provide detailed analysis of the papers reviewd so that intersted reader can maximize their understanding on the concept of VMI, how is it modeled ,what are assumptions of the problem , what are the cost structures of supplier and buyer, what costs are changed or transferred when implementing VMI, how VMI is applied in real world and what is the benefits, challenges and success factors of VMI adaption. Section 2 of this paper states the methodology employed for this research and presents the final classification scheme. Section 3 present the classification scheme ,sections and subsections. Finally we provide conclusion and propositions of future work

2. Methodology

We followed the approach mentioned in [5] by default. Papers were collected mainly from the following data base (i.e. Google scholar , Science direct ,Emerald management , Taylor and Francis) with focus on papers from 2000-2013.Only two retrieved papers are from 90s which we couldn’t ignore due to their valuable contributions . The research words used were “vendor managed inventory” or “VMI”. The preliminary search resulted in 116 papers from variety of journals. The collected paper were analyzed to check relevancy .We checked if the terms “VMI” or “Vendor managed inventory “ were used in all papers (search inside the papers) .This way we could identify 25 papers which were about general integration of supply chain and not specific to VMI.As a result theses 25 papers were excluded from the study. The rest of the papers were classified by a preliminary classification. The preliminary classification sections were (1) General (2) Modeling (3) Case studies. Later thorough analysis of the papers was done to obtain a more detailed classification. We could find that modeling papers are taking the highest portion among all other contributions (almost 60%) of the total papers. So we focus on sub sectioning the modeling papers . First we could identify that modeling papers are either analytical (mathematical) or simulation models and that the ratio of mathematical to simulation model is (3.5:1),so the sub sectioning was focused on mathematical models and we could classify mathematical models into 5 sub section. The final classification is presented below (figure 1):The research duration was almost 2 months. Due to time limitation only 50 out of the 91 remaining papers were effectively analyzed and included in this research. The figure 2 below shows the final number

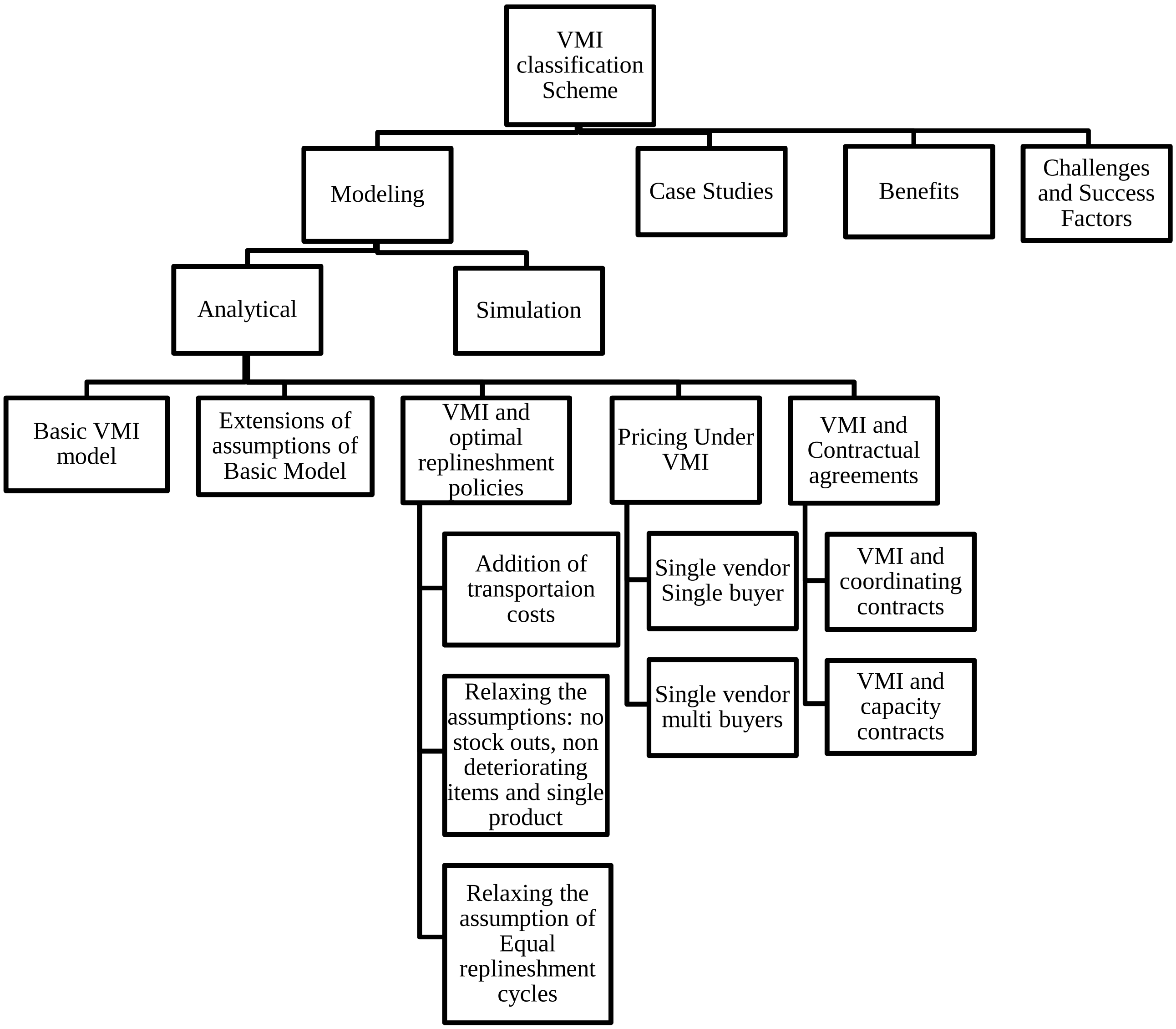

Figure 1：Final Classification Scheme

of papers considered. Figure 3 shows that more than 50 % of the papers included in the study are mathematical models of VMI. Finally referencing was managed via Mendeley reference manager and PDF organizer. Table 1 below shows the time duration assigned to different tasks performed to complete the project.

