A supply chain performance analysis of a pull inspired supply strategy faced to demand uncertainties

Guillaume Marquès, Jacques Lamothe, Caroline Thierry, Didier Gourc

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Abstract Vendor Managed Inventory (VMI) is currently seen as a short-term replenishment pull system. Moreover, VMI is usually synonymous with a distribution context and stable demand. However, industrial partners are faced with uncertainty in the context of a B to B relationship. Thus, an adaptation of the actors' planning processes is needed and the question is posed of the interest of VMI in a context of uncertain demand. The purpose of this paper is firstly to analyze the link between VMI and pull logic. Secondly, we explore the extension of VMI notions to the relationship between industrial partners and we confront VMI with uncertain demand in terms of trend, vision of the trend and variability in order to verify the usual stable demand assumption. We also present an integration of VMI into a simulation tool called LogiRisk that we have developed for the evaluation of risks of in supply chain collaboration policies, and a small case study.

Keywords Vendor Managed Inventory · Pull · Simulation · Risk · Uncertainty

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Introduction

During the past decade the industrial context has changed. The production economic has trended from a market where consumers buy standard products offered by manufacturers to a market characterized by the personalization and the uncertainty concerning the demand and its forecast. Therefore, using supply chain collaboration more strategically has become crucial. It enables the creation of new revenue opportunities, efficiencies and customer loyalty (Ireland and Crum 2005). Among these supply chain collaborations, Vendor Managed Inventory (VMI) is today used in industry and has inspired a large number of academic works.

However, in terms of implementation it clearly appears that VMI is limited to particular situations. For example, VMI is today almost exclusively synonymous with a distribution context. So the focus must be on ways to extend Distribution-VMI notions to the relationship between industrial partners. Furthermore, many authors agree with the idea that the VMI has to be set against stable demand.

We can project this stability of demand on different planning horizons. In a strategic horizon, a forecast could be represented by a demand trend. It would be qualified as stable if the trend stays the same all over. Conversely, a change in the trend, such as an increase or a decrease, leads to instability. In a shorter horizon, the term stability characterizes real demand. For example, the stability of this real demand could be measured thanks to a standard deviation around a mean: a small standard deviation for stable demand and a large one for an unstable demand. In this paper, we focus on the strategic aspect in order to analyze the impact of this instability on the supply chain performance.

We use a discrete events simulation tool called LogiRisk in order to simulate the strategic choices, exchanges and decisions in a given supply chain (Lamothe et al. 2007). This tool enables risk evaluation of different collaboration policies. A collaboration policy being the gathering of:

- the **collaboration protocol** that defines decisional processes between the partners. Here, the protocol is defined by two main aspects: the type of forecast (*internal* based on historical forecasts or *external* transmitted by the partner) and the type of supply (*push*, *pull* or *VMI*);
- and the union of the partners' **decisional behaviours** during their decisional activities. Here, we focus on the strategy of inventory security level (expressed in weeks).

The purpose of this paper is twofold: on one hand, identifying the pull aspects of the VMI throughout the definition of its objectives and decision levers. On the other hand, we aim to study the impact of a changing market demand trend on these objectives and the decision levers from a risk analysis process point of view. Consequently, a literature review allows VMI objectives and decision levers to be defined. This first part particularly underlines the shared aspects and differences with classic push and pull systems. In a second part, we present the elements of our model. In a third part, we discuss the simulation results of a case study. Finally, we give several conclusions and present future research works.

Literature review

Many articles deal with VMI. But what VMI actually is and how can it be concretely implemented in the supply chain is not obvious. In this part we aim to emphasize the link between VMI and pull logic, through the analysis of its objectives and decision levers.

VMI systems

The Supply Chain Council (2008) defines VMI as "a concept for planning and control of inventory, in which the supplier has access to the customer's inventory data and is responsible for maintaining the inventory level required by the customer. Re-supply is performed by the vendor through regularly scheduled reviews of the on-site inventory".

The traditional VMI implementation success story is the partnership between Wal-Mart and Procter & Gamble. Other sectors have been explored ever since: house hold electrical appliances (De Toni and Zamolo 2005), automobile (Gröning and Holma 2007), grocery (Clark and Hammond 1997; Kaipia et al. 2002; Deakins et al. 2008), others (Tyan and Wee 2002; Henningsson and Lindén 2005; Kauremaa et al. 2007; Claassen et al. 2008; Gronalt and Rauch 2008).

These case study papers underline the fact that VMI is more than an operational replenishment system. First, VMI is part of a larger collaboration partnership that includes tactical and strategic exchanges between partners. Secondly, these exchanges imply information technology changes (Holmström 1998; Achabal et al. 2000; Vigtil 2007; Vigtil and Dreyer 2008).

The main objectives of VMI have been widely studied. According to Tang (2006), the customer's target is to ensure higher consumer service levels with lower inventory costs. The supplier's target is to reduce production, inventory and transportation costs. Some authors identify common subobjectives which permit the building of a better collaboration between partners, thereby reaching the main objectives. These authors claim that VMI also aims at speeding up the supply chain (Holweg et al. 2005) and so at reducing the bullwhip effect (Disney and Towill 2003; Holweg et al. 2005; Achabal et al. 2000; Cetinkaya and Lee 2000).

VMI concepts have been defined (Marques et al. 2008) as follows:

- a replenishment pull inspired system;
- where the supplier is responsible for the customer's inventory replenishment;
- within a collaborative pre-established medium- or long-term scope.

Moreover, VMI introduces information sharing and common decision-making processes. The integration of VMI into partners' planning and scheduling processes results in a new collaboration protocol. Three levels in this protocol have been highlighted. The partnering agreement specifies the integration of the planning processes of the partners into a "VMI replenishment planning process". The Logistical agreement fixes the parameters, which regulate the management of each article (minimum maximum inventory level, minimum delivery quantity, transport schedule, etc.) (Gröning and Holma 2007). The Production and dispatch process monitors short-term pull decisions such as production dispatch and transport.

Why is VMI pull inspired?

The comparison between push and pull systems has been often studied in the literature (Benton and Shin 1998; Spearman and Zazanis 1992; Ho and Chang 2001). Benton and Shin (1998) define three ways to distinguish the nature of push and pull systems:

- *order release:* removing an end item in pull and anticipating future demand in push. In other terms, the question: "What is the triggering event of the process?" is asked;
- *structure of the information flow:* local and decentralized in pull, global and centralized in push. In other terms, the question: "What is the information we have to make the decision?" is asked;

- *Work In Progress (WIP)* management: open queuing network with infinite queue space in push and closed queuing network in pull. In other terms, the question: "Which control of the WIP?" is asked.

The first objective of this paper is then to study in which way VMI inherits pull philosophy. Thus, we first subject VMI to these three questions.

An order release based on the demand

Lack of demand visibility has been identified as an important challenge for supply chain management, resulting in inefficient capacity utilization, poor product availability and high stock levels for each partner (Smaros et al. 2003). According to this, increasing the demand visibility for production and inventory control was a first step to improving this collaboration between members of the supply chain. In this view, Quick Response (QR) was born in the early 80s in order to reduce the delay needed to serve customers in the textile industry. The supplier receives point of sale data from the customer and uses this information to synchronize production. In the early 90s, Continuous Replenishment Policy (CRP) was developed: based on consumer demand, the CRP pull system, based on real product consumption rate (Ip et al. 2007) replaces historical push systems based on demand forecast. Between traditional supply, QR and CRP, suppliers' decisional sphere gradually grew until VMI, which transfers responsibility for the totality of the customer's inventory replenishment decisions to the supplier (Tyan and Wee 2002). VMI inherits this pull logic and ODETTE (2004) clearly underline this link:

- a replenishment signal is sent after the product consumption;
- delivery quantities and times are predefined based on consumed quantity (supplier reacts);
- forecast/planned consumption is not taken into account to make the dispatch decision (but it is taken into account in the min and max calculation).

