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Collaboration for a Two-Echelon Supply Chain in the Pulp and Paper Industry: The Use of Incentives to Increase Profit

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Abstract. International competition, the increase of energy and production costs, and the need to change ineffective production equipment, are some of the reasons why the Canadian pulp and paper industry is currently facing an important crisis that forces enterprises to revise their way of doing business. Via an efficient optimization of the entire network activities and the establishment of strategic collaborations with suppliers, distributors and retailers, several enterprises have chosen to adopt these new strategies in order to exchange goods and information adequately throughout the network. Thus, collaboration approaches like Collaborative Planning, Forecasting and Replenishment (CPFR) may be used to better synchronize operational activities. However, the success of their implementation mainly depends on gains obtained by each partner. It is therefore necessary to choose an appropriate collaboration approach and to develop proper incentives in order to guarantee that each partner will obtain enough gains from collaborations. In our research, we study the case of a pulp and paper producer who decides to establish a partnership with one buyer. Using two different types of relationship, namely a traditional system without any collaboration scheme and CPFR, we develop decision models describing the producer and the buyer planning processes. We also identify which approach is more profitable for each actor as well as for the network, based on real costs and parameters obtained from the industrial case. We then test how different incentives can improve the traditional system and provide higher gains for each partner. Our results show that using incentives can increase the system's profit by up to 4% if parameters are well defined.

Keywords. Enterprise collaboration, incentives, supply chain management, contracts.

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1 Introduction

Considering the effects of international competition, the development of new technologies and the increase of operation and energy costs, enterprises must optimize their way of doing business if they want to survive and be better than the competition. In Canada, some industrial sectors like the pulp and paper industry are more affected by this economic situation. Enterprises must improve their supply chain and tend towards new logistics strategies in order to efficiently manufacture and deliver products throughout the network. One way of doing this is to establish collaborations with suppliers, retailers and customers, so as to coordinate activities and exchange more information.

In our research, we study the case of a pulp and paper producer who decides to establish a partnership with one of his clients in order to improve production and distribution planning. The producer is specialised in the production and sale of paper, pulp and wood, and has multiple mills and warehouses all across Canada and the United States. The producer is one of the main paper suppliers in the country. The production process is characterized by a limited capacity, so the producer must plan his operations in order to satisfy the demand of the partner and the demand of all the other clients. The partner is a merchant, thus he buys products from the producer, keeps them in stock and then sells them to the final consumer without transforming the products. The merchant has two warehouses in the province of Quebec, and offers more than two thousand different products to his Canadian and American customers. These two actors therefore decided to collaborate in order to better respond to market demand, under the constraint that each partner still aims for maximum profit. The producer tries to optimize his production, distribution and inventory costs, while the merchant tries to optimize his ordering, buying and inventory costs. Consequently, it is necessary to identify a collaboration mode that leads to an efficient products exchange and that generates maximum profits for the network and for each actor. To realize this, we compare two types of relationship, namely a traditional system characterized by a local optimization without any collaboration scheme, and CPFR (Collaborative Planning, Forecasting and Replenishment), a collaborative technique that attempts to optimize network activities. For each of these approaches, we develop decision models that illustrate the planning decisions from the point of view of the producer and from the point of view of the merchant. We then try to identify which one is more profitable for each partner as well as for the network, based on real costs and parameters obtained from the industrial case. We also develop three types of incentives with the aim of increasing the profit of the traditional system. More precisely, we investigate the impact of a bonus for optimized orders, a share of savings when shipments are optimized, and quantity discounts.

In summary, our goal is to explore two types of relationship for a real industrial case. When analysing profits for the network and for each partner, it is observed that a particular collaboration mode is not necessarily advantageous for both of them. Moreover, some incentives are also examined. They contribute to increase the network profit of the traditional system, without requiring an important information exchange or a complex implementation. Therefore, using incentives in a two-echelon supply chain can be an efficient strategy to obtain a greater network profit. This article is organized as follows: In Section 2, a brief literature review is proposed. In Section 3, we describe our case study and the decision models developed. In Section 4, the computational study, the analysis, and the incentives are detailed. Finally, we provide some concluding remarks in Section 5.

2 Literature review

The pulp and paper supply chain is relatively complex (Carlsson *et al.*, 2006). 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. More particularly, a key factor concerns the planning and scheduling of different production stages to manufacture a large number of products. 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 (intermediate products). 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 producer can choose to produce in order to stock products (Make to Stock), he can realize all the production stages and then cut the paper to obtain different types of sheets depending on the demand (Sheet to Order), or he can manufacture products on demand (Make to Order) (Chauhan *et al.*, 2005). In addition, the producer must deliver products quickly and respect the transportation capacity. The more these different activities are coordinated, the more advantageous it can be. As an example of this, Nafee *et al.* (2004) demonstrate that if production and distribution operations are synchronized, some important gains can be obtained and costs can be optimized.

However, to aim for an efficient planning of supply chain activities, it is necessary that each actor has a good knowledge of the features and the needs of the network. As many authors demonstrate in their studies (see for example Chen, 2003), the supply chain is characterized by asymmetric information. For example, when the merchant sells different types of paper to printers, he has access to specific demand information and he can choose to share or not this knowledge with the producer. If he chooses to keep this information for himself, the producer will have to plan the production based on merchant orders and not on the real demand of printers. This lack of information can lead to inefficient utilization of capacity, stock in excess or shortages, poor quality of service, etc., throughout the network (Lee *et al.*, 1997). Therefore, in an ideal world, supply chain partners should share their knowledge so as to decrease negative effects of decentralized planning.

Even if all the information is exchanged, it is also necessary to use some collaborative approaches in order to correctly use this knowledge. Through the years, different industries have developed methods to better synchronize activities and tend towards a more centralized production and distribution planning. 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) (Martel, 2000). 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 (Baratt and Oliveira, 2001). An interesting case study on the application of VMI to the household electrical appliances sector is presented by De Toni and Zambolo (2005), in which they show how the implementation of the VMI model results in more gains 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 (VICS, 2004). 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 differences in the forecasts or inventory, in order to correct the problems before they negatively impact sales or profits. As Thron *et* *al.* (2005) demonstrate in their paper, developing CPFR in the supply chain can lead to substantial benefit, depending on the context studied. CPFR can also be more efficient than the VMI mode, especially when the demand is variable (Cigolini and Rossi, 2006).