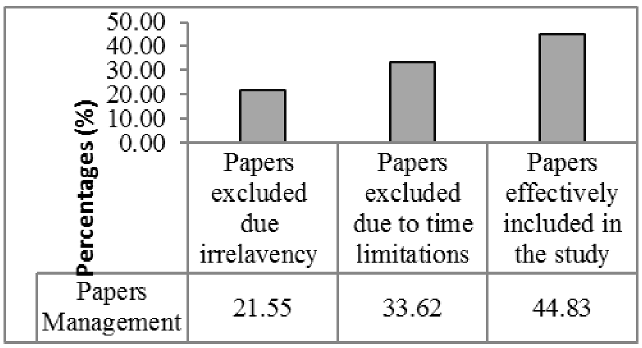

Figure 2 : Papers Management

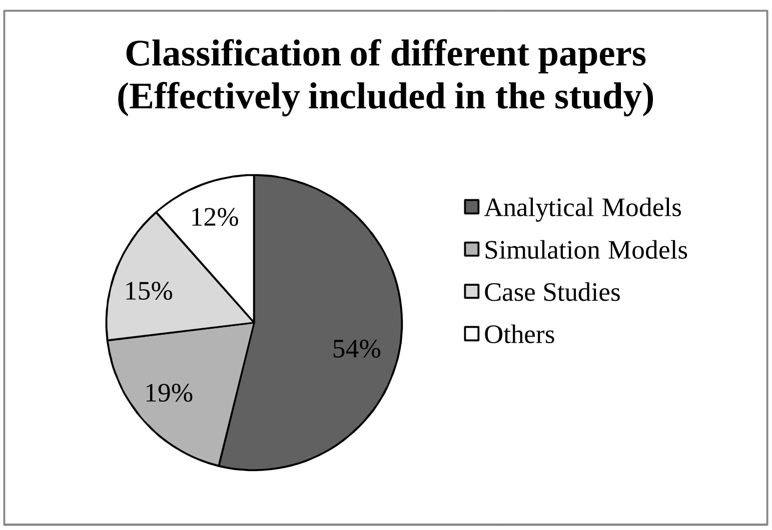

Figure 3 : Papers contributions

#	Tasks	Time Duration (days)
1	Paper collection through databases	3
2	Irrelevant paper elimination	2
3	Analysis of the papers	3
4	Preliminary papers classification	2
5	Final decision on paper included in the study	5
6	Thorough analysis and reading of papers	14
7	Final classification	7
8	Reading , summarizing & write up	20
9	Close-up	4
	Total	2 months

Table 1 : Tasks and time durations

3. The Classification Scheme

3.1. Modeling VMI systems

Modeling VMI is done either through analytical model which looks for mathematical traceability and simulation models which allows investigating the behavior of VMI systems under multiple scenarios and more realistic circumstances.

3.1.1. Analytical and Mathematical Models

Modeling the VMI system has been proposed by plenty of papers. Models differ based on the number of entities included in the problem, the assumptions the authors take in their papers and the complexity of the problem. In our paper we base our modeling review on two echelon supply chain where two stages are included e.g. supplier/vendor/manufacturer (upstream) and retailer (downstream). Basically in our paper we look at single vendor single retailer models and single vendor multi retailers' models.

a) Basic VMI Inventory Model

In their paper [7] have constructed two inventory models (with and without VMI) in a two stage supply chain with a single supplier and a single retailer models with the assumption of

1) Deterministic demand
2) Zero lead time
3) Single supplier-single buyer
4) Single non deteriorating item product
5) No backlogging allowed
6) Only ordering and carrying costs are included in the inventory model
7) The supplier order quantity is an integer multiple of the buyer's quantity

For the case decentralized supply chain (No VMI), the supplier is receiving orders from the retailer based on his economic order quantity which is the optimal order size obtained when minimizing the retailer cost function. The optimal order quantity is computed through the formula

$$\mathrm{EOQ}_{\mathrm{R-No\ VMI}} = \mathrm{q}^* = \sqrt{\frac{2\mathrm{cD}}{\mathrm{h}}}$$

$$\mathrm{TC^*}_{\mathrm{R-No\ VMI}} = \sqrt{2\mathrm{chD}}$$

Where D is the retailer demand, c is the retailer ordering cost per order , h is the retailer holding cost per item per time period .

Similarly the vendor optimal replenishment policy is based on his EOQ

$$\mathrm{EOQ}_{\mathrm{V-No\ VMI}} = \mathrm{Q}^* = \sqrt{\frac{2\mathrm{CD}}{\mathrm{H}}}$$

$$\mathrm{TC^*}_{\mathrm{V-No\ VMI}} = \sqrt{2\mathrm{CHD}}$$

They have assumed that the demand is equal for both the supplier and the buyer that all units shipped from the supplier to retailer are all sold to end consumers.

The cost function of the decentralized case:

$$\mathrm{TC^*}_{\mathrm{No\ VMI}} = \sqrt{2\mathrm{chD}} + \sqrt{2\mathrm{CHD}} = \sqrt{2\mathrm{D}}(\sqrt{\mathrm{ch}} + \sqrt{\mathrm{CH}}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Now the case of VMI is different from decentralized in that inventory for both entities will be managed by the supplier ,so the supplier has full access to the buyer demand information .Normally in inventory model the supplier order quantity is assumed to be an integer multiple of the buyer that $\mathrm{Q} = \mathrm{m}_{\mathrm{VMI}}\,\mathrm{q}$ and now the supplier has to decide on both his optimal Q and the buyer optimal q and the replenishment frequency m_{VMI} in order to minimize system's total cost.

