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

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Abstract. Because of international competition, the development of new technologies and the increase of production and energy costs, enterprises must improve their supply chain and change their way of doing business. They also have to collaborate with their suppliers, distributors and retailers in order to better respond to market demand. This kind of relationship can be based on well-known collaboration models like Collaborative, Planning, Forecasting and Replenishment (CPFR) or Vendor Managed Inventory (VMI), so as to correctly exchange products and information. However, it is necessary to choose the right collaboration approach that will be profitable for all partners. In this article, we study different collaboration strategies between a pulp and paper producer and its retailer. For this particular context we identify the collaboration mode that is the most profitable for each actor, based on real costs and parameters obtained from the industrial case. We also develop a method to better share collaboration benefits and ensure a relationship advantageous for everyone. We demonstrate that if the producer shares a part of the transportation or inventory savings with its partner, the CPFR method can be profitable for both partners and generate the greatest total system profit.

Keywords. Win-Win approach, enterprise collaborations, two-echelon supply chain, producer-retailer relationship, pulp and paper industry, case study, Collaborative, Planning, Forecasting and Replenishment (CPFR), Vendor Managed Inventory (VMI), incentives, mixed-integer linear programming.

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1 Introduction

In order to promptly satisfy customer demand and beat the competition, enterprises have been revising their way of doing business and testing new strategies. Their aim has been to capture leverage from inter-firm collaborations such as efficient synchronized networks and lower operational costs.

In Canada, pulp and paper enterprises usually adopt traditional methods like the order-based mode to satisfy market demand. But in the current economic context characterized by high production and energy costs, intense competition and incessant technological progress, some companies such as Domtar (2004) have decided to implement formal collaborations models so as to improve the profit of the entire network. By managing the inventories for the client or exchanging more information on sales and stock levels rather then pushing products into the system, they aim to improve lead times and correctly use the production capacity. However, the establishment and the management of an efficient inter-firm collaboration can be difficult. Partners have to choose the right collaboration approach depending on their context and make sure that the relationship is profitable for everyone. As Ireland and Bruce (2000) mentioned in their study, it can not be a case of “I win/you go and figure out how to win”, since a partner who does not obtain enough benefits from the relationship will probably prefer to work with someone else. Long-term collaborations have to be based on mutual benefits and risk sharing (Baratt, 2004). This has raised the need for optimized collaboration incentives.

In our study, we analyze different collaboration strategies between a pulp and paper producer and its retailer. For this industrial case, we try to verify if a relationship based on one of these four approaches, namely Make to Order (MTO), Regular Replenishment (RR), Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR), can facilitate the operations planning process and increase the profit of the network. We also analyze if one particular approach can be profitable for both the producer and the retailer, based on real costs and parameters obtained from the industrial case. In addition, we propose a method to better share collaboration benefits and tend towards a collaboration mode advantageous for all partners. This article is organized as follows. In Section 2, a brief literature review is proposed. In Section 3, we describe the industrial case retained for our study and the planning models developed. In Section 4, the experimentation and an analysis of the results are given. Finally, we offer some concluding remarks in Section 5.

2 Literature review

In order to create efficient enterprise collaborations, it is necessary to ensure a continuous exchange of information. More precisely, if actors have access to the demand of the final consumer, the number of products kept in stock at each location, the quantity ordered in the past few years, etc, and are ready to cooperate, they can make planning decisions that will have a positive impact on the system. Take, for example, the case of a retailer who observes consumer consumption at the point of sales. The retailer has access to specific information that he can choose to share or not with other network members. If the retailer decides to keep this knowledge for himself, the producer will have to plan its operations based on the orders of the retailer rather than the real demand of the final consumer. And this type of behaviour will negatively affect the performance of the supply chain. Lee *et al.* (1997) demonstrated in their study on the bullwhip effect that lack of information can lead to inefficient utilization of capacity, stock in excess or shortages, poor quality of service, etc. Moreover, a detailed review on information sharing presented by Chen (2003) illustrates the role of information in achieving supply chain coordination.

When the information is shared, it is essential to use this knowledge efficiently. Therefore, it is necessary to implement some collaboration approaches so as to facilitate the synchronization of network activities and the operations planning process. For example, ECR or Efficient Consumer Response is a strategy used by the food industry 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) (Martel, 2000). VMI is another technique developed during the eighties in which the producer is responsible for managing the inventories of its products for the client (Baratt and Oliveira, 2001). A case study realized by De Toni and Zambolo (2005) on the application of VMI to the household electrical appliances sector demonstrates that VMI results in more benefits than traditional replenishment systems for all the network members. The more recent collaboration strategy, CPFR, was created in order to improve the flow of goods from the raw material suppliers, to the manufacturer, to retailer shelves (VICS, 2004). By sharing information such as sales history, product availability, lead times, etc., and through the establishment of a unique plan shared by all partners, it is possible to better synchronize activities and eliminate excess inventory. This method has also been designed to proactively identify any changes in forecasts or inventory in order to correct the problems before they negatively impact sales or profits. Thron *et al.* (2005) showed that a collaboration based on CPFR can lead to substantial benefits for the network depending on the context. In addition, Cigolini and Rossi (2006) demonstrated that the CPFR mode can be more efficient for the supply chain than VMI, especially when the demand is variable.

