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October 2007

CIRRELT-2007-38

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Collaboration and Decision Models for a Two-Echelon Supply Chain: A Case Study in the Pulp and Paper Industry

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Abstract. With the current economic context, enterprises aim to improve collaboration and enhance information exchange with their suppliers or customers in order to better coordinate their activities and respond promptly to their customer. A demonstration of this trend is the development of formal collaboration models like Vendor Managed Inventory (VMI) or Collaborative Planning, Forecasting and Replenishment (CPFR) which are now used to facilitate product and information exchange between partners. However, the setup of efficient inter-firm collaborations requires time and investment with no guarantee of success or failure of the relationship. Although many of the emerging approaches are promising, the need to identify and apply the best collaboration model for the context considered remains. In this paper, we study different collaboration strategies between a producer and a retailer in the pulp and paper industry. For this industrial context, we define a methodology to analyze and compare the impact of collaboration modes on the network profit. Using a rolling horizon of two weeks and a total planning period of one year, we also proceed with numerical experiments. Our tests reveal that the CPFR method is the more gainful collaboration approach for the case studied providing up to 18% of transportation costs reduction over order-based relation.

Keywords. Logistics, supply chain management, linear programming, enterprise collaboration, producer-retailer relationship.

Acknowledgements. Financial support for this work was provided by the Fonds québécois de la recherche sur la nature et les technologies (FQRNT) and by the Natural Sciences and Engineering Research Council of Canada (NSERC). This support is gratefully acknowledged.

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Dépôt légal – Bibliothèque nationale du Québec,
Bibliothèque nationale du Canada, 2007

1 Introduction

Considering the effects of globalization, incessant technology progress and development of specialized and niche markets where customers know exactly what they want, enterprises aim for more agility through creative partnership with their suppliers, distributors and retailers.

Enterprise collaboration can take multiple forms, depending on the enterprise's objectives and strategies. For example, a supplier and its retailer can tend towards Vendor Managed Inventory (VMI) collaboration, where the supplier is now responsible for managing the inventories of its products for the retailer. Collaborative Planning, Forecasting and Replenishment (CPFR) can also be used, where a joint demand forecast is used to better plan needs for the entire network. In every case, the success of the collaborative experience depends on the level of cooperation between players. Therefore, it is necessary to ensure that each partner makes decisions that are good for the entire network. The use of incentives is a tool to encourage this. Guaranteed volume, pricing agreements and quantity discounts are some examples of incentives that can be used. However, it is not an easy task to choose the right collaboration model or the best incentive to use within the partnership. These decisions are complex since an enterprise has usually more than one customer to satisfy and operates with a set of production and distribution constraints.

Our work considers this problem from a real industrial perspective. More precisely, we try to characterize the dynamic of the relationship between partners in the pulp and paper industry. The supply chain for this industrial sector is relatively complex because of the paper making process. While some enterprises control all of the activities from the forest to the final consumer, others work with subcontractors for specific operations. In all cases, high operational costs, international competition and new technologies motivate them to efficiently manage their network. For this context, we use collaboration approaches, namely Make to Order (MTO), VMI, regular replenishment and CPFR, to develop decisional models for both a producer and a retailer. We also define a specific methodology and proceed with numerical experiments in order to identify which collaboration model seems to be more efficient depending on the context. The paper is organized as follows. In Section 2, a brief literature review is proposed. In Section 3, we describe the collaboration approaches and the industrial case retained for our study. In addition, we present the decision models developed and the notation used. In Section 4, a description of the experimenting methodology and the results obtained are exposed. Finally, we offer some concluding remarks in Section 5.

2 Literature review

Many authors have discussed the potential key elements required to ensure efficient and viable collaboration across businesses within the supply chain. In particular, information sharing has been analyzed in the literature as a first step to better coordinate activities between partners. In all enterprise networks, members do not have access to the same information and they can choose to share this knowledge or not [5]. For example, the retailer can directly observe consumer consumption at the point of sales. If he chooses to keep this information for himself, the manufacturer will have to plan the production based on retailer orders and not on the real demand. In their study of the bullwhip effect, Lee *et al.* [9] demonstrate that this lack of information can lead to inefficient utilization of capacity, stock in excess or shortages, poor quality of service, etc. A detailed review on information sharing and supply chain coordination is presented by Chen [5] to better understand the role of information in achieving supply chain coordination.

Another key element for efficient and viable partnerships is that using appropriate collaboration approaches can increase coordination in the enterprise network. For example, Efficient Consumer Response (ECR) is an illustration of a strategy implemented by the food industry in which each partner collaborates in order to deliver the right product at the right place with the best price to customers. The different concepts of ECR can be grouped into three areas: demand management (category management), product replenishment (continuous replenishment) and enabling technology (EDI) [10]. VMI is another approach developed during the eighties in which the manufacturer is responsible for managing the inventories of its products for the client. This helps end stock-outs and facilitates better replenishment [1]. An interesting case study on the application of VMI to the household electrical appliances sector is presented by De Toni and Zambolo [6], in which they show how the implementation of the VMI model results in more benefits than traditional replenishment systems. Another strategy, CPFR, has been designed to improve the flow of goods from the raw material suppliers, to the manufacturer, to retailer shelves [17]. The idea is to share information such as sales history, product availability, lead times, etc., to better synchronize activities and eliminate excess inventory. It was also developed to rapidly identify any changes in the forecasts or inventory, in order to correct the problems before they negatively impact sales or profits. As Thron *et al.* [15] demonstrated, developing CPFR in the supply chain can lead to substantial benefit, depending on the context studied.