Now observe the below inventory profiles (buyer & supplier)

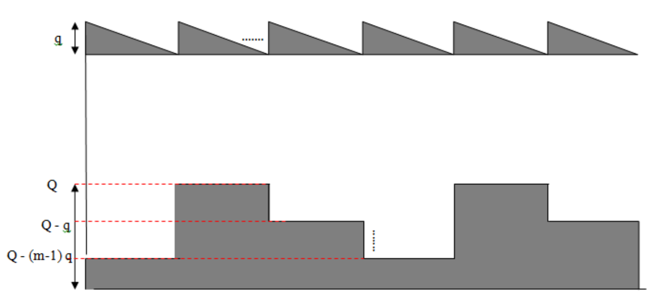

Figure 4: Buyer (at the top) and Supplier inventory Profiles

For the buyer : Average inventory is $q/2$

For the supplier (There are m_{VMI} replenishment of q in each supplier inventory cycle) reduces to Q-q after first shipment to the buyer. After second shipment the inventory level drops to Q-2q and after $m_{VMI} - 1$ shipments is Q-$(m_{VMI} - 1)$q. The $(m_{VMI} - 1)$ is the last shipment after which the inventory of the supplier drops to 0 and the supplier receives a replenishment that brings the inventory back to Q.

Now the supplier average inventory is computed as (Max+Min)/2

Max = Q

Min= Q-$(m_{VMI} - 1)$q.

I = (Q+ Q-$(m_{VMI} - 1)$q)/2 = Q- $(m_{VMI} - 1)$q/2

The total inventory cost of the integrated supply chain :

$$TC_{VMI} = \frac{CD}{Q} + HI + \frac{c'D}{q} + \frac{hq}{2}$$

Since $q = \frac{Q}{m_{VMI}}$

$$TC_{VMI} = \frac{CD}{Q} + H\,(Q- \quad (m_{VMI} - 1)q/2) \quad + \frac{c'D\, m_{VMI}}{Q} + \frac{hQ}{2m_{VMI}} \text{...........(2)}$$

Where first term is supplier ordering cost, second term is supplier inventory cost ,third term is buyer ordering cost (assumed non zero but relatively small) , Last term is buyer inventory cost.

Taking the first derivative of Eq(2) in terms of Q and m_{VMI} will give the optimal quantity and optimal replenishment frequency. m_{VMI} is a continuous variable. After some algebraic steps we obtain the following

$$m^*_{VMI} = \sqrt{\frac{C(H+h)}{c'\,H}}$$

$$Q^* = \sqrt{\frac{2CD}{H}} \qquad q^* = \sqrt{\frac{2c'D}{H+h}}$$

$$TC^*_{VMI} = \sqrt{2D}\left(\sqrt{CH} + \sqrt{c'(H+h)}\right) \text{................ (3)}$$

b) *Extensions of assumptions of basic VMI model*

- Single vendor multiple buyer : [2], [8-22]
- Non deterministic demand [e.g. stochastic : following a distribution function / a function of retail price and/or service level]: [10],[23-26],[14-16].

- Backlogging allowed: [11], [27]
- Deteriorating items: [19], [27]
- Multiple products [28], [29]
- Addition of transportation and distribution costs: [2], [56]
- Unequal replenishment cycle: [9], [22]

c) *VMI and Optimal Replenishment & Dispatching policy*

As illustrated in basic VMI model, [7] have constructed a two level supply chain with one supplier and one buyer. Based on certain assumptions they could derive the optimal replenished quantity for the buyer and the supplier and the optimal replenishment frequency under decentralized supply chain and under VMI respectively. He also demonstrated that the benefits generated from VMI depend on supplier and buyer parameter (holding costs and ordering cost before and after implantation of VMI: note that only ordering cost of the buyer is changed after the implementation of VMI). First they have shown that the replenishment frequency is increased with VMI and that the frequency tends to be higher when the buyer order cost with VMI is more reduced. Also the frequency tends to be higher when the buyer holding cost is large relative to supplier holding cost. In this case the buyer tend to order small quantities more frequently to minimize average inventory levels. Also they have demonstrated that total inventory costs savings decrease when the ratio of supplier order cost to the buyer order cost before VMI is large. The larger ratio means that the buyer order cost before implementation of VMI is small given that ordering cost of the supplier is unchanged with the implementation of VMI. Also the total inventory cost saving increase when the ratio of supplier order cost to the buyer order cost after VMI is large. This means that cost saving can be realized through order cost reduction. Generally the greater the reduction in the buyer's order cost, the higher the total benefits generated. Also it was found that the supplier inventory cost increases with VMI while the buyer inventory cost decrease. This is may be understood like shifting the inventory upstream the supply chain with VMI. Finally it was indicated that the benefits generated from VMI are not distributed equally between supplier and buyer and that supplier bears additional costs because of the shift of inventories upstream (supplier/manufacturer).

(1) The addition of transportation ,shipping and distribution costs

[56] has revisited [7] model and has indicated that the Yao's model ignores the shipping cost (i.e. order picking, shipping and transportation) from supplier to buyer and has indicated that these costs should not be ignored since they may comprise over 50% of total logistics costs at the supplier. In this paper the authors presented five different case, two from which are under no VMI setting and the other three are under VMI . The two cases in no VMI differ in the way the way the buyer is charged by the supplier. The two cases are (1) unit pricing : The unit cost

of the product covers the delivery costs (2) Service based pricing: The supplier charges the buyer a fee for each delivery. The three cases of VMI differ in the timing of replenishment orders at the supplier. The cases are Yao+ (the frequency is an integer while in Yao was assumed to be natural number) (2) unlinked VMI with unlinked timing of replenishment orders (3) Synchronized. In addition they have demonstrated that the reduction of ordering cost in the buyer side will result of an increase of the delivery costs by the supplier(more frequent shipping), so the sum of the ordering and transportation costs per order/shipment remains almost the same before and after VMI. Also interestingly they have shown that VMI unlinked and synchronized cases results in larger shipment size from supplier to buyer. Also they have indicated that unlike [7], they found that VMI whether synchronized or not increase the inventory at the buyer side. Also unlike Yao, they found that VMI whether synchronized or not decrease the inventory at the supplier side.