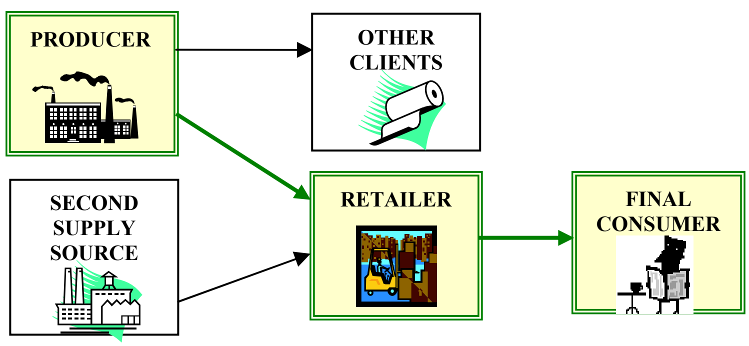
None of these collaboration approaches is necessarily equally profitable to all partners. Some players can obtain more benefits such as lower operational costs or shorter lead times, while others can observe an increase of their stock level (see for example Dudek and Stadtler, 2005 or Yao *et al.*, 2007). An enterprise can also try to impose the rules of the game or adopt an opportunistic behaviour that leads to unequal distribution of costs and benefits. Narayanan and Raman (2004) found, in more than 50 supply chain they studied, that companies regularly did not act in ways that maximized the network profit. Kurnia *et al.* (2006) also mentioned the frequent lack of cooperation among supply chain partners. In order to avoid this kind of situation, it is often necessary to find a method to influence player decisions and better share network benefits. Thus, many authors have studied the use of incentives such as pricing agreements or quantity discounts to improve the effectiveness of supply chain collaborations. A detailed review of these methods and their impacts can be found in Cachon (2003). A first incentive frequently studied considers the price charged by the producer to the retailer (wholesale price contract). The idea is to propose a lower price before the sale season and a higher price during the season to correctly use production capacity and share inventory cost. Cachon (2004) demonstrated that this incentive can play an important role in the coordination of the network depending on the context. Another incentive is based on product returns, known as buyback contracts. The retailer can return some or all the items ordered in exchange for compensation (see for example Bernstein and Federgruen, 2005). In this way, the retailer is incited to order the optimal quantity for the supply chain. 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 Giannoccaro and Pontrandolfo, 2004). The quantity flexibility contract is another incentive in which the retailer can adjust his order using more accurate knowledge of demand (see for example Tsay, 1999). Regularly used, quantity discounts also encourage the buyer to order more than usual (see for example Munson and Rosenblatt, 2001). Other incentives have been analyzed in the literature to coordinate player decisions and increase network efficiency.

Nevertheless, choosing the right collaboration strategy or finding the best method to correctly share supply chain benefits is not simple. It is indispensable to take into account the industrial context of each partner (pattern of demand, product characteristics, lead times, etc.) as well as the impact of the collaboration approach on the system (Schneeweiss and Zimmer, 2004). Several authors study this problem using game theory and NASH equilibrium (see for example Cachon, 2003). However, these techniques limit the number of parameters studied or the length of the planning period considered. Consequently, the models developed do not keep industrial realities in view. So, to take into account the effect of a particular collaboration mode on the planning decisions of each partner, we study the problem using mixed-integer linear programs. In this way, we can illustrate the impact of applying a particular collaboration mode on network profit and how the relationship affects the production and distribution systems. Based on various scenarios, we also identify the situations where a collaboration approach is not profitable for each partner. This article is different from preceding ones (Lehoux *et al.*, 2007a, b) since each collaboration approach is compared based on the profit of each actor. We also propose a method to share collaboration benefits and tend towards a win-win relationship. The next sections detail the research.

3 Collaboration approaches and planning models

In order to study different forms of collaboration between a pulp and paper producer and its retailer, four approaches have been selected: MTO, Regular Replenishment, VMI and CPFR. For each of these strategies, we developed a planning model from the point of view of the producer and a planning model from the point of view of the retailer, for a total of seven models (details of each model were presented for the first time in Lehoux *et al.*, 2007a). Each model has been elaborated to take the characteristics of a real industrial case into account (Figure 1).

Figure 1 Illustration of the case study



In this context, the producer has to plan adequately operations in order to satisfy the demand of the retailer and the demand of other clients. The paper making process can be summarized as follows. 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 then 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, thus capacity and setup times must be considered (Rizk *et al.*, 2005). For the other production stages, sufficient capacity is assumed. During the delivery process, transportation capacity must also be considered and can differ from one period to another. Moreover, some inventory (small rolls and sheets) can be present in the system since setup costs are very high. The retailer 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 *Mathematical notation*

After identifying four potential collaboration modes for the case study, mixed-integer linear programming is used to develop planning models from the point of view of both the producer and the retailer. To formulate the models, the following mathematical notation is used.

Set description

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
FPF= The set of finished products proposed by the producer
FPS = The set of finished products proposed by the second supply source
FP = The set of finished products (FPF $\cup$ FPS)
M = The set of machines that manufacture intermediate products

Parameter description

t = A planning period
τ = Production lead time
i= An intermediate or finished product
cf = Conversion factor indicating number of units of intermediate products to produce
a^m_{it}= Production capacity consumption rate of intermediate product *i* 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 product *i*
$tset^m_i$= Setup time to manufacture intermediate product *i* on the machine *m* at the beginning of period *t*
d_{it}= Demand for finished product *i* ordered by the other clients at period *t*
d^{cc}_{it}= Demand for finished product *i* ordered by the final consumer at period *t*
stc^c_{it}= Consumption forecast for the producer's finished product *i* used by the retailer at period *t*
de^{cc}_{it}= Demand for finished product *i* ordered by the final consumer and estimated by the partners at period *t*
c^m_t= Production capacity of machine *m* at period *t*
cap_t= Transportation capacity of a truck at period *t*
c^m_{it}= Production cost of the intermediate product *i* on the machine *m* at period *t*
h_{it}= Inventory holding cost of the finished product *i* at the mill at period *t*
h^c_{it}= Inventory holding cost of the finished product *i* at the retailer site at period *t*
ctru= Transportation cost of finished products delivered to the retailer
cord= Ordering cost of the retailer
pSS_{it}= Price for finished product *i* proposed by the second supply source at period *t*
p_{it}= Price for finished product *i* proposed by the producer at period *t*
pc_{it}= Price for finished product *i* proposed by the retailer to the final consumer at period *t*
g= A large number