A transfer of information for a transfer of a decision

Whatever the type of classic protocol, push or pull, the demand received by the supplier is composed of two main dimensions:

- the real requirements (or net requirement) related to the market demand requirements (through the production requirements): gross requirement less inventory level;
- the indirect requirements related to the risk management (demand, supply or internal risks): safety stock (in pieces or in days). They are added to the real requirements when the supply decision is made.

In push or pull systems, the supplier can not differentiate these two types of requirements but simply has to meet the order. Regarding a customer characterized by a limited risk aversion, the security inventory level could be very large and the supplier could have some difficulties to respect all the orders. This is one of the primary interests of VMI. With VMI, the customer delegates ordering and replenishment planning decisions to the supplier (Tang 2006). As Disney and Towill (2003) argue, moving to VMI alters the fundamental structure of supply chain ordering. If the order release remains the customer's demand, the principle of VMI rests on a transfer of responsibility for the customer's inventory replenishment decision. Most authors agree on the interest of transferring the customer's inventory responsibility from customer to supplier (Dong et al. 2007; Holweg et al. 2005; Kaipia and Tanskanen 2003; Tang 2006; Kuk 2004).

Holweg et al. (2005) explain that the supplier has to base replenishment decisions on the same information that the customer previously used to make its purchase decisions. When VMI is implemented, the supplier has a better vision of the customer's demand (Kaipia and Tanskanen 2003). Thanks to this improved visibility, the supplier is able to smooth the peaks and the valleys in the flow of goods (Kaipia and Tanskanen 2003). In other terms, it could reduce the bullwhip effect. Disney and Towill (2003) have demonstrated that VMI can reduce this effect by 50%, mainly thanks to the visibility of the demand through the in-transit and customer's inventory levels. Yao and Dresner (2007) show that information sharing reduces the supplier safety stock, thereby reducing the average inventory level.

Even if it is one of the main causes of VMI failure (Tyan and Wee 2002), this information sharing is the key aspect of VMI. Being cognizant of a better structure of the demand could have great consequences on dispatch decisions, and therefore on supply performance. These consequences should be explored more deeply.

A min/max to control the WIP

In pull systems, strategies as kanban or conwip aim at limiting inventory level, respectively, at each stage of a production process or at the whole production line (Gaury et al. 2000). With VMI, the supplier has to maintain the customer's inventory level within certain pre-specified limits (Tang 2006) based on a minimum and maximum range (ODETTE 2004). These bounds allow the quantity sent to the customer to be limited and controlled. That is why, even if there are no kanban-style stickers, the supplier monitors in-transit and inventory quantities. The supplier must keep sufficient inventory at the customer's site so that the customer's service level

Table 1 Push/pull VMI inspiration comparison

	Order release	Structure of the information flow	Work in progress
Push	**Forecast** (future demand)	**Global middle long** term customer information	**Infinite** queuing
Pull	**Real** product consumption rate (removing an end item)	**Local short term** customer information	**Fixed** quantity
VMI	**Real** product consumption rate (end item stock level)	**Local short middle term** customer and supplier information	**Limited** interval

is unchanged (Yao and Dresner 2007). ODETTE (2004) emphasize the fact that min/max inventory levels have to be agreed mutually by the partners. They give an example of this calculation:

- Average Planned Daily Usage (ADU) = (Forecast total/(actual number of weeks with > zero planned usage))/5
- Min calculation = Days of safety stock * ADU
- Max calculation = Min + (5/Weekly ship freq.*ADU) + (Transit days * ADU)

In addition to the decrease of inventory levels, this minimum and maximum quantity of components constraint in the customer's inventory implies more small quantities and higher delivery frequencies. Implementing VMI leads to higher replenishment frequencies with smaller replenishment quantities (Yao et al. 2007; Dong et al. 2007) and so to greater inventory cost savings (Cetinkaya and Lee 2000). With VMI, the supplier obtains a new degree of liberty. It has the liberty of making decisions on quantity and timing of replenishment (Rusdiansyah and Tsao 2005).

Synthesis

Table 1, below summarizes points underlined in the three last parts. The three columns represent the three previously identified questions: What is the triggering event of the process? What is the information we have to make the decision? Which control of the WIP?

VMI clearly appears as a pull inspired strategy. The main difference of this supply strategy when compared to a pull strategy is the transfer of replenishment decision responsibility that modifies the structure of the information flow. We can add the fact that with VMI removing an end item does not imply obligatory an order as with pull. A degree of freedom is given to the new decision maker: the supplier. Consequently, even if the WIP is not fixed by a real quantity as in pull, it is controlled through a limited interval defined by the partners.

Simulation model and approach

We have established a direct relation between pull and VMI and extracted a VMI process. In order to test some common assumptions about VMI, we have implemented this VMI process inside a simulation tool. This section is dedicated to the global approach and a description of the simulation models.

A simulation and risk oriented approach

In this study, we seek to help managers with strategic decision-making in order to define a collaboration strategy. This collaboration strategy is built up from both a specified collaboration protocol (or process) and the different partners' local planning behaviors. According to this idea, we propose a simulation approach that helps the decision-maker to fix his/her choice on a collaboration strategy enabling the evaluation of the risks of different protocols and behaviors.

After defining the structure of the supply chain, we identify possible decisions and events that can impact the performance of the chain. We distinguish three types of element: demand market scenario, collaboration protocols and actors' local planning behaviors. This defines an experimental plan that is processed using a simulation. Each experiment in the plan is processed by a simulation tool and defined by several parameters. Two types of parameters are distinguished:

- *Structural parameters*: These parameters are shared by all the experiments. They define the structure of the supply chain under study and its different products. Furthermore, they could define elements of the demand market.
- *Simulation parameters*: Each simulation parameter has a given set of values for each experiment. They are defined according to the questions the manager formulates. We differentiate parameters that are *decisions* of actors or group of actors and the *events* that occur during the simulation.

The global performance of the supply chain and performance of each actor are evaluated. Managers base their decision-making on these evaluations. When all the experiments are performed, the target is to analyze the impact of each simulation parameter on the performance.

A simulation tool: LogiRisk

Our approach is based on an extension of a simulation tool dedicated to risk evaluation of supply chain planning

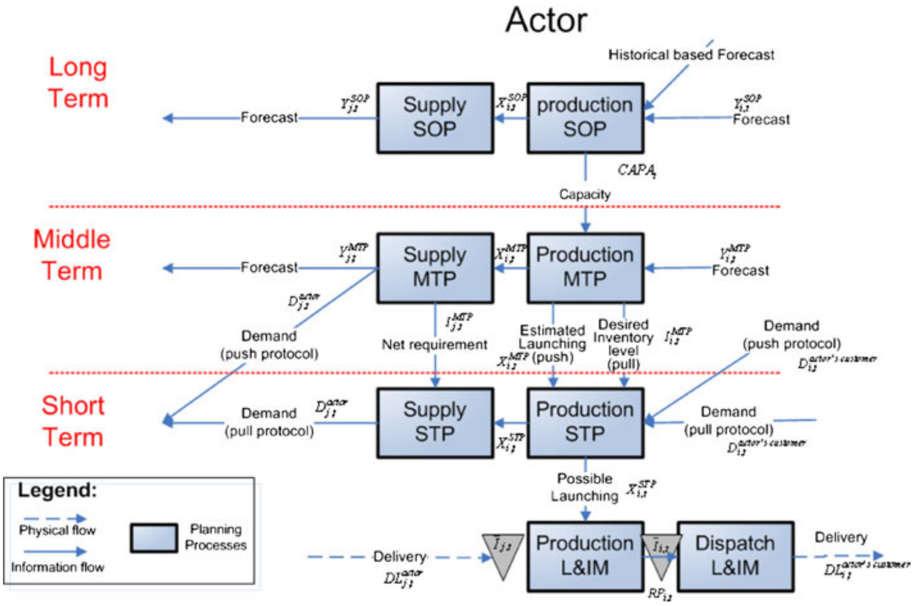


Fig. 1 The generic LogiRisk representation of the supply chain actor's planning processes

processes. In this part, we first give a general description of the macro processes of the tool that have been the subject of detailed presentations in previous articles (Lamothe et al. 2007; Mahmoudi 2006). Then, as VMI processes have been implemented in the existing models, we study the impact of VMI implementation on these in greater detail.