[2] developed an analytical model to coordinate inventory & transportation decision in VMI environment. The particular contribution of the paper is that the authors considers a case at which the vendor doesn’t response to retailers’ orders immediately however it holds the order until a specific dispatching time (T) for which the vendor assumes that an economic shipment quantity (ESQ) accumulates .The retailers are assumed to be willing to wait when their shelf space is limited for carrying extra stock, or else carrying inventory for certain items is not desirable. This situation is particularly common for retail stores making catalog sales. Renewal theoretic model is used to obtain ESQ and the dispatch frequency (T) with the objective of minimization of total cost (procurement, transportation, inventory carrying, and waiting costs). In their paper they have considered that the vendor replenishes his inventory based on (s,S) policy and dispatches with regard to time based policy.

In another paper [20] have revisited the paper of [2] and has considered same problem setting ,but with different dispatching policy namely quantity based dispatching policy and hybrid policies instead of time based policy used in [2]. They have indicated that a time based policy assures a specific time of dispatching ,but may not ensure economical shipment. On the other hand quantity based policy ensures transportation economics, but not a specific time of dispatching. Another alternative is the hybrid policy which balances the transportation cost saving resulting from quantity based policy and timely deliveries associated with time based policies. The results of the analytical model and numerical example show that the savings from a quantity based policies can be substantial in compare to time based policies and hybrid policies. Hybrid policies (Hybrid quantity policy and Hybrid time policy) performance is found to be better than time-based policies. Though hybrid policies are not better than quantity based policies in terms of costs, they result in better service (measured as long run cumulative waiting time).Also hybrid policies may be attractive since they outperforms time based policies in terms of costs and outperforms quantity based policy in terms of service level.

(2) Relaxing the assumptions : non deteriorating item , single product and no stock outs allowed (backlogging allowed)

[27] have developed an EOQ models considering deteriorating items before and after the implementation of VMI with and without shortages to investigate the impact of vendor managed inventory system. Two echelon supply chain of a single vendor single retailer is considered in the paper. Assumptions used in the paper in addition to deteriorating items are (1) lead time is assumed zero (2) The customer demand is deterministic (3) The deterioration of the product starts after some time (t1) and there is no replacement for the deteriorating inventory. Two parameters are of interest in the case of no shortages allowed (1) Non VMI optimal order quantity (2) VMI optimal order quantity (3) Non VMI cycle time (4) VMI cycle time .In case 2: shortages allowed and stock outs are fully backordered,the decision variables are beside the order quantities and cycle time under VMI and non VMI situation are 5) the maximum backorder level in non VMI (6) the maximum backorder level in VMI setting. The variables are obtained through the objective of minimization the chain wide costs. The results show that the order quantity is increased in VMI setting with shortages and no shortages and the total cost is decreased in all condition in VMI setting.

A supplier buying fast deteriorating raw materials to produce slowly deteriorating finished product and distribute it to multiple retailers case was considered in [19]. In this paper decision variables were (1) common replenishment cycle of the product (2) raw material replenishment frequency in the common replenishment cycle .Assumptions mode in the paper are (1) the deterioration rate of the raw material and finished product are deterministic (2) The deterioration cost of the finished product at the retailer and the vendor are the retail price and the wholesale price (3) The deterioration cost of raw material is the purchasing price (4) The replenishment frequencies of raw material is limited to upper bound in each replenishment cycle. The model was developed by (1) obtaining the total cost of finished product at retailers side including ordering , holding and deterioration cost (2) the total cost of finished product at the vendor side including set up, holding and deterioration costs of finished products (3) the total cost of raw material at vendor's side including ordering cost and holding cost of raw material. The objective was to minimize the total inventory and deterioration costs of the CS system. The model is a non linear integer programming model. The algorithm used to solve the model is golden search algorithm which generates optimal solution for C and n respectively at minimum joint total cost.

Backlogging allowed in studies like [11],[27] & multiple products case is considered in [28],[29]

(3) Relaxing the assumption of equal replenishment cycle

An interested reader can refer to [9],[22]. A summary of [9] approach and key findings is presented in VMI and Contractual agreement on capacity constraints subsection.

d) *Pricing under VMI*

Pricing under VMI include setting pricing parameters i.e. purchase quantity, retail price and wholesale price that maximizes the system wide profits. Detailed discussion of pricing under VMI is presented by [30]

(1) Single vendor single buyer

[18] developed two models to determine optimal purchase quantity (y*) and optimal contract or purchase price (w*) based on assumptions of deterministic demand and lead time and no shortages allowed .The first model was based on non VMI condition. The procedure of determining the optimal parameters was as following: First the profit function of buyer and supplier were obtained by subtracting revenues and costs. The sales price used to calculate buyer revenue is assumed to be a function decreasing in y: demand, purchase quantity .The cost structure of the buyer includes: ordering ,holding and purchasing costs. On the other hand cost structure on the supplier side include : production and distribution , carrying and order set up cost. Now the buyer as a leader is knowledgeable about supplier costs and ability to supply at a given purchase price (w) as to maximize his (supplier) profit. The buyer realizes the supplier reaction towards a given (w) and offers (w*) to the supplier in order to get an optimal quantity (y*) that maximizes its profit (the buyer). When both parties decides to implement VMI , the inventory costs are transferred from the buyer to the supplier and the same procedure is used to determine optimal (y*) and (w*).This method illustrated by Dong & Xu is referred in literature as iterative heuristic[DX] method for single buyer-single supplier [13], [17] .