Variable description

π^{m}_{it} = Binary variable equal to 1 if the product *i* is manufactured on the machine *m* at period *t*, 0 otherwise

ρ^{m}_{it} = Binary variable equal to 1 if a setup for the product *i* is made on the machine *m* at period *t*, 0 otherwise

Q_{it} = Quantity of finished product *i* manufactured at period *t*

Q^{m}_{it} = Quantity of intermediate product *i* manufactured on the machine *m* at period *t*

D^{c}_{it} = Quantity of finished product *i* bought from the producer at period *t*

R_{it} = Quantity of finished product *i* shipped by the producer at period *t*

RC_{it} = Quantity of producer's finished product *i* received by the retailer at period *t*

QSS_{it} = Quantity of finished product *i* bought from the second supply source at period *t*

RSS_{it} = Quantity of finished product *i* received by the retailer from the second supply source at period *t*

I_{it} = End of period inventory level of finished product *i* at the mill at period *t*

IF^{c}_{it} = End of period inventory level of producer's finished product *i* at the retailer site at period *t*

ISS^{c}_{it} = End of period inventory level of finished product *i* bought from the second supply source at period *t*

$Ntru_{t}$ = Number of trucks needed at period *t*

δ_{t} = Binary variable equal to 1 if the retailer orders producer's finished products at period *t*, 0 otherwise

δSS_{t} = Binary variable equal to 1 if the retailer orders second supply source's products at period *t*, 0 otherwise

3.2 Planning models

Each strategy has some distinct characteristics. First of all, the MTO mode is a traditional system that is not very collaborative but still frequently used by the pulp and paper industry. The producer manufactures the product after receiving the order from the retailer and then ships the merchandise. Since the producer can not see the real demand of the final consumer, operations are planned based on retailer orders. The producer also has to ship the right quantity and respect lead times. The retailer orders products according to its needs and the quantity ordered can be different from one period to another. The retailer knows the production and distribution lead times of the producer and has to take into consideration this information when planning.

Therefore, MTO planning models reflect this situation. Specifically, the objective function of the retailer based on MTO maximizes revenues generated from sales and minimizes the ordering cost, buying price and inventory cost (equation 1). The retailer must order and keep sufficient products in stock to satisfy the demand of the final consumer (constraints (2), (3) and (4)). The retailer also has to distinguish stock origins, specifically products delivered by the producer and products delivered by the second supply source (constraints (5) and (6)). If the retailer chooses to order from the producer, the merchandise is received after production and transportation lead times (constraint (7)). If the retailer prefers to order from a second supply source, it is assumed that inventory is on hand so only a transportation lead time is considered (constraint (8)). In all cases, an ordering cost (*cord*) must be considered each time the retailer purchases some products (constraints (9), (10), (11) and (12)).

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

$$- \sum_{t\in T}\sum_{i\in FP_F} h_{it}^{c} IF_{it}^{c} - \sum_{t\in T}\sum_{i\in FPS} h_{it}^{c} ISS_{it}^{c} \tag{1}$$

subject to

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

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

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

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

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

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

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

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

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

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

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

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

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

For the producer, the objective function based on MTO maximizes revenues and minimizes production, distribution and inventory costs (equation 15). The producer has to evaluate the number of intermediate products needed to manufacture finished products (constraint (16)). Only one intermediate product can be manufactured on a paper machine per period, with set-up at each product change (constraints (17), (18) and (19)). The producer also has to manufacture enough products in order to satisfy the demand of the partner and the demand of other clients (constraints (20) and (21)). Since the production of intermediate products creates a bottleneck, the production capacity must be considered (constraint (22)). Moreover, the transportation capacity also needs to be taken into account (constraint (23)).

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

subject to

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

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

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

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

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

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

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

$$\sum_{i\in FP_F} r_i R_{it} \le cap_t \times Ntru_t \qquad \forall t \in T \tag{23}$$

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

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

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

With the VMI mode, the producer is responsible for the inventory of its partner and has to maintain enough stock at the retailer site to guarantee a high service level. Therefore, the objective function of the producer based on VMI is similar to (15), with a new inventory cost ($h_{it}^{c} IF_{it}^{c}$) for products kept in stock at the retailer site. The objective function will now lead to the maximization of revenues and the minimization of production, distribution and inventory costs for products kept in stock at the mills and products maintained at the retailer site (equation 27). The replenishment process is based on stock consumption (constraint (28)) and it must be scheduled so as to maintain the stock level between minimum (s) and maximum (S) values (constraint (29)).

$$Max \sum_{t \in T} \sum_{i \in FP_F} stc_{it}^{c} p_{it} + \sum_{t \in T} \sum_{i \in FP_F} d_{it} p_{it} - \sum_{t \in T} \left[\sum_{m \in M} \left[\sum_{i \in IP} c_{it}^{m} Q_{it}^{m} \right] + \sum_{i \in FP_F} h_{it} I_{it} \right]$$
$$- \sum_{t \in T} \sum_{i \in FP_F} h_{it}^{c} IF_{it}^{c} - ctru \sum_{t \in T} Ntru_t \tag{27}$$

subject to (16 – 20, 22 – 26) *and*

$$R_{i(t-ld)} + IF_{it-1}^{c} - IF_{it}^{c} = stc_{it}^{c} \qquad \forall i \in FP_F; \quad \forall t \in T \cup \{0\} \tag{28}$$

$$s \leq IF_{it}^{c} \leq S \qquad \forall i \in FP_F; \quad \forall t \in T \tag{29}$$

For the retailer, the objective function based on VMI (equation (30)) includes the buying price for producer's products and the access to a second supply source if necessary (for example, if producer's forecasts are wrong and the retailer does not have sufficient stock to satisfy demand).

$$Max \sum_{t \in T} \sum_{i \in FP} d_{it}^{cc} pc_{it} - \sum_{t \in T} \sum_{i \in FP_F} RC_{it} p_{it} - \sum_{t \in T} cord\, \delta SS_t$$
$$- \sum_{t \in T} \sum_{i \in FPS} QSS_{it} pSS_{it} - \sum_{t \in T} \sum_{i \in FPS} h_{it}^{c} ISS_{it}^{c} \tag{30}$$

subject to (3 – 6, 8, 10, 12 – 14).

