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A Note on Decision Models for a Two-Echelon Supply Chain

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Abstract. With the current economic context, enterprises must improve collaboration with their suppliers or customers in order to better coordinate activities, exchange more information and respond adequately to client demand. In particular, collaboration models like Vendor Managed Inventory (VMI) or Collaborative Planning, Forecasting and Replenishment (CPFR) have been created and used to facilitate product and information exchange between partners. However, the setup of efficient inter-firm collaborations requires time and investment with no guarantee of the possible success or failure of the relationship. Therefore, it is necessary to identify and apply the best collaboration model for the context considered. In this paper we will study different collaboration strategies between a producer and a retailer in the pulp and paper industry. For this particular industrial context, we will analyze the value of different collaboration modes and their impact on the profit of each partner.

Keywords. Logistics, enterprise collaboration, producer-retailer relationship, contract.

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1 Introduction

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

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

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

2 Literature review

Many authors have discussed the potential key elements required to ensure efficient and viable collaboration across businesses within the supply chain. In particular, information sharing has been analyzed in the literature as a first step to better coordinate activities between partners. In all enterprise networks, members do not have access to the same information and they can choose to share this knowledge or not [5]. For example, the retailer can directly observe consumer consumption at the point of sales. If he chooses to keep this information for himself, the manufacturer will have to plan the production based on retailer orders and not on the real demand. In their study of the bullwhip effect, Lee *et al.* [8] demonstrate that this lack of information can lead to inefficient utilization of capacity, stock in excess or shortages, poor quality of service, etc. A detailed review on information sharing and supply chain coordination is presented by Chen [5] to better understand the role of information in achieving supply chain coordination.

Another key element for efficient and viable collaboration is that using appropriate logistics strategies can increase coordination in the enterprise network. For example, efficient consumer response (ECR) is an illustration of a strategy implemented by the food industry in which each partner collaborates in order to deliver the right product at the right place with the best price to customers. The different concepts of ECR can be grouped into three areas: demand management (category management), product replenishment (continuous replenishment) and enabling technology (EDI) [9]. VMI is another approach developed during the eighties in which the manufacturer is responsible for managing the inventories of its products for the client. This helps end stock-outs and facilitates better replenishment [1]. An interesting case study on the application of VMI to the household electrical appliances sector is presented by De Toni and Zambolo [6], in which they show how the implementation of the VMI model results in more benefits than traditional replenishment systems. Another strategy, CPFR, has been designed to improve the flow of goods from the raw material suppliers, to the manufacturer, to retailer shelves [16]. 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.* [14] demonstrated, developing CPFR in the supply chain can lead to substantial benefit, depending on the context studied.

Every collaboration approach requires cooperation between partners in order to optimize the entire network. But in reality, participants may be tempted to pull out or trick the collaboration in their favor. This would be the case of an opportunist player who tries to impose the rules of the game or make decisions considering penalties and rewards locally rather than globally [13]. To avoid this kind of situation, it is often necessary to use incentives such as pricing agreements or quantity discounts to influence player decisions and tend towards an optimization of the global network. Many authors have studied these incentives applied to supply chain management. Cachon [3] presents a detailed review of these articles. The first incentive regularly studied considers the price charged by the manufacturer to the retailer. This is referred to as wholesale price. Cachon [4] demonstrates that, depending on the context, wholesale price can play a role in the coordination of the system. Another incentive is based on product returns, known as buyback contracts. The retailer can now return some or all the items ordered in exchange for compensation (see for example [2]). A different incentive concerns network revenue. With a revenue sharing contract, the retailer shares revenue generated from sales with his supplier in return for a lower supplier price (see for example [7]). 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 [15]). Frequently used, quantity discounts also encourage the buyer to order more than usual (see for example [10]). Several other incentives have been studied, having the same objective, coordinate player decisions and optimize supply chain profit. Each type of incentive commands a particular management cost, a different tolerance toward risk and different levels of information sharing.