(2) Single vendor multiple buyer

Single vendor multiple buyer pricing schemes under VMI were discussed in [13-17]. In their paper [17] have formulated a mathematical model to obtain three parameters namely sales quantity, sales price and the purchase (contract) price between the buyer and the supplier. which is considered as nonlinear integer programming problem (NIP). In their formulation they have assumed sales price of linear behavior (linear demand function) which varies from buyer to buyer based on their location and other factors and that the sales quantity lies between a minimum and maximum level. In addition the contact price is assumed to lie between the sales price and the cost of manufacturing and is affected by certain factors. Cost structure used in this paper for both buyer & supplier is same as for [18] under VMI . The acceptable contract price that will satisfy both the buyer & supplier is derived from the revenue share ratio (profit supplier/ profit buyer). The objective function was to maximize the channel profit under VMI subject to constraint on sales quantity and supplier capacity. The solution of the formulated model provides the optimal sales quantity and the other parameters (sales price & purchase price) are derived by substituting the optimal sales quantity in their corresponding functions. Genetic algorithm heuristic (GA) is proposed to obtain optimal or near optimal solution for the (NIP) problem and the methodology is applied on a case study at a dairy company which supplies to three retailers for which the supplier is working independently from the buyers. In addition the authors have compared the solution obtained from GA algorithm with the optimal solution obtained from LINGO optimization solver. The comparison shows very small deviation from optimal solution in LINGO. Also the author indicated that reduction the number of buyers to one will result in [18] problem. The author compared the GA algorithm with iterative heuristic (DX)and the LINGO outputs results. All comparisons indicate that GA algorithm is an efficient method for solving the existing problem.

In another recent paper [13] have considered Two-echelon Single-Vendor–Multiple-Buyers. Particle Swarm Optimization (PSO) and a hybrid of Genetic Algorithm and Artificial Immune System (GA–AIS) are proposed to solve this TSVMBSC problem. The same case considered in [17] is considered in this paper and both algorithm performance is compared to LINGO solver outputs and other heuristic performance in two cases. Case1 reduces the problem to single vendor single buyer problem [18]. The results of comparing the two proposed methods with LINGO , GA and DX show that PSO performs better than GA-AIS and that GA-AIS is not generating a comparable solution to the other methods. Case 2 is single vendor multiple buyer . In this case again PSO generates a solution close to the optimal solution while GA-AIS deviates from the optimal solution. Robustness of the model was done through changing multiple model parameters namely changing lower and upper limits sales quantity, demand slope, holding cost and set up cost.

Pricing through Stackleberg game theory under VMI has been considered in some reviewed paper [14-16]. In their paper [14] considered single manufacturer who sells single product with capacity constraint to multiple retailers serving independent markets . In this paper the manufacture as a leader is assumed to determine his operating parameters that will maximize its own profit while the retailer as a follower will consider the decisions of the manufacturer when deciding on its optimal parameter to maximize its own profit. The game model is formulated where the manufacture and the retailers are under VMI agreement and formulation is done through several steps. First the net profit of the retailers is determined as the difference between revenues (price* demand) and the sum of procurement costs and inventory cost that will be paid back to the manufacturer for managing retailers inventory. Then the net profit for the manufacture is established. The cost structure include the inventory cost of the retailers side (sum of ordering cost and carrying costs for managing the retailer inventory and backorder costs minus the amount paid by the retailer back to the manufacturer) and the inventory cost at the manufacturer side (order cost + holding cost of inventory at his side) and the manufacturing and transportation costs. When both profit function are obtained the game model was formulated with the objective of maximizing the net profit of the manufacturer and retailers subject to certain constraints. The mechanism of the game start by the manufactures decision as being the leader and being aware of the retailer reaction .The manufacturer has to determine three parameters namely : the equal replenishment cycle , the backorder fraction and wholesale price. The retailers determine their optimal retail prices. Then the manufacturer make adjustment in his optimal parameters in order to maximize his profit and the process continues until the " stackleberg equilibrium" is reached and no further improvement can be done. An algorithm has been proposed to solve the game model and to obtain the " stackleberg equilibrium".

e) VMI and contractual agreement

Though VMI is considered a type of contractual agreement between supplier and buyer(s),it was found that VMI combined with some other contract result in substantial benefits that are very close to the benefits from centralized setting (perfect coordination). Examples are given below in this section.

(1) Coordination through contracts and VMI

Four identified papers have considered coordinating decentralized supply chain through contracts with and without VMI. [10],[24-26] In their paper [24] have modeled a decentralized CS consisting single manufacturer single buyer in two different settings: Retailer managed inventory and Vendor managed inventory. For each case three type of coordinating contracts are modeled: (1) price-only contract (2) Revenue sharing contract (3) Revenue sharing plus linear rebate and side-payment contract to investigate the impact of different contact on the performance of the supply chain. The study aimed to plan the replenishment/lot size and pricing decisions over multi period planning horizon with the presence of deteriorating goods and used calculus based formulation and dynamic programming techniques to solve for the different problem decisions. Basically the problem considers the manufacturer as a leader. There are two alternatives of inventory management as discussed in the paper .Retailer managed inventory where the retailer is responsible for the replenishment scheduling/quantity and retail price decisions while the manufacturer is responsible for wholesale price decisions only. The other alternative is the VMI mode, where the manufacturer is fully responsible for the replenishment scheduling/quantity decisions in the channel as well as for the wholesale price. This study obtains the retail and wholesale prices for the retailer and manufacturer respectively, for an arbitrary period [zi-1, zi],

And solves for the rest of the periods by utilizing dynamic programming techniques (backward tracking). Six policies were considered under RMI and VMI. RMI with PO (Policy I) ,VMI with PO (Policy II).Policies (III & IV) are concerned with Revenue sharing contract where the manufacturer reduce the wholesale price and the retailer share some of their revenue with the manufacturer in response to the reduction of the wholesale price. Policies (V &VI) modeled RSRS-plus-RL contract under RMI & VMI respectively. In policies (III-VI) anther decision variable was to be determined which is the revenue sharing allocation among the manufacturer and the retailer. A numerical example was illustrated in the paper for all policies and for each policy the different parameters were obtained and it was found that policy VI (VMI with RS-plus-RL contract obtained the best results among all policies based decentralized system efficiency (measured as ratio between the decentralized profit and the centralized system profit (perfect coordination) where the decentralized efficiency was 98%. So policy (VI) coordination almost reached the ideal setting generated by the centralized coordination & have achieved pareto improvement for the decentralized supply chain.