Actor's planning processes

Lamothe et al. (2007) propose a simulation tool called LogiRisk developed in Perl language. This simulator is based on a discrete event simulation modeling approach. They have established a generic representation of the different planning processes (SOP, MTP, STP and L&IM) for each supply chain actor. These four planning levels could be seen according to two points of view: internal (production SOP, production MTP, …) that expresses one's own production decisions, and external that expresses the material requirement sent to the supplier (supply MTP, supply STP, …) or the delivery decisions (dispatch L&IM). The Fig. 1, below summarizes these planning processes. Dotted lines separating the different horizons illustrate the aggregation/desegregation transformations which are currently made in LogiRisk.

The actor's model is centred on the strategic (SOP) and, to a lesser extent, the tactical processes (MTP). LogiRisk does not simulate the short-term but only makes a weekly flow assessment in order to know, for each week, what the actors wanted to produce (STP) and what they actually produced (L&IM). In the Table 2 below, we have cited the main models that define each process (columns 1 and 2). Then, for each model, we particularly underline parameters associated to the actors' behavior. Finally, we give main equations that take into account these parameters. For further explanations, we refer to Lamothe et al. (2007). In column 1, we see that SOP and MTP use the same models. In fact, if the models are the same, the input data taken into account are different (granularity, originated process).

The *Sales and Operations Planning (SOP)* processes detail the various decisions taken throughout long-term planning. The most important outputs of these processes are the production capacities (production SOP) and long-term forecast of supply requirement (supply SOP) (see Fig. 1). This model includes the products sale forecasting model. If no demand forecast is transmitted, the production SOP process internally computes its forecasts using simple, double, triple or Holt and Winters Smoothing algorithm (Eq. (1) Table 2). In other cases, it sums up the forecasts transmitted by customers (Eq. (1')). According to the demand forecasts, the workload is computed and smoothed over several time periods (Eq. (2)) in the infinite capacity net requirement model. The resulting workload defines a capacity plan that must be validated by the SOP manager (Eq. (3)). This latter has a specific planning behavior: s/he compares the proposed capacity plan to the one validated in the previous SOP process, and accepts a given percentage of capacity variation. From this capacity plan, a planned production is calculated that allows a long term raw material procurement plan to be computed (Eqs. (4)–(8)).

The *Medium-Term Planning (MTP)* processes compute the estimated production release of final products, as well as the required raw materials to order from the suppliers, or inventory levels (Eqs. (2), (4)–(8)) in function of the actor's behavior in term of production type (push or pull). As in the SOP processes, the demand forecasts are either updated internally or aggregated from the demand forecast information received from the customers (Eqs. (1) or (1′)).

Table 2 Details of actor's planning processes (inspired from Lamothe et al. 2007)

Processes	Process models		
	Models	Actors' behaviors parameters	Main equations
P. SOP,P. MTP	Products sale forecasting	Internal forecasting (and type of forecasting: F)	$F_{i,t}^{p} = F\,(Historic\ demand\ for\ i)$ (1) *with a function F: Holt and Winters algorithm, simple, double or triple smoothing*
		External forecasting	$F_{i,t}^{p} = \sum Forecasts\ transmitted\ for\ i$ (1′)
P. SOP P. MTP	Infinite capacity net requirement	Products Safety Inventory level ($SS_{i,t}$)	$\mathrm{NR}_{i,t}^{p} = F_{i,t+l_i}^{p} - RP_{i,t+l_i} - I_{i,t+l_i-1}^{p} + SS_{i,t+l_i}$ (2)
P. SOP	Production capacities plan defining	Capacity variation acceptation (δ), Algorithm smooth_1	$CAPA_t = \delta \times smooth\_1\left(\left\{NR_{i,t}^{\mathrm{SOP}}\right\}^{i}\right) + (1-\delta) \times previousCAPA_t)$ (3)
P. SOP, P. MTP	Production and products inventory levels planning	Production smoothing algorithm Smooth_2	$X_{i,t}^{p} = smooth\_2\left(\left\{NR_{i,t}^{p}\right\}^{i}, CAPA_t\right)$ (4) $I_{i,t}^{p} = I_{i,t-1}^{p} - F_{i,t}^{p} + RP_{i,t} + X_{i,t-l_i}^{p}$ (5) $GR_{j,t}^{p} = X_{i,t}^{p} \times BOM_{i,j}$ (6)
S. SOP, S. MTP	Supply requirement and component inventory level planning	Component Safety Stock ($SS_{j,t}$)	$Y_{i,t}^{p} = GR_{j,t+l_j}^{p} - RP_{j,t+l_j} - I_{j,t+l_j-1}^{p} + SS_{j,t}$ (7) $I_{j,t}^{p} = I_{j,t-1}^{p} - GR_{j,t}^{p} + RP_{j,t}$ (8)
P. STP	Desired production computing	Push production	$XD_{i,t} = X_{i,t}^{MTP}$ (9)
		Pull production	$XD_{i,t} = I_{i,t}^{MTP} - \overline{I}_{i,t} + D_{i,t}$ (9′)
	Admissible production computing		$X_{i,t}^{STP} = \min\left(XD_{i,t};\ \frac{XD_{i,t}}{\sum_i XD_{i,t}} \times CAPA_{i,t} \times \beta_{i,t}\right)$ (10) $GR_{j,t}^{STP} = X_{i,t}^{STP} \times BOM_{i,j}$ (11)
S. STP	Procurement order computing		$D_{j,t} = \begin{cases} Y_{j,t}^{MTP} & if\ protocol\ is\ push \\ GR_{j,t}^{STP} + I_{j,t}^{MTP} - \overline{I}_{j,t} & if\ protocol\ is\ pull \end{cases}$ (12)
P. L&IM	Effective production launching		$X_{i,t}^{L\&IM} = \min\left(X_{i,t}^{STP};\ \frac{DL_{j,t-l_j} + \overline{I}_{j,t}}{BOM_{i,j}}\right)$ (13)
	Planned receipt planning		$RP_{i,t+l_i} = X_{i,t}^{L\&IM}$ (14)
D. L&IM	Deliveries computing		$DL_{i,t}^{\mathrm{tot}} = \frac{\min\left(D_{i,t} + I_{i,t}^{-}\ ;\ RP_{i,t} + \overline{I}_{i,t}\right)}{D_{i,t} + I_{i,t}^{-}}$ (15) $DL_{i,t}^{C} = DL_{i,t}^{\mathrm{tot}} \times \left(D_{i,t}^{C} + I_{i,t}^{-,C}\right)$ (16)

The *Short-Term Planning (STP)* and the *Launch & Inventory Management (L&IM)* processes both detail the various short-term decisions. The *Short-Term Planning* process takes into account the calculation of the desired production release (desired production computing model), the actor's own constraints (i.e. breakdowns in admissible production computing model) and the demand sent to the suppliers (procurement order computing model) (Eqs. (9)–(12)).

The *Launch & Inventory Management* process is responsible for taking into account the other actors' constraints (i.e. insufficient delivery, etc.) and the products inventories update. It deduces the real production release and finally the quantities to be dispatched to each customer (Eqs. (13)–(16)).

Hypothesis applied to express the models in Table 2:

- Each actor manages a single resource: the bottleneck. Production lot sizes equal to 1
- Products are considered as families as seen from the SOP process point of view. Each item of each actor is composed of one unique component.
- For a given process, all the actors use the same horizon, granularity, and replanning period. When disaggregating plans, quantities are equitably distributed over the time buckets of each planning period.

Notations used in the Table 2:

- i: product i.
- j: component j (component of product i).