Nevertheless, the exchange of information and the use of collaborative methods do not guarantee an immediate success. The more partners need to work together, the more time and money will have to be spent to ensure a viable collaboration. Moreover, the partnership will not continue if one of the members does not obtain enough gains or if a participant attempts to divert the collaboration in his favour. This would be the case of an opportunist player who tries to impose the rules of the game or makes decisions considering penalties and rewards locally rather than globally (Simatupang and Sridharan, 2002). To avoid this kind of situation, it is often necessary to use incentives such as pricing agreements or quantity discounts to influence actor decisions and tend towards an optimization of the global network. Many authors have studied these incentives applied to supply chain management. Cachon (2003) 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 (2004) 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 for compensation (see for example Bernstein and Federgruen, 2005). 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). 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 Tsay, 1999). Frequently used, quantity discounts also encourage the buyer to order more than usual (see for example Munson and Rosenblatt, 2001). The guarantee of a certain profit margin is another way to change the behaviour of partners (Urban, 2007).

Because it is difficult to study inter-firm collaborations without considering their impact on production planning, several authors have taken into account characteristics of production and distribution systems to define how many units to produce or to order, so as to better coordinate decisions of each network member. More precisely, authors have studied the negotiation process between two or more partners in order to develop a planning model with minimum information exchange (Dudek and Stadtler, 2007, Jung *et al.*, 2008, Zhu *et al.*, 2007). However, Dudek and Stadlter (2007) observe that an efficient network planning must be associated with the use of an incentive like the share of savings to ensure that each partner gains a true advantage. This is why the decision models presented in the next section include different operational parameters and the use of incentives. By considering characteristics of production and distribution systems and different types of network rewards, we are able to develop decision models that reflect industrial reality. Also, by applying three different incentives to a traditional system, we thus propose an approach that better coordinates planning decisions of each partner and increases the profit of the network, without requiring an important implementation cost.

3 Decision models and case study

In order to compare different types of relationship for a two-echelon supply chain and to identify which one generates the greatest profit for the network and for each partner, we develop decision models from the point of view of both the producer and the merchant that illustrate all their planning decisions[1]. More precisely, using mixed-integer linear programming, we identify the costs, revenues and constraints involved in using a traditional system without any collaboration scheme and the CPFR method. The idea is to select two approaches with different levels of interaction. The traditional system is frequently used in the pulp and paper industry since it does not necessitate an important interaction level, whereas CPFR requires a real cooperation between partners and specific information has to be exchanged. So it is interesting to compare these two opposite cases in order to evaluate their impact on the network profit. The case study concerns a pulp and paper producer who decides to establish a partnership with one of his clients. Because the production capacity is limited, the producer must plan activities adequately to satisfy the demand of the partner and the demand of a large number of clients. The partner can buy products from the producer or from another supply source depending on the price and lead times offered (Figure 1).

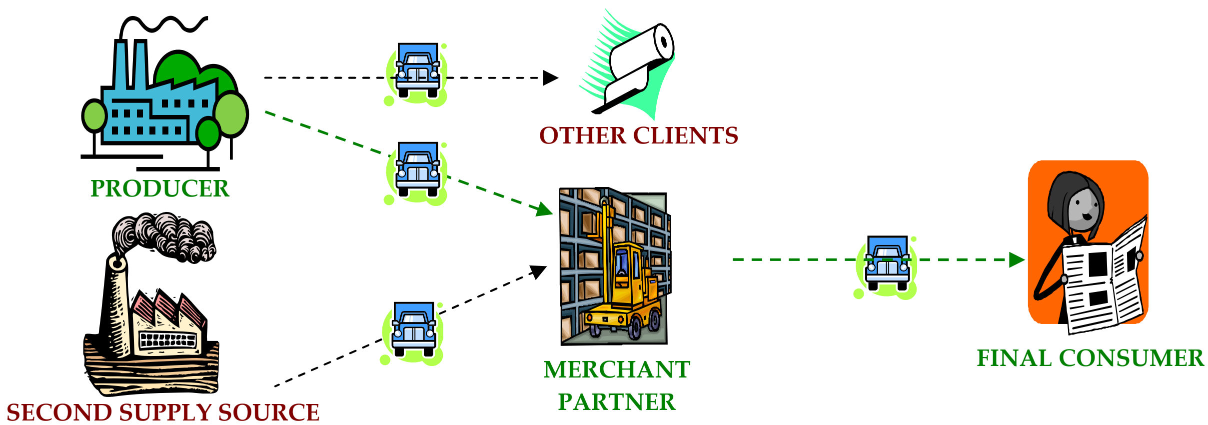

Figure 1: Description of the case study

3.1 Mathematical notation

After choosing a traditional system and the CPFR mode as potential types of relationship for the case study, we use mixed-integer linear programming to define decision models that illustrate the planning process of each partner. To formulate the models, the following mathematical notation is required:

Sets

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 $\cup$ 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

Parameters

[1] The producer decision model has some similarities with the model presented by Rizk *et al.* (2005).

$t =$ A planning period
$\tau =$ 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 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
$tset^m_i =$ 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
$d^{cc}_{it} =$ Demand for finished products ordered by the final consumer at period t
$de^{cc}_{it} =$ Demand for finished products 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 on machine m at period t
$h_{it} =$ Inventory holding cost of finished products at the mill at period t
$h^c_{it} =$ Inventory holding cost of finished products at the merchant site at period t
$ctru =$ Transportation cost of finished products delivered to the merchant at period t
$cord =$ Ordering cost of the merchant
$pSS_{it} =$ 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 merchant to the final consumer at period t
$bonus =$ Bonus for small orders that are avoided
$nbro =$ Number of orders made by the merchant without using an incentive
$cmin =$ Minimum truckload use to get the incentive (% truckload $*$ cap_t)
$qmin =$ Minimum quantity to order by the merchant to obtain a discount
$pds_{it} =$ Price after discount for additional units ordered at period t
$w =$ Point where the line with discount crosses the y-axis
$g =$ A large number

Decision variables

$\pi^m_{it} =$ Binary variable equal to 1 if the product is manufactured on machine m at period t, 0 otherwise
$\rho^m_{it} =$ Binary variable equal to 1 if a setup for the product is made on machine m at period t, 0 otherwise
$Q_{it} =$ Quantity of finished products manufactured at period t
$Q^m_{it} =$ Quantity of intermediate products manufactured on machine m at period t
$D^c_{it} =$ 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 merchant 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 merchant 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 merchant 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
δ_t = Binary variable equal to 1 if the merchant orders producer's finished products at period t, 0 otherwise
δSS_t = Binary variable equal to 1 if the merchant orders second supply source's products at period t, 0 otherwise
NSO_t = Binary variable equal to 1 if a bonus is given at period t, 0 otherwise
D^{c1}_{it} = Quantity of finished products bought from the producer without a discount at period t
D^{c2}_{it} = Quantity of finished products bought from the producer with a discount at period t
$V1_t$ = Binary variable equal to 1 if the quantity ordered is lower than the minimum quantity at period t, 0 otherwise
$V2_t$ = Binary variable equal to 1 if the quantity ordered is higher than the minimum quantity at period t, 0 otherwise

The following section describes each decision model.