Another paper by [10] looked at coordinating a decentralized supply chain consisting of single supplier and multi retailers through sales rebate contract under VMI. Sales rebate contract is applicable in VMI setting since manufacturer in VMI has continuous update on actual sales data and in this case sales rebate contract is easily implemented and managed. Also sales rebate contract encourage retailers to promote sales to take advantage of the rebate paid for sold item to end users. The paper considers two cases : (1) retailer are independent and prices of each retailer doesn't affect the demand of other retailers (2) competing retailers where price of one retailer affect the demand among the other retailers. So the study proposes coordination scheme of a VMI decentralized supply chain and to evaluate how sales rebate contract impact the decentralized SC performance. The demand is assumed stochastic and multiplicative based on newsvendor model with decrepitated items and supplier uses periodic review policy with inventory base stock level. The decision procedure is a stackleberg game where manufacture is the leader and determines the base stock level based on retailer's customer services and determines wholesale price while the retailer reacts to the wholesale price and set his retail price. For case one : independent retailers ,the model is reduced to single supplier single retailer problem. Implementation of sales rebate contract is considered effective only if retailer performs better with the coordination otherwise the retailers will not have incentive to be part of the contract. The author have indicated through some proofs that the retailers in sales rebate contract are motivated to lower their retail prices to obtain more customer demand and to get advantages of more sales and more rebates. Also under VMI and sales rebate contract, supplier spends less administrative costs to manage the sales data of the retailer than in RMI setting for which retailers may overestimate their sales data to benefit from the rebate incentive. In case two : competing retailer ,it was concluded that the intensity of the competition influences the profit allocation between the supplier and retailers, greater profit is allocated to the supplier when the competition becomes more intense. The results demonstrate that the sales rebate contract combined with the VMI mechanism achieves perfect coordination where retailers make price decisions to maximize the aggregate chain profit. In properly designed rebate contract, the retailers lower prices to the system-wide optimal prices so as to increase demand and further improve the aggregate chain profit.

(2) Contractual agreement on capacity constraints

Single vendor multi retailer supply chain in which the vendor is not allowed to exceed certain limits on retailer inventory levels which are agreed upon among the supplier and retailer and exceeding these limits results in penalty cost paid by the supplier is considered in [8] paper. The vendor and buyer are working under VMI agreement. Ownership of the inventory is the responsibility of the buyer. That is the current situation is VMI and not consignment stock for which ownership of the inventory is the responsibility of the vendor. Under VMI since the retailer own the inventory, the supplier usually push the inventory to the retailers' side. In this case retailer set an upper bound on the received inventory to eliminate excess inventory from the supplier . Assumptions in development the model are the following: (1) the demand is deterministic (2) Equal replenishment period. Decision variables are (1) vendor order quantity (2) dispatch quantities for each retailer (3) number of shipments (4) Total cost of the system (5) the number of retailer whose capacity constraints are violated. The objective was to minimize the total system cost (supplier + retailers) subject to certain constraints .The optimal solution is determined by finding all Karush–Kuhn–Tucker (KKT) points associated with the cost function. The problem considered is (NLP) problem which is a complex problem. The authors have proposed an efficient algorithm to solve this complex problem and the proposed algorithm has reduced the computational effort significantly form 2^m to m+1 where m is the number of retailers.

[9] Extended Darwish & Odah model by considering unequal replenishment cycles or unequal reorder interval (URI) as referred in their paper. They have followed same assumptions of single vendor multiple buyers , deterministic demand on the buyer side and storage capacity (limits on inventory level at the retailers side) .The decision variables were (1) Vendor replenishment cycle /reorder interval (2) reorder interval for each retailer (3) number of delivers for each retailer (4) shipping quantity to each retailer . They have modeled the problem with the objective of minimization the supply chain costs and developed a heuristic procedure for the mixed integer non -linear problem to generate near-optimal ordering policy. The results of an illustrative example which study a specific problem has shown that using unequal reorder interval generates cost saving in compare to the equal order cycles.

3.1.2. Simulation Models

Simulating the VMI systems differs from analytical model in that it does not look for mathematical traceability however it allows investigating the behavior of VMI systems under multiple scenarios and more realistic circumstances [1]. Simulating VMI systems was performed extensively in the literature [31-40] proposed simulation based optimization procedure to solve the replenishment problem faced by a manufacturer who manage inventory of apparel retailers in textile industry. The study presented two different replenishment strategies namely non-optimized and optimized strategies. The non optimized strategy was merely based on simulation with regard to targeted CSL. The optimized strategy incorporates GA and simulation (dynamic rolling optimization). Two experiments were done with regard to one retailer to elaborate the optimization procedure. Each experiment was done with regard to two different objective functions namely minimize lost sales or maximize production balance. The results show that the proposed optimized procedure can benefit the manufacturer with balanced production and could maintain the customer service level at a certain level taking in to account the forecasting error for customer demand is minimized. [1] used discrete event simulation to investigate the performance of VMI with regard to different scenarios. The study considers a multi-echelon supply chain consisting of four level (i.e. plant with limited capacity & single product , warehouse, distributer & retailer). The simulation was done used Crystal Ball, an Excel add-in published by Decisioneering which uses Monte Carlo simulation in a spreadsheet environment for random data generation. In addition two scenarios namely traditional supply chain and VMI structures were considered for comparison. The retailer's demand is characterized by Gama distribution and it allowed the generation of seasonal and non seasonal customer demand. Four independent factors (1)type of supply chain (2) available production capacity on the plant (3) customer demand uncertainty (4) lead times were considered in the experiment design to explore the impact on three dependent variables (1) Average inventory of supply chain(2) Total cost of SC (3) CSL of the retailer. Using MANOVA tests on the simulation outputs allows to study the effect of individual factors as well as the interaction among the different factors on the dependent variables. The interaction between SC type and the three other independent factors one by one result in the following conclusions :(1) The performance of VMI decrease with the increase of demand uncertainty (2) As the capacity of the non participating outside supplier decreases the outcomes from VMI decrease (3) As long as the ratio of lead time of the supplier and retailer is constant , the increase result of VMI remains unchanged. In another study by[39] ,simulation model was constructed to compare two SC initiatives namely VMI and CPFR. The same SC structure is considered as in [1] with same assumption of demand distribution. Same four independent factors are used ,but only two dependent factors are considered (1) Total cost of SC (2) CSL of retailer. MANOVA results has shown that CPFR is outperforming VMI where it results in higher reduction in