- C: customer of the actor
- l_i: production lead time of the product i (resp. component j).
- F_i: Sales Forecasted of the product i (resp. component j).
- $NR^p_{i,t}$: infinite capacity net requirement of product i at t, by the Process p (∈[SOP;MTP]).
- $\left\{NR^p_{i,t}\right\}^i$: set for all products i of associated net requirement.
- $CAPA_t$: Capacity decided for period t.
- $X^p_{i,t}$: Planned Production of product i (resp. component j), for period t, by the Process p (∈[SOP;MTP;STP; L&IM]).
- $RP_{i,t}$: Planned Receipt of product i (resp. component j), for period t.
- $I^p_{i,t}$: Inventory level of product i (resp. component j) planned for the end of period t, by the Process p (∈[SOP;MTP;STP;L&IM]).
- $SS_{i,t}$: Safety Stock expressed in days of stock of product i (resp. component j) for period t.
- $GR^p_{i,t}$: Gross Requirement of product i (resp. component j) for period t, by the Process p (∈[SOP;MTP;STP; L&IM]).
- $BOM_{i,j}$: Bill of Material link between the product i and its component j
- $Y^p_{i,t}$: Planned supply requirement of product i (resp. component j) for period t, by the Process p (∈[SOP;MTP;STP; L&IM]).
- $\overline{I}^p_{i,t}$: Actual inventory position of product i (resp. component j).
- $D_{i,t}$: Total orders of product i (resp. component j) received by the actor for the time t.
- $D^C_{i,t}$: Total orders of product i (resp. component j) received by the actor from the customer C for the time t.
- $\beta_{i,t}$: Availability rate of the capacity affected to the product i (resp. component j) at time t. Capacity less breakdowns.
- $DL^{\text{tot}}_{i,t}$: Total deliveries of product i (resp. component j) at time t decided by the actor.
- $DL^C_{i,t}$: Total deliveries of product i (resp. component j) at time t decided by the actor for customer C.
- $I^-_{i,t}$: Total of inventory shortage of product i (resp. component j) at time t.
- $I^{-,C}_{i,t}$: Inventory shortage of product i (resp. component j) at time t toward customer C.

Specific notations for VMI processes (part 3.2.2.)

- $VMI\_\min_{j,t}$ $VMI\_\max_{j,t}$: targeted inventory min/max fixed by a customer.
- α: supplier's behaviour towards the interval [min;max].
- $\alpha\_\text{VMI}_{j,t}$: Targeted inventory fixed by the supplier for its SOP and MTP processes.
- $D^{\text{real}}_{i,t}$, $D^{\min}_{i,t}$, $D^{\max}_{i,t}$: Total real/min/max requirement seen by the supplier.
- $D^{\text{real},C}_{i,t}$, $D^{\min,C}_{i,t}$, $D^{\max,C}_{i,t}$: Customer's C real/ min/max requirement received by the supplier.

Collaboration processes

In this part we describe the collaboration process models that are simulated by the tool. In this study three different collaboration protocols are implemented:

- *Push*: modelled by a medium-term component orders.
- *Pull*: inspired from kanban method: short-term orders with kanban quantity revision associated to STP processing.
- VMI: modelled with a medium-/ long-term agreement (LA) and a supply STP decision transfer from the customer to the supplier.

The Figs. 2–4, below, illustrate the different collaboration processes considered in this study. Simulation processing order is as defined by the numbers (1 to 16 or 17).

In the next part we detail the models of processes that are impacted by VMI implementation (shown in red in the Fig. 4).

VMI impact on the strategic horizon: the min/max calculation

On the strategic horizon, partners have to collaborate in order to fix the customer's minimum and maximum inventory level in the LA. However, in reality VMI implementation is most of time originated by a powerful customer. In this case, there is no effective negotiation. A true negotiated LA is not realized. The min/max inventory levels only include customers' constraints. The supplier has to choose a strategy between the min and the max in order to fix targeted inventory for his own production SOP and MTP processes. The model integrates this vision. In the model, for a time t, the min/max calculation is only based on the customer's long-term forecasted gross requirement for components (j), expressed as $GR^{\text{SOP}}_{j,t}$. This $GR^{\text{SOP}}_{j,t}$ results from the customer's production SOP planning process. We introduce two parameters: cover_min_j and cover_max_j. They are two coefficients applied to the $GR^{\text{SOP}}_{j,t}$ in order to obtain two levels of customer's targeted inventory min/max.

$$\text{VMI\_}\min_{j,t} = \sum_{t=0}^{t=\text{cover\_min}_j} GR^{\text{SOP}}_{j,t} \quad couv\_\min_j \in \Re^+ \quad (17)$$

$$\text{VMI\_}\max_{j,t} = \sum_{t=0}^{t=\text{cover\_max}_j} GR^{\text{SOP}}_{j,t} \quad couv\_\max_j \in \Re^+ \quad (18)$$

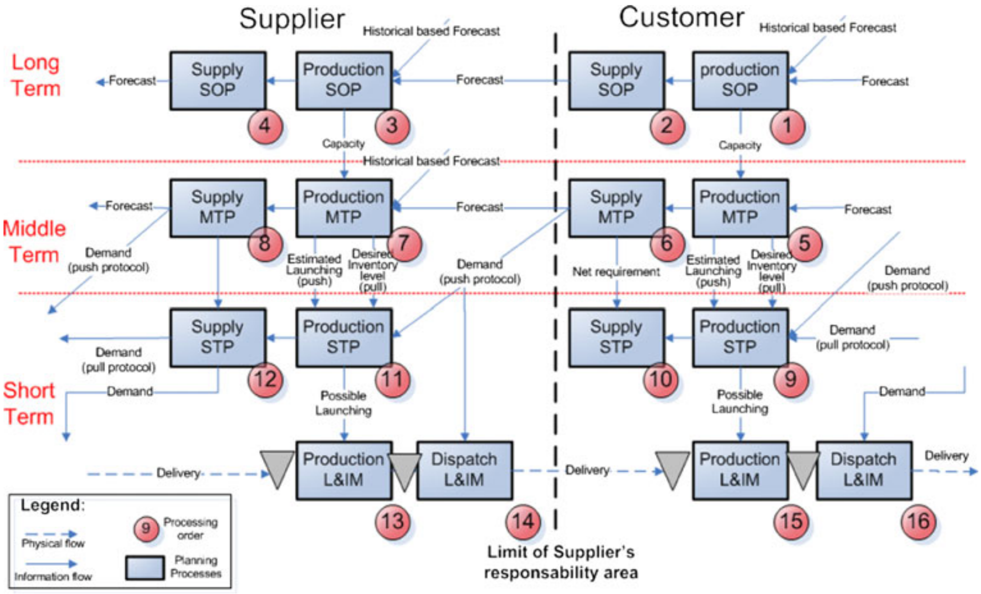


Fig. 2 Push collaboration process

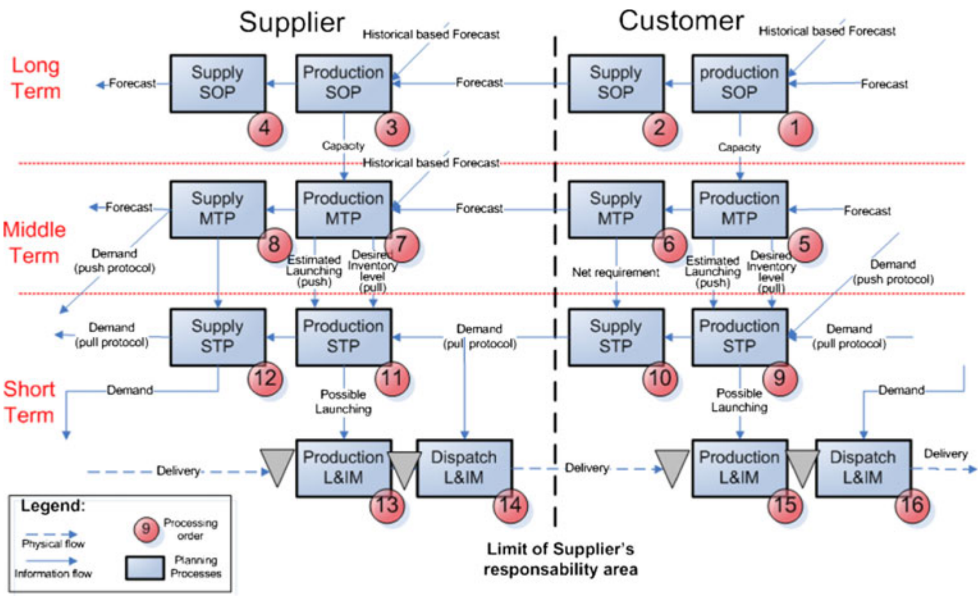


Fig. 3 Kanban collaboration process

Then the supplier has to express his behavior toward this min/max level. In consequence, we introduce a parameter, expressed as α, that translates the supplier's behavior towards the interval [min;max] that it receives. This variable defines the planned level of replenishment that the supplier wants to achieve.