With the Regular Replenishment mode, 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 the merchandise at the right moment. The planning models based on Regular Replenishment are practically the same as the MTO models with two new constraints. More precisely, the retailer will receive orders exactly at the period specified (constraint (31)).

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

In addition, the producer knows in advance the order and has to deliver it at the right moment (constraint (32)).

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

If the collaboration is based on a CPFR mode, partners will have to jointly estimate the demand and then plan their activities. Since the CPFR reference model has been designed to fit many scenarios, we study this approach using an elaborate scheme to efficiently synchronize network activities (VICS, 2004). As a result, we assume a real collaboration between partners and the exchange of all the information. Planning decisions are made in order to maximize the profit of both partners and respect each of their local constraints. We also suppose that the retailer never uses the second supply source for this particular collaboration mode.

The CPFR objective function is the result of the sum of revenues and costs of each partner (equation (33)). The buying price is eliminated because it represents a cost for the retailer and revenue for the producer. The ordering cost is also excluded since the retailer does not have to plan specific orders. The quantity produced and delivered is determined by the two partners, based on a joint demand forecast (constraint (34)).

$$\begin{aligned} Max \sum_{t \in T} \sum_{i \in FP_F} de_{it}^{cc} pc_{it} + \sum_{t \in T} \sum_{i \in FP_F} d_{it} p_{it} - \sum_{t \in T} \left[\sum_{m \in M} \left[\sum_{i \in IP} c_{it}^{m} Q_{it}^{m} \right] + \sum_{i \in FP_F} h_{it} I_{it} \right] \\ - \sum_{t \in T} \sum_{i \in FP_F} h_{it}^{c} IF_{it}^{c} - ctru \sum_{t \in T} Ntru_t \end{aligned} \quad (33)$$

subject to (16 – 20, 22 – 26) *and*

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

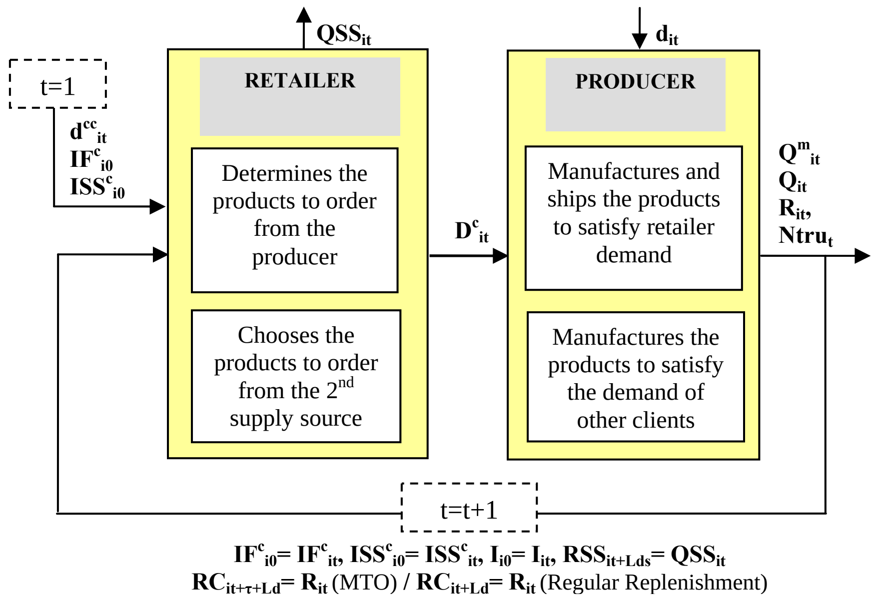
4 Experimentation and analysis

After developing the seven planning models from the point of view of both the producer and the retailer, we then proceed with numerical experiments using AMPL Studio and Cplex solver. Each test is realized using a rolling horizon of two weeks, for a total planning period of one year. The studied context is characterized by a variable demand known for the first week and an estimated one for the second week (we use the real demand of the producer). All the parameters are obtained from the industrial case. We consider 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. We also assume production and transportation lead times of one period.

4.1 Methodology to test each model

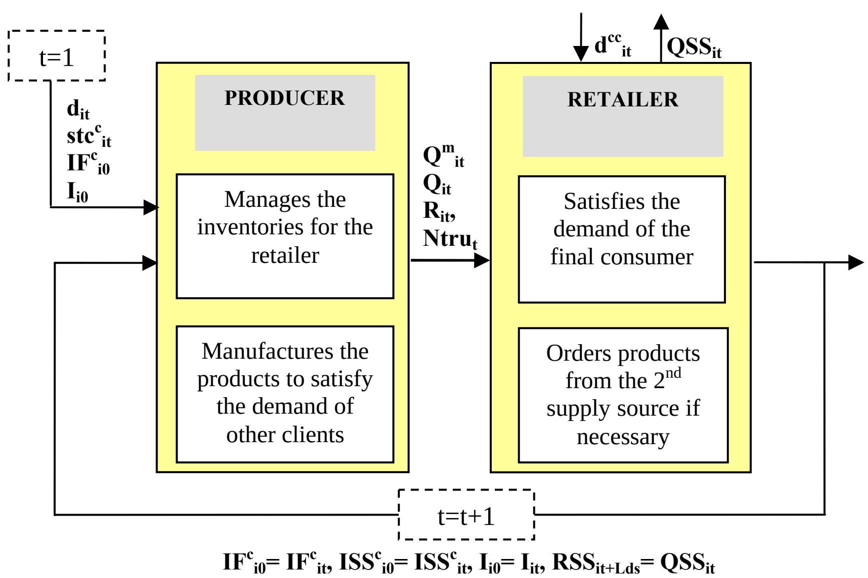
Since the collaboration mode directly affect how partners make their planning decisions, we define a methodology to take this characteristic into account in our experimentation. Specifically, for a relationship based on MTO and Regular Replenishment, the retailer determines the optimal quantity to order 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 the stock level into consideration (Figure 2).

