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Identifying Key Factors for the Success of a Regional Logistic Center

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Abstract. The forest industry, facing an evolving market with a diversified resource and divergent production processes, has to revise its business practices and its sorting and transportation operations in particular. Our project aims to identify the parameters having an influence on the profitability of a regional logistic center comprising both a sorting yard and the sharing of transportation resources. Using a profit maximization model and a forest products supply chain encompassing six mills in the Mauricie region of Quebec, Canada, we tested four scenarios involving the use or not of a sort yard and the use of one delivery vs combined deliveries at a time. Results show that both the sort yard and the use of routing bring higher profits for the supply chain. A sensitivity analysis conducted for four parameters (transportation costs, distances to forests, number of oversize trucks, and sorting costs at the yard) also highlights that lower sorting costs at the sort yard has the greatest impact on the logistic center profitability.

Keywords: Forestry, logistics, sorting, transportation, optimization.

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INTRODUCTION

The forest industry represents an important part of Canada's economic activity with about $19.8 billion in revenues annually (http://www.nrcan.gc.ca/forests). Concerns about environmental issues are putting greater pressure on this sector to review its practices, especially regarding the optimization of its transportation and sorting operations. The scientific literature emphasizes that the sharing of transportation resources can be profitable, both economically and environmentally (Epstein *et al.*, 2007), through the use of backhauling and routing. Nevertheless, many authors have pointed out that this can be quite complex to implement (Frisk *et al.*, 2010).

The creation of a sort and consolidation yard, distinct from the harvesting sites, can offer many opportunities for maximizing revenues and minimizing operational costs through more efficient sorting processes and the coordination of transportation. However, inserting this type of yard into an existing forest products supply chain can be challenging, especially in terms of implementation cost, changing demand, multiple sorting decisions, resources sharing, and transport route definitions.

The question of how such a center could be profitable, as well as which specific advantages it could represent in terms of cost control and value creation for the entities using it, is furthermore difficult to answer. Benefits will greatly depend on the business environment. Intuitively, one can easily perceive that the greater the level of diversity of the raw materials, the more interesting it should be to proceed to sorting in this type of strategic facility. Similarly, low handling costs would also favor a greater use of sorting. Considering trade-offs between these and other factors is essential to properly analyze and justify the decision to implement a sort and consolidation yard.

The objective of this article is to identify the parameters having the biggest influence on the profitability of a logistic center dedicated to both sorting operations and transportation management optimization. To achieve this, we propose a profit maximization model for a forest products supply chain that can include (or not) a yard specifically dedicated to sorting while allowing forest products companies to combine different deliveries to reduce the number of empty transportation returns. The model simultaneously considers harvesting, transportation, sorting, production, and inventory operations, as well as the impact of wood aging on the value and the density of the products. This type of modeling and management of a logistic center has seldom been studied in the scientific literature up to now, even though it may represent a means to increase agility and cost efficiency. In Canada, transportation costs represent over 30% of overall forest operation costs (El Hachemi *et al.,* 2013).

To test this model, we built a database using data obtained from various reliable sources such as the Quebec government's office responsible for selling wood to forest products companies. We also validated our model through an in-depth series of optimizations. In the base instance, the use of both the sort yard and routing procedures led to a gain of $0.88 per available cubic meter. We then conducted a sensitivity analysis to identify the factors influencing the profitability of the proposed center. The results of this analysis showed that lower sorting costs at a dedicated sort yard followed by higher transportation costs could contribute to increasing the positive effect of the logistic center. Higher distances to forest sites, lower sorting costs at a sort yard and a greater number of oversized trucks also had a significant impact on either the profitability of the use of a sort yard or routing. We finally conducted a linear regression analysis which established that a very high portion of the variations in profit increases for three different scenarios (with only a sort yard, only the use of routing or both a sort yard and routing) could be explained through differences of the level of the four parameters already mentioned (with R^2 at or above 85% for each scenario)

The rest of this article is structured as follows: we first examine the relevant scientific literature dealing with transportation, sort yard operations, and mathematical modeling applied to the forest sector. Afterwards, we describe the methodology used to develop the optimization model. The results obtained and the sensitivity analysis conducted are presented next. A discussion and conclusion end the paper.

LITTERATURE REVIEW

Forest products supply chain

According to Lehoux *et al.* (2011), the forest products supply chain includes all of the businesses or business units participating in the supply, production, and processing of a wood product. This supply chain is traditionally built based on a push system (D’Amours *et al.,* 2010), mainly because it depends on a natural resource, which implies an element of supply uncertainty.

Generally, harvesting operations include three basic steps: (1) Trees are cut and branches are taken out. (2) Trees are cut into logs which are placed on the side of the road. (3) The wood is delivered to mills or to yards to be temporarily stocked (D’Amours *et al.,* 2008). A rudimentary sorting, including a certain degree of “*merchandising,*” is conducted in the forest. Although mills have yards where sorting can be done, the lack of space typically reduces the possibilities. It is therefore possible that businesses use a yard specifically dedicated to sorting (Han *et al.,* 2011).

The ageing of the wood, especially during the summer, leads to a loss of humidity (Beaudoin *et al.,* 2007). On the one hand, lower humidity will lighten the weight of the wood (Wengert, 2006) and make it less expensive to transport. On the other hand, wood that is too old will change colour, become more brittle, and lose value (*Ibid*.).

Sorting operations

As mentioned by Lehoux *et al.* (2011), sorting is typically done according to three characteristics: (1) per species, (2) per size, and (3) per log quality. Dramm *et al.* (2002) define five basic approaches to sorting: (1) Use a sort yard. (2) Do sorting in the forest. (3) Conduct some pre-sorting at the landing. (4) Sort at a mill yard, and (5) Do no sorting.

According to (Dramm *et al.,* 2002), sorting in the forest is justified when there are few different inputs to sort as well as when an important portion of the wood encompasses high-value logs. The argument is that sorting in the forest allows separating the main species from one another. It is then possible to reduce handling at the yards and at the mills. A low volume of high-value logs usually leads to a sorting at the mill, the volume being not sufficient to justify the creation of a sort yard.

The interest in sort yards has risen with the decline (quantitatively and qualitatively) of forest resources and the need to recover the potential value from them (Dramm *et al.,* 2002). Therefore, it is generally recognized that yards dedicated to sorting facilitate the correct allocation of logs to the most profitable destinations.

Nevertheless, the impacts produced by the presence of such a yard are complex to model. Depending on its location, the yard can allow the use of trucks with oversized loads traveling on private roads (Chan *et al.* 2009) as well as b-trains. B-trains are ill adapted to forest sites, and are therefore limited to travelling from the yard to the mills and from one mill to another mill. On the other hand, the yard may lead to higher handling (Dramm *et al.*, 2002) and transportation costs for the wood having to transit by this site (Sessions *et al*, 2005). The costs for setting up and operating such a yard must also be carefully estimated.

Planning

The allocation of harvesting sectors to the users and the planning of harvest operations (Lehoux *et al.*, 2011) are among the most important decisions that can be taken regarding the management of forests. Over a horizon of several years, transportation planning can be integrated with harvesting operations (Epstein *et al.*, 2007). In Canada, one of the specificities of the forest industry is the seasonal character of harvesting operations, as the weather leads to periods of inactivity. This particularity intensifies the need to do advanced planning (Lehoux *et al.* 2011).

Wood transportation

For Audy *et al*. (2012a), the entities of the supply chain can optimize full-load travel times or the use of capacity and transportation assets through collaboration and backhauling. Frisk *et al.* (2010) observed that despite potential benefits, collaboration in transport operations between two or more companies is rare in the forest products industry. However, Epstein *et al.* (2007) asserted that the trend in the last few years is for a greater centralization of planning as well as a greater radius of operation for trucks, partly because of the greater use of GPS systems. These instruments allow planners and dispatchers to know the daily demand for and the available inventory of a given product at different sites and demand points. The extended transportation planning problem with a warehouse or inventory site becomes a well-documented transshipment site problem.