Every collaboration approach requires cooperation between partners in order to optimize the entire network. But in reality, participants may be tempted to pull out or trick the collaboration in their favor. This would be the case of an opportunist player who tries to impose the rules of the game or make decisions considering penalties and rewards locally rather than globally [14]. To avoid this kind of situation, it is often necessary to use incentives such as pricing agreements or quantity discounts to influence player decisions and tend towards an optimization of the global network. Many authors have studied these incentives applied to supply chain management. Cachon [3] presents a detailed review of these articles. The first incentive regularly studied considers the price charged by the manufacturer to the retailer. This is referred to as wholesale price. Cachon [4] demonstrates that, depending on the context, wholesale price can play a role in the coordination of the system. Another incentive is based on product returns, known as buyback contracts. The retailer can now return some or all the items ordered in exchange for compensation (see for example [2]). A different incentive concerns network revenue. With a revenue sharing contract, the retailer shares revenue generated from sales with his supplier in return for a lower supplier price (see for example [8]). In order to offer increased flexibility to the partner, the quantity flexibility contract is another incentive in which the retailer can adjust his order using more accurate knowledge of demand (see for example [16]). Frequently used, quantity discounts also encourage the buyer to order more than usual (see for example [11]). Several other incentives have been studied, having the same objective, coordinate player decisions and optimize supply chain profit. Each type of incentive commands a particular management cost, a different tolerance toward risk and different levels of information sharing. It is however difficult to study inter-firm collaborations and incentives without considering their impact on production planning [13]. Therefore, many authors like Cachon [3], Tsay [16] and

Chen [5] analyzed the question, using the game theory and Nash equilibrium. However, this kind of approach limits the number of parameters studied or the length of the planning period. Nevertheless, the collaboration model chosen will directly affect the way goods and information are exchanged between partners, as well as how they make their planning decisions. For example, if a supplier makes a commitment to deliver a certain quantity or offers a lower sales price, he must consider operation costs, production and distribution capacities, lead times, etc., before making a decision. Otherwise, he will most likely not be able to respect the agreement. Thus, in order to take into consideration characteristics of production and distribution systems, we decide to study the problem using this method: First, we identify four potential collaboration approaches for the case study. Next, we represent each of them as mixed integer linear programs that integrate all the decisions faced by the partners. Then, via a set of operational parameters and variables, we test and compare the models. In this way, we mainly focus on the impact of inter-firm collaborations since it needs to be addressed prior to incentive settings. The next sections summarize the method applied.

3 Collaboration approaches and decision models

To better understand the two-echelon supply chain dynamic and be able to identify a specific interaction model for a partnership between a producer and a retailer, four collaboration approaches have been chosen: MTO, VMI, regular replenishment and CPFR. For each of these approaches, we developed a decision model from the point of view of the retailer and a decision model from the point of view of the producer, for a total of seven decision models. Each model has also been defined in order to address the pulp and paper industry perspective. More precisely, the case study concerns a producer of pulp and paper who decides to establish a partnership with one of its retailers. The producer has to satisfy the demand of this client and the demand of other retailers (Fig. 1).

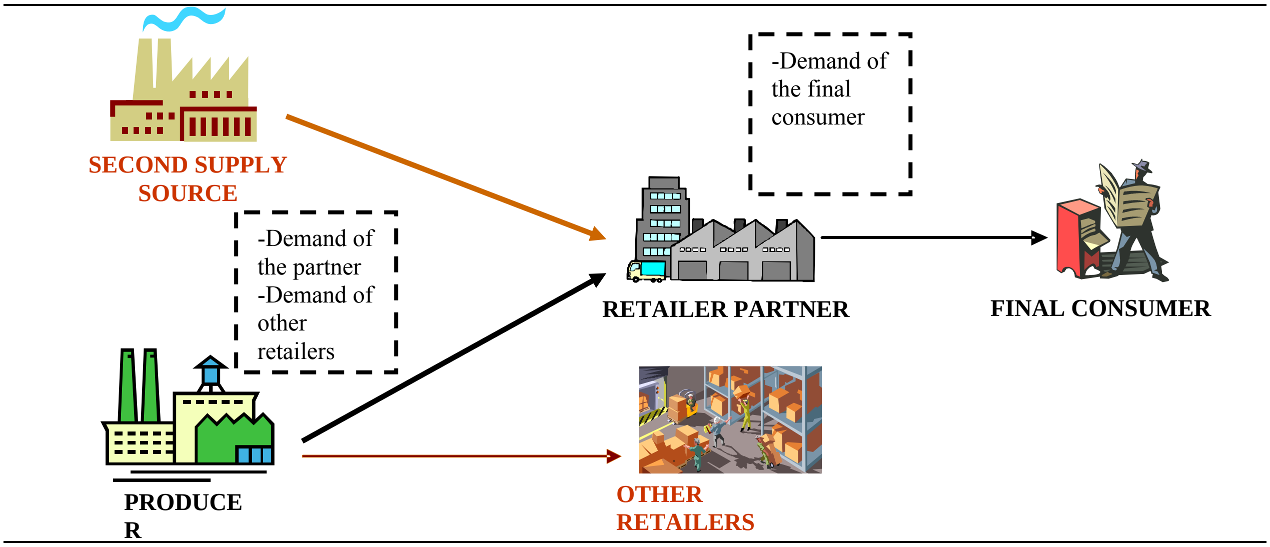

Fig. 1. The industrial case

The production system involves multiple stages. In very general terms, paper rolls and sheets are produced from trees or logs which are first chipped. The chips are mixed with chemicals and water to produce the pulp. The pulp is than transformed into jumbo rolls of paper. These paper rolls are large in size and cannot normally be kept in storage for long. They are therefore cut into smaller rolls or sheeted when needed. The production of these intermediate products (jumbo rolls) on parallel machines creates a bottleneck, consequently capacity and setup times must be considered [12]. For the other production stages, we consider sufficient capacity. During the delivery process, transportation capacity must also be considered and can be different from a period to another. In addition, some stock (small rolls and sheets) can be present in the system because of diversified demand for products. The retailer is a merchant, so he buys products from the producer or from a second supply source, keeps them in stock and then sells them to the final consumer without transforming the product.

3.1 Description of the models

Each collaboration approach has some distinct characteristics. MTO is a traditional method that is not very collaborative but still frequently used; therefore, we develop the corresponding model for comparison purposes. The producer manufactures the product after receiving the order from the retailer and then ships the merchandise. Because the producer cannot see the real demand at the point of sales, she has to plan the production based on different retailer orders. The retailer can choose to order entirely from the producer or purchase the product from another supply source, depending on the price and lead time offered (Fig. 2).

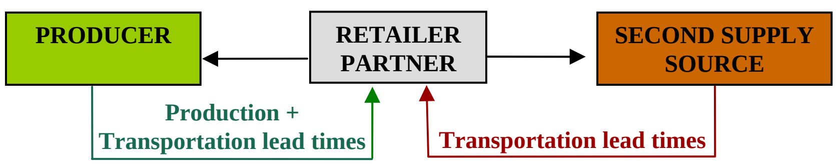

Fig. 2. Relationship based on a MTO mode

With the VMI approach (Fig. 3), the producer is responsible to maintain the partner's inventory levels and has to consider inventory holding costs for its products at the retailer site. The producer also has to make sure that the inventory is sufficient so that the retailer will be able to satisfy his own demand. Real demand at the point of sales is again unknown, thus the production planning will be based on the stock consumption made by the partner. The retailer does not have to support ordering and inventory holding costs for the producer's products. Furthermore, the retailer has access to a second supply source if necessary (for example, if the producer's forecasts for stock consumption are wrong and the retailer does not have sufficient stock to satisfy demand).

