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An Optimization and Simulation Framework for Integrated Tactical Planning of Wood Harvesting Operations, Wood Allocation and Lumber Production

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Abstract. This research addresses the problem of tactical planning in a lumber supply chain. It proposes a framework for incorporating together data from two software, which simulate harvesting operations and lumber production, into an optimization module called LogiOpt. Using this framework, decisions regarding harvesting, transportation, wood allocation and lumber production can be integrated. Although the idea of global optimization is not entirely new, the main challenge has always been to obtain the data required. With the proposed framework, simulation allows us to obtain the information needed. Thus, by rethinking the tactical planning process and making it focus on value rather than on costs, we provide an optimal solution to the tactical planner, helping him make better decisions. Experiments carried-out using industrial data from a large Canadian company indicate that many opportunities are lost because the planner focuses more on cost-related considerations. These results illustrate why the forest supply chain needs to be considered as a whole rather than by its individual components. They also show the potential of using both simulation and optimization together in order to capture those gains.

Keywords. Forest products industry, lumber, supply chain optimization, tactical planning, divergent processes, supply chain simulation.

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1. Introduction

In the lumber industry, a supply planner's job is to produce a tactical plan that will allow for efficient operations from a global perspective (from the forest to finished lumber products). The goal is to exploit the logistics network in an optimized way, in order to create the maximum value from the available wood resource (D'Amours et al. 2008). The plan must state: (1) cutblocks to harvest, (2) wood quantities to harvest, (3) bucking patterns to use (which define types of logs that will be obtained), (3) sawmills where logs will be transformed into lumber, (4) types and quantities of logs to be processed at each sawmill, and (5) sawmill setup/configurations (which change the lumber products that will be obtained). This problem is particularly complex, especially since a mill output will vary according to many factors (Rönnqvist 2003). These factors include: cutblocks from which wood is harvested (stems distribution changing from one cutblock to another), bucking strategy, and the sawmill used to process wood, since equipment and productivity will vary from one sawmill to another.

An informal graphical representation of the tactical planning problem can be seen in Figure 1.