Epstein *et al.* 2007 showed that backhauling and routing, where several deliveries are combined, could lead to cost savings within a range of 2% to 20%. According to Carlsson and Rönnqvist (2005), a further advantage of this technique is that it can allow the inclusion of more wood species and a greater number of procurement zones.

Logistic centers and modeling

The scientific literature tends to suggest that using a sort yard could improve the agility of the forest products supply chain while facilitating the trading of wood and the pooling of inventories between competitors. In addition, it seems relevant to link forest planning and transportation operations to production scheduling at the mills. A logistic center could also offer unique opportunities for more efficient routing. Unfortunately, most of the models designed to evaluate the profitability of sort yards usually consider an incomplete number of the parameters recognized as important. For instance, none of the models integrate transportation and sorting costs simultaneously, and "*merchandising*" is mentioned in the models only in relation to wood chips supply (Kong *et al.*, 2012, Sessions & Paredes, 1987, Broad, 1989, and Chan *et al.*, 2009). They are also not supported by a thorough sensitivity analysis (Chan *et al.*, 2009, Kong *et al.*, 2012). Moreover, only a few models found in the literature happened to be mixed integer linear programs (MIP). For example, Chan *et al.*, (2009) dealt with a wood chip-producing yard, which allowed diminishing the network costs by 6.8%. Beaudoin *et al.* (2007) developed a model covering operations between harvesting or forest sites and mills, but without a sort yard or transportation coordination. Carlgren *et al.* (2006) presented a cost minimization model with backhauling possibilities where binary variables were used to select the sorting strategy to use.

As the forest industry is characterized by divergent and interdependent processes as well as multiple time planning horizons, it becomes relevant to use operations research (OR) techniques to better evaluate the possibilities offered by a logistic center. In the following sections, we describe the OR model developed to assess the potential profitability of this center.

OBJECTIVE AND METHODOLOGY

The main objective of this research is to identify the parameters having the highest impact on the profitability of a logistic center encompassing product sorting and transportation coordination. To achieve this goal, we have built an optimization model which maximizes the profit of a forest products supply chain encompassing multiple mills, a dedicated sort yard, and routing operations.

A preprocessing routing phase first allows the generation of all the valid routes to consider in the model. The model is then solved in a two-phase process, using the same planning horizon for each phase: In the first phase, the model is run to determine the threshold of production that both the mills and the sort yard must reach for each period, the processes that should be considered in the second phase as well as the preselected routes allowing for a transportation cost reduction. The effects of the age of the wood fiber are not considered in this phase, the purpose here being to find an initial design that considers the main constraints of the problem while limiting the increase in the size of the model. The relationship between the two phases of our model is therefore not equivalent to the dynamic that exists between a tactical and an operational model.

In Phase 2, the model decides on a final design, determining the optimal harvesting levels, the quantities needed for each raw material, and the type and volume of intermediary products going through the different sorting and production processes. We only use routes preselected in the previous phase to guarantee that only interesting routes will be available. By the same token, amongst processes that were preselected in Phase 1 the model should pick those that are the most best adapted to the network's context. The flow of materials throughout the transportation network, levels of inventories, and the number of products sold are also determined in this phase. In both phases, variables, which concern the number of deliveries per origin-destination pairs (OD pairs), are relaxed and expressed as continuous variables to make it easier to find a valid solution within a reasonable amount of time. Troncoso *et al.* (2015) used a somewhat similar method of model decomposition. Figure 1 illustrates the methodology followed to explore the profitability of a logistic center, highlighting how the two-phase process is conducted and the information transmitted from one stage to another.

Methodology

We first assume that wood in the forest is harvested, sorted based on different categories (sawing and pulp together and peeling or sawing together), and stored at the side of the road. Somewhere in the supply chain, there can be sites serving as logistic centers, i.e., dedicated sort yards distinct from the harvesting sites and the mills. Wood can be delivered to this yard to be sorted more accurately than at the forest sites before being delivered to one of the mills. We also assume that sorting costs are lower at a sort yard than at the forest sites because of the greater specialization of the equipment used. The raw materials sorted are then delivered to the mills. The mills process the logs into finished products before selling them to different clients. Coproducts, such as wood chips generated when processing wood, are delivered to other mills (especially pulp and paper mills). Figure 2 illustrates the forest products supply chain optimized by the model.

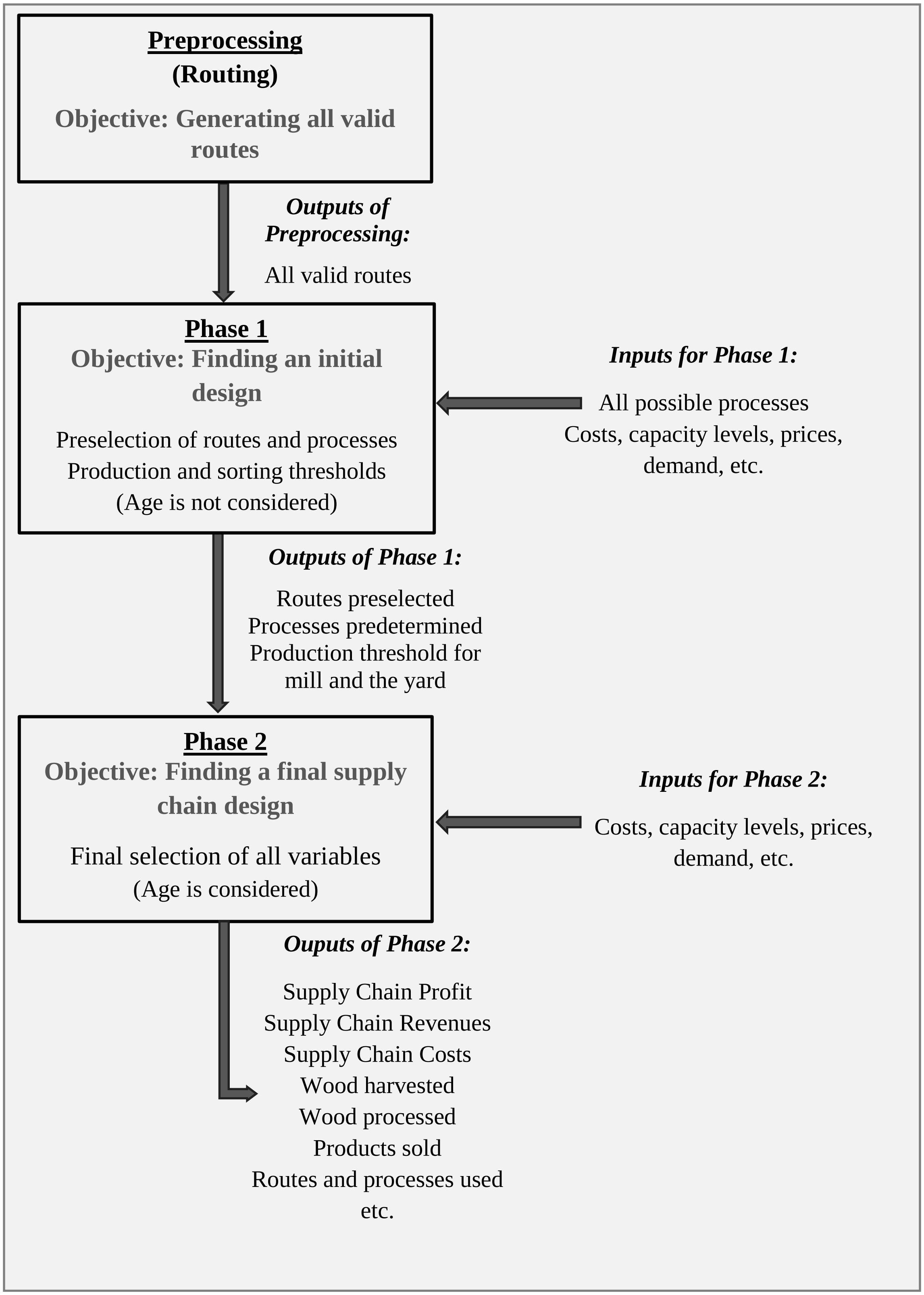

Figure 1: Relationship between Phase 1 and Phase 2

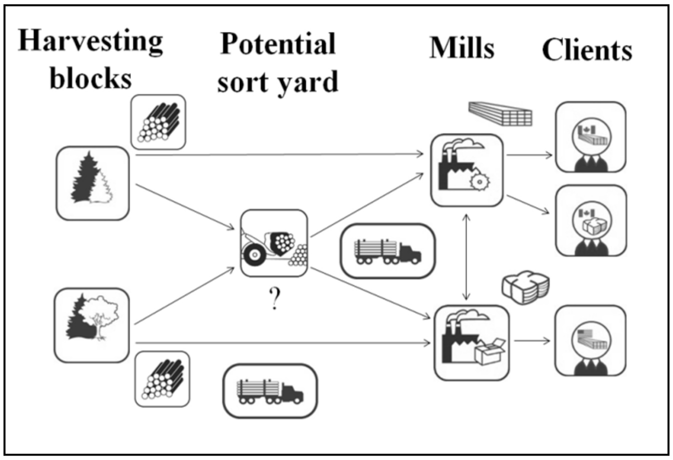

Figure 2: Forest supply chain with potential logistic center.