Figure 2 Methodology to test MTO and Regular Replenishment models



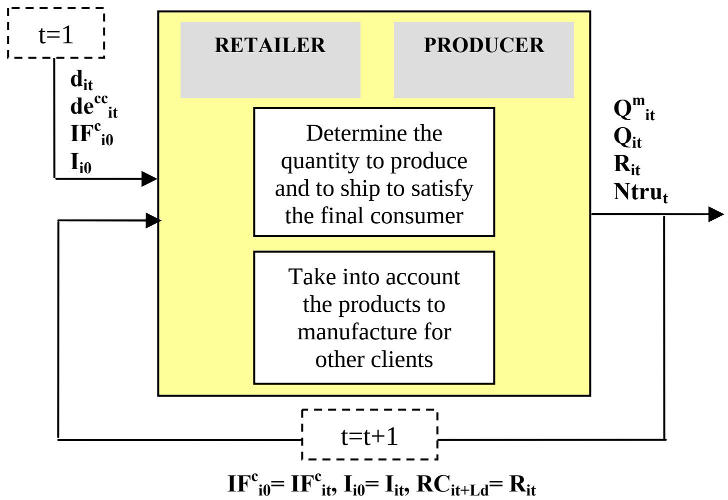
With the VMI mode, the producer determines the optimal quantity to manufacture and to ship to the retailer site, depending on the demand coming from the other customers, the stock consumption and the inventory level. Next, using the quantity delivered by the producer, the retailer satisfies its own demand (Figure 3).

Figure 3 Methodology to test VMI models



Since the CPFR mode is characterized by a common model, all decisions are made simultaneously (Figure 4).

Figure 4 Methodology to test the CPFR model

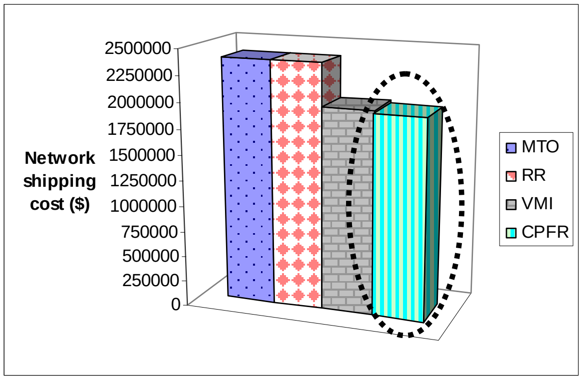


4.2 Analysis based on the profit and costs of the network

Using the methodology described previously, we test several scenarios. First of all, we analyze the situation where the price proposed by the producer is lower than the price offered by the second supply source. We also consider a price of the producer equal to the price of the second supply source. Afterwards, we compare the impact of a transportation lead time of one and two periods. Finally, we test different types of demand profile. More precisely, using the same variable demand profile, we organize the data differently to create new patterns. In particular, we calculate the mean of the variable demand for each product, namely we divide the sum of all the demands by 365 days, in order to develop a constant demand profile. In addition, so as to obtain an accumulated demand, we calculate the sum of the variable demand for three and six days for each product (for more details, see Lehoux *et al.*, 2007a).

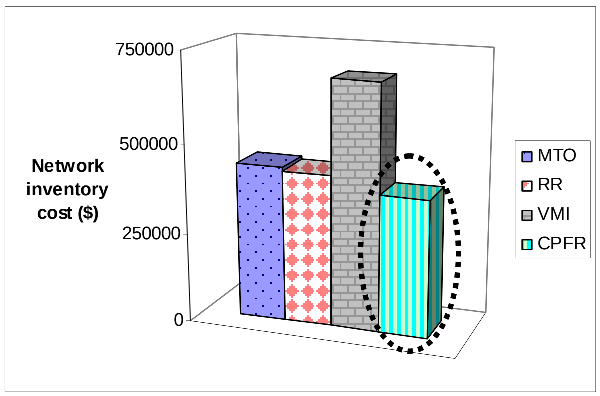
For all the scenarios, results show that CPFR is an efficient strategy to improve shipping and inventory costs of the system. For example, when the demand is variable, the price of the producer is lower than the price of the second supply source and the transportation lead time is equal to one period, the CPFR shipping cost is up to 18 percent lower than the shipping cost of other models (Figure 5).

Figure 5 Comparison of each collaboration approach according to the shipping cost



In addition, for the same scenario, the CPFR network inventory cost is up to 44 percent lower than the cost of other models (Figure 6).

Figure 6 Comparison of each collaboration approach according to the inventory cost

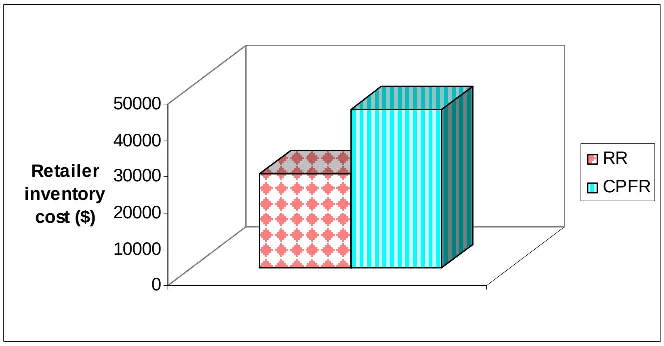


Consequently, the system profit obtained with this collaboration approach is greater than the profit generated by the other strategies. The VMI model obtains the second best result since the shipping cost is optimized (the inventory cost for this approach is significant because we assume a large stock level at the retailer site to guarantee a high service level). Regular Replenishment and MTO modes do not improve the transportation cost or the inventory cost at the producer site. Consequently, the system profit obtained with these strategies is inferior.