SC costs and increase in CSL. Also the interaction effect of the type of SC and the three other independent variable shows very interesting findings. First the performance of VMI and CPFR are significantly affected by the three independent variables. Second moving from VMI to CPFR may not be justified if the lead time is short or if the plant capacity is limited and tight. Another finding is that as demand variability increase the performance of VMI is less the performance of CPFR and that CPFR is more invulnerable to demand uncertainty. So moving from VMI to CPFR has to be well justified and that the specific business conditions has to be taken into consideration in making this decision.

In investigating the effect of VMI on transport operations , [35] used dynamic simulation on two echelon supply chain with three different structure (1) a traditional supply chain (2) a situation where batching occurs within the order rule and (3) VMI supply chain. The results shows that a smoother response is achieved under VMI which enable manufacturing cost reduction. In addition potential short and long term savings transport savings are expected under VMI. Two reviewed studies investigated the effect of VMI on bullwhip effect.[34], [36]. [34] considered a two echelon supply chain under two structures(1) Traditionally serially linked (2) VMI and used simulation to study the effect of these two structures on bullwhip effect. It was found that in all the studied cases VMI result in significant reduction in the bullwhip effect ,also VMI has better ability to respond for uncertain demand which result from discounted ordering or variation in prices.

3.2. Case Studies

In his paper [41] has answered three research questions that are related to the practical implementation of VMI system specifically (1) What transfer data are required from the customer to the supplier (2) What are the data transfer means (3) How important is advanced shipment notice (ASN) on the success of VMI. The study outcomes were based on extensive literature survey and on data collected through interviews with companies who adapted VMI or are planning to. A total of five cases were involved in the study where in all cases the supplier or the customer is a manufacturer. Case 1 was a pilot study in which the VMI project is still in planning phase. The other cases indicated as case 1-4 were considered in multiple industries i.e. machining industry; Water installation; Automotive; Agriculture machinery. Some of the studied cases were considered successful and others were not. Regarding the answers of the three research questions the following was concluded: (1) Regarding the required data to be transferred from customer to supplier, it was found that Inventory level was identified of massive important transferred information .Also it was found that when the customer is following a make to stock policy production schedule and stock withdrawals data are to be transferred. Forecasting data are to be transferred for better forecasting. On the other hand when the customer is making to order then information on incoming orders are to be transferred and forecasting data could be transferred for better control. For question 2, It was found that Electronic data transfer could be seen as an enabler but doesn't guarantee successful implementation nor a prerequisite for successful VMI. Last question was answered as follows: "ASN information important for planning purposes when the receiving warehouse operates with limited capacity and resources".

In their paper [6] have followed similar approach of [41] and based their research outcomes on extensive literature survey and on multiple case studies to answer two questions (1) what kind of benefits are to be realized from the implementation of VMI (operational & strategic); (2)How the benefits are shared among the supplier & buyer. The authors considered five dyads (supplier & buyer under VMI agreement) which implemented VMI and got positive results (success). Qualitative & Quantitative Data were collected to study the impact of VMI on the selected organizations. The quantitative data are obtained through various interviews and quantitative data that measure the impact of VMI include ,but not limited to (1) inventory levels for buyer(2) supplier production efficiency (3) material availability from supplier to buyer (4) supplier's forecast accuracy & others. The study consists of two phases (1) within-case analysis (2) cross-case analysis was performed in the second phase. Based on the results from cross-case analysis, three VMI patterns were identified (1) Basic(2) cooperative (3) synchronized. Each of the three patterns characteristics are identified and explained in the paper and the five dyads were classified based on VMI pattern. Benefits from VMI were discussed with regard to the different patterns. Also inhibitors for VMI impact were discussed for example it was shown that if the buyer has an advanced purchasing system(automated information system) already in place the impact of VMI is limited (2)If the size of delivery package of supplier is large relative to the buyer's demand, this would limit reducing buyer inventory (3) Small share of business limits supplier's possibilities to benefit from VMI. A third study was concerned with the applicability of VMI in German blood supply chain[42]. In this study 13 hospitals were considered to evaluate if VMI can be implemented in the blood SC and to investigate the benefits that could be obtained through the successful implementation. It was indicated that the transfusion laboratories were of charge of managing inventories of hospital ,for this reason the transfusion laboratories were identified as the unit of analysis. Through cross-case analysis it was found that VMI was not implemented in any of the hospitals. Though the hospitals were able to apply VMI based on structural and technical enablers, the laboratories doubts the ability of VMI to control such a critical recourse such as blood and they don't see that the VMI benefits presented in the literature could be obtained in blood supply chain, so they are hesitant towards VMI. A second study by [43] looked at VMI in healthcare sector. The study presents case study at which inventory control is optimized through an integrated supply chain management. The supply chain consists of three levels , pharmaceutical companies , a wholesaler and hospitals with the focus on the wholesaler and the hospitals. The proposed system is a VMI system for which information sharing is the core of successful implemented system. The shared information will allow the wholesaler to accurately forecast the demand through the ability of receiving information about inventory levels. The paper discussed the requirements of the proposed system. The benefits of the implemented system were substantial however at first changes in the current operation have received great objection.[44] presented a case in an Indian enterprise where a vendor responsible for making and distributing bakery stuff to retailers and was suffering from a lot of stock outs and excessive urgent calls from his retailers. The company was operating in traditional way i.e. no IT system to monitor orders or inventory. A pilot study was performed to check the applicability of VMI to the enterprise. In this pilot study partial implementation of VMI one retailer was selected and two years daily sales were retrieved to obtain forecasts using various forecasting methods and now vendor is deciding on how to replenish quantities instead of the retailer. Results have shown that even a small enterprise which has no sophisticated IT system can benefit from the adaption of VMI .The forecasting accuracy and the selection of a good method of forecasting has proved to have a strong impact on the improvement of a company performance. Benefits outlined in the study were: reduction in bullwhip effect (demand variance) , reduce excess or shortages in inventory and increase customer level.