The fictitious forest products supply chain considered is based on a real one located in the Mauricie region in the Province of Quebec, Canada (See Figure 3). The supply chain includes one peeler mill, three sawmills (one processing hardwood and two others processing softwood) and two pulp and paper mills (see Figure 4). The volume available for harvesting is based on annual planning over a two-year horizon. The conversion rates for the sorting processes, which represent the number of units of “out products” exiting a sorting process for one unit of the “in product”, were deduced from data obtained from the *MÉRIS* software used by the *Bureau de mise en marché des bois (BMMB)*. This tool contains estimates of the allowable cut per wood species and diameter for different forest management units (FMUs) of the Mauricie region, as well as the conversion rates between the raw materials and different log grades per species. Different FMUs have different conversion rates as they have different yield levels, i.e., level of wood quality as well as different percentages of each species. For instance, white birch wood from one forest site might have a greater percentage of high value logs than the same wood from another one, depending on the FMU to which the forest site corresponds. The reason for this is that to simplify our model, we presume that wood is harvested in clear cuts. This means that whenever the wood is harvested in each forest site, it must be representative of all wood species and log grades of this site. Decisions about which units to harvest (and how to process the logs) will therefore partly depend on the level of wood quality at each forest site as well as the processes available at each site in the network (forest, mill or the yard). Demand seasonality for the different products was also introduced to mimic what can be observed in practice.

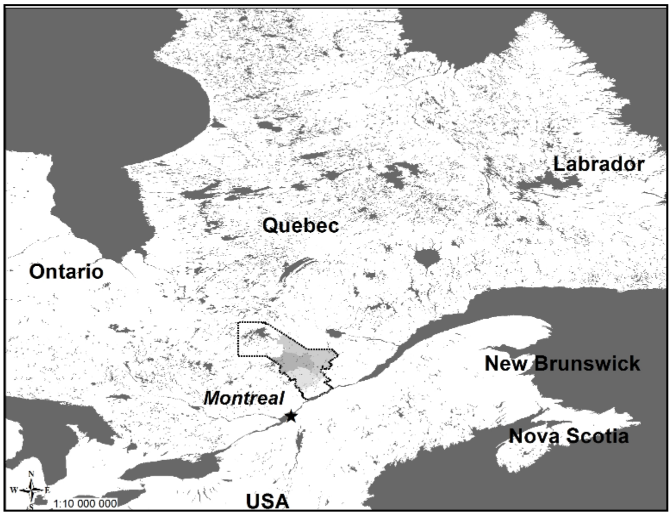

Figure 3: The Mauricie region (Source: Ministère de l'énergie et des ressources naturelles du Québec).

The FMUs used for our series of optimization are the ones situated in the south of that region (042-51, 043-52, and 041-51, see Figure 4). Transportation costs have been obtained through data coming from the software *FPInterface* used by the forest research center *FPInnovations*. The revenues for the finished products were also calculated using this software. The level of stumpage fees for different grades of logs was established based on documents obtained from the *Ministère des forêts, de la faune et des pêches du Québec* (*MFFP*). The distances between the nodes of the supply chain were obtained from a road database. A total of 3,788,268 cubic meters (avail. m^3) of wood was considered for harvesting over the two-year period. Seventeen different wood species are present, spruce and fir being the dominant ones. The site available to build a sort yard is located next to one of the paper mills. Nine harvesting areas (which represent an aggregation of different harvesting sites) are available to supply six mills. They were defined by dividing the FMUs into three areas each. Each mill and the sort yard can be used as a vehicle terminal.

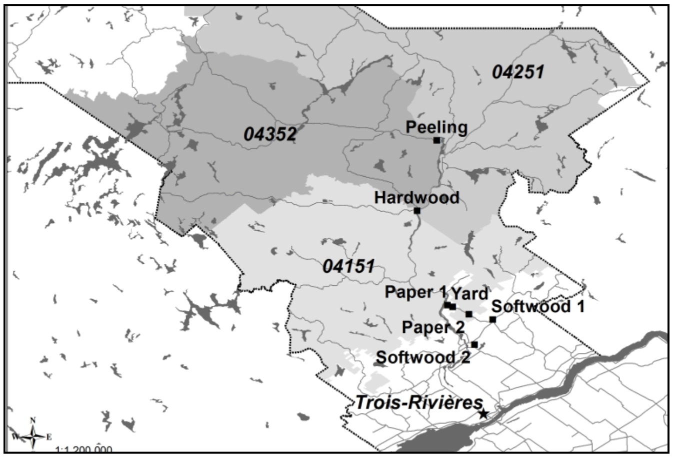

Figure 4: Forest Management Units (FMU's) of the Mauricie region (http://www.ftgq.qc.ca)

The following section describes the mathematical model developed to optimize the forest products supply chain considered in the study.

MODELING AND ROUTE GENERATION

Mathematical modeling

The main elements included in the model are as follows:

<u>Sets</u>

Products and processes

PDV : Set of finished products available for sale.
MP : Set of raw materials.
PEC : Set of intermediary products.
PE : Set of products entering a process such as $PE = MP \cup PEC$.
PS : Set of products exiting a process PS, such as $PS = PEC \cup PDV$.

PR : Set of products over which mills must pay a stumpage fee to the government.
P : Set of all products p, such as $P = MP \cup PEC \cup PDV$.
SPE : Set of sorting processes.
$SPDV$: Set of production processes.
S : Set of all transformation processes s such as $S = SPE \cup SPDV$.

Sites, truck types, routes, time periods, and clients

F : Set of forest harvesting sites f.
Y : Set of potential sites for a sort yard y.
M : Set of mills m.
N : Set of all nodes such as $N = F \cup Y \cup M$.
D : Set of all destination nodes such as $D = Y \cup M$.
B : Set of vehicle terminals (or bases) b.
O : Set of all origin nodes such as $O = F \cup Y \cup M$.
T : Set of truck types t.
L : Set of time periods l for the time horizon (including $l = 0$, to define a starting inventory).
L^{+} : Set of time periods other than zero $(l > 0)$. $l^{\max}$ is the last period of the horizon.
U : Set of all clients u.
U^{+} : Set of all clients minus the virtual client called “Loss” which “buys” product at a price of \$0 to evacuate products which are not profitable.
R : Set of r routes.

Transportation operations

E^{t} : Volume capacity of type t vehicles.
Q_{ij}^{lt} : Weight limit for a delivery with transportation mode t between sites i and j during period l.
$\square^{t}$: Maximum fleet size of type t vehicles.
β^{t} : Maximum time on the road for one month for a type t vehicle.
η_{ij}^{rt} : Number of times that the combination of sites i and j and type t vehicles is en route r.
μ^{r} : Number of hours required for route r.
W^{rt} : Parameter, which equals to 1 if route r is done by a type t vehicle, 0 otherwise.
W_{b}^{r} : Parameter, which equals to 1 if route r is done by a vehicle based at terminal b, 0 otherwise.