3.2 Decision models

The development of a specific relationship will directly affect the way goods and information are exchanged between partners, as well as how the partners make their planning decisions. Thus, enterprises do not make the same decisions if the relationship is based on a CPFR method rather than a traditional system. Specifically, if the relationship is based on a traditional system without any collaboration scheme, the merchant orders products depending on his needs, and the quantity ordered can be different from one period to another. The merchant knows the production and distribution lead times of the producer and must take into consideration this information in his planning (Figure 2). The producer can use the stock on hand to satisfy the demand of the partner and the demand of other clients or he can manufacture the products on demand. The producer cannot see the real demand at the point of sales and must plan the production based on different merchant orders. The producer also has to deliver the right quantity and respect lead times.

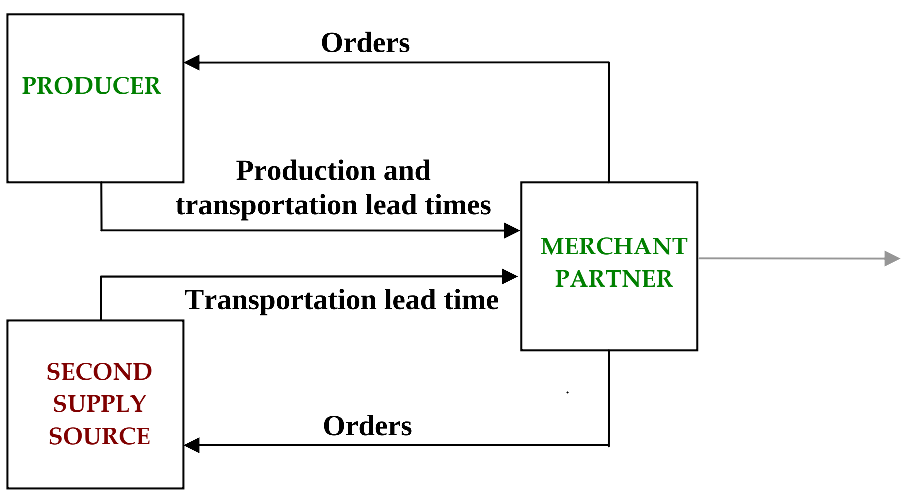

Figure 2: Relationship based on a traditional system

Therefore, decision models based on a traditional system reflect these characteristics. More precisely, the merchant decision model based on a traditional system is presented 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 merchant wants to maximise his revenue and minimize his ordering, buying and inventory costs if he orders from the producer and/or from a second supply source (equation (1)). The merchant has to make sure that he orders and keeps sufficient stock to satisfy the demand of the final consumer (constraints (2), (3) and (4)). He 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 he chooses to order the producer's products, he will receive his merchandise after production and transportation lead times (constraint (7)). If he purchases from the 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 must be taken into account each time the merchant orders products from the producer or from the second supply source (constraints (9), (10), (11) and (12)).

The producer decision model based on a traditional system is presented as follows:

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

subject to

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

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

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

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

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

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

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

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

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

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

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

The producer tries to maximise his revenues and minimize his 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 quantity produced and/or stocked must be adequate to satisfy the demand of the partner and the demand of other clients (constraints (20) and (21)). In addition, production and transportation capacities need to be respected (constraints (22) and (23)).

When the relationship is based on a CPFR approach, partners have to estimate the demand and then use this forecast in their planning. Since the CPFR reference model is designed to fit many scenarios, we chose to study the method using an elaborate scheme in order to efficiently synchronize the network activities (VICS, 2004). Thus, 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 (Figure 3). We also suppose that the merchant never uses the other supply source for this particular collaboration mode.

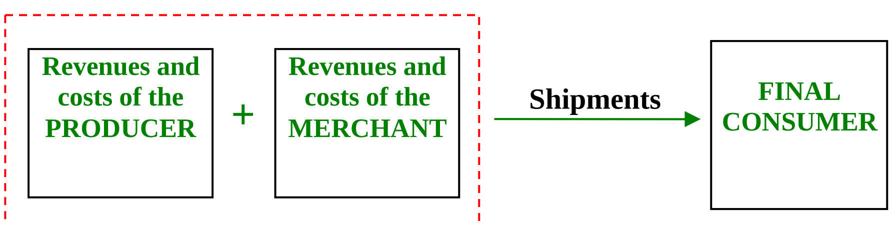

Figure 3: Relationship based on the CPFR method

The objective function based on CPFR is the result of the sum of revenues and costs of each partner (equation (27)). The buying cost is eliminated from the objective function because it represents a cost for one partner and revenue for the other one. The ordering cost is also eliminated since the merchant 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 (28)).

$$Max \sum_{t\in T} \sum_{i\in FP_F} de_{it}^{cc} pc_{it} + \sum_{t\in T} \sum_{i\in FP_F} d_{it} p_{it}$$

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

$subject\ to$ (16 – 20, 22 – 26) and

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

4 Computational study

After developing decision models based on a traditional system and CPFR, we proceeded with numerical experiments in order to compare each approach and to identify which one generates the greatest profit for the network and for each partner. Experiments were run on AMPL Studio with Cplex solver. Each test is experimented 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 estimated for the second week (2% error on the forecast). All the costs and the parameters used in the models have been obtained from the industrial case, but there are not detailed in this article because of the confidential aspect. We consider the demand for twenty finished products grouped into four families, each family corresponding to one intermediate product. We assume production and transportation lead times of one period. The producer and the second supply source offer the same products. The producer manufactures products with two paper machines, the bottleneck stage of the production process.