It is however difficult to study inter-firm collaborations and incentives without considering their impact on production planning [12]. If a supplier makes a commitment to deliver a certain quantity, offers a lower sales price or provides some quantity discounts, he must consider operation cost, production and distribution capacities, lead times, etc., before making a decision. Otherwise, he will most likely not be able to respect the agreement. This is why the collaboration models presented in the next section include different operational parameters. By considering characteristics of production and distribution systems, we are able to develop decision models that reflect industrial reality.

3 Logistics strategies and decision models

To better understand the collaboration dynamic and be able to identify a specific interaction model for a partnership between a producer and a retailer, four logistics strategies have been chosen: MTO, VMI, regular replenishment and CPFR. To improve our understanding of each of these strategies, we modeled them as mixed integer linear programs. Afterwards, we integrated them in a decision model from the point of view of both the retailer and producer. The idea is to illustrate the dynamic of the collaboration considering all the decisions faced by the partners. The development of a specific collaboration type will directly affect the way goods and information are exchanged between partners as well as how the partners make their planning decisions. Thus, enterprises will not make the same decisions if they base their collaboration on a CPFR method rather than a MTO system.

Each model has also been developed in order to address the pulp and paper industry perspective. More precisely, the case study concerns a producer of pulp and paper who decides to establish a partnership with one of its retailers. The producer has to satisfy the demand of this client and the demand of other retailers. The production system involves multiple stages. In very general terms, paper rolls and sheets are produced from trees or logs which are first chipped. The chips are mixed with chemicals and water to produce the pulp. The pulp is than transformed into jumbo rolls of paper. These paper rolls are large in size and cannot normally be kept in storage for long. They are therefore cut into smaller rolls or sheeted when needed. The production of these intermediate products (jumbo rolls) on parallel machines creates a bottleneck, consequently capacity and setup times must be considered [11]. For the other production stages, we consider sufficient capacity. During the delivery process, transportation capacity must also be considered and can be different from a period to another. In addition, some stock (small rolls and sheets) can be present in the system because of diversified demand for products. The retailer is a merchant, so he buys products from the producer, keeps them in stock and then sells them to the final consumer without transforming the product.

3.1 Description of the models

For the specific industrial case described previously, seven decision models, describing the producer and the retailer planning processes, have been developed to study the four logistics strategies presented. The first two models concern the MTO mode, a traditional method that is not very collaborative but still frequently used. The producer manufactures the product after receiving the order from the retailer and then ships the merchandise. Because she cannot see the real demand at the point of sales, the producer has to plan the production based on different retailer orders. The retailer can choose to order entirely from the producer or purchase the product from another supply source, depending on the price and lead time offered. The third and the fourth models are based on the VMI approach, in which the producer must maintain the partner's inventory levels. The producer must now consider inventory holding costs for its products at the retailer site. She also has to make sure that the inventory is sufficient so that the retailer will be able to satisfy his own demand. Real demand at the point of sales is again unknown, thus the production planning will be based on the stock consumption made by the partner. The retailer does not have to support ordering and inventory holding costs for the producer's products. Furthermore, the retailer has access to a second supply source if necessary (for example, if the producer's forecasts for stock consumption are wrong and the retailer does not have sufficient stock to satisfy demand). The fifth and sixth models concern regular replenishment. Deliveries are done regularly based on an order plan defined and updated by the retailer. This order plan, covering several days, is sent in advance to the producer, so the information can be integrated in the production planning to ensure that the retailer will receive his merchandise at the right moment. The last model is based on the CPFR method. Partners have to conjointly estimate the demand and then use the forecast in their planning. All the decisions will be made in order to maximize the profit of all the partners and respect each of their local constraints. A specific buying price is now unnecessary, because it represents revenue for one and a cost for the other. We also suppose that the retailer never uses the other supply source for this particular collaboration mode. Table 1 presents the different characteristics for each producer and retailer model.