4.3 Analysis based on the profit of each actor

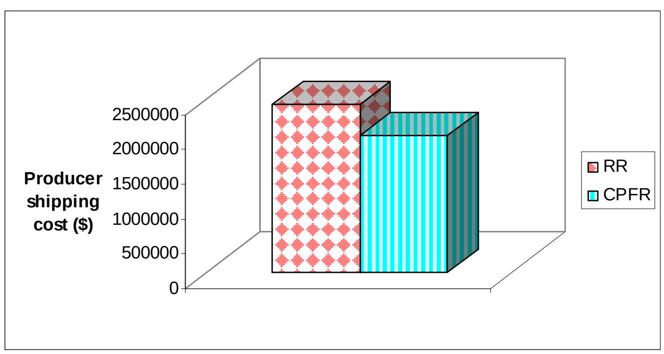
Since CPFR seems to be profitable for the system, we verify whether this strategy is also advantageous for all partners. To realize this, we first allocate the different costs of the CPFR objective function to obtain the profit of each actor. As a result, the profit of the producer includes production costs, distribution costs and inventory costs at the mill, while the profit of the retailer takes into account inventory costs at the retailer site. Afterwards, we compare all the approaches in regards to the profit and costs of each actor. This analysis reveals that CPFR is the most profitable approach for the producer, while the Regular Replenishment mode is the most advantageous for the retailer. Specifically, with Regular Replenishment, the retailer can order products depending on its needs so as to efficiently optimize its own inventory cost. However, when the relationship is based on CPFR, the retailer has to maintain more stocks to better use production and transportation capacities. Consequently, inventory cost increases considerably (up to 68% for a cumulated demand of 6 days and a lead time of one period, Figure 7).

Figure 7 Inventory cost of the retailer when the demand is cumulated for 6 days, ld=1 period



For the producer, if the collaboration is based on a Regular Replenishment mode rather than CPFR, he does not have access to the demand of the final consumer or the stock level of the retailer, so operations can not be synchronized adequately. As a result, shipping cost increases up to 22% (for a variable demand and a lead time of two periods, Figure 8). But when CPFR is implemented, operations are coordinated and costs of the producer improved. Therefore, no approach can provide a win/win situation for both partners.

Figure 8 Shipping cost of the producer when the demand is variable, ld=2 periods



For these first tests, we assume an ordering flexibility for the retailer when a Regular Replenishment relationship is established, to take the particularities of our industrial case into account. More precisely, the retailer elaborates an order plan covering fourteen days, but has the possibility to change the plan every day as the knowledge on the demand improves. Considering this, we test the situation where the flexibility is limited for the second week. In this way, the retailer can now adjust the order plan up to 30 percent for periods 8 to 14, but can not modify the plan for periods 1 to 7.

Results show that the MTO mode becomes the more profitable approach for the retailer, except for the scenarios where demand is constant (for these scenarios, since demand is identical at each period, the retailer does not have to change the order plan). For the producer, the CPFR is again the most advantageous collaboration strategy (Table 1). Nevertheless, even if the relationship is based on MTO, the producer is not able to optimize operational costs efficiently. Thus, neither MTO nor CPFR can be simultaneously advantageous for the two partners.

Table 1 The most profitable approach for each actor when flexibility is limited

Scenario tested	**Approach to obtain maximum profit**	
	PRODUCER	*RETAILER*
ld=1 period		
-Variable demand		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO
-Constant demand		
$p_{it}<pSS_{it}$	CPFR	Regular Replenishment
$p_{it}=pSS_{it}$	CPFR	Regular Replenishment
-Cumulated demand for 3 days		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO
-Cumulated demand for 6 days		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO
ld=2 periods		
-Variable demand		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO
-Constant demand		
$p_{it}<pSS_{it}$	CPFR	Regular Replenishment
$p_{it}=pSS_{it}$	CPFR	Regular Replenishment
-Cumulated demand for 3 days		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO
-Cumulated demand for 6 days		
$p_{it}<pSS_{it}$	CPFR	MTO
$p_{it}=pSS_{it}$	CPFR	MTO

4.4 Method to better share collaboration benefits

Since for all scenarios, no collaboration approach can simultaneously generate maximum profit for each actor, we determine how to better distribute collaboration benefits to encourage the retailer to tend towards a CPFR mode rather than towards Regular Replenishment or MTO. The proposed method employs an incentive based on sharing of the savings. Specifically, if a CPFR relationship is created, the producer better plans activities and decreases operational costs. However, to synchronize operations and correctly use the transportation capacity, more stocks have to be kept at the retailer site (with MTO or Regular Replenishment, the retailer always prefers to maintain minimum stock). Consequently, if the producer does not accept to share a part of the savings generated from CPFR, the retailer does not obtain maximum profit from the partnership. But if the producer proposes an incentive to better share collaboration benefits, the retailer has no interest to work with someone else. The need for sharing benefits could also be increased if the customer has the greatest bargaining power. In such case, it would be in the interest of the producer to propose such a deal. Therefore we analyse whether the share of transportation or inventory savings could be sufficient to create a win-win relationship advantageous for everyone (an example of the savings that can be shared is presented in Table 2).

Table 2 The use of an incentive to better share collaboration benefits

Scenario	**Producer cost type**	**Total cost**		**Incentive**
		Regular Replenishment	*CPFR*	*Savings that can be shared*
ld=1, $p_{it}<pSS_{it}$ Variable demand	Transportation	$ 2,388,284.10	$ 1,953,009.30	$ 435,274.80
	Inventory	$ 395,624.81	$ 326,976.44	$ 68,648.37

More precisely, we consider a share of 10 to 100 percent of transportation and inventory savings. We observe that for all the scenarios, if CPFR savings are correctly shared, the profit of the retailer is higher than the one generated by MTO or Regular Replenishment. For example, for the scenario where the demand is variable, the price of the producer is lower than the price of the second supply source and the transportation lead time is one period, the results show that a share of more than 56 percent of the inventory savings or a share of more than 10 percent of the transportation savings will guarantee maximum profit for the retailer (Figures 9 and 10).