The experiments start with the models based on a traditional system. More precisely, the merchant decision model is solved first in order to identify the optimal quantity to order, depending on the demand to satisfy, the inventory level and the deliveries planned. Next, based on this optimal order and the demand of other clients, the producer decision model is solved, taking into consideration the stock level (Figure 4).

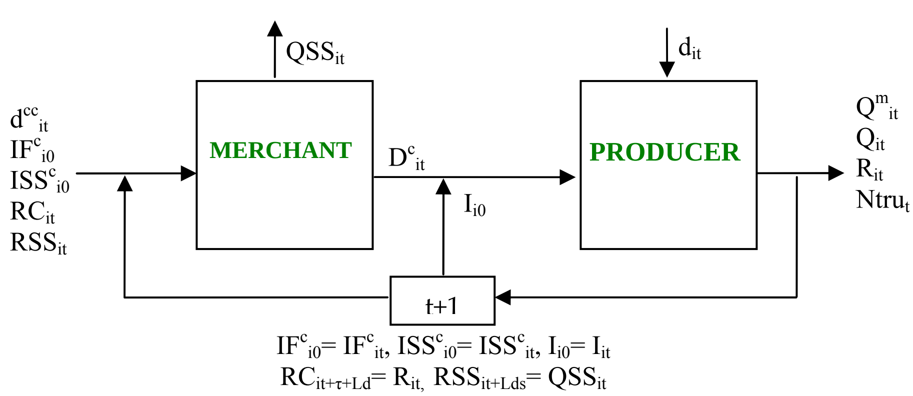

Figure 4: Procedure for testing the traditional system

Afterwards, the CPFR decision model is solved. Specifically, using all the costs and revenues of each partner, the optimal quantity to manufacture and to ship is found so as to maximize the profit of the network (Figure 5).

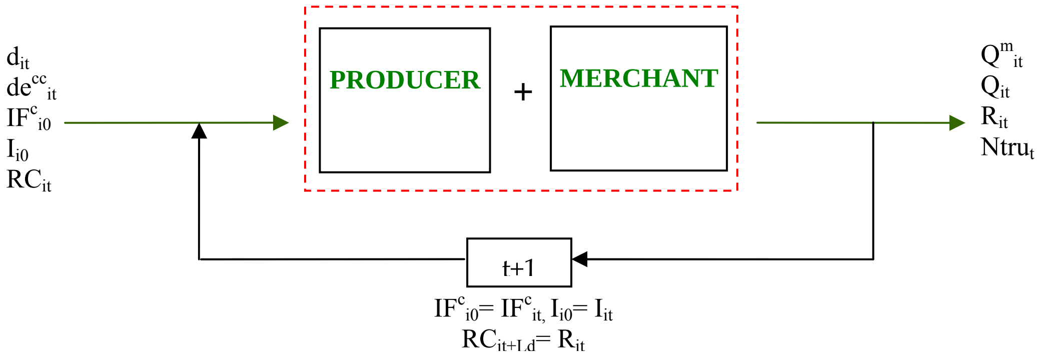

Figure 5: Procedure for testing the CPFR approach

4.1 Analysis of the network profit

Based on the testing procedure described in the precedent section, several scenarios have been tested. More precisely, a first scenario where the prices of the producer are lower than the prices of the second supply source is compared to a second scenario were the prices of the producer are equal to the prices of the second supply source. Afterwards, different transportation lead times are evaluated. Finally, different types of demand profile are analyzed (for more details, see Lehoux *et al.*, 2007). The results reveal that the CPFR method generates the greatest total system profit, mainly because of an efficient optimization of the transportation cost (reduction of 18%, Figure 6). In fact, with the CPFR method, the producer can choose to keep more stock in the system in order to decrease the shipping cost. But with the traditional system, the producer must deliver the quantity ordered by the merchant, even if the transportation capacity is not entirely used. Consequently, the traditional system obtains the lowest total system profit.

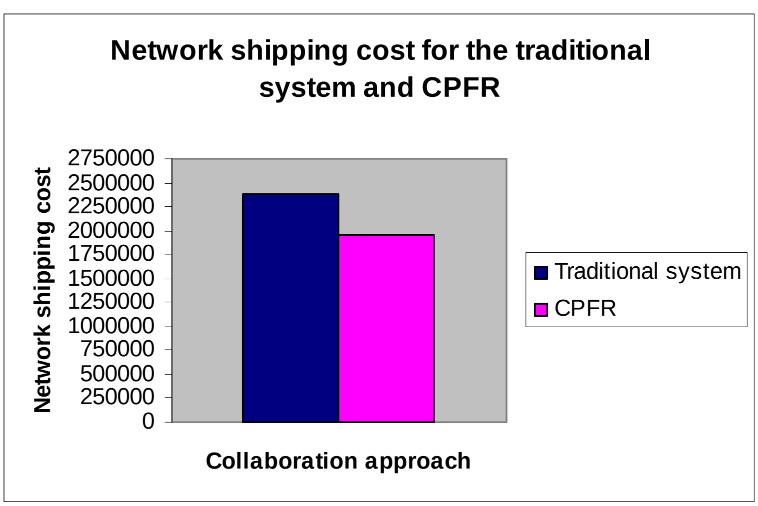

Figure 6: Network shipping cost obtained with the use of a traditional system and the CPFR mode

4.2 Analysis of the profit of each actor

In this section, we study a method to better share network benefits. More particularly, since CPFR generates the greatest profit for the network, we checked if the use of this collaboration mode could be profitable for both the producer and the merchant. To realize this, the objective function of the CPFR is divided in order to obtain the profit of each partner. As a result, the profit of the producer now includes production costs, distribution costs and inventory costs at the mill, while the profit of the merchant takes into account inventory costs at the merchant site. The scenario considered is characterized by a price of the producer lower than the price of the second supply source, a transportation lead time of one period and a variable demand.

We observe that CPFR is the most beneficial for the producer, whereas the traditional system generates the greatest profit for the merchant. This result shows that if one of these approaches is used by the network, the partnership is not profitable for at least one partner. More precisely, one of the partners does not take advantage of the collaboration and will work on changing the type of relationship or choose to work with someone else (Table 1).