Capacity levels for the processes

H_{f}^{+pl} : Level of harvesting capacity of product p at forest site f during period l.
Q^{l} : Harvesting capacity per period for the entire network in m^3.
Q_{f} : Harvesting capacity for the time horizon in m^3 at forest site f.

Q_f^p : Available quantity of product $p \in PR$ at forest site f. Built by using the conversion rates between raw materials and intermediary products.

Costs and revenues

c_f^p : Amount of royalty that must be paid for product $p \in PR$ and harvested at forest site f to the government.

c_f^{pl} : Harvesting cost of product p at forest site f and during period l.

c_y^+ : Installation cost for a capacity block of 250 000 m^3 at yard y for the entire time horizon.

c_y : Fixed cost for setting up site y as a sorting yard y for the entire time horizon.

c_{ij}^{plt} : Variable transportation cost (in \$/m^3) of product p from site i to j during period l with truck type t.

c_i^{sp} : Sorting cost of product p entering sorting process s at site i.

c_i^p : Inventory cost per month (in \$/m^3) of product p at site i.

c^r : Fixed cost of route r.

V^p : Value (in \$) of product p.

Sorting and production capacity

Q_m^l : Production capacity for mill m for period l. It only applies for finished products.

Q_y^l : Sorting capacity for sort yard y for period l. It only applies for intermediary products.

Q_m : Production capacity for mill m for the entire time horizon.

$Threshold_i$: Minimal amount of production or sorting that must be performed per month for site i (either the yard or a mill). It is used only in Phase 2 and is based on the results of Phase 1.

Q_y : Sorting capacity for sort yard y for the entire time horizon.

E_i : Volume capacity or space limit for inventory for a given period.

$\max_y$: Maximum number of capacity blocks that can be installed at site y.

Others

d_u^{pl} : Demand level of product p at demand point u during period l.

v^l : Number of months of period l.

$l^{\max}$: Last period of the time horizon.

$g^{sp'p}$: Conversion rate between the quantity of products p' and p obtained in the sorting process s.

o^p : Metric tons per m^3 for product p.

Variables

Transportation operations

x_b^{lt} : Number of types t of vehicles that operate from terminal b during period l.

x^{rl} : Number of times that route r is done during period l.

x_{ij}^{plt} : Number of deliveries of product p from site i to site j during period l with a type t vehicle.

q_{ij}^{plt} : Quantity of product p delivered from site i to site j during period l with a type t vehicle.

Products

x_f^{pl} : Quantity of product p harvested at forest site f during period l.

x_f^{p}: Quantity of product p over which a royalty must be paid to the government for logs made of wood harvested from forest site f.

x_{fj}^{p}: Quantity of product p over which a royalty must be paid to the government for logs made of wood harvested from forest site f and assigned to site $j \in Y \cup M = D$.

x_i^{spl} : Quantity of product p treated by sorting/production process s at site i during period l.

$\Im_i^{spl}$: Quantity extracted of product p for the sorting or production process s during period l at site i.

x_{iu}^{pl} : Quantity of product p sold from site i to client u during period l.

Others

n_y : Number of capacity blocks (each representing 250,000 m^3) of sorting processes installed at yard y.

I_i^{pl} : Level of inventory of product p and at site i during period l.

z_y : Binary variable which equals 1 if site y is selected to become a sorting yard, 0 otherwise.

The objective function and the different constraints of the model used in Phase I are now described.

Objective function: *Maximize*

$$\sum_{i}\sum_{u\in U^{+}}\sum_{p}\sum_{l}V^{p}x_{iu}^{pl}-\sum_{f}\sum_{p\in MP}\sum_{l}c_{f}^{pl}x_{f}^{pl}-\sum_{p\in PR}\sum_{f}\sum_{j\in D}c_{f}^{p}x_{fj}^{p}-\sum_{s}\sum_{p\in PE}\sum_{l}\sum_{i}c_{i}^{sp}x_{i}^{spl}-\sum_{i}\sum_{j}\sum_{p}\sum_{l}\sum_{t}c_{ij}^{plt}q_{ij}^{plt}-\sum_{r}\sum_{l}\sum_{t}c^{r}x^{rl}$$

$$-\sum_{y}c_{y}z_{y}-\sum_{y}c_{y}^{+}n_{y}-\sum_{i}\sum_{p}\sum_{l}c_{i}^{p}v^{l}I_{i}^{pl} \qquad (1)$$

The objective function (1) maximizes profit, i.e., the sum of revenues from the sale of finished products minus harvesting costs, stumpage fee, sorting and mill processing costs, transportation costs, sort yard implementation costs, and inventory costs.

Subject to:

$$x_f^{pl} \le H_f^{+pl} \qquad \forall f \in F, p \in MP, l \in L^+ \qquad (2)$$

$$\sum_p \sum_l x_f^{pl} \le Q_f \qquad \forall f \in F \qquad (3)$$

$$\sum_p \sum_l x_f^{pl} \ge 0.9 * Q_f \qquad \forall f \in F \qquad (4)$$

$$\sum_f \sum_p x_f^{pl} \le Q^l \qquad \forall l \in L^+ \qquad (5)$$

Constraints of group (2) specify a maximum level of harvesting in the forest sites per period. Constraints of group (3) establish a harvesting capacity for the entire planning horizon. Those of group (4) force the system to harvest a minimal amount of wood for each site (currently 90% of the wood available). There is also a harvest limit for the entire supply chain for each period (5).

$$\sum_p I_i^{pl} \le E_i \qquad \forall i \in N, l \in L^+ \qquad (6)$$

$$I_f^{pl} = I_f^{pl-1} + x_f^{pl} - \sum_t \sum_{j \in D} q_{fj}^{plt} - \sum_s x_f^{spl} - \sum_u x_{fu}^{pl} \qquad \forall f \in F, p \in MP, l \in L^+ \qquad (7)$$

$$I_f^{pl} = I_f^{pl-1} + \sum_s \mathfrak{I}_f^{spl} - \sum_t \sum_{j \in D} q_{fj}^{plt} - \sum_s x_f^{spl} - \sum_u x_{fu}^{pl} \qquad \forall f \in F, p \in PEC, l \in L^+ \qquad (8)$$

$$I_f^{pl} = I_f^{pl-1} + \sum_s \mathfrak{I}_f^{spl} - \sum_u x_{fu}^{pl} \qquad \forall f \in F, p \in PDV, l \in L^+ \qquad (9)$$

$$I_i^{pl} = I_i^{pl-1} + \sum_t \sum_{j|j \ne i} q_{ji}^{plt} - \sum_t \sum_{j|j \ne i} q_{ij}^{plt} - \sum_s x_i^{spl} - \sum_u x_{iu}^{pl} \qquad \forall i \in D, p \in MP, l \in L^+ \qquad (10)$$

$$I_i^{pl} = I_i^{pl-1} + \sum_t \sum_{j \ne i} q_{ji}^{plt} + \sum_s \mathfrak{I}_i^{spl} - \sum_t \sum_{j|j \ne i} q_{ij}^{plt} - \sum_s x_i^{spl} - \sum_u x_{iu}^{pl} \qquad \forall i \in D, p \in PEC, l \in L^+ \qquad (11)$$

$$I_i^{pl} = I_i^{pl-1} + \sum_s \mathfrak{I}_i^{spl} - \sum_u x_{iu}^{pl} \qquad \forall i \in D, p \in PDV, l \in L^+ \qquad (12)$$

$$I_i^{pl^{\max}} \ge I_i^{pl} \qquad \forall i \in N, p \in P \mid l = 0 \qquad (13)$$

We establish an inventory capacity for each site with constraints from group (6). Constraints from groups (7) to (12) guarantee flow conservations for sites and for each product traveling through them. Constraints from group (13) specify that the inventory level for a given product will always be equal to or higher than what it was at the beginning (for the same site), to avoid consuming “free” products (i.e. products in stock at the beginning of the planning horizon that would be sold during the same planning horizon without involving any production cost).