$$\alpha\_\mathrm{VMI}_{j,t} = (1-\alpha) \times \mathrm{VMI}\_\min_{j,t} + \alpha \times \mathrm{VMI}\_\max_{j,t} \qquad (19)$$

This planned level of replenishment is taken into account in the customer's supply SOP and MTP. It replaces the Safety Stock level in the equations (2):

$$SS_{j,t} = \alpha\_\mathrm{VMI}_{j,t} \qquad (20)$$

Impact of VMI on the operational horizon: supply and dispatch decisions

LogiRisk distinguishes three protocols

- **Push:** The production MTP process defines planned production under capacity constraints expressed by the production SOP process. This planned production of item i at time t is expressed as $X_{i,t}^{\mathrm{MTP}}$. Then, the customer's supply

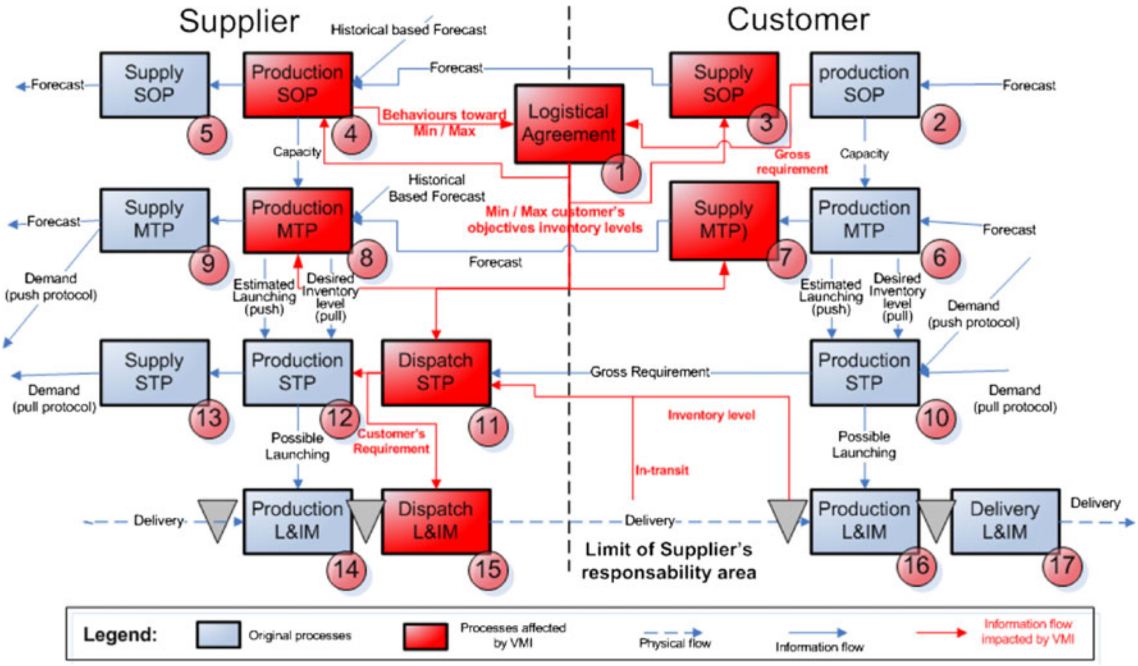


Fig. 4 VMI collaboration process

MTP calculates the firm orders of component j at time t, expressed as $D_{j,t}$. The Bill Of Material link between i and j is expressed as $BOM_{i,j}$. In the push protocol, $D_{j,t}$ is a direct expression of supply requirement planned at time t for component j defined by the customer's supply MTP and expressed as $Y^{\mathrm{MTP}}_{j,t}$.

$$D_{j,t} = Y^{\mathrm{MTP}}_{j,t} \tag{12}$$

$Y^{\mathrm{MTP}}_{j,t}$ integrates both real requirements related to the market demand requirements and indirect requirements related to the risk management, as referred to in part 2.2.2.

- **Kanban:** In kanban supply, $D_{j,t}$ is built thanks to the planned inventory level of j at time t defined by the customer's MTP ($I^{\mathrm{MTP}}_{j,t}$), the customer's actual inventory level ($\overline{I}_{j,t}$) and the production requirements transmitted by the customer's production STP ($X^{\mathrm{STP}}_{i,t}$).

$$D_{j,t} = I^{\mathrm{MTP}}_{j,t} - \overline{I}_{j}, t + BOM_{i,j} \times X^{\mathrm{STP}}_{i,t} \tag{12}$$

$I^{\mathrm{MTP}}_{j,t}$ represents the indirect requirements related to risk management. The rest of the expression is real requirements related to market demand.

- **VMI**: In VMI supply, the customer's supply STP is replaced by a supplier's dispatch STP (transfer of responsibility). Consequently, with VMI, customers' requirement is not a quantity but an interval in which the supplier can express its new degree of freedom: the delivery quantity. In this case, customers' requirements comprise three values:

$$D^{\mathrm{real}}_{j,t} = BOM_{i,j} \times X^{\mathrm{STP}}_{i,t} - \overline{I}_{j,t}$$

$$D^{\min}_{j,t} = \mathrm{VMI\_min}_{j,t}$$

$$D^{\max}_{j,t} = \mathrm{VMI\_max}_{j}, t$$

As in kanban, we find the expression of the customers' real requirements related to market demand ($D^{\mathrm{real}}_{j,t}$). However, indirect requirements related to risk management are not expressed by $I^{\mathrm{MTP}}_{j,t}$ but by the results of min/max calculation ($\mathrm{VMI\_min}_{j,t}$ and $\mathrm{VMI\_max}_{j,t}$). In the interval characterized by the triplet ($D^{\mathrm{real}}_{i,t}$, $D^{\min}_{i,t}$, $D^{\max}_{i,t}$) the supplier's dispatch STP process fixes a targeted dispatch level in order to organize the production. Thus, the Eq. (12) is replaced by the following equation:

$$D_{j,t} = D^{\mathrm{real}}_{j,t} + (1-\alpha) \times D^{\min}_{j,t} + \alpha \times D^{\max}_{j,t} \quad \text{with} \quad \alpha \in [0; 1] \tag{12'}$$

The output of the suppliers dispatch L&IM process is a delivery quantity of i (a supplier's item i is a customer's component j) sent to the customer C at time t, expressed as $DL^{C}_{i,t}$. The structure of the demand transmitted to the supplier has an impact on this process:

- **Push/kanban**: in the initial dispatch model, the supplier compares its actual end products inventory level and the

Table 3 Possible values of $DL_{i,t}^{\text{tot,real}}$, $DL_{i,t}^{\text{tot,min}}$ and $DL_{i,t}^{\text{tot},\alpha}$ in function of inventory level ($\overline{I}_{i,t}$)