Table 1: Profit of each partner for one year obtained with a traditional system and the CPFR mode

MERCHANT PROFIT		PRODUCER PROFIT	
Traditional system	*CPFR*	*Traditional system*	*CPFR*
1347290 $	1318734 $	7712488 $	**8030342 $**

For this reason, we identify a method to share benefits in order to obtain a CPFR collaboration that is profitable for each partner. More precisely, we observe that if the producer accepts to share a part of the transportation savings with the merchant, the profit of the merchant is higher than the profit obtained with a traditional system (Figure 7), and the producer obtains a higher profit than the one generated by the other approach.

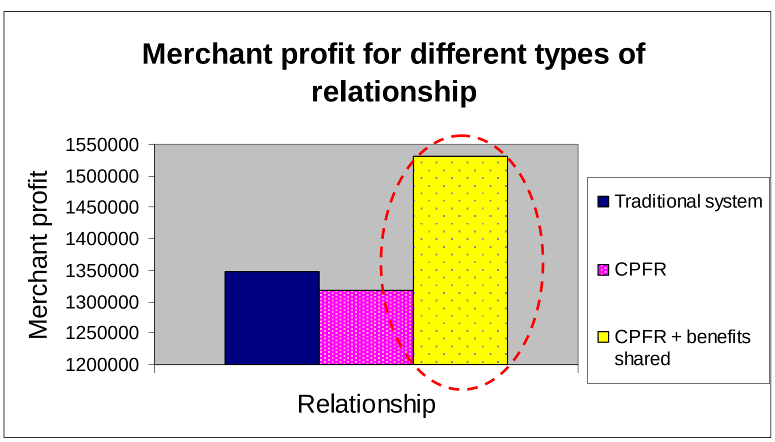

Figure 7: Merchant profit for different types of relationship

So for our case study, even if the CPFR generates the greatest total system profit, this approach needs to be used with an adequate method to share benefits like the share of transportation savings so as to be profitable for every partner. Otherwise, the merchant obtains a lower profit and he will probably bring the collaboration with the producer to an end.

4.3 The use of incentives to increase the profit of the traditional system

In this section, we study the use of some incentives to increase the profit of the network. In particular, the CPFR method is regularly used by enterprises to better coordinate activities and eliminate excess inventory. However, this kind of collaboration approach requires an important implementation cost and considerable investments. Also, specific information has to be exchanged even if enterprises frequently prefer to keep this information for themselves. Considering this, how can partners be incited to make decisions that are good for the entire network, in order to obtain a total system profit similar to the one generated by the CPFR mode? Which incentive should be used to change partner behaviours without requiring an important information exchange? To respond to these questions, three different incentives are developed: 1- a bonus if orders are optimized with regards to shipments, 2- the share of transportation savings if the transportation capacity is well used, and 3- a quantity discount if the merchant orders more than usual. We then apply these incentives to the model based on a traditional system in order to verify whether their use improves the profit of the network or not.

The first incentive studied is based on the use of a bonus to optimize orders. More precisely, the merchant orders each day (one order/day), but the quantity regularly ordered does not exploit full transportation capacity. Consequently, a lot of trucks are not entirely loaded. So, with this incentive, the merchant is encouraged to order less frequently, but with larger orders, so as to better use transportation capacity. In return, the producer gives a bonus for small orders that are avoided. We assume that partners have negotiated the bonus before any process takes place.

With these new characteristics, the objective function of the merchant based on a traditional system will now include the bonus given when small orders are not placed (equation (29)). Also, a new constraint is necessary to calculate the number of small orders avoided (constraint (30)).

$$
\begin{aligned}
Max \sum_{t\in T}\sum_{i\in FP} d_{it}^{cc}\, pc_{it} - \sum_{t\in T} cord\, \delta_t - \sum_{t\in T} cord\, \delta SS_t - \sum_{t\in T}\sum_{i\in FP_F} D_{it}^{c}\, p_{it} \\
- \sum_{t\in T}\sum_{i\in FPS} QSS_{it}\, pSS_{it} - \sum_{t\in T}\sum_{i\in FP_F} h_{it}^{c} IF_{it}^{c} - \sum_{t\in T}\sum_{i\in FPS} h_{it}^{c} ISS_{it}^{c} \\
+ \sum_{t\in T} NSO_t\, bonus
\end{aligned}
\tag{29}
$$

$$\textit{subject to } (2-14) \textit{ and}$$

$$
nbro - \sum_{t\in T} \delta_t = \sum_{t\in T} NSO_t \tag{30}
$$

Using different values for the bonus, one can rapidly observe a profit of the system greater than the profit obtained with a traditional system (Figure 8).

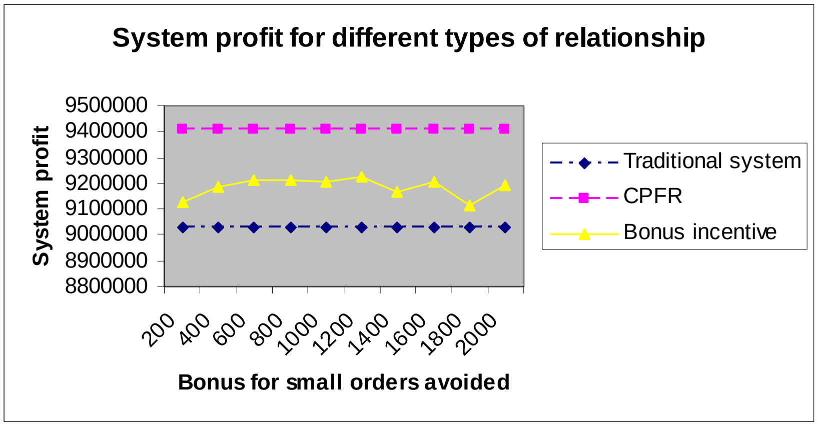

Figure 8: The impact of using a bonus on the profit of the system

More precisely, the merchant orders less frequently and the transportation capacity is better used (Table 2).

Table 2: Quantity ordered by the merchant with and without a bonus

	Number of products A ordered for one week	
T	*Without Bonus*	*With Bonus = 600$/small orders avoided*
1	3263	3741
2	478	0
3	50934	77178
4	26244	0
5	26353	58762
6	32409	0
7	8758	17767

Moreover, for a large number of bonus values, adding this incentive is profitable for both the merchant (Figure 9) and the producer (Figure 10). Specifically, since the transportation capacity is well used, the producer obtains a lower shipping cost. For the merchant, even if the stock level is higher, the bonus is sufficient to obtain a greater profit.