$$\Im_i^{spl} = \sum_{p'\in PE} g^{sp'p} x_i^{sp'l} \qquad \forall i \in N, p \in PS, l \in L^+, s \in S \qquad (14)$$

$$n_y \leq \max{}_y \qquad \forall y \in Y \qquad (15)$$

Constraints from group (14) establish the relationship between the quantities of products entering and exiting any given sorting or production process. Constraints from group (15) establish a maximum number of capacity blocks that can be added to the yard (for this experimentation, 10 blocks of 250,000 m^3 each were defined). The number of blocks was defined arbitrarily at 10 for all scenarios, a number neither too small nor too big, to reflect the procurement areas capacity in the region that inspired our study.

$$\sum_{s\in SPE} \sum_{p} \sum_{l} x_y^{spl} \leq n_y Q_y \qquad \forall y \in Y \qquad (16)$$

$$\sum_{s\in SPE} \sum_{p} x_y^{spl} \leq n_y v^l Q_y^l \qquad \forall l \in L^+, y \in Y \qquad (17)$$

$$\sum_{s\in SPE} \sum_{p} x_y^{spl} \geq \frac{v^l}{2 * \sum_{l} v^l} * \sum_{s\in SPE} \sum_{p} x_y^{spl} \qquad \forall y \in Y, l \in L^+ \qquad (18)$$

$$\sum_{s\in SPDV} \sum_{p} \sum_{l} x_m^{spl} \leq Q_m \qquad \forall m \in M \qquad (19)$$

$$\sum_{s\in SPDV} \sum_{p} x_m^{spl} \leq v^l Q_m^l \qquad \forall m \in M, l \in L^+ \qquad (20)$$

$$\sum_{s \in SPDV} \sum_{p} x_m^{spl} \geq \frac{\nu^l}{2 * \sum_{l} \nu^l} * \sum_{s \in SPDV} \sum_{p} x_m^{spl} \qquad \forall m \in M, l \in L^+ \qquad (21)$$

Constraints (16) and (17) establish sorting capacity limits for the entire horizon and per period for the sort yard while constraints from group (18) establish a minimum threshold of sorting to reach at the yard to ensure a certain level of activity throughout the horizon. Constraints (19) to (21) do the same for production at the mills.

$$\sum_{r} (W_b^r \mu^r W^{rt} x^{rl}) \leq \nu^l \beta^t x_b^{lt} \qquad \forall b \in B, l \in L^+, t \in T \qquad (22)$$

$$\sum_{b} x_b^{lt} \leq \square^{\,t} \qquad \forall l \in L^+, t \in T \qquad (23)$$

$$q_{ij}^{plt} \leq x_{ij}^{plt} E^t \qquad \forall i \in O, j \in D, p \in P, l \in L^+, t \in T \qquad (24)$$

$$o^{pl} q_{ij}^{plt} \leq x_{ij}^{plt} Q_{ij}^{lt} \qquad \forall i \in O, j \in D, p \in P, l \in L^+, t \in T \qquad (25)$$

$$o^{pl} q_{ij}^{plt} \geq \frac{x_{ij}^{plt} Q_{ij}^{lt}}{2} \qquad \forall i \in O, j \in D, p \in P, l \in L^+, t \in T \qquad (26)$$

$$\sum_{p} x_{ij}^{plt} = \sum_{r} \eta_{ij}^{rt} x^{rl} \qquad \forall i \in O, j \in D, l \in L^+, t \in T \qquad (27)$$

$$\sum_{i} x_{iu}^{pl} \leq d_u^{pl} \qquad \forall u \in U^+, p \in PDV, l \in L^+ \qquad (28)$$

Constraints from group (22) ensure that the fleet of vehicles of each type has the time to achieve all the routes that were selected. Constraints from group (23) guarantee that the sum of trucks of type t assigned to different bases is smaller than or equal to the fleet size of this same truck type. Constraints from group (24) guarantee that there will be enough space for each truck fleet to deliver the quantities that have been assigned to them. Constraints from group (25) do the same regarding the weight capacity of the vehicles. Constraints from group (26) ensure that trucks being selected for deliveries will always be at least half full. Constraints from group (27) ensure that the number of deliveries per combinations of origin-destination pairs and truck type (ODT combinations) is equal to the number of times these combinations are present in the selected routes. Constraints from group (28) specify that we cannot sell more units of a product than the market demand for a given period.

$$\frac{x_f^p}{Q_f^p} = \frac{\sum_{p \in MP} \sum_{l} x_f^{pl}}{Q_f} \qquad \forall f \in F, p \in PR \qquad (29)$$

$$\sum_{j \in D} x_{fj}^p = x_f^p \qquad \forall f \in F, p \in PR \qquad (30)$$

$$\sum_{f} x_{fj}^p \geq \sum_{u} \sum_{l} x_{ju}^{pl} + \sum_{s} \sum_{l} x_j^{spl} \qquad \forall j \in D, p \in PR \qquad (31)$$

Constraints from group (29) ensure that there is consistency between the level of harvesting of each forest site and the sum of logs originating from a given forest site that is assigned to each mill. Constraints from group (30) ensure that the sum of logs from a forest site assigned to different mills is equal to the number of such logs that are available, considering the level of harvesting. Constraints from group (31) specify that the sum of logs assigned to a site must be higher than or equal to the sum of logs that was “sold” (at a loss) or transformed at that same site.

$$z_y \in \{0;1\} \qquad \forall y \in Y, f \in F \qquad (32)$$

$$I_i^{pl}, x_f^{pl}, x_i^{spl}, q_{ij}^{plt}, x_{ij}^{plt}, x^{rl}, x_{fj}^p, x_{iu}^{pl}, x_f^p, x_b^{lt}, n_y, \Im_i^{spl} \geq 0 \quad \forall i, j \in N, m \in M, f \in F, s \in S, p \in P, l \in L, t \in T, y \in Y \qquad (33)$$

Constraints from group (32) ensure that the variables related to the opening and use of a potential sort yard site are defined as binaries. For this article, we have decided to compare scenarios with one or no site selected. Finally, the group of constraints (33) ensures that all variables and invariants are non-negative.

In Phase 2, the same objective function as well as the same constraints are once again used, except that constraints from groups (18) to (21) are replaced with constraints (34) and (35).

Specific constraints for Phase 2

$$\sum_{s \in SPE} \sum_{p} x_y^{spl} \geq v^l Threshold_y \qquad \forall y \in Y, l \in L^+ \qquad (34)$$

$$\sum_{s \in SPDV} \sum_{p} x_m^{spl} \geq v^l Threshold_m \qquad \forall m \in M, l \in L^+ \qquad (35)$$

The right-hand side of the equations has been replaced by the parameter $Threshold_y$ which was obtained from results of Phase 1. For each mill as well as for the yard, the total amount of production (or sorting for the yard) was divided by the total number of months for the time horizon (2 years = 24 months). This number was then divided by two to obtain the minimum amount of production or sorting that each mill or yard must reach for a given month.

Route generation

In the model, we assumed that trucks carry only one product at a time. Routes must be generated before the optimization takes place. This is done through a procedure based on the MaxTour algorithm presented by Gingras *et al*. (2007), itself inspired by the heuristic developed by Clarke & Wright (1964). We consider an origin (O) as a business unit delivering a product and a destination (D) as the point of delivery. The OD pair links the origin to the destination. Four different types of trucks are considered, three carrying regular-sized loads and one carrying over-sized loads. Trucks for over-sized loads are limited to forest-to-sort-yard roads, while b-trains travel only from yard-to-mill and from mill-to-mill. First, each OD pair is combined with valid truck types to create ODT combinations. Then, each ODT combination is associated to every terminal to find the best ODT-terminal combinations. This becomes a series of one-delivery routes. Only routes with one delivery can be “merged” with other deliveries to form routes with two deliveries. This is done progressively to reduce the time and distance travelled. For each generated route, we compare the cost of the route with the sum of the costs for the two deliveries of that route if they were made separately. This process is done in an Excel file before the optimization itself takes place (Routing preprocessing, see Figure 1). Once routes are generated, they are copied into an Access file. The OPL Studio software reads into this file to extract the model’s inputs (amongst them are the valid routes) which are then submitted to CPLEX for resolution.