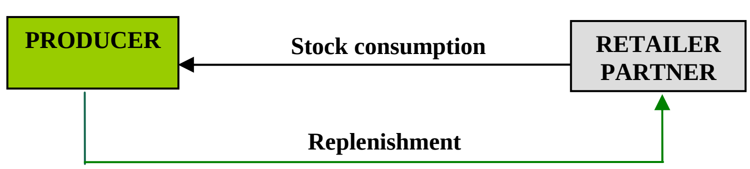

Fig. 3. Relationship based on VMI

For the regular replenishment mode (Fig. 4), deliveries are done regularly based on an order plan defined and updated by the retailer. This order plan, covering several days, is sent in advance to the producer, so the information can be integrated in the production planning to ensure that the retailer will receive his merchandise at the right moment.

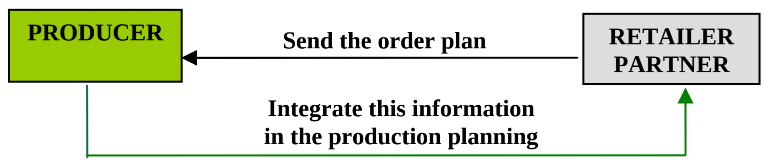

Fig. 4. Relationship based on a Regular Replenishment mode

The last strategy refers to the CPFR method (Fig. 5). Partners have to conjointly estimate the demand and then use the forecast in their planning. All the decisions are made in order to maximize the profit of all the partners and respect each of their local constraints. A specific buying price is now unnecessary, because it represents revenue for one and a cost for the other. We also suppose that the retailer never uses the other supply source for this particular collaboration mode. Table 1 summarizes the different characteristics for each producer and retailer model.

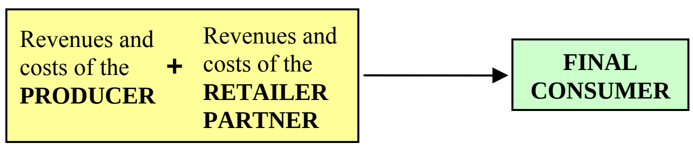

Fig. 5. Relationship based on the CPFR method

Table 1: Characteristics of each decision model

	MAKE TO ORDER, Producer model	
Activity	*Description*	*Cost*
Production	-Production planning based on retailer orders and demand of other clients -Production lead time to satisfy the retailer -Capacity in each period	-Production cost including setup cost
Inventory	-Inventory holding capacity	-Inventory holding cost for finished products
Distribution	-Transportation lead time -Transportation capacity	-Delivery cost
	MAKE TO ORDER, Retailer model	
Activity	*Description*	*Cost*
Supply	-Two supply sources with specific products and lead times	-Buying price, can be different from one source of supply to another,

		depending on the product and the period -Ordering cost
Inventory	-Inventory holding capacity	-Inventory holding cost
	VMI, Producer model	
Activity	*Description*	*Cost*
Production	-Production planning based on stock consumption made by the retailer and demand of other clients	-Production cost including setup cost
Inventory	-Management of inventories for the retailer -Minimum and maximum level of stock to respect at each period - Inventory holding capacity	-Inventory holding cost for finished products at the mill -Inventory holding cost for finished products at the retailer site
Distribution	-Transportation lead time considered in the production planning -Transportation capacity	-Delivery cost
	VMI, Retailer model	
Activity	*Description*	*Cost*
Supply	-Access to another supply source if necessary	-Buying price for replenishment made by the producer -Buying price if access to the second supply source -Ordering cost if order from the second supply source
Inventory	-No inventory management for the producer's products	-Inventory holding cost for products bought from the second supply source
	REGULAR REPLENISHMENT, Producer model	
Activity	*Description*	*Cost*
Production	-Production planning based on an order plan and demand of other clients	-Production cost including setup cost
Inventory	- Inventory holding capacity	-Inventory holding cost for finished products at the mill
Distribution	-Transportation lead time considered in the production planning - Deliveries based on the order plan -Transportation capacity	-Delivery cost
	REGULAR REPLENISHMENT, Retailer model	
Activity	*Description*	*Cost*
Supply	-Order plan covering several days sent in advance -Quantity delivered in accordance with the order plan	-Buying price for producer's products -Buying price if access to the second supply source -Ordering cost each time the plan is

	-Access to another supply source if necessary	sent -Ordering cost if order from the second supply source
Inventory	-Inventory holding capacity	-Inventory holding cost

CPFR, **Producer-Retailer model**

Activity	*Description*	*Cost*
Production	-Production planning based on joint demand forecasts and demand of other clients -Capacity constraint considered in the common decision model	-Production cost including setup cost
Inventory	-Optimization of all the stock of the system	-Inventory holding cost for finished products at the mill -Inventory holding cost for finished products at the retailer site
Distribution	-Transportation lead time considered in the production planning	-Delivery cost

3.2 Mathematical notation

For each model, notation is as follows:

<u>Set description</u>

T = The length of the planning period
IP = The set of intermediate products
Suc_i= The set of finished products that can be obtained from the intermediate products
FP = The set of finished products (FPF ∪ FPS)
FPF= The set of finished products proposed by the producer
FPS = The set of finished products proposed by the second supply source
M = The set of machines that manufacture intermediate products

<u>Parameter description</u>

t = A planning period
τ = Production lead time
i= A intermediate or finished product
cf = Conversion factor indicating number of units of intermediate products to produce
a_{it}^{m}= Production capacity consumption rate of intermediate products at machine m at period t
ld= Transportation lead time of the producer
lds= Transportation lead time of the second supply source
r_i= Transportation resource absorption rate for finished products
$tset_i^{m}$= Setup time to manufacture intermediate products on the machine m at the beginning of period t
d_{it}= Demand for finished products ordered by the other clients at period t
d_{it}^{cc}= Demand for finished products ordered by the final consumer at period t

stc_{it}^{c}= Consumption forecast for the producer's finished products used by the retailer at period t
de_{it}^{cc}= Demand for finished products ordered by the final consumer and estimated by the partners at period t
c_{t}^{m}= Production capacity of machine m at period t
cap_{t}= Transportation capacity of a truck at period t
c_{it}^{m}= Production cost of the intermediate product on the machine m at period t
h_{it}= Inventory holding cost of the finished products at the mill at period t
h^{c}_{it}= Inventory holding cost of the finished products at the retailer site at period t
ctru= Transportation cost of finished products delivered to the retailer at period t
cord= Ordering cost of the retailer
pSS_{it}= Price for finished products proposed by the second supply source at period t
p_{it}= Price for finished products proposed by the producer at period t
pc_{it}= Price for finished products proposed by the retailer to the final consumer at period t
g= A large number