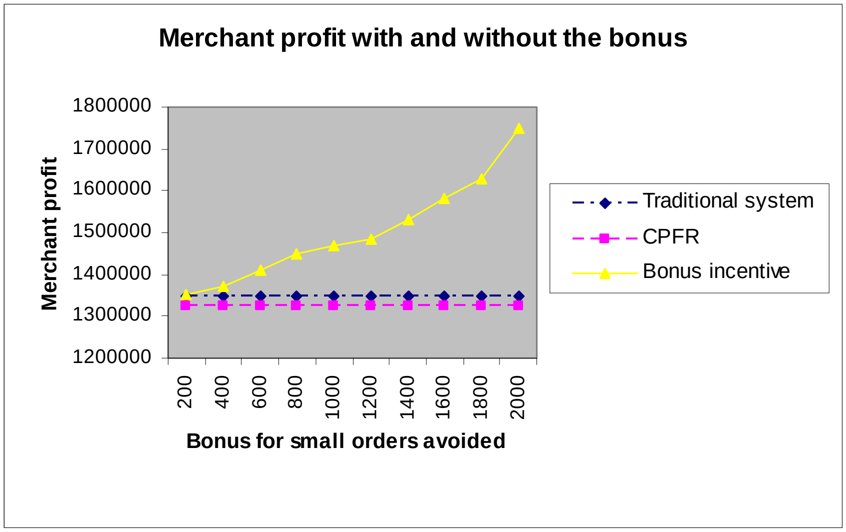

Figure 9: The impact of using a bonus on the profit of the merchant

Nevertheless, if the incentive is too high, the profit of the producer decreases because the cost to encourage the merchant to order less frequently becomes more important than the transportation savings (Figure 10).

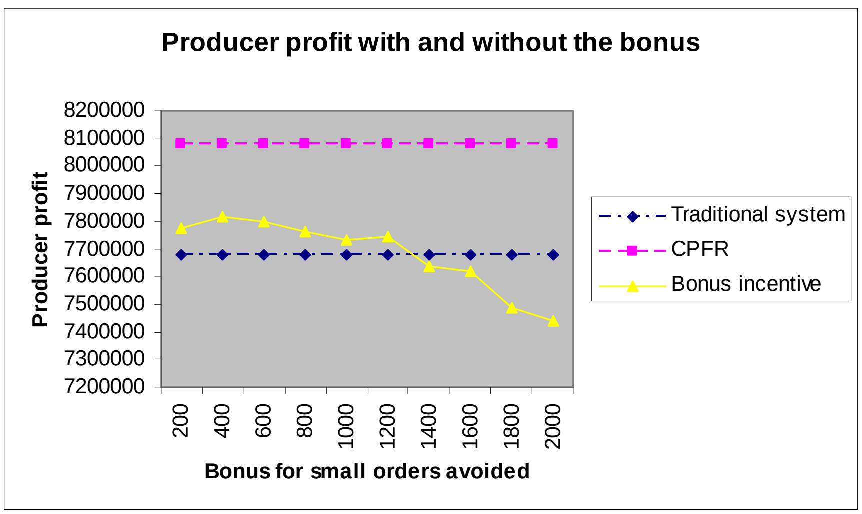

Figure 10: The impact of using a bonus on the profit of the producer

The second incentive developed is based on the share of transportation savings. Specifically, if the merchant orders enough products to efficiently use the transportation capacity (% truckload), the producer shares a part of the savings with him (% of the transportation savings).

Again, the merchant decision model based on a traditional system is used, but with new constraints: the merchant now takes into consideration the transportation capacity and must order between minimum and maximum values (constraints (31) and (32)).

$$\text{cmin}\, Ntru_t \leq \sum_{i \in FPF} D_{it}^{c} \qquad \forall t \in T \tag{31}$$

$$\sum_{i \in FPF} D_{it}^{c} \leq cap_t \, Ntru_t \qquad \forall t \in T \tag{32}$$

Results show that the profit of the system is considerably improved in comparison with the profit obtained using a traditional system (Figure 6).

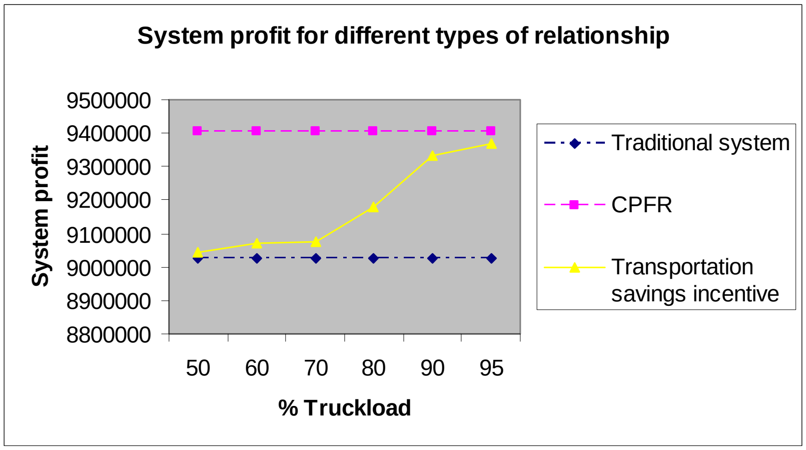

Figure 11: System profit for a traditional system, CPFR and the use of a transportation savings incentive

Since the merchant orders a sufficiently large number of products to efficiently use the transportation capacity, less trucks are needed and the transportation cost is considerably improved (Table 3).

Table 3: Number of trucks needed with and without the use of an incentive

	Number of trucks used for one week	
T	*Without the share of transportation savings*	*With the share of transportation savings (50%) Truckload >= 80%*
1	0	0
2	1	1
3	1	0
4	4	3
5	3	3
6	2	2
7	3	3

If the transportation savings are adequately shared, each partner obtains more profit with a better use of the transportation capacity (Figure 12 and 13). In addition, since fewer trucks are required to ship the products, it is also an interesting strategy from an environmental point of view.