Every route leading to a certain saving while not exceeding a maximum driving time (i.e., 14 hours in Quebec) is selected. After running the model numerous times, it was found that routes containing three or four delivery routes were almost never selected by the solver. It was therefore decided to generate routes with only one or two deliveries to limit the resolution time. We specified that no OD pair can be used more than once in a route to avoid cycling patterns. As mentioned earlier, each route has a predetermined base or vehicle terminal b, as well as a vehicle of type t. This information is used by the OPL software to determine the value of the parameters W^{rt} and W_b^r.

Figure 5 illustrates how we calculated the gain obtained when a segment was merged with a pre-existing route. Route A starts from one of the pulp and paper mills. The truck then goes to the forest site to pick up wood that is then delivered to the mill, travelling 106 km twice for a total of 212 km. Route B starts at the yard. The truck travels 34 km and delivers wood to the sawmill. There, it picks up wood chips and delivers them to the pulp and paper mill, traveling 50 km. It then travels back empty 16 km to its base (the yard). The distance for route B is 100 km, for a total of 312 km for both routes. The merged route follows the same path as route B, up to the point where it reaches the pulp and paper mill. It then travels empty 98 km to the forest site, to pick up the wood that was harvested there. The wood is delivered to the other pulp and paper mill, 106 km to the south. It then goes to the sort yard, which is only 2 km away. The total distance traveled is 290 km for a gain of 312 – 290 = 22 km. The saving is 7.1% (22/312).

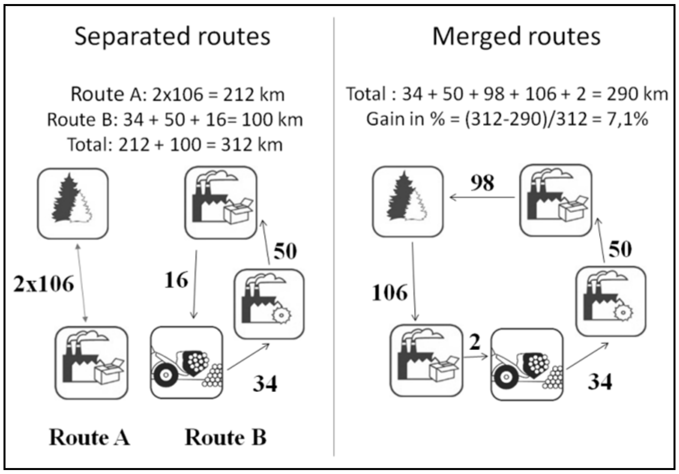

Figure 5: Routing generation. Numbers represent km between network nodes

EXPERIMENTATION AND ANALYSIS

Experimentation

When solving complex problems, it is considered very important to do a thorough validation of the model developed (Tardif *et al*., 2010; Landry *et al*., 1983). We therefore validated the model by making sure that all the constraints considered were respected for multiple instances. We also verified that all the costs as well as the revenues included in the model were compiled accurately. An Excel file encompassing the results of each resolution was built for that purpose.

Once the model was validated, we tested four scenarios based on the presence or absence of a sort yard as well as the use of routing (combining multiple deliveries vs one delivery at a time). After obtaining results for a base instance, 56 other instances were tested. They involved different modifications regarding transportation costs, distances to forest sites, the number of trucks delivering oversized loads, and the sorting costs. A sensitivity analysis was conducted to identify the parameters that had the greatest impact on the profitability of the logistic center.

Base instance

The model has been modeled via the OPL Studio software (version 12.6) and solved using the CPLEX solver. The total resolution times vary between 30 and 45 minutes for the scenario with no sort yard or routing, and around 90 minutes to 3 hours for the scenario with both a yard and routing. Resolution times are significantly longer for the second phase than for the first (by a ratio of around 4 to 1).

Table 1: Profits by scenario

	Transportation	
Sorting	*No Routing*	*Routing*
No Yard	$46,209,995	$47,917,187
Sort Yard	$48,098,832	$49,536,769

The results of the base instance (Table 1) show a continuing profit growth from one scenario to another. The total profit for the forest products supply chain is $ 46,209,995 in the base scenario (neither sort yard nor routing). The profit increases to $ 47,917,187 when routing is used alone. The profit rises to $ 48,098,832 when a sort yard is introduced without the use of routing. The highest profit value, i.e. $ 49,536,769, is obtained when both a sort yard and routing are used at the same time. All amounts presented are in Canadian dollars. Since, profits represent a difference rather than a sum, they tend to be an improper point of comparison when they are presented in relations to total costs. Therefore, all our comparisons are written in $/available m^3 to ensure a stable point of reference.

Table 2: Gains by scenario (in \$/avail. m^3)

	Transportation	
Sorting	*No Routing*	*Routing*
No Sort Yard	-	+ \$0.45
Sort Yard	+ \$0.50	+ \$0.88

If the gains are divided by the 3,788,268 m^3 of wood available for harvesting (Table 2), it becomes possible to see that performing routing increases profits by \$0.45 per m^3. Adding a sort yard raises profit by \$0.50/available m^3. Combining both the sort yard and routing leads to a gain of \$0.88/available m^3.

Table 3: Variation in revenues and costs (in \$/avail. m^3)

Revenues/Costs	Routing	Sort Yard	Sort Yard & Routing
Revenues	\$ 0.03	\$ -0.13	\$ -0.11
Harvesting/Fees	\$ 0.01	\$ -0.10	\$ -0.07
Sorting/Production	\$ 0.00	\$ -0.71	\$ -0.49
Transportation	\$-0.44	\$ -0.13	\$ -0.71
Yard Operations	\$ -.--	\$ 0.32	\$ 0.28
Inventory	\$ 0.00	\$ -0.01	\$ -0.01
PROFITS	**\$ 0.45**	**\$ 0.50**	**\$ 0.88**

If we look more closely at how the gains occurred (Table 3), we can see that lower transportation costs account for almost all the variations taking place when routing is used alone (\$-0.44/available m^3), followed by higher revenues (\$0.03/avail. m^3). Because these numbers are rounded, they may not add up exactly to variations in profits. Lower sorting costs represent most of the variations in the scenario with a sort yard only (\$0.71/avail.

m^3), followed by a decrease in transportation costs as well as lower revenues (both at \$-0.13/avail. m^3). We also note lower harvesting costs and royalties (\$ -0.10/avail. m^3). The sort yard costs 0.32/avail.m^3 to be put in place. In the scenario with both a sort yard and routing, transportation costs go down by \$0.71/avail. m^3 while sorting costs diminish by \$0.49/avail. m^3. There is also a small decrease in revenues (\$0.11/avail. m^3) while the yard itself generates extra costs of about \$0.28/avail. m^3. Harvesting costs also diminish by \$ 0.07/avail. m^3. Inventory costs stay basically the same for all scenarios.

A closer look at the results shows that all the available wood is harvested in the base scenario, which explains why harvesting costs stay the same for all the scenarios.

Table 4: Variations in transportation costs (in \$/avail. m^3)

Transportation cost type	**Routing**	**Sort Yard**	**Sort Yard & Routing**
Variable	\$ 0.01	\$ 0.92	\$ 0.53
Fixed	\$ -0.45	\$ -1.05	\$ -1.24

In terms of transportation costs, we see in Table 4 that variable costs (which relate to the weight transported) are higher in all the scenarios with either routing or the sort yard, or both simultaneously. Fixed transportation costs, on the other hand, go down, especially when the sort yard is used. In fact, with the use of a yard, an important part of the volume is no longer delivered directly from the forest sites to the mills. As a result, the wood has to be transported over longer total distances, since the sum of the distances between forest sites and the yard and between the yard and the mills will likely exceed the distances between the forest sites and the mills.

If we look at the reductions in revenue when using a yard, they reveal that wood which was previously transformed and sold by sawmills is now shipped to one of the pulp and paper mills situated very near to the sort yard. This allows the model to reduce transportation costs by using trucks transporting oversized loads. Once the wood is sorted, it is shipped to the adjacent mill at a negligible cost (within 2 km between the yard and the mill). This leads to an increase in the revenues generated through the sales of paper but a decrease in the sales of sawmills. Because there is a greater reduction in transportation costs, there is an overall increase in total profits for the supply chain. Results obtained for the base instance show that the concept of a logistic center can be profitable for the modeled forest products supply chain by increasing profits by $ 0.88/avail. m^3. This could represent up to $1,663,774 in extra profit each year for the entire network.