Variable description

π_{it}^{m}= Binary variable equal to 1 if the product is manufactured on the machine m at period t, 0 otherwise
ρ_{it}^{m}= Binary variable equal to 1 if a setup for the product is made on the machine m at period t, 0 otherwise
Q_{it}= Quantity of finished products manufactured at period t
Q_{it}^{m}= Quantity of intermediate products manufactured on the machine m at period t
D_{it}^{c}= Quantity of finished products bought from the producer at period t
R_{it}= Quantity of finished products shipped by the producer at period t
RC_{it}= Quantity of producer's finished products received by the retailer at period t
QSS_{it}= Quantity of finished products bought from the second supply source at period t
RSS_{it}= Quantity of finished products received by the retailer from the second supply source at period t
I_{it}= End of period inventory level of finished products at the mill at period t
IF^{c}_{it}= End of period inventory level of producer's finished products at the retailer site at period t
ISS^{c}_{it}= End of period inventory level of finished products bought from the second supply source at period t
$Ntru_{t}$= Number of trucks needed at period t
δt = Binary variable equal to 1 if the retailer orders producer's finished products at period t, 0 otherwise
δSSt = Binary variable equal to 1 if the retailer orders second supply source's products at period t, 0 otherwise

3.3 Decision models based on MTO

The first two models represent a relation based on the MTO mode. Before ordering, the retailer must consider the buying price proposed by the producer and the one proposed by the second supply source. He also has to take into consideration the ordering cost, inventory holding cost and sales income. For the producer, the quantity of finished products to manufacture depends on the retailer demand and the demand of other clients. She also has to consider production, inventory and distribution costs, production and transportation capacities and sales income (the setup cost is included in the production cost).

For the retailer, the decision model in a MTO mode is proposed as follows:

$$Max \sum_{t\in T}\sum_{i\in FP} d_{it}^{cc} pc_{it} - \sum_{t\in T} cord\ \delta_t - \sum_{t\in T} cord\ \delta SS_t - \sum_{t\in T}\sum_{i\in FP_F} D_{it}^{c} p_{it} - \sum_{t\in T}\sum_{i\in FPS} QSS_{it}\, pSS_{it} - \sum_{t\in T}\sum_{i\in FP_F} h_{it}^{c} IF_{it}^{c} - \sum_{t\in T}\sum_{i\in FPS} h_{it}^{c} ISS_{it}^{c} \quad (1)$$

subject to

$$RC_{it} + IF_{it-1}^{c} - IF_{it}^{c} = d_{it}^{cc} \qquad \forall i \in FP \notin FPS;\quad \forall t \in T \quad (2)$$

$$RSS_{it} + ISS_{it-1}^{c} - ISS_{it}^{c} = d_{it}^{cc} \qquad \forall i \in FP \notin FPF;\quad \forall t \in T \quad (3)$$

$$RC_{it} + RSS_{it} + IF_{it-1}^{c} + ISS_{it-1}^{c} - IF_{it}^{c} - ISS_{it}^{c} = d_{it}^{cc} \qquad \forall i \in FPF \cap FPS;\quad \forall t \in T \quad (4)$$

$$IF_{it}^{c} \le RC_{it} + IF_{it-1}^{c} \qquad \forall i \in FPF;\quad \forall t \in T \quad (5)$$

$$ISS_{it}^{c} \le RSS_{it} + ISS_{it-1}^{c} \qquad \forall i \in FPS;\quad \forall t \in T \quad (6)$$

$$D_{it}^{c} = RC_{i(t+\tau+ld)} \qquad \forall i \in FPF;\quad \forall t \in T \quad (7)$$

$$QSS_{it} = RSS_{i(t+lds)} \qquad \forall i \in FPS;\quad \forall t \in T \quad (8)$$

$$D_{it}^{c} \le g\delta_t \qquad \forall i \in FP \notin FPS;\quad \forall t \in T \quad (9)$$

$$QSS_{it} \le g\delta SS_t \qquad \forall i \in FP \notin FPF;\quad \forall t \in T \quad (10)$$

$$D_{it}^{c} \le g\delta_t \qquad \forall i \in FPF \cap FPS;\quad \forall t \in T \quad (11)$$

$$QSS_{it} \le g\delta SS_t \qquad \forall i \in FPF \cap FPS;\quad \forall t \in T \quad (12)$$

$$D_{it}^{c} \ge 0,\ QSS_{it} \ge 0,\ RC_{it} \ge 0, RSS_{it} \ge 0, IF_{it}^{c} \ge 0, ISS_{it}^{c} \ge 0, \qquad \forall i \in FPF;\quad \forall i \in FPS;\quad \forall t \in T \quad (13)$$

$$\delta_t, \delta SS_t \in \{0,1\} \qquad \forall t \in T \quad (14)$$

The objective function (1) maximizes retailer profit. Constraints (2), (3) and (4) ensure flow conservation. Constraints (5) and (6) distinguish stock origin. Constraint (7) concerns the MTO mode, thus the retailer will receive his order after the production and transportation operations. If he purchases at the second supply source, a transportation lead time will be necessary (8). Finally, constraints (9), (10), (11) and (12) ensure an ordering cost if the retailer orders products.