	$\overline{I}_{i,t} = 0$	$\overline{I}_{i,t} \leq D_{i,t}^{\text{real}}$	$D_{i,t}^{\text{real}} < \overline{I}_{i,t} \leq D_{i,t}^{\text{real}} + D_{i,t}^{\min}$	$D_{i,t}^{\text{real}} + D_{i,t}^{\min} < \overline{I}_{i,t} \leq D_{i,t}$	$D_{i,t} < \overline{I}_{i,t}$
$DL_{i,t}^{\text{tot,real}}$	0	$\frac{\overline{I}_{i,t}}{D_{i,t}^{\text{real}}}$	1	1	1
$DL_{i,t}^{\text{tot,min}}$	0	0	$\frac{\overline{I}_{i,t} - D_{i,t}^{\text{real}}}{D_{i,t}^{\min}}$	1	1
$DL_{i,t}^{\text{tot},\alpha}$	0	0	0	$\frac{\overline{I}_{i,t} - D_{i,t}^{\text{real}} - D_{i,t}^{\min}}{\alpha\left(D_{i,t}^{\max} - D_{i,t}^{\min}\right)}$	1

sum of all the demand from its customers. Two cases are distinguished. If the inventory level is bigger than the total of demand, the supplier delivers $D_{i,t}^{C}$ to each customer C. If the inventory level is smaller, the supplier delivers a proportion of $D_{i,t}$. This proportion is calculated and distributed to customers as follow:

$$DL_{i,t}^{\text{tot}} = \frac{\min\left(D_{i,t} + I_{i,t}^{-}\ ;\ RP_{i,t} + \overline{I}_{i,t}\right)}{D_{i,t} + I_{i,t}^{-}} \tag{15}$$

$$DL_{i,t}^{C} = DL_{i,t}^{\text{tot}} \times \left(D_{i,t}^{C} + I_{i,t}^{-,C}\right) \tag{16}$$

- **VMI**: With VMI, a better vision of demand ($D_{i,t}^{\text{real}}$, $D_{i,t}^{\min}$, $D_{i,t}^{\max}$) allows the process to be broken down. The supplier does not try to directly achieve $D_{i,t}$. First, it tries to satisfy $D_{i,t}^{\text{real}}$, then $D_{i,t}^{\min}$ and finally $D_{i,t}$. In consequence, we have distinguished 5 cases to adapt the Eq. (15). they are a function of the actual inventory level. For example, if the inventory of i is not sufficient to satisfy the real demand of all the customers, this process gives each customer a part of its real demand. The details of cases are given in the following Table 3:
Finally, we adapt the Eq. (16) as follow :

$$DL_{i,t}^{C} = DL_{j,t}^{\text{tot,real}} \times D_{j,t}^{\text{real},C} + DL_{j,t}^{\text{tot,min}} \times D_{j,t}^{\min,C} + DL_{j,t}^{\text{tot},\alpha} \times \alpha\left(D_{j,t}^{\max,C} - D_{j,t}^{\min,C}\right) \tag{16$'$}$$

Consequently, even if the contractual min is not always kept, the dispatch VMI increases the performance in terms of customer's component stock out.

Performance measurement during the simulation

As a complex system the supply chain has to confront potentially conflicting objectives. On the one hand, the supply chain is globally evaluated through the final consumer service level. On the other hand, each partner has to monitor its production using local objectives and constraints. Consequently, two levels of performance could be analyzed:

- a *global performance*, for example: a demand market stock out.
- a *local performance*, for example:
  - component and finished product inventory levels;
  - quantity of production that customers have not made due to component stock out;
  - amplitude of production capacity variations;
  - , etc.

LogiRisk allows all these performance to be measured for each period (week) and saved throughout the simulation.

VMI simulation and risk evaluation: case study illustration

In the present study, we want to test the demand trend stability hypothesis currently associated to VMI. Based on this, we examine two problem statements through the utilization of LogiRisk for a given supply chain:

- PS1: Can we justify VMI implementation despite a change in the demand trend?
- PS2: Which are the influential parameters of the VMI model implemented?

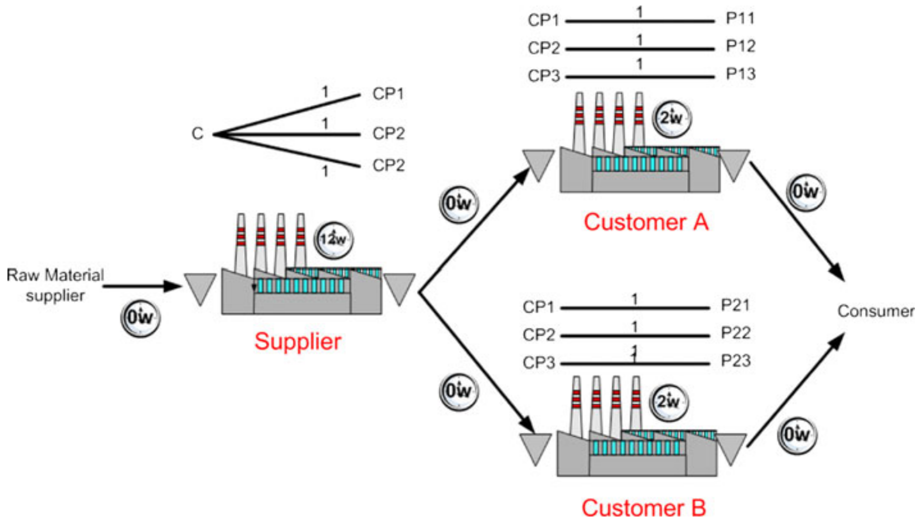
Structural parameters

Actors and products

The supply chain considered (Fig. 5) comprises one supplier and two customers, where:

- customer A makes three products (P11, P12 and P12) with three different components (CP1, CP2 and CP3) in a same pulled production unit with the same production time and the same production lead time: 2 weeks;
- customer B has the same characteristics as customer A, except the three finished products are named P21, P22 and P23, and use the same components);

Fig. 5 Supply Chain structure



- the supplier makes three products (CP1,CP2 and CP3) with a same component (C) in a same pushed production unit and a production lead time of 12 weeks.

The Fig. 5 synthesizes the general structure of the relationship, production and delivery time and the Bills Of Materials (BOM).

Table 4, below, gives the values for the initial inventories. They have been defined so that each actor can produce 5,00,000 units/week. There is no work in process initially.

Real demand variability

A normal distribution is used to represent uncertainty due to the gap between real and forecasted demand. The mean is the forecasted demand for the period and we introduce a standard deviation of 20%. We use the Mersenne Twister algorithm (Matsumoto and Nishimura 1998) to generate the real demand. This is a pseudorandom number generator that generates series of values from a seed. Each experiment has been replicated with ten seeds. In the following results, the performance values associated to each experiment are a mean of the performance values obtained with each seed.

Simulation duration

All the experiments of the plan are simulated over 600 weeks. In order to build all historical data for each actor and to obtain a stable state of the supply chain, the first 156 weeks are devoted to an initialization step. All analyses below are based on performance measures made between $t = 156$ and $t = 450$. The final 150 weeks are not taken into account in order to prevent time limit effects.

Simulation parameters

The two problem statements (justification of VMI despite a change in the demand trend and the VMI parameter choice) involve distinguishing two types of parameter: general simulation parameters and VMI-specific parameters. Each type is associated to a particular problem statement.

VMI-specific simulation parameters

In order to characterize the VMI, we add three VMI-specific parameters. These VMI parameters illustrate the decision levers emphasized in the literature review and the definition proposed:

Customer's Decision lever	LA frequency (called $S1$: 4; 8; 12; 24), expressed in weeks; levels of minimum and maximum customer levels (expressed in weeks) used in min/max calculation: cover_min (called $S2$) and cover_max (called $S3$).
Supplier's Decision lever	VMI coefficient expressed as α in our model (called $S4$), expressed by a real number inside [0; 1].

General simulation parameters

According to the approach described in "Simulation model and approach", we identify decisions and events among the general simulation parameters.

Decisions

Different replenishment systems between the actors are considered in the simulation. Thus the first general simulation

Table 4 Initial inventory levels

Actor	Product Id	Type	Initial inventory
Supplier	CP1	P	2,000,000
Supplier	CP2	P	2,000,000
Supplier	CP3	P	2,000,000
Customer A	CP1	RM	84,000
Customer B	CP1	RM	84,000
Customer A	CP2	RM	84,000
Customer B	CP2	RM	84,000
Customer A	CP3	RM	84,000
Customer B	CP3	RM	84,000
Customer A	P11	P	334,000
Customer B	P21	P	334,000
Customer A	P12	P	334,000
Customer B	P22	P	334,000
Customer A	P13	P	334,000
Customer B	P23	P	334,000

parameter is the type of supply (supply_type called $G1$: push; kanban; VMI).