Table 1: Characteristics of each decision model

MAKE TO ORDER, Producer model		
Activity	*Description*	*Cost*
Production	-Production planning based on retailer orders and demand of other clients -Production lead time to satisfy retailer MTO -Capacity in each period	-Production cost including setup cost
Inventory	-Inventory holding capacity	- Inventory holding cost for finished products
Distribution	-Transportation lead time -Transportation capacity	-Delivery cost

MAKE TO ORDER, Retailer model		
Activity	*Description*	*Cost*
Supply	-Two supply sources with specific products and lead times	-Buying price, can be different from one source of supply to another, depending on the product and the period -Ordering cost

Inventory	-Inventory holding capacity	- Inventory holding cost

VMI, Producer model

Activity	*Description*	*Cost*
Production	-Production planning based on stock consumption made by the retailer and demand of other clients	-Production cost including setup cost
Inventory	-Management of inventories for the retailer -Minimum and maximum level of stock to respect at each period - Inventory holding capacity	- Inventory holding cost for finished products at the mill - Inventory holding cost for finished products at the retailer site
Distribution	-Transportation lead time considered in the production planning -Transportation capacity	-Delivery cost

VMI, Retailer model

Activity	*Description*	*Cost*
Supply	-Access to another supply source if necessary	-Buying price for replenishment made by the producer -Buying price if access to the second supply source -Ordering cost if order from the second supply source
Inventory	-No inventory management for the producer's products	- Inventory holding cost for products bought from the second supply source

REGULAR REPLENISHMENT, Producer model

Activity	*Description*	*Cost*
Production	-Production planning based on an order plan and demand of other clients	-Production cost including setup cost
Inventory	- Inventory holding capacity	- Inventory holding cost for finished products at the mill
Distribution	-Transportation lead time considered in the production planning - Deliveries based on the order plan -Transportation capacity	-Delivery cost

REGULAR REPLENISHMENT, Retailer model		
Activity	*Description*	*Cost*
Supply	-Order plan covering several days sent in advance -Quantity delivered in accordance with the order plan -Access to another supply source if necessary	-Buying price for producer's products -Buying price if access to the second supply source -Ordering cost each time the plan is sent -Ordering cost if order from the second supply source
Inventory	-Inventory holding capacity	- Inventory holding cost

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

Using these models, we can now evaluate and compare each partner's profit. Depending on the logistics strategy used, the retailer or the producer decision model will be optimized first. More precisely, for the MTO and replenishment modes, the retailer determines the optimal quantity to order depending on the demand to satisfy and the inventory level. Next, based on the retailer's order and the demand of other clients, the producer optimizes the production planning in order to maximize the objective function. In the VMI mode, the producer determines the optimal quantity to produce and the quantity to ship to the retailer site. Next, using the quantity delivered by the producer, the retailer satisfies his own demand. The CPFR is a common model and all the decisions are made simultaneously.

3.2 Mathematical notation

For each model, notation is as follows:

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
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

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_{it}^{m}= Production capacity consumption rate of intermediate products at machine m at period t
Ld= Transportation lead time of the producer
LdS= Transportation lead time of the second supply source
r_i= Transportation resource absorption rate for finished products
$Tset_i^m$= Setup time to manufacture intermediate products on the machine m at the beginning of period t
d_{it}= Demand for finished products ordered by the other clients at period t
d_{it}^{c}= Demand for finished products ordered by the retailer at period t
d_{it}^{cc}= Demand for finished products ordered by the final consumer at period t
stc_{it}^{c}= Consumption forecast for the producer's finished products used by the retailer at period t
de_{it}^{cc}= Demand for finished products ordered by the final consumer and estimated by the partners at period t
C_t^m= Production capacity of machine m at period t
Capt= Transportation capacity of a truck at period t
c_{it}^{m}= Production cost of the intermediate product on the machine m at period t
h_{it}= Inventory holding cost of the finished products at the mill at period t
h^{c}_{it}= Inventory holding cost of the finished products at the retailer site at period t
Ctru= Transportation cost of finished products delivered to the retailer at period t
Cord= Ordering cost of the retailer
pSS_{it}= Price for finished products proposed by the second supply source at period t
p_{it}= Price for finished products proposed by the producer at period t
pc_{it}= Price for finished products proposed by the retailer to the final consumer at period t
M= A large number