For the producer, the decision model with a MTO mode has some similarities with the model presented by Rizk *et al.* [12]. Its formulation is:

$$Max \sum_{t \in T} \sum_{i \in FP_F} D_{it}^{c} p_{it} + \sum_{t \in T} \sum_{i \in FP_F} d_{it} p_{it} - \sum_{t \in T} \left[\sum_{m \in M} \left[\sum_{i \in IP} c_{it}^{m} Q_{it}^{m} \right] + \sum_{i \in FP_F} h_{it} I_{it} \right] - ctru \sum_{t \in T} Ntru_t \qquad (15)$$

subject to

$$\sum_{m} Q_{it}^{m} - \sum_{Suc_i} Q_{jt} / cf = 0 \qquad \forall i \in IP; \quad \forall t \in T \qquad (16)$$

$$\sum_{IP} \pi_{it}^{m} \leq 1 \qquad \forall m \in M; \quad \forall t \in T \qquad (17)$$

$$\pi_{it}^{m} \leq \pi_{it-1}^{m} + \rho_{it}^{m} \qquad \forall m \in M; \quad \forall i \in IP; \quad \forall t \in T \setminus \{1\} \qquad (18)$$

$$\pi_{it-1}^{m} + \rho_{it}^{m} \leq 1 \qquad \forall m \in M; \quad \forall i \in IP; \quad \forall t \in T \setminus \{1\} \qquad (19)$$

$$Q_{it} + I_{i(t-1)} - I_{it} - R_{it} = d_{it} \qquad \forall i \in FP_F; \quad \forall t \in T \cup \{0\} \qquad (20)$$

$$R_{i(t+\tau)} = D_{it}^{c} \qquad \forall i \in FP_F; \quad \forall t \in T \qquad (21)$$

$$a_{it}^{m} Q_{it}^{m} + \rho_{it}^{m} tset_{i}^{m} \leq c_{t}^{m} \pi_{it}^{m} \qquad \forall m \in M; \quad \forall i \in IP; \quad \forall t \in T \qquad (22)$$

$$\sum_{i \in FP_F} r_i R_{it} \leq cap_t \times Ntru_t \qquad \forall t \in T \qquad (23)$$

$$Q_{it}^{m} \geq 0 \qquad \forall m \in M; \quad \forall i \in IP; \quad \forall t \in T \qquad (24)$$

$$Q_{it} \geq 0, I_{it} \geq 0, Ntru_t \geq 0, R_{it} \geq 0 \qquad \forall i \in FP_F; \quad \forall t \in T \qquad (25)$$

$$\pi_{it}^{m}, \rho_{it}^{m} \in \{0,1\} \qquad \forall m \in M; \quad \forall i \in IP; \quad \forall t \in T \qquad (26)$$

The objective function (15) maximizes the producer profit. Constraint (16) is used to calculate how many intermediate products are needed to manufacture finished products. Constraint (17) ensures that only one intermediate product is manufactured per period. Note that this constraint is imposed by the pulp and paper industry context. Constraints (18) and (19) make sure that a setup is made at each product change. Constraint (20) ensures flow conservation. Because of the MTO mode, constraint (21) specifies that the product is manufactured after order processing. Finally, constraints (22) and (23) indicate the production and transportation capacity to respect.

3.4 Decision models based on VMI

These two models represent a VMI relationship in which the producer is responsible for the inventory of the partner. The producer objective function is similar to (15), but now includes inventory holding cost for the products stocked at the retailer site. The replenishment is based on the stock consumption and inventory must be kept between a minimum and a maximum level. For the retailer, the buying price is the only one to consider when he uses the producer's products. However, if he chooses to buy some merchandise from the second supply source, ordering cost, buying price and inventory holding cost must be considered.

For the retailer, the new objective function is formulated as follows:

$$Max \sum_{t\in T}\sum_{i\in FP} d_{it}^{cc} pc_{it} - \sum_{t\in T}\sum_{i\in FP_F} RC_{it} p_{it} - \sum_{t\in T} cord\,\delta SS_t - \sum_{t\in T}\sum_{i\in FPS} QSS_{it} pSS_{it} - \sum_{t\in T}\sum_{i\in FPS} h_{it}^c ISS_{it}^c \quad (27)$$

$$subject\ to\ (3-6,\ 8,\ 10,\ 12-14).$$

In the retailer VMI model, constraints (2), (7), (9) and (11) have been removed since the retailer does not have to manage inventory for the producer's products. Constraints (3), (4), (5), (6), (8), (10), (12), (13) and (14) are the same as in the MTO retailer model (in (13) and (14), variables not used are removed).

For the producer, the new formulation is:

$$Max \sum_{t\in T}\sum_{i\in FP_F} stc_{it}^c p_{it} + \sum_{t\in T}\sum_{i\in FP_F} d_{it} p_{it} - \sum_{t\in T}\left[\sum_{m\in M}\left[\sum_{i\in IP} c_{it}^m Q_{it}^m\right] + \sum_{i\in FP_F} h_{it} I_{it}\right]$$
$$- \sum_{t\in T}\sum_{i\in FP_F} h_{it}^c IF_{it}^c - ctru \sum_{t\in T} Ntru_t \quad (28)$$

$$subject\ to\ (16-20,\ 22-26)\ and$$

$$R_{i(t-ld)} + IF_{it-1}^c - IF_{it}^c = stc_{it}^c \qquad \forall i \in FP_F;\quad \forall t \in T \cup \{0\} \quad (29)$$

$$s \le IF_{it}^c \le S \qquad \forall i \in FP_F;\quad \forall t \in T \quad (30)$$

All constraints are the same as in the MTO producer model (except (21)), but two other constraints must be added: one for the flow conservation at the customer site (29) and one to keep inventory between a minimum (s) and a maximum (S) level (30).

3.5 Decision models based on regular replenishment

We suppose now that replenishment is made according to an order plan elaborated and updated by the retailer. The retailer has to consider ordering cost each time he sends the plan. The producer knows what the retailer wants several days in advance and must integrate this information in the production planning.

The decision model based on regular replenishment for the retailer is practically the same as the MTO model (1-6, 8, 10, 12-14). However, the retailer does not have to take into consideration the transportation lead time in his planning. He just has to specify the number of products needed at each period and the producer will schedule deliveries in respect with this order plan. So constraint (7) is replaced by (31). The new constraint to add is:

$$RC_{it} = D_{it}^c \qquad \forall i \in FP_F;\quad \forall t \in T \quad (31)$$

Again, the decision model based on regular replenishment for the producer is practically the same as the MTO model (15-20, 22-26), except that constraint (21) is replaced by (32) since the producer knows in advance the order and has to deliver it at the right moment. The new constraint to add is:

$$R_{i(t-ld)} = D^{c}_{it} \qquad \forall i \in FP_F; \quad \forall t \in T \tag{32}$$

3.6 CPFR decision model

In the last model corresponding to the CPFR strategy, we simultaneously optimize the profit of each partner. The objective function (33) includes the revenues and costs of each partner. The buying price has been logically eliminated.

$$\begin{aligned} Max & \sum_{t\in T}\sum_{i\in FP_F} de^{cc}_{it}\, pc_{it} + \sum_{t\in T}\sum_{i\in FP_F} d_{it}\, p_{it} \\ & - \sum_{t\in T}\sum_{i\in FP_F} h^{c}_{it} IF^{c}_{it} - \sum_{t\in T}\left[\sum_{m\in M}\left[\sum_{i\in IP} c^{m}_{it} Q^{m}_{it}\right] + \sum_{i\in FP_F} h_{it} I_{it}\right] - ctru \sum_{t\in T} Ntru_t \end{aligned} \tag{33}$$

subject to $(16-20,\, 22-26)$ *and*

$$R_{i(t-ld)} + IF^{c}_{it-1} - IF^{c}_{it} = de^{cc}_{it} \qquad \forall i \in FP_F; \quad \forall t \in T \cup \{0\} \tag{34}$$

The system planning is now based on a joint demand forecast (34). In addition, all the production and transportation constraints must be considered (constraints (16) to (20) and (22) to (26) in the MTO producer model). The second supply source is also removed from the model.