In the next sub-section, we describe the results of a sensitivity analysis conducted on key parameters such as transportation costs, sorting costs, distances from the mills and the yard to forest sites, and the number of trucks carrying oversized loads.

Sensitivity analysis

Transportation and sorting costs appear to be the factors that most greatly influence the logistic center's profitability. To confirm these findings, we decided to isolate (1) transport and (2) sorting costs at the yard, (3) distances from the forest sites, and (4) the number of oversized trucks, and then to test the impact their variation may have on profits. We use the values of these parameters in the base instance and modify them to observe the effect such variations may have on total profits. Transportation costs and distances to forests vary from -50% to +50% of their values in the base instance with intervals of 10%. Sorting costs at the yard in the base instance represent 85% of sorting costs at forest sites. We observe the effects of making them vary between 50% and 100% of sorting at forest sites (at intervals of 5%). As for trucks transporting oversize loads, we verify the results when their fleet size varies between 0 and 25.

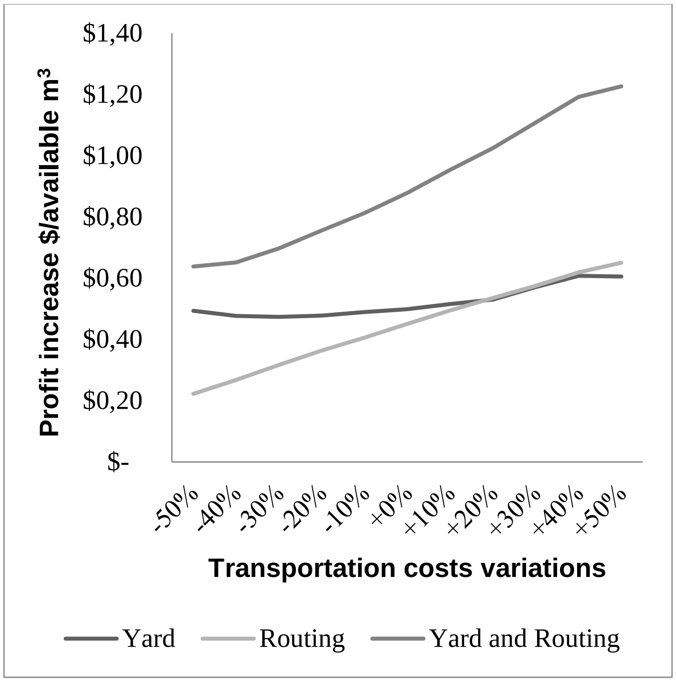

Figure 6: Evolution of profit increases relative to variations in transportation costs

In regards to transportation costs variations, higher transportation costs bring smaller profits for all four scenarios. However, as we can see in Figure 6 an increase of this cost seems to have a positive impact on the gains that the sort yard brings when it is coupled with the use of routing. The reason for this counterintuitive result is that the presence of the yard allows a greater use of oversized trucks, which coupled with the use of routing partially compensates for the rise in transportation costs. This ultimately leads to a bigger gap between the profit obtained in the base scenario and the scenario where only a yard is used, as profits for this scenario fall less rapidly. The same pattern can be observed when the sort yard is used alone, although variations are much smaller. The gains when only routing is used are more constant, as the use of routing alone becomes more profitable than the use of only the yard when transportation costs are increased by 20% or more.

Another explanation for these results is the evolution of revenues for the different scenarios in relation to higher transportation costs. As these costs rise, revenues tend to fall in all scenarios, but more sharply when neither a yard nor routing are used. The reason is that some forest sectors become relatively less profitable and see their harvesting level decline. Again, the use of a yard and/or routing can partially mitigate this pattern.

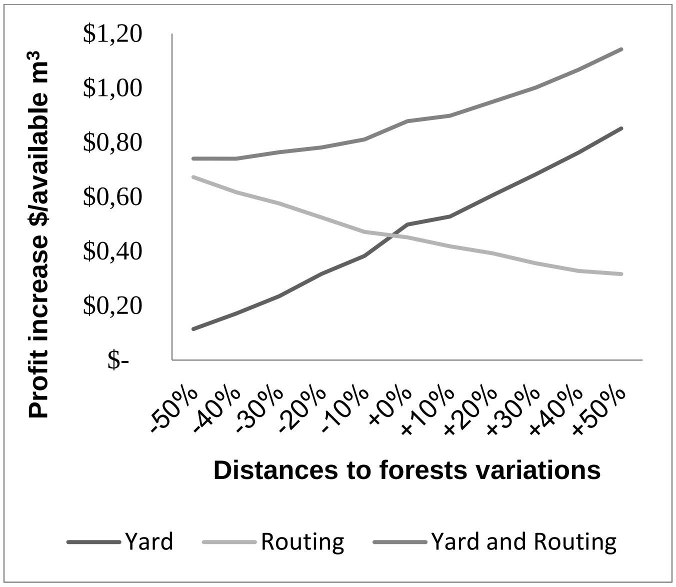

Figure 7: Evolution of profit increases relative to variations in the distances to forests sites

If we look at Figure 7, which presents the variations of distances between the forest sites and the rest of the supply chain, we can see that higher distances tend to make the use of a yard more profitable when coupled with routing. This trend is even more pronounced when it is used alone. The same pattern that we observed when transportation costs rise is also at play here. The use of routing alone is, however, progressively less interesting with higher distances to forest sites. As distances increase, it becomes more and more difficult to combine different deliveries together while respecting the legal driving time limit imposed in the Province of Quebec (14 hours). For instance, we could generate 2,483 routes when distances to forests sites were decreased by 50%, but only 896 when they were increased by the same percentage. This represents a decline of 64% in the number of routes generated for the scenario where routing is used alone. The same pattern can be observed in the scenario with both a sort yard and the use of routing (4,954 to 2,075 routes for a decline of 58%).

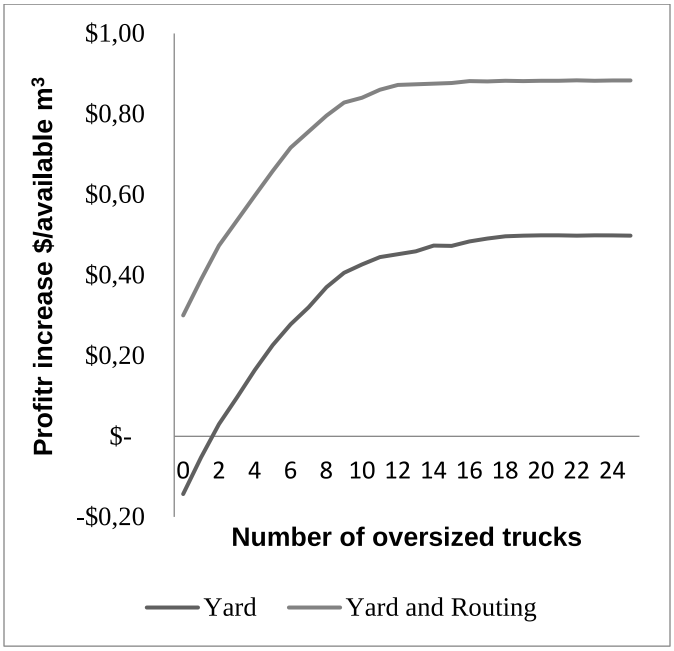

Figure 8: Evolution of profit increases relative to variations in the number of oversize trucks

Figure 8 shows the effect of using an increasing number of oversized trucks. This parameter seems to have an important effect on the scenario with a sort yard and the use of routing, up to approximately 14 trucks (with a peak in profit increase of $0.88 /m^3). When only a sort yard is considered, the effect reaches a plateau at 18 trucks (with a gain of $0.50, as shown in Figure 8). Since oversized trucks cannot be used without the presence of the sort yard, we did not include the scenario where only routing is used in the graph.