In terms of actors' local planning behaviors, we introduce a general parameter: SS_coef. It allows different safety stock levels to be simulated (expressed in weeks). We differentiate two SS_coef: for the supplier's finished product inventory, called SS_coef_FP_S ($G2$: 0, 3; 0, 4) and for the customer's component inventory, called SS_coef_Cpt_C ($G3$: 0, 2; 0, 3).

Events

Whatever the type of replenishment, the demand market trend is always stable during a first period (t = 312). However, at t = 312, we simulate three different trends (demand_trend called $G4$): increased, stable and decreased. Figure 6, below, shows the demand we have simulated and the different periods we have distinguished for the analysis (T1 = [156; 291], T2 = [292; 364], T3 = [365; 450]).

We also take into account the vision of this market change: when do the actors know the market trend has changed and modify their forecasts? In order to translate this potential lag, we introduce a third simulation parameter expressed in weeks: the market_vision_variation (called $G5$: −20w; 0w; 10w). It is negative if the actors know the variation before its appearance, and positive otherwise.

The Table 5, below, summarizes the notations used:

Figure 7 summarizes the experimental plan carried out. It generates 2664 simulations.

Performance indicators

In terms of performance measurement, in this study we adopt the supply chain point of view. The whole analysis is based on two indicators:

- demand market stock out (called $C1$): for each week, we sum the quantity of orders customers have not respected (all customers and products taken into account);
- total inventory level in the chain (called $C2$): for each week, the sum of suppliers' and customers' component and finished product inventories (all products and components taken into account).

Depending on the dimension of the manipulated figures and the granularity level of our model, we round up all results to the nearest thousand.

Results and discussion

We have broken down the problem analysis into two main steps. First, we have analysed the influence of VMI parameters faced with the two types of events in addition to real demand variability: the trend (increased, decreased or stable) and the vision of the trend change (−20, 0, 10 weeks). From this analysis, we have identified which VMI parameters were influential, in order to make the comparison to pull and push supply processes. This is the second step of the study in which we answer PS2, i.e. can we

Fig. 6 Market demand

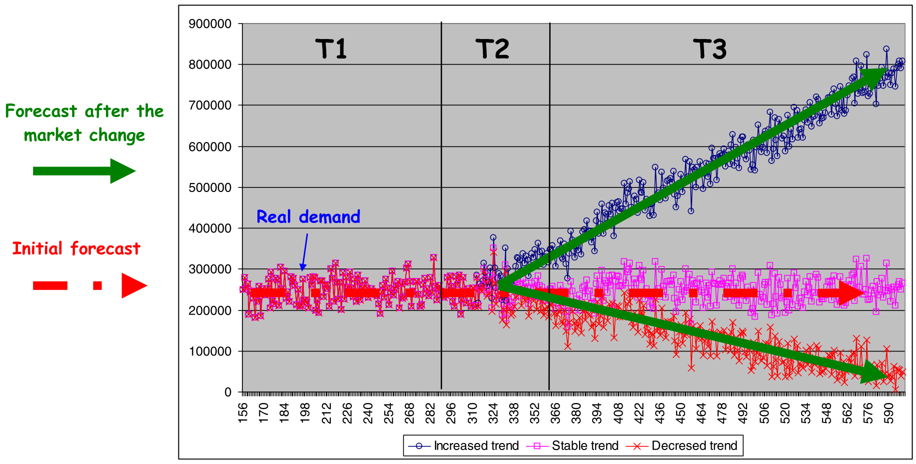


Table 5 Notations used in the analysis

Decisions		*VMI*	
G1	supply_type	**S1**	LA frequency
G2	SS_coef_FP_S	**S2**	cover_min
G3	SS_coef_Cpt_C	**S3**	cover_max
G3′	SS_coef_Cpt_C or cover_max	**S4**	coef_VMI
Performance measures		*Events*	
C1	Demand market stock out	**G4**	demand_trend
C2	Total Supply chain inventory level	**G5**	market_vision_variation

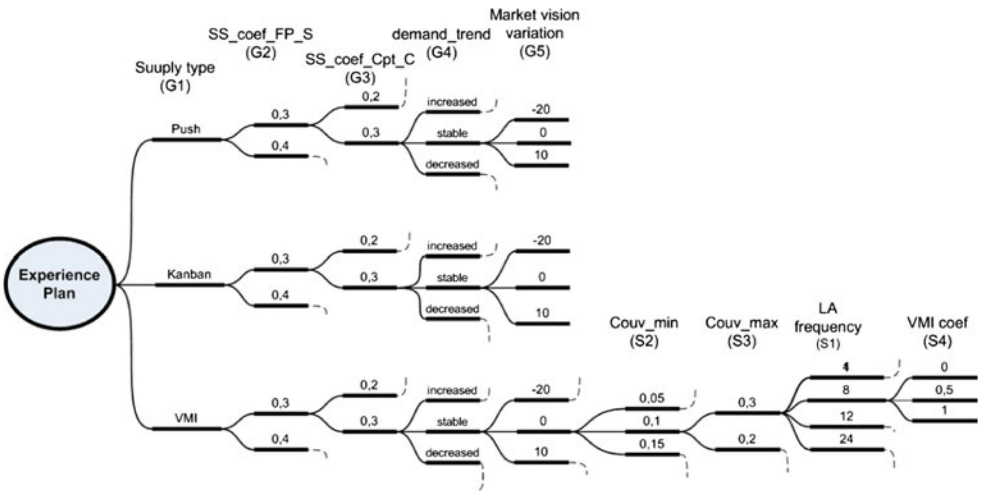


Fig. 7 Simulation parameters

justify VMI implementation despite a change in the demand trend?

Step 1: VMI parameters influence analysis (PS1)

In this step of the analysis, we have analysed the effect of the VMI parameters (S1, S2, S3 and S4) on the performance levels. It represents an experimental plan where the factors are: S1, S2, S3, S4, G4 and G5.

In this step, we have chosen to prioritise market satisfaction. In consequence, we first minimize market stock out (C1).

In order to analyze the results of this experimental plan, we firstly used Tagushi's method that allows effects of factors and interactions to be measured. In addition to this measurement, we applied Fisher Snedecor variance test to the model (with a probability of 0.05) which allows the significant effects of an experimental plan to be identified.

Table 6 Results of the VMI experimental plan during T2 for G4 = increased

S4	S3	S2	G5					
			C1			C2		
			−20	0	10	−20	0	10
0	0, 2	0, 05	12,000	18,000	117,000	401,000	351,000	261,000
		0, 1	11,000	16,000	110,000	430,000	378,000	283,000
		0, 15	10,000	15,000	103,000	460,000	406,000	306,000
	0, 3	0, 05	12,000	18,000	117,000	401,000	351,000	261,000
		0, 1	11,000	16,000	110,000	430,000	378,000	283,000
		0, 15	10,000	15,000	103,000	460,000	406,000	306,000
0, 5	0, 2	0, 05	11,000	15,000	107,000	445,000	392,000	294,000
		0, 1	10,000	15,000	103,000	460,000	406,000	306,000
		0, 15	10,000	14,000	100,000	474,000	419,000	318,000
	0, 3	0, 05	10,000	14,000	100,000	474,000	419,000	318,000
		0, 1	10,000	13,000	98,000	489,000	433,000	329,000
		0, 15	10,000	13,000	95,000	504,000	447,000	341,000
1	0, 2	0, 05	10,000	13,000	98,000	489,000	433,000	329,000
		0, 1	10,000	13,000	98,000	489,000	433,000	329,000
		0, 15	10,000	13,000	98,000	489,000	433,000	329,000
	0, 3	0, 05	9,000	11,000	87,000	547,000	489,000	377,000

Table 7 Results at T1

G1	G2	G3′	C1	C2
Kanban	0, 3	0, 2	16,000	470,000
		0, 3	14,000	519,000
	0, 4	0, 2	14,000	519,000
		0, 3	12,000	568,000
VMI	0, 3	0, 2	16,000	476,000
		0, 3	14,000	519,000
	0, 4	0, 2	14,000	525,000
		0, 3	12,000	568,000
Push	0, 3	0, 2	19,000	472,000
		0, 3	15,000	520,000
	0, 4	0, 2	17,000	520,000
		0, 3	13,000	569,000

Conclusion 1 the Fisher Snedecor variance test shows that the LA_frequency has no significant effect on the two performance measurements.