4 Methodology and experiments

In order to compare and analyze the seven decision models developed, we used *AMPL Studio* and *Cplex Solver* to proceed with the experiments. Each test has been solved using a rolling horizon of two weeks, for a total planning period of one year. We consider a variable demand known for the first week and an estimated one for the second week. When the first iteration is completed, decisions are revised and data updated, then the experiment starts for the next day. The parameters used in the model are based on an industrial case. The total system profit and costs of each partner are used to compare each scenario and measure the impact of the collaboration model chosen.

4.1 Description of the methodology

Since the collaboration approach influences the decision-making process, we developed a methodology that reflects this dynamic. More precisely, for the MTO and regular replenishment modes, the retailer determines the optimal quantity to order, depending on the demand to satisfy, the inventory level and the deliveries planned. Next, based on the retailer's order and the demand of other clients, the producer optimizes the production planning, taking into consideration the stock level (Fig. 6). The initial inventory level at the retailer site ((35) producer's products, (36) second supply source's products), the initial inventory level at the mill (37) and the deliveries planned ((38) from the producer, (39) from the second supply source) are updated at the beginning of each period.

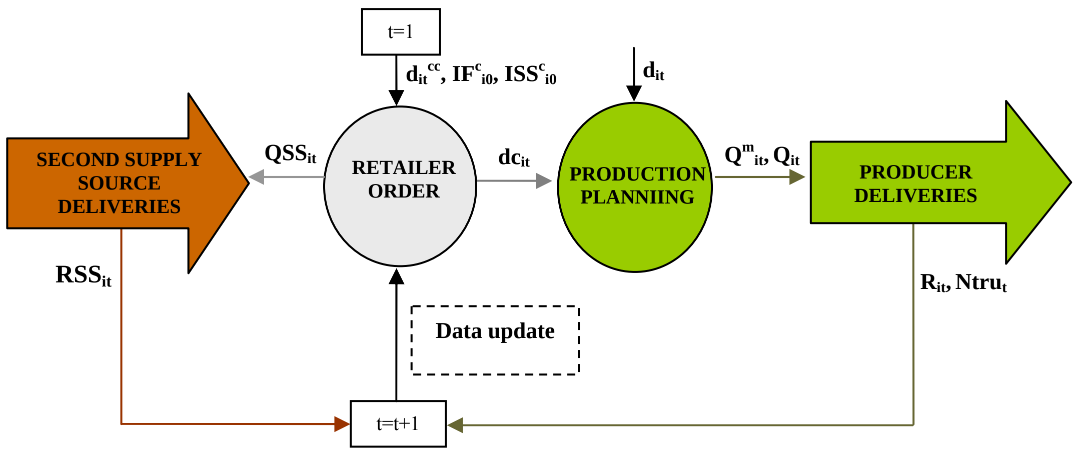

Fig. 6. Methodology for MTO and Regular Replenishment modes

Data update

$$IF^{c}_{i0} = IF^{c}_{it} \tag{35}$$

$$ISS^{c}_{i0} = ISS^{c}_{it} \tag{36}$$

$$I_{i0} = I_{it} \tag{37}$$

$$RC_{i(t+\tau+ld)} = R_{it}\ (MTO)\ or\ RC_{i(t+ld)} = R_{it}\ (regular\ replenishment) \tag{38}$$

$$RSS_{i(t+lds)} = QSS_{it} \tag{39}$$

In the VMI mode, the producer determines the optimal quantity to produce and the quantity to ship to the retailer site, depending on the demand to satisfy, the stock consumption and the inventory level. Next, using the quantity delivered by the producer, the retailer satisfies his own demand (Fig. 7). Again, the initial inventory level at the retailer site ((40) producer's products, (41) second supply source's products), the initial inventory level at the mill (42) and the deliveries planned ((43) if the retailer chooses to order at the second supply source) are updated at the beginning of each period.

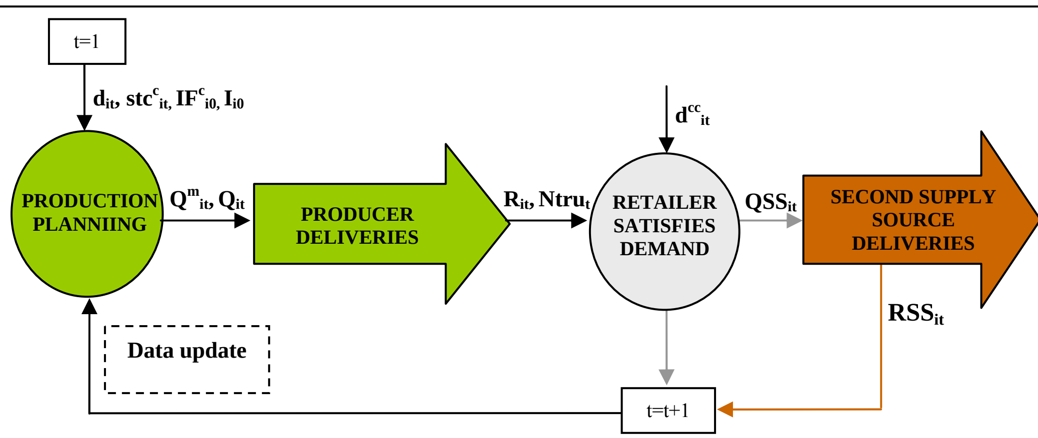

Fig. 7. Methodology for the VMI approach

Data update

$$IF^{c}_{i0} = IF^{c}_{it} \quad (40)$$

$$ISS^{c}_{i0} = ISS^{c}_{it} \quad (41)$$

$$I_{i0} = I_{it} \quad (42)$$

$$RSS_{i(t+lds)} = QSS_{it} \quad (43)$$

CPFR is a common model and all the decisions are made simultaneously (Fig. 8). Since the retailer never uses the second supply source for this particular mode, the initial inventory level of producer's products at the retailer site (44), the initial inventory level at the mill (45) and the deliveries planned ((46) from the producer) are the only variables updated at the beginning of each period.