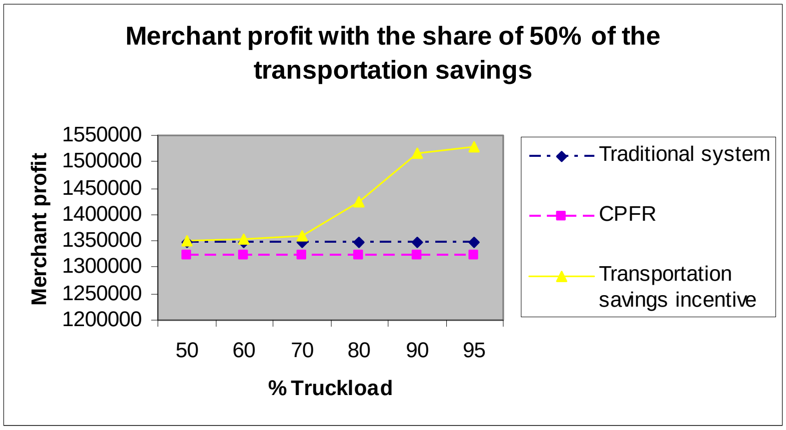

Figure 12: The impact of sharing transportation savings on the profit of the merchant

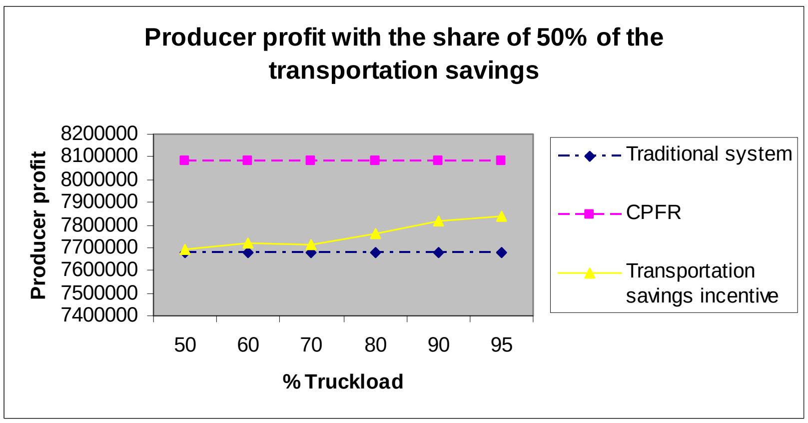

Figure 13: The impact of sharing transportation savings on the profit of the producer

The last incentive studied refers to quantity discounts. More particularly, the producer gives a discount in \$/kg on additional units (pds_{it}) if the quantity ordered (D^{c2}_{it}) is higher than a certain value (qmin) (Figure 14).

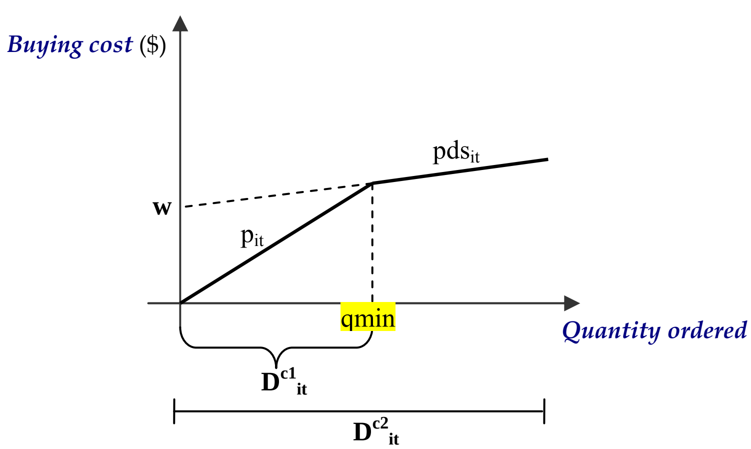

Figure 14: Discount for additional units if the minimum quantity is ordered

With this new incentive, the objective function of the merchant now includes a new price (after discount) for additional units ordered (equation (33)) and constraints are added to verify if the quantity ordered is higher than a certain value (constraints (34), (35), (36) and (37)). We again assume that partners first define the value of the discount and the minimum quantity to order before implementing the incentive.

$$
\begin{aligned}
&Max \sum_{t\in T}\sum_{i\in FP} d_{it}^{cc}\, pc_{it} - \sum_{t\in T} cord\,\delta_t - \sum_{t\in T} cord\,\delta SS_t \\
&- \sum_{t\in T}\sum_{i\in FPS} QSS_{it}\, pSS_{it} - \sum_{t\in T}\sum_{i\in FP_F} h_{it}^{c} IF_{it}^{c} - \sum_{t\in T}\sum_{i\in FPS} h_{it}^{c} ISS_{it}^{c} \\
&- \sum_{t\in T}\sum_{i\in FP_F} D_{it}^{c1}\, p_{it} - \sum_{t\in T}\sum_{i\in FP_F} D_{it}^{c2}\, pds_{it} - \sum_{t\in T} w V2_t \qquad (33)\\
&subject\ to\ (2-14)\ and
\end{aligned}
$$

$$V1_t + V2_t \leq 1 \quad \forall t \in T \qquad (34)$$

$$\sum_{i\in FPF} D_{it}^{c1} \leq gV1_t \quad \forall t \in T \qquad (35)$$

$$\sum_{i\in FPF} D_{it}^{c2} \leq gV2_t \quad \forall t \in T \qquad (36)$$

$$0 \leq \sum_{i\in FPF} D_{it}^{c1} \leq \text{qmin} \quad \forall t \in T \qquad (37)$$

If the discount and the minimum quantity to order are adequately defined, the profit of the system can again be higher then the profit obtained with the traditional system (Figure 15).

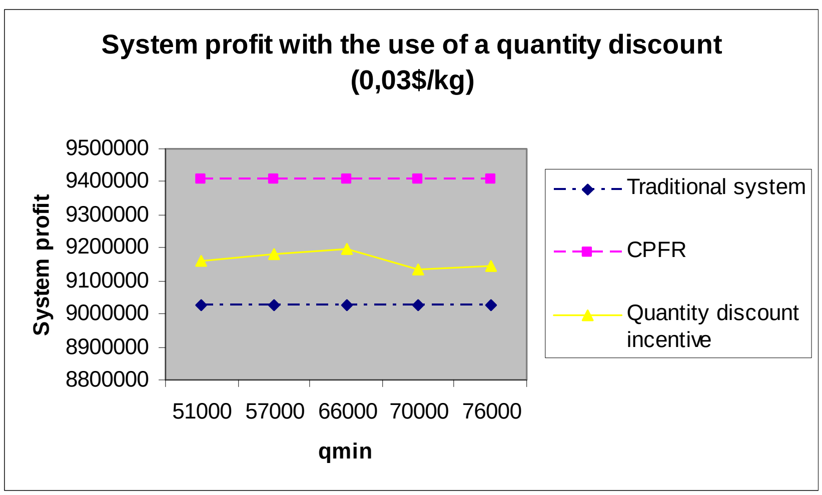

Figure 15: Impact of quantity discounts on the system profit

Since the discount is significant, the merchant can obtain important benefits using this incentive (Figure 16), even if the number of products kept in stock increases.