Figure 9 Retailer profit with sharing of inventory savings, variable demand and ld=1 period

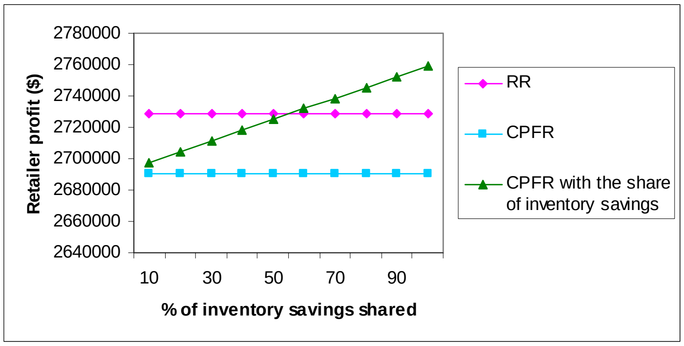
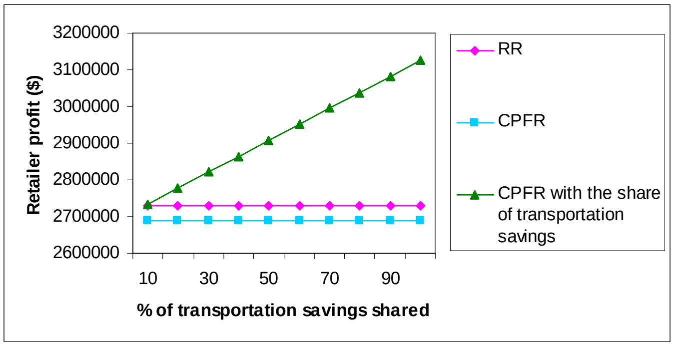


Figure 10 Retailer profit with sharing of transportation savings, variable demand and ld=1 period



For the producer, even if part of the savings is shared, a greater profit is obtained with this strategy than the one generated by other collaboration approaches. In particular, if the producer shares up to 100 percent of the inventory savings or up to 65 percent of the transportation savings, he obtains a higher profit than the one generated by the second best approach, that is the VMI mode (Figures 11 and 12, since the producer profit obtained with MTO is similar to the one obtained with Regular Replenishment, we remove this approach to facilitate comprehension of the graphic). The impact of each approach on the profit of the producer is limited because the profit margin of the producer is high and the quantity ordered by the merchant is very small in comparison with the ones purchased by the other customers.

Figure 11 Producer profit with sharing of inventory savings, variable demand and ld=1 period

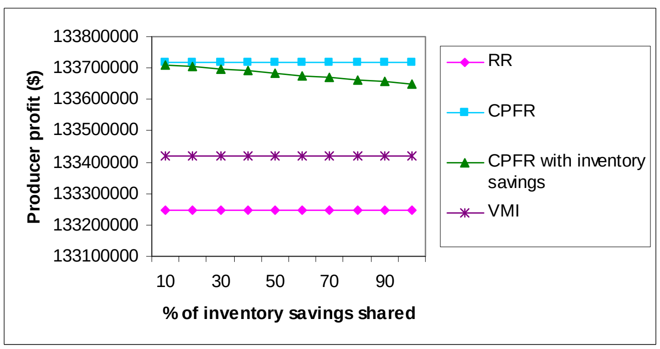
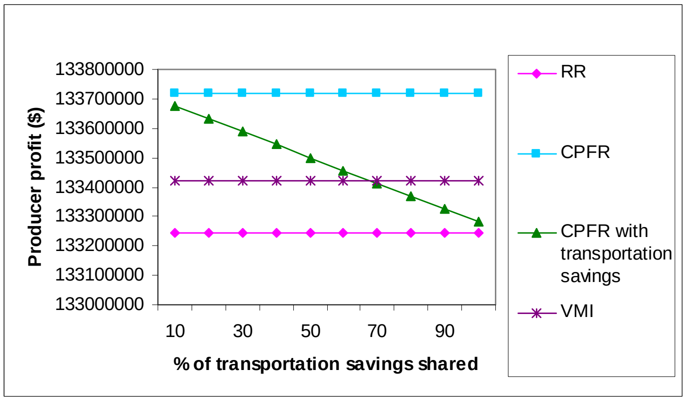


Figure 12 Producer profit with sharing of transportation savings, variable demand and ld=1 period



However, the value of savings shared depends on the context. For example, if the demand is cumulated for six days with a transportation lead time of two periods, the sharing of 10 percent of the transportation savings or the sharing of 56 percent of the inventory savings is not sufficient to adequately increase the profit of the retailer. Since the profit of the retailer obtained from regular replenishment is higher for this scenario, the producer has to share a greater part of the savings (Figures 13 and 14).