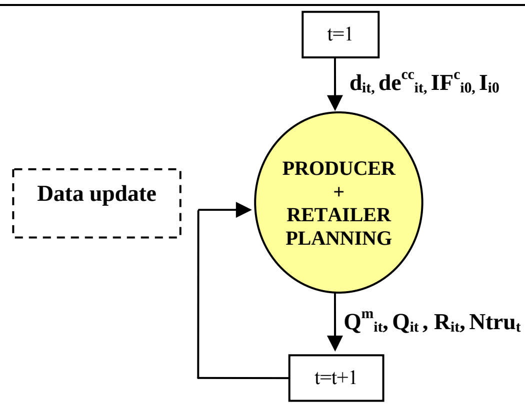

Fig. 8. Methodology for the CPFR method

Data update

$$IF^{c}_{i0} = IF^{c}_{it} \quad (44)$$

$$I_{i0} = I_{it} \quad (45)$$

$$RC_{i(t+ld)} = R_{it} \quad (46)$$

4.2 Numerical study

A numerical study has been experimented considering the demand for twenty finished products grouped into four families, each family corresponding to one intermediate product. The producer and the second supply source offer the same products. In addition, we assume production and transportation lead times of one period. The producer can manufacture the product on two paper machines (with different capacities), the bottleneck stage of the production process. Different scenarios have been studied: 1-the prices of the producer are lower than the prices of the second supply source versus the prices of the producer are equal to the prices of the second supply source, 2-three different transportation lead times and 3- three types of demand profile: variable, constant and accumulated demand.

4.3 Higher and equal market price

We first assume that the prices of the producer are lower than the prices of the second supply source. Our experiments led us to some observations. To begin with, the CPFR model generates the greatest total system profit because of an efficient optimization of both shipping and inventory costs. In particular, the CPFR shipping cost is up to 18 percent lower than the shipping cost of other models. In addition, the CPFR network inventory cost is up to 44 percent lower than costs of other models (Fig. 9).

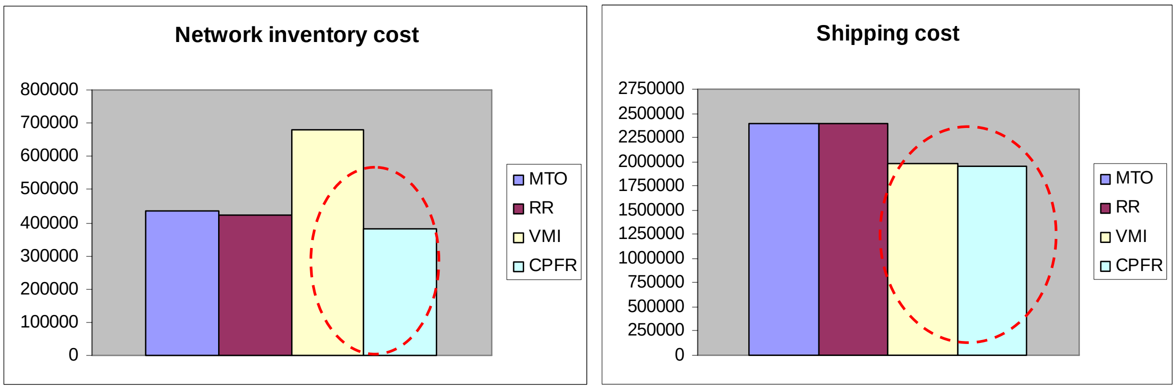

Fig. 9. Inventory and shipping costs of each collaboration approach

The VMI model is second best because of a saving in shipping costs (inventory cost for this approach is considerable since we assumed an important stock level at the retailer site to guarantee a good service level). The regular replenishment and MTO modes obtain the lowest total system profit. This last observation is not necessarily obvious since the regular replenishment approach is generally an efficient collaboration model for enterprise networks. In fact, we assume a total flexibility, thus the retailer can adjust the order plan every day depending on his needs. As a result, the regular replenishment approach becomes similar to the MTO mode with the difference that the demand visibility spans over a few more days.

When the prices of the producer are the same as the prices of the second supply source, results are very similar. More precisely, the collaboration is not affected by the competition and partners maintain their relationship. However, this is not the case for the MTO mode since the retailer chooses to buy all his merchandise at the second supply source. In particular, the retailer selects the supply source with the lowest lead time, the second supply source (transportation lead time of one period), rather than his partner (production lead time of one period + transportation lead time of one period). As a result, the total system profit declines by more than 3%.

4.4 Different transportation lead times

We also compare three different transportation lead times of one, two and three periods. We observe an important impact of this parameter on the inventory cost of the system for collaborations based on VMI and CPFR. More precisely, with a transportation lead time of two and three periods, each of these two approaches obtains a higher inventory cost than with a transportation lead time of one period (Fig. 10). In fact, with the VMI mode or the CPFR method, the producer can choose to keep more stock in the system in order to decrease the shipping cost. However, when the transportation lead time becomes more important, the producer has less flexibility to correctly plan the production and optimize costs. Nevertheless, CPFR is again the most profitable collaboration approach.

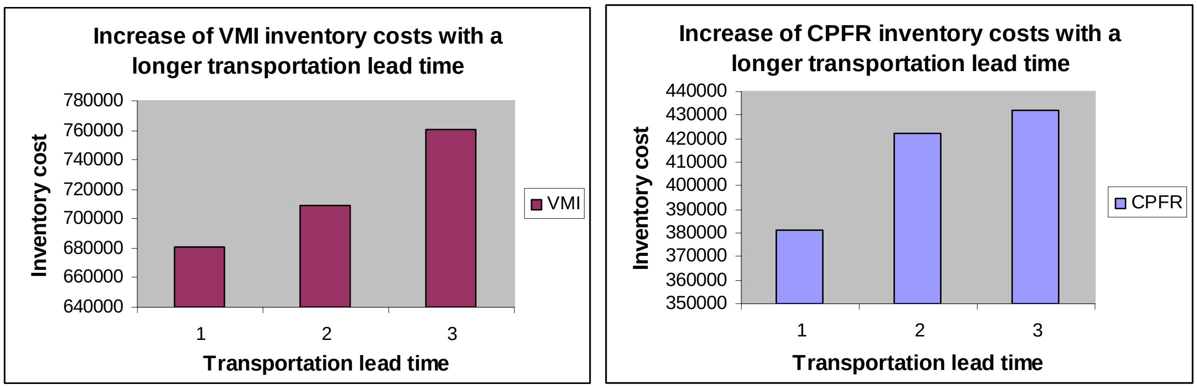

Fig. 10. Increase of the inventory cost for VMI and CPFR

These results confirm that it is not sufficient to simply choose and apply the best collaboration model for a specific relationship. It is also essential to efficiently manage inventory costs and keep lead times as low as possible in order to maintain a profitable collaboration.