An interested reader in application of VMI can refer to some more case studies in other industries for example: a case for managing blood products [45], a case for household electrical appliances sector [46], a case in textile industry [47], a case in construction sites [48].

3.3. Benefits

Please refer to table 1 for reviewed general benefits of VMI.

3.4. Challenges & Success Factors

3.4.1. Challenges

The adaption of VMI has several challenges. First though information sharing from retailers proved to have significant positive impact on the supply chain (i.e. reducing the bullwhip effect) , the retailers have no willingness to share information with suppliers assuming that the only parties who benefit are the supplier [32]. In his paper [1] has found that the increase of demand uncertainty reduces the improvement that could be obtained through VMI. Shared information in this case will be of significant importance to the supplier to account for this uncertainty. Information like marketing plans and range strategies are among information that retailer doubts to share [49]. Second some obstacles that hinder the implementation of VMI are the investment required to achieve integrated supply chain .In addition long distances among participants is a potential obstacle [46]. Anther challenges reported by [47] is the difficulty to balance benefits among players . A larger number of retailers may be difficult to manage by the supplier [49]. In an interesting study [1] has shown that the poor performance of a non-participating supplier (the plant) may cause the failure of VMI systems and based on his review of literature could conclude that two factors lead to failure of VMI systems which are (1)Sharing of out of date or inaccurate information regarding sales and inventory data ; the absence of proper IT systems and the lack of trust among parties (2) Generating inaccurate demand forecasts of customer demand.

3.4.2. Success Factors

For a successful adaption of VMI all participant shall share information. By sharing information timely and exact data can be gathered ,so demand is forecasted more accurately and the supply is timely and cost effectively [43]. Sharing information regarding sales forecasts and current inventory levels have to be available to the supplier and that the focus should be on data transfer upstream (from retailer to supplier). It is also found that the automated data transfer and the adaption of EDI systems improves efficiency and should be taken into consideration [50]. Also seekers of implementation of VMI shall understand their business conditions very well before immediate adaption of VMI. [46] have mentioned in his paper some applicability conditions of VMI: (1) Short supplier-retailer distances (2) Reliabilty and accuracy of demand forecast (3) High level of know-how (4) The availability of advanced IT (5) criticality of supply. Successful implementation of VMI usually depends on computerized information systems and product identification and tracking systems (Bar codes) [50-53] though some researchers have shown that EDI is an enabler , not a requirement for VMI [51],[44]. Lastly a large degree of cooperation among supplier and retailer contributes to the success of VMI.A lot of conflicts between parties will result in negative impact and may lead to VMI failure. [52]

(R,V)

Table 3: Benefits of VMI for vendors (V), retailers (R) & both

Study / Benefits	[47]	[51]	[3]	[1]	[44]	[18]	[54]	[34]	[35]	[43]	[55]
Balanced production	V										
Better utilization of recourses	V	V	V								
Improving CSL	R	R		R	R						R
Reduction of SC average inventory (unit)			R	R , V						R	R
Reduction of SC costs				R , V							
Reduction of shortages and overstocks		V			R						
Reduction of manufacturing costs											
Reduction of Bullwhip effect/demand uncertainty		V						V			V
Flexible replenishment strategy		V									
Long term benefits to the supplier						V	V				
Better control of goods flow											
Reduction of transportation costs		V	V						V		
Improved procurement processes										R	
Decrease inventory related costs							R				
Shorter lead times					R						
More accurate forecasting											R,V

4. Conclusion and Propositions for Future Research

In this paper vendor managed inventory systems literature was analyzed and a classification scheme was proposed. We base our classification on four sections namely: Modeling which accounts for more than 50% in the selected papers, case studies, benefits and challenges and success factors. For the modeling section we analyzed mathematical and simulation models. For mathematical models we divided the contributions in to five subsections namely: basic VMI model , extensions of the assumptions of basic model , optimal replenishment and dispatching policies which is divided in to three subsections , Pricing under VMI which is divided in to two subsections , VMI and contractual agreements which is divided in to two subsections as well. Through this extensive literature survey we could see that there exist some research gaps that have not been investigated yet. Examples of future research propositions are

1) Simulating scenarios where a supplier managing competing and non competing retailers.
2) Propose a method that allocate the benefits fairly between a supplier and a retailer to encourage suppliers to engage in VMI partnerships
3) Analyzing cost/benefit analysis by quantifying the cost of investment required to implement IT technologies (i.e. bar codes, RFID) in compare to the long run benefits associated with VMI.
4) Analyzing how the performance of VMI is affected when a supplier manages two types of retailers: retailers who implement electronic data exchange systems and other who simply don't.
5) Studying how VMI policies and agreement between suppliers and retailers should be changed when a new retailer is entered to the agreement and studying the impact on current VMI performance.
6) Propose a model that decides on the maximum number of retailers a supplier can manage in order to optimize profits of the whole supply chain.
7) Study how the distance between suppliers and retailers can have an impact on the performance of VMI. Incorporate a facility location model to optimize locations of warehouses or retailers distribution centers.
8) More research is needed to check whether IT systems are enablers or a requirement for the success of VMI.

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