Figure 13 Retailer profit with sharing of inventory savings, cumulated demand for 6 days, ld=2 periods

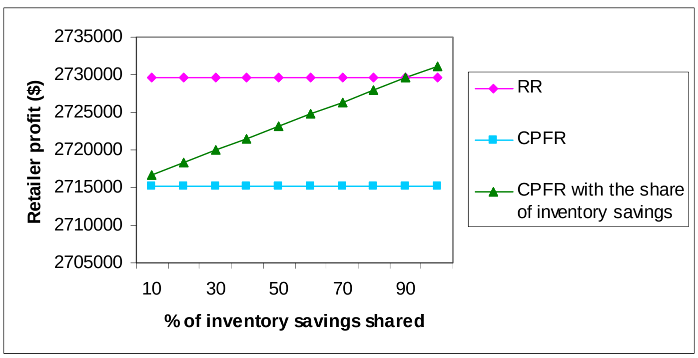
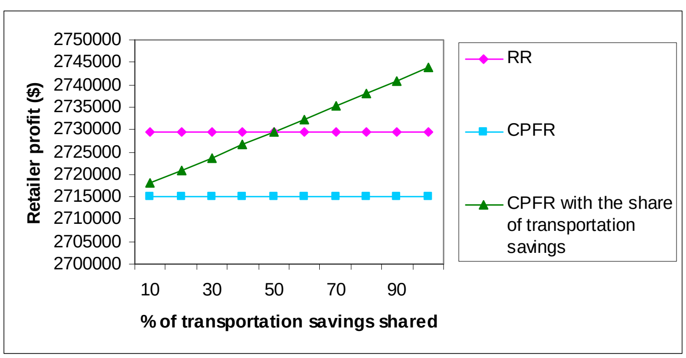


Figure 14 Retailer profit with sharing of transportation savings, cumulated demand for six days, ld=2 periods



Therefore for our case study, if partners want to work together using a CPFR scheme, the producer has to share a part of the savings with the retailer in order to guarantee a relationship advantageous for everyone. To implement this incentive, a price discount in $/ton proportional to the savings shared could be proposed to the retailer (Table 3). Nevertheless, a contract would be necessary to ensure that each partner respects the agreement.

Table 3 The use of a price discount to correctly share collaboration benefits

Scenario	Annual quantity ordered by the retailer	Savings to share	Price discount
ld=1, $p_{it}<pSS_{it}$ Variable demand	12,709 tons	$ 65,292	$ 5.14/ton

A look at the industrial case

It is interesting to compare the results obtained from the experimentation with the reality of the case study. In fact, the producer first created a partnership with its retailer based on a Regular Replenishment mode. The idea was to gradually increase the level of interaction between partners and be ready to establish a long-term relationship. After working together for a few months, the partners decided to put a collaboration approach similar to CPFR into practice. Consequently, they exchanged more information and allocated additional resources. However, in regards with our results, this new form of collaboration will not be equitably profitable for everyone. Since at the beginning of the partnership, the relationship was based on a Regular Replenishment mode with ordering flexibility, the retailer obtained maximum profit from the collaboration, whereas the producer was not in a good position to optimize operational costs. But, with the new collaboration approach the producer is able to better synchronize activities and improve transportation and inventory costs. However, the retailer probably has to keep a higher level of stock. Thus, the producer is better off to share a part of the savings generated from CPFR to sustain this relation. Otherwise, as we mentioned in our study, it is possible that the retailer may prefer to work with someone else.

5 Conclusion

In this article, we study different collaboration modes between a pulp and paper producer and its retailer. To realize this, we first develop seven planning models from the point of view of both the producer and the retailer, based on MTO, Regular Replenishment, VMI and CPFR. We then proceed with numerical experiments so as to compare each approach. Several scenarios are tested, namely a price proposed by the producer lower or equal to the price offered by the second supply source, a transportation lead time of one and two periods and different patterns of demand. For each scenario, we look at the profit of the network and the profit of each actor to identify the most profitable collaboration mode depending on the context. We also develop a method to adequately share collaboration benefits and tend towards a win-win relationship profitable for everyone.

Our first tests reveal that CPFR is the best strategy to optimize transportation and inventory costs and generate the greatest total system profit. VMI is second best since the transportation cost can be significantly decreased. The Regular Replenishment approach and MTO obtain the lowest system benefits. When we look at the profit of each actor, we observe that CPFR generates the greatest profit for the producer while the Regular Replenishment mode is the most profitable strategy for the retailer. Specifically, since the CPFR mode facilitates the synchronization of all activities, the producer can better plan its operations and considerably reduce transportation cost. On the other hand, the retailer must accept to stock more products. When the relationship is based on Regular Replenishment, the retailer can order products depending on its needs, so as to maintain minimum stocks at each period. However, since the producer has no access to the demand of the final consumer or the stock level of the retailer, activities can not be coordinated efficiently. When we limit the ordering flexibility, that is we authorize the retailer to change the order plan by up to 30% for periods 8 to 14 without any change for periods 1 to 7, the MTO mode becomes the most advantageous strategy for the retailer (except for scenarios with constant demand). Since no approach can simultaneously generate the greatest profit for both actors, we try to see if the share of transportation or inventory savings obtained from CPFR could be sufficient to incite the retailer to put this strategy into practice. We observe that if the producer accepts to share part of the transportation or inventory savings, the profit of the retailer is higher than the profit obtained with Regular Replenishment or MTO, and the producer obtains a higher profit than the one generated by other collaboration approaches. For our case study, if this incentive is correctly applied, no player has an interest to work with another organization since the CPFR collaboration is profitable for everyone.

Nevertheless, in practice, it is not always easy to correctly share network benefits. Partners need to use historical data to analyze their industrial context. They also have to negotiate the price, discount, percentage of savings shared, etc., so as to tend towards a relationship profitable for both partners; however the negotiation of the value of the incentive can be very laborious. In addition, some performance indicators must be defined to evaluate the impact of the collaboration and make sure that no opportunistic behaviour affects the relationship. Even though it is complicated, this procedure is indispensable to establish a long-term relationship.

This paper contributes to illustrate that a specific collaboration mode is not necessarily profitable for all partners. In addition, we show that the sharing of savings could be a good strategy to motivate the partner to implement a specific collaboration mode. For future research, it would be interesting to determine how to develop and adjust a financial incentive for different industrial contexts, in order to create long-term partnerships advantageous for all network members. It would also be interesting to analyze how competition impacts the efficiency of collaborations and the choice of the incentive to implement. This could lead to a better knowledge of collaboration dynamics and the importance of adequate benefit sharing.

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