This result is proved by the current LA model. In the model, the min/max calculation is imposed by the powerful customer. No negotiation is done.

Tables 6–10 below, summarizes the results obtained for the different experiments at T1, T2 and T3. We have analysed the results for each time period: T1, T2 and T3 for each trend. All the following conclusions are the same for each time period and each trend.

Conclusion 2 the minimum of market stock out is obtained for $\alpha = 1 (S4 = 1)$.

α (S4) translates the replenishment level chosen by the supplier. When α is equal to 1, the supplier targets are all over maximum. Larger is the customer's component inventory level; lower is level of market stock out. In consequence, we fix $\alpha = 1$ in step 2.

Table 8 Results at T2 for C1 (market stock out)

×1000			G5								
			−20			0			10		
			G4			G4			G4		
G1	G2	G3′	Decreased	Stable	Increased	Decreased	Stable	Increased	Decreased	Stable	Increased
Kanban	0, 3	0, 2	18	15	10	17	15	15	17	15	82
		0, 3	15	13	9	15	13	12	14	13	70
	0, 4	0, 2	15	13	9	15	13	12	14	13	70
		0, 3	13	11	8	13	11	10	13	11	61
VMI	0, 3	0, 2	18	15	10	17	15	15	17	15	82
		0, 3	15	13	9	15	13	12	14	13	71
	0, 4	0, 2	15	13	9	15	13	12	14	13	71
		0, 3	13	11	8	13	11	10	13	11	61
Push	0, 3	0, 2	22	18	13	21	18	17	21	18	86
		0, 3	17	14	10	17	14	13	16	14	73
	0, 4	0, 2	19	16	11	19	16	14	18	16	74
		0, 3	15	13	9	15	13	12	15	13	63

Table 9 Results at T2 for C2 (total chain inventory)

×1000			G5								
			−20			0			10		
			G4			G4			G4		
G1	G2	G3′	Decreased	Stable	Increased	Decreased	Stable	Increased	Decreased	Stable	Increased
Kanban	0, 3	0, 2	417	437	519	436	437	467	489	437	335
		0, 3	461	485	578	481	485	524	535	485	384
	0, 4	0, 2	461	485	577	481	485	524	535	485	384
		0, 3	506	535	636	527	535	582	582	535	436
VMI	0, 3	0, 2	417	437	519	437	437	466	490	437	335
		0, 3	461	486	578	482	486	522	536	486	384
	0, 4	0, 2	461	486	578	482	486	523	536	486	384
		0, 3	506	535	636	528	535	580	583	535	436
Push	0, 3	0, 2	421	439	520	439	439	469	492	439	338
		0, 3	463	486	578	483	486	525	536	486	387
	0, 4	0, 2	465	487	578	484	487	526	538	487	388
		0, 3	508	536	636	528	536	582	583	536	438

Conclusion 3 results C1 and C2 show that, when $\alpha = 1$, the minimum target level has no effect (S2).

According to the model and the role of α in the choice made between minimum and maximum, when $\alpha = 1$ is chosen, any minimum target could be fixed. In consequence, we fix the minimum to 0.1 in step 2.

Conclusion 4 the effect of the maximum target (S3) is too significant to be ignored in step 2. It will be a variable of step 2.

Step 2: collaboration processes comparison (PS2)

In this stage of the analysis we seek to test the demand stability hypothesis. We therefore analysed the experimental plan comprising: G1, G2, G3, G4, G5 and S3. G3 and S3 play the same role in the LogiRisk model: the first when G1 is push or kanban, the second when G1 is VMI. So, in the rest of the analysis we consider a parameter called G3’ that brings them together.

Table 10 Results at T3

×1000			G4					
			C1			C2		
G1	G2	G3′	Decreased	Stable	Increased	Decreased	Stable	Increased
Kanban	0, 3	0, 2	49	25	4	319	411	720
		0, 3	43	21	3	349	459	808
	0, 4	0, 2	43	21	3	348	459	808
		0, 3	38	17	3	379	507	896
VMI	0, 3	0, 2	49	25	4	319	411	720
		0, 3	43	20	3	348	459	808
	0, 4	0, 2	43	20	3	348	459	808
		0, 3	38	17	3	379	507	896
Push	0, 3	0, 2	57	29	4	327	413	720
		0, 3	47	22	3	353	459	808
	0, 4	0, 2	51	24	3	357	460	808
		0, 3	42	19	3	384	508	896

The Fisher–Snedecor variance test shows that all parameters can be taken into account in our analysis, except G4 and G5 at T1 and G5 at T2.

The results are summarized is the tables below. Minimum values appear in grey.

Conclusion 5 Kanban and VMI are very close from the supply chain point of view (C1 and C2).

In this case study, the partnership is dominated by powerful customers. We can find similar contexts in industry where the customer imposes VMI implementation. In this case, the relationship is imbalanced and no negotiation occurs between partners to fix the min/max levels. Furthermore, inspired by the industrial case, we modeled a supplier which does not exploit its degree of freedom—the interval within which it could choose the delivery quantities. This type of supplier checks the customer inventory weekly and always replenishes the inventory to the same level. Here, the level is the maximum defined in the LA. The different results show that a customer confronted with this type of supplier, and which has implemented a kanban-based supply, has no particular interest in switching over to VMI.

Conclusion 6 Kanban and VMI are justified despite all the variability we have simulated: real demand variability (20%), change in the demand trend and vision in the change of trend.

The different tables show that VMI and kanban allow better performance even if some G2 or G3’ adjustments give similar results for push, kanban and VMI. We can also stress that performance is not disturbed by the change in the demand trend and vision in the change of trend.

Conclusion

In this study, we aimed at testing the assumption mainly made when implementing a VMI collaboration strategy: demand stability. Faced with a very large amount of literature covering this recent type of supply, we first studied the concept. Through the literature review we have emphasized the closeness of the reasonings underlying VMI and pull. Then, we have implemented a VMI model inside a simulation tool called LogiRisk.

The case study illustrates that the similarities between pull and VMI are significant enough to particular implementations to provide similar supply chain performance. Nevertheless, it must be noted that the granularity level of our model does not allow particular operational VMI characteristics to be simulated. For example, the delivery frequency increase reported in the literature has not been tested here.

The main target was to confront VMI with different types of variability: real demand variability but also change in the demand trend and vision of the change of trend. Our case study shows that in this particular context, VMI or kanban performance is justified despite demand variability. This result calls into question the widespread assumption of demand stability and suggests that study could be made of VMI in combination with promotional operations and other forms of instability.

However, in order to obtain more general conclusions about VMI we have to explore other research axes. On the one hand, in term of modeling improvement:

- model negotiation in the LA. The actors have to organize a shared and common planning which is used to parameterize the customer's inventory min/max level. This common plan is built around exchanges between the partners. The customer expresses its component requirement plan. The supplier gives a delivery plan. Each actor includes its constraints in its plan. The modelling of this common plan could rest on the collaboration planning proposed by Dudek and Stadtler (2005) based on an exchange process that help to achieve convergence between each actors' point of view.
- model utilization of the supplier's degree of freedom in terms of delivery quantities. In other terms, authorize a variation of α over time.

These improvements could help us to analyze another VMI aspect: backing up of stocks from the customer to the supplier warehouse, as reported by Blatherwick (1998).

On the other hand we need to confront VMI with other sources of variability. Thus we also plan to:

- simulate different real demand variability;
- study the cumulative effects of increase and decrease instead of simple increase or decrease;
- analyse the effects of actors' internal constraints: breakdown, quality level, etc.
- analyse the effects of external events as strikes, disasters, etc.

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