4.5 Various patterns of demand

All the results presented in the precedent sections were obtained using a variable demand profile that reflects our industrial case. However, the methodology we developed allows us to study various patterns of demand without increasing the solution time. Therefore, in order to illustrate other possible industrial realities, we decided to test the impact of a constant and an accumulated demand profiles.

More particularly, using the same variable demand profile, we organized the data differently to create new patterns. Thus, in order to develop a constant demand profile, we calculated the mean of the variable demand for each product, namely we divided the sum of all the demands by 365 days. In addition, in order to obtain an accumulated demand, we calculated for each product, the sum of the variable demand for three days. We then used these new profiles in our experiments to measure their impact on the production planning.

When we compare the results based on a variable demand with the results obtained using a constant demand, we observe an important difference between the shipping costs, mainly for MTO and regular replenishment. More precisely, the use of a constant demand rather than a variable demand contribute to decrease MTO and regular replenishment shipping costs by more than 13% (Table 2). Because the demand is more important, the capacity of the transportation is better used and shipments decrease. However, the impact is not significant for VMI and CPFR.

Table 2: Decrease of the shipping cost with a constant demand

Collaboration approches	***% Decrease shipping cost***
MTO	13,07
RR	13,31
VMI	0,00
CPFR	-0,88

With the use of an accumulated demand, we again note an important decrease of the shipping cost in comparison with results obtained using a variable demand (Table 3). The difference is more important for MTO and regular replenishment.

Table 3: Decrease of the shipping cost with an accumulated demand

Collaboration approches	***% Decrease shipping cost***
MTO	13,79
RR	13,79
VMI	0,87
CPFR	1,32

Since we assume an accumulation of only three periods, the impact of this pattern of demand on the inventory cost is limited. For our next experiments, we use a higher number of periods in order to illustrate the real impact of this parameter on the system. However, we note that an accumulated demand contributes to increase the stock level of the system for CPFR and VMI, whereas the effect tends to be the opposite for MTO and regular replenishment (Table 4). More particularly, for the MTO mode and the regular replenishment approach, the retailer adopts the same behaviour as the demand, namely order for an accumulated number of periods. The producer has consequently more time to plan the production and optimize costs, and the stock level of the system is minimized. For the VMI and the CPFR approach, an accumulated demand will decrease the flexibility of the producer to adequately optimize the stock level and the shipping cost simultaneously. Therefore, the cost of the inventory system will be higher.

Table 4: Decrease of the inventory cost of the system with an accumulated demand

Collaboration approches	***% Decrease inventory cost of the system***
MTO	2,62
RR	2,29
VMI	-2,15
CPFR	-1,42

These results show that, for our industrial case, MTO and regular replenishment are more profitable with a constant or an accumulated demand rather than a variable one. The retailer can manage efficiently his inventory and shipments of the producer are well optimized. VMI and CPFR are more useful when the demand is variable, because of the optimization of both inventory and shipping decisions. Therefore, as many authors observed (see for example [7] or [18]), these results confirm that the coordination between players become more profitable in a context with variable demand.

5 Discussion and conclusion

In this article, we study different collaboration approaches integrated in decision models. Our objectives are to evaluate collaboration dynamics and their impact on the decision making and profit of each partner. Four strategies are retained: MTO, VMI, regular replenishment and CPFR. For each one, we develop specific decision models from the point of view of both the retailer and producer. We also propose a methodology to analyze and compare all the models. The parameters and variables used in the models are defined based on a real industrial case. Using different data and a rolling horizon of two weeks, we evaluate all the models in order to identify those with higher profitability depending on the context studied.

Different scenarios have been experimented, based on the prices of the producer, the lead times offered and the demand profile. Our results show that when the prices of the producer are lower or the same as the prices of the second supply source, the CPFR method generates the higher total system profit because of an efficient optimization of both inventory and shipping costs. VMI is second best since the shipping cost is optimized efficiently. The regular replenishment and the MTO mode obtain the lowest total system profit. When the prices offered by the producer are the same as the prices of the second supply source, the relationship is not affected by the competition if the collaboration is based on VMI, CPFR or regular replenishment. However, for the MTO mode, the retailer prefers to buy merchandise from the second supply source because of a lower lead time. When we compare models using three different lead times, we observe that the inventory cost for VMI and CFPR is higher with a longer lead time. The CPFR method is particularly affected with an increase of the inventory cost of more than 12%. We also compare various patterns of demand: variable, constant and accumulated. We noted that MTO and regular replenishment are more profitable in a context with a constant or an accumulated demand, since shipping and inventory costs are lower than costs obtained with a variable demand. VMI and CPFR become very advantageous when the demand is variable, because it is now possible to optimize efficiently both shipping and inventory costs. All the scenarios tested confirm that it is very important that partners correctly identify their collaboration context in order to choose the collaboration approach that reflects their industrial reality.

In order to correctly compare the models, all the operational costs associated with each collaboration strategy are included in the profit function of the players. However, we do not consider implementation costs in our current study. Since this cost can be very important for strategies with more interaction like the CPFR method, a specific fixed cost could be added to each profit function in order to take into consideration this characteristic. We also do not take into account the transit cost in our objective functions. Whereas this cost can be significant especially when the lead time is important, it could be interesting to add this parameter to the models.

This paper contributes to illustrate the differences between each of logistics strategies often used by industry. The methodology defined allows us to study various collaboration approaches in complex contexts that have not been thoroughly explored before. For future research, it would be interesting to realize additional experiments, using an assortment of parameters like lead times and varying prices. Studying the impact of applying some incentives like buyback contracts or quantity discounts on the behavior of each player is also an area worth of investigation. This could lead to a better understanding of the dynamics of enterprise collaboration and the importance of the model chosen on current decision making.

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