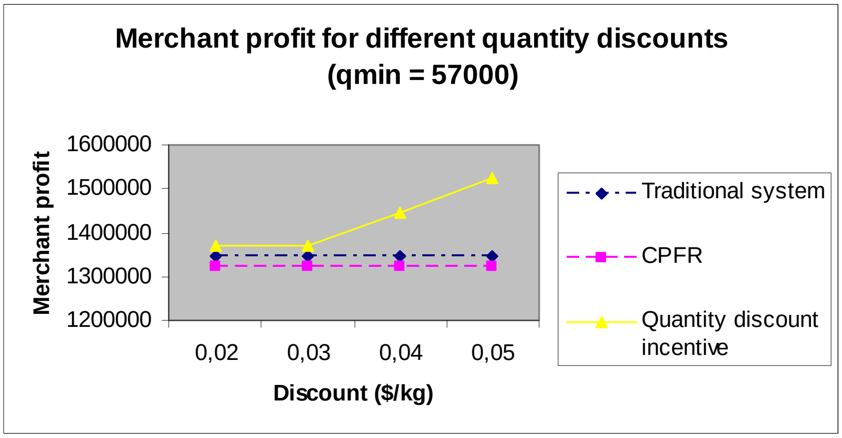

Figure 16: Impact of quantity discounts on the merchant profit

However, the producer has to correctly define parameters. Otherwise, the discount can be too high in comparison with the savings in transportation costs (Figure 17).

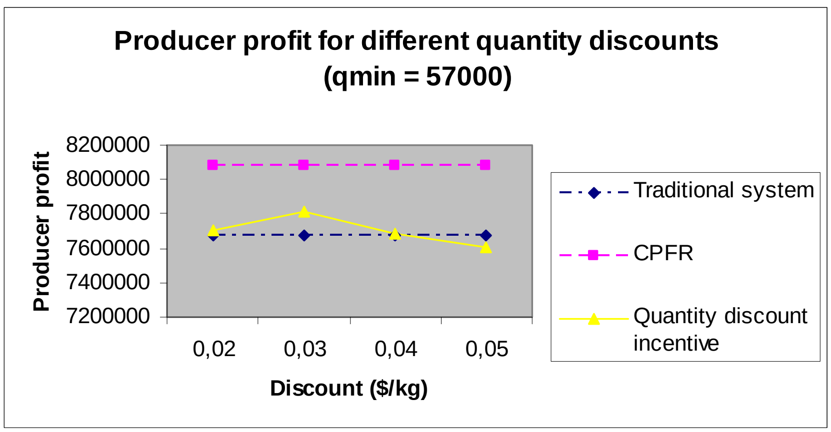

Figure 17: Impact of quantity discounts on the producer profit

These results demonstrate the role of incentives in a two-echelon supply chain and their impact on the network profit. Some changes on the parameters could certainly modify partners' gains. Furthermore, the impact of each incentive will not be the same according to the revenue of each partner. However, as summarized in Table 4, if the partners correctly define the bonus, discount, revenue sharing, etc., depending on their context, they can obtain important gains without exchanging strategic information. So for our case study, if partners do not want to change their way of doing business considerably, the use of some incentives would be a good strategy to obtain higher profits without important investments.

Table 4: The use of incentives to increase the traditional system profit

Incentive	Parameters	Merchant gains	Producer gains
Bonus for small orders avoided	800$/small orders avoided	7,04 %	2,05 %
Share of transportation savings	% truckload>= 90% % savings shared= 50%	11,18 %	1,77 %
Quantity discounts	qmin= 57000 discount = 0,03$/kg	1,55 %	1,72 %

5 Conclusion

In this article, the dynamic of the collaboration between a pulp and paper producer and his merchant is examined. Two types of relationship are studied: a traditional system characterized by a local optimization without any collaboration scheme, and CPFR, a collaborative technique that leads to the optimization of network activities. For each of these approaches, decision models from the point of view of both the producer and the merchant are developed. We then identify which one is more profitable for each actor as well as for the network. Some incentives are also developed in order to measure their impact on profits of the system and of each partner.

After testing different scenarios, it was observed that CPFR is the most profitable approach for the producer and the system as a whole, while the traditional system is the most advantageous method for the merchant. Because no approach can simultaneously generate the highest profit for each partner, an analysis is made to identify a method to better share collaboration benefits. It is shown that if the relationship is based on CPFR, the producer has to share a part of the transportation savings with his partner in order to correctly split the system profit. Otherwise, the merchant does not obtain enough benefits of the collaboration and he will certainly prefer to work with someone else. Since CPFR is a complex technique that necessitates an important implementation cost, we also investigate the use of three different incentives so as to increase the profit of a traditional system and tend towards a profit similar to the one obtained with CPFR. More precisely, with the use of a bonus if orders are optimized, a share of transportation savings and quantity discounts, the partner behaviours are modified and the network profit improved. We demonstrate that if incentives are adequately defined, they can considerably improve the profit of both the producer and the merchant, and consequently the profit of the system. Because the transportation cost for our case study is a key parameter to optimize, we based our incentives on this particularity. If the merchant orders more products and uses the transportation capacity efficiently, gains can be very important. Thus, with the use of incentives, partners can share these benefits and obtain a greater profit than the one obtained with a traditional system, without totally changing their way of doing business or exchanging more information.

However, in practice, these kinds of strategies are not always easy to implement. For our case study, if partners decide to apply a bonus for optimized orders or a share of transportation savings, they must use historical data to correctly define a reward that profits to everyone. They also have to respect the agreement and evaluate the impact of the collaboration regularly via key performance indicators. Otherwise, without win-win conditions, the enterprise collaboration will not continue for long. For future research, characteristics involved in the implementation of collaboration approaches, namely information needs, technological tools, etc., could be detailed. In addition, an analysis of the trade-off between implementation costs and network gains and a specific methodology could be proposed in order to illustrate how different collaboration strategies and incentives can be applied in practice.

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