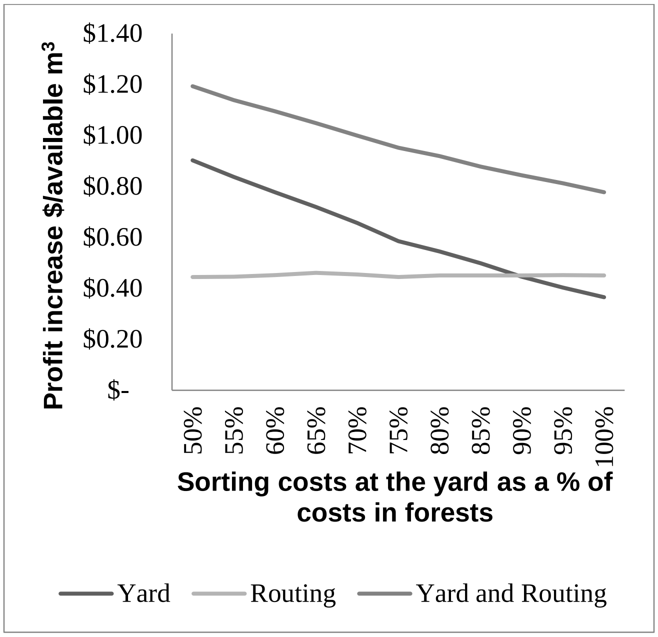

Figure 9: Evolution of profit increases relative to variations in sorting costs at the yard

Figure 9 highlights the influence of sorting costs. Even when sorting costs at the yard are the same as at the forest sites, the yard remains profitable. Furthermore, the gains generated when both a sort yard and routing are used simultaneously tend to decrease more moderately with an increase of sorting costs at the yard. The proportion of sorting costs at the yard in comparison to sorting costs at forest sites has been fixed at 85% for the base instance. This approximation was calculated based on data found in Favreau (1995).

Statistical analysis

We also conducted a linear regression with Minitab 18 to establish whether there is a significant correlation between the profit improvement of the scenarios with a sorting and/or the use of routing and the four parameters introduced in the previous section.

In the regression formula below, y_i represents the variation of profits obtained in scenario i and β_{ni} represents the regression coefficients for the independent variables. The independent variables refer to the parameters tested in the sensitivity analysis, namely:

x_{1i} : Variation of distances to forest sites in scenario i.

x_{2i} : Variation of transportation costs in scenario i.

x_{3i} : Variation of sorting costs at the yard in scenario i.

x_{4i} : Variation in the number of oversized trucks in scenario i.

The regression formula is formulated as follows:

$$y_i = \beta_{0i} + \beta_{1i} x_{1i} + \beta_{2i} x_{2i} + \beta_{3i} x_{3i} + \beta_{4i} x_{4i}$$

Results obtained from the regression are shown in Table 5. They reveal that the R^2 is around 85% when the yard is used alone or combined with routing, while it goes up to 98% when only routing is used. All the p-value for the parameters are below 0.05, except for transportation costs in the scenario with a sort yard and the use of routing (p-value of 0. 0.109) as well as for sorting costs at the yard in the scenario with routing only (p-value of 0.300). Two of the three constants (the value of the regression when all the variables take a value of 0) also have a p-value above 0.05 (for the scenario with a yard only and both a yard and routing).

Every coefficient is measured in relation to a 1% increase in the value of the parameters in the base instance. When the influence of the number of oversized trucks was measured, the coefficient obtained was corrected by dividing it by 100/n, n being the maximum number of oversized trucks in the scenario. The regression for the scenario with only a sort yard was conducted with 0 to 18 oversized trucks, since using supplementary trucks produces no more profit in this scenario. For the scenario with both the yard and routing, instances with up to 14 trucks were included. Since there are no oversized trucks or sort yard when routing is used alone, we did not include these factors in the linear regression for that scenario.

Sorting cost variations is the factor that has the greatest impact on profit variations. It has a coefficient of $ -0.0104 in the scenario with only a sort yard. It goes up to $ -0.0076 when both a yard and routing are used. This confirms the findings presented earlier. Transportation costs have the impact when both a yard and routing are considered (+ $0.0064), followed by the scenario with routing (+ $0.043). Distances to forest sites when a sort yard is used, with or without the use of routing, also have an important impact (with coefficients of + $ 0.0074 and + $ 0.0040). The number of oversized trucks has a more moderate influence when only a sort yard is used (+ $ 0.0027), and an even smaller impact when both the yard and routing are deployed (+ $ 0.0019). P-values for both coefficients are nevertheless equal to 0.00. Profit variations tend to be smaller in the scenario with only the use of routing.

For two of the four parameters, the most important coefficient was in the scenario with the use of a sort yard only. Nevertheless, the scenario with both a yard and the use of routing is the only one where the p-value of each parameter was equal to 0. Since routing implies longer consecutive driving time as deliveries are merged together, longer distances make it less advantageous, as many routes will exceed the driving time limit of 14 hours. The other exception is sorting costs at the yard. Since this parameter is strictly related to yard operations, it naturally has a greater impact on the profitability of using a yard alone.

DISCUSSION AND CONCLUSION

Discussion

Using dedicated sort yards is not generalized in the industry, which raises the question of the necessary conditions for its profitability. Results found in this study highlighted that lower sorting costs at the yard were the most important factor in making a sort yard more profitable. As transportation costs and distances to forest sites increase, the use of a yard can also lead to higher revenues, as it makes the exploitation of some of the forest sites less costly and therefore more profitable. Another important benefit of such a center could be the reduction of transportation costs, by using oversized trucks and b-trains as well as routing procedures.

Each vehicle in the fleet considered has 325 hours available each month to deliver the wood. This explains why adding trucks transporting oversized loads contributes to increasing the profitability of using the yard and routing. However, once a fleet is big enough to have sufficient time to make deliveries optimally, supplementary vehicles no longer add new possibilities for extra profits. From Figure 9, we can see that profit increases level out with 14 trucks when both the yard and routing are used, while they peak at 18 trucks when the yard is used alone

Table 5: Results of a linear regression

Coefficients represent profit increases relative to 1% variations in comparison to the Base scenario

Parameter/Scenario	**Yard**		**Routing**		**Yard and Routing**	
	Coefficient	*p-value*	*Coefficient*	*p-value*	*Coefficient*	*p-value*
Constant	0.0015 $	0.407	0.0036 $	0.000	0.0017 $	0.3150
Distances to forests (x_{1i})	0.0074 $	0.000	-0.0036 $	0.000	0.0040 $	0.0000
Transportation costs (x_{2i})	0.0014 $	0.109	0.0043 $	0.000	0.0064 $	0.0000
Sorting costs at the yard (x_{3i})	-0.0104 $	0.000	0.0003 $	0.300	-0.0076 $	0.0000
Number of oversized trucks (x_{4i})	0.0027 $	0.000			0.0019 $	0.0000
R^2	85,49%		98.25%		84.97%	

Conclusion

The main objective of this paper was to identify the parameters having the greatest influence on the profitability of a logistic center comprising both a dedicated sort yard and the use of routing procedures. Results showed that a logistic center could procure a profit increase of \$ 0.88/available m^3 to the forest products supply chain considered. Moreover, we have demonstrated through a linear regression that there exists a significant correlation between all the parameters considered in the analysis and the increase in profit obtained for all the scenarios where both a sort yard and routing are used. We have established that for the supply chain under investigation, sorting costs at the yard and distances to forests have the greatest influence on the profitability of the logistic center, followed by transportation costs. The model could also be used to compare other alternatives, for example the expansion of one of the mills, the influence of spatial factors or other elements such as the error rates in the sorting processes. These scenarios, however, are beyond the scope of this paper aiming at identifying the parameters having the highest impact on the profitability of a logistic center.

Our results have been obtained for a specific supply chain. It would be interesting to measure the profitability of this type of logistic center with other sort yard locations and other supply chain configurations. Such research, combined with the results of this study, would be very a valuable tool to guide forest products companies considering the possibility of building such a logistic center.

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