Variable description
π_{it}^{m}= Binary variable equal to 1 if the product is manufactured on the machine m at period t, 0 otherwise
ρ_{it}^{m}= Binary variable equal to 1 if a setup for the product is made on the machine m at period t, 0 otherwise
Q_{it}= Quantity of finished products manufactured at period t
Q_{it}^{m}= Quantity of intermediate products manufactured on the machine m at period t
R_{it}= Quantity of finished products shipped by the producer at period t
RC_{it}= Quantity of producer's finished products received by the retailer at period t
QSS_{it}= Quantity of finished products bought from the second supply source at period t
RSS_{it}= Quantity of finished products received by the retailer from the second supply source at period t
I_{it}= End of period inventory level of finished products at the mill at period t

IF^c_{it}= End of period inventory level of producer's finished products at the retailer site at period t
ISS^c_{it}= End of period inventory level of finished products bought from the second supply source at period t
$Ntru_t$= Number of trucks needed at period t
δt = Binary variable equal to 1 if the retailer orders producer's finished products at period t, 0 otherwise
δSSt = Binary variable equal to 1 if the retailer orders second supply source's products at period t, 0 otherwise

3.3 Decision models based on MTO

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

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

$$Max \sum_{t\in T}\sum_{i\in FP} d^{cc}_{it}\, pc_{it} - \sum_{t\in T} Cord\ \delta_t - \sum_{t\in T} Cord\ \delta SS_t - \sum_{t\in T}\sum_{i\in FPF} d^{c}_{it}\, p_{it} - \sum_{t\in T}\sum_{i\in FPS} QSS_{it}\, pSS_{it} - \sum_{t\in T}\sum_{i\in FPF} h^c_{it} IF^c_{it} - \sum_{t\in T}\sum_{i\in FPS} h^c_{it} ISS^c_{it} \quad (1)$$

subject to

$$RC_{it} + IF^c_{it-1} - IF^c_{it} = d^{cc}_{it} \qquad \forall i \in FP \notin FPS;\quad \forall t \in T \quad (2)$$

$$RSS_{it} + ISS^c_{it-1} - ISS^c_{it} = d^{cc}_{it} \qquad \forall i \in FP \notin FPF;\quad \forall t \in T \quad (3)$$

$$RC_{it} + RSS_{it} + IF^c_{it-1} + ISS^c_{it-1} - IF^c_{it} - ISS^c_{it} = d^{cc}_{it} \qquad \forall i \in FPF \cap FPS;\quad \forall t \in T \quad (4)$$

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

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

$$d^c_{it} = RC_{i(t+\tau+Ld)} \qquad \forall i \in FPF;\quad \forall t \in T \quad (7)$$

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

$$d^c_{it} \le M\delta_t \qquad \forall i \in FP \notin FPS;\quad \forall t \in T \quad (9)$$

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

$$d^c_{it} \le M\delta_t \qquad \forall i \in FPF \cap FPS;\quad \forall t \in T \quad (11)$$

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

$$d^c_{it} \ge 0,\ QSS_{it} \ge 0,\ RC_{it} \ge 0, RSS_{it} \ge 0, IF^c_{it} \ge 0, ISS^c_{it} \ge 0, \qquad \forall i \in FPF;\quad \forall i \in FPS;\quad \forall t \in T \quad (13)$$

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

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

For the producer, the decision model with a MTO mode has some similarities with the model presented by Rizk *et al.* [11]. Its formulation is:

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

subject to

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

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

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

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

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

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

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

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

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

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

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

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

3.4 Decision models based on VMI

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

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

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

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

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

For the producer, the new formulation is:

$$\begin{aligned} Max & \sum_{t\in T}\sum_{i\in FP_F} stc_{it}^{c}\, p_{it} + \sum_{t\in T}\sum_{i\in FP_F} d_{it}\, p_{it} - \sum_{t\in T}\left[\sum_{m\in M}\left[\sum_{i\in IP} c_{it}^{m} Q_{it}^{m}\right] + \sum_{i\in FP_F} h_{it} I_{it}\right] \\ & - \sum_{t\in T}\sum_{i\in FP_F} h_{it}^{c} IF_{it}^{c} - Ctru \sum_{t\in T} Ntru_t \end{aligned} \tag{28}$$

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

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

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

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

3.5 Decision models based on regular replenishment

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

The decision model based on regular replenishment for the retailer is practically the same as the MTO model (1-6, 8, 10, 12-14), but the retailer will now receive his order exactly at the period he specified. So constraint (7) is replaced by (31). The new constraint to add is:

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

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

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

3.6 CPFR decision model

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

$$Max \sum_{t \in T} \sum_{i \in FP_F} de_{it}^{cc} pc_{it} + \sum_{t \in T} \sum_{i \in FP_F} d_{it} p_{it}$$
$$- \sum_{t \in T} \sum_{i \in FP_F} h_{it}^{c} IF_{it}^{c} - \sum_{t \in T} \left[\sum_{m \in M} \left[\sum_{i \in IP} c_{it}^{m} Q_{it}^{m} \right] + \sum_{i \in FP_F} h_{it} I_{it} \right] - Ctru \sum_{t \in T} Ntru_t \tag{33}$$

subject to (16 − 20, 22 − 26) *and*

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

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

3.7 Computational study

We can now use all seven decision models to proceed with different computational studies in order to understand the impact of the collaboration model on the profit of each player. All the experiments used a rolling horizon of two weeks, with a known demand for the first week and an estimated one for the second week. Using this rolling horizon, each model is solved day by day, for a total period of one month. 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 and lead times. In addition, we assume a production lead time of one period. Experiments are run on AMPL Studio (version 2004) and Cplex solver. The total system profit and the profit of each partner are used to compare each scenario and measure the impact of the collaboration model used by the network.

Our first experiments led us to some observations. To begin with, the CPFR model generates the higher total system profit because of the simultaneous optimization of both shipping and production costs. In particular, the CPFR shipping cost is 15 to 23 percent lower than the shipping cost of other models. The regular replenishment model is second best, since the producer is in a better position to optimize the production cost and the retailer does not have to pay an ordering cost at each period. The MTO and VMI modes obtain the lowest total system profit. This last observation is not necessarily obvious since the VMI approach is generally an efficient collaboration model for enterprise networks. In fact, we assumed an important stock level at the retailer site in order to guarantee a good service level (97%) and the inventory cost is thus considerable. It would be interesting to consider a stock level for the other retailer models in order to measure and compare its impact on the profit. A saving in shipping costs is nevertheless obtained with the VMI model.

Since it takes considerable time to solve the CPFR model and the VMI producer model, additional work is needed to improve the solution time. By using Cplex solver's options and parameters, we hope to reduce the solution time and experiment longer planning periods (six to twelve months). We will also proceed with different sensitivity analyses using price fluctuations, varying lead times and restrictions on the quantity ordered to understand the impact of these incentives on the network profit.

4 Discussion and conclusion

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

All the operational costs associated with each collaboration strategy are included in the profit function of the players to correctly compare the models. However, we have not considered implementation costs in our current study. Since this cost can be very important for strategies with more interaction like the CPFR method, a specific fixed cost could be added to each profit function.

This paper contributes to illustrate the differences between each of the logistics strategies often used by industry. In developing and analyzing different decision models, we are now in a better position to understand all the dynamics of enterprise collaboration and the importance of the model chosen on current decision making. In the future, an industrial validation with real data will allow us to evaluate our methodology and verify if it is possible to identify the best collaboration model to use in a real context.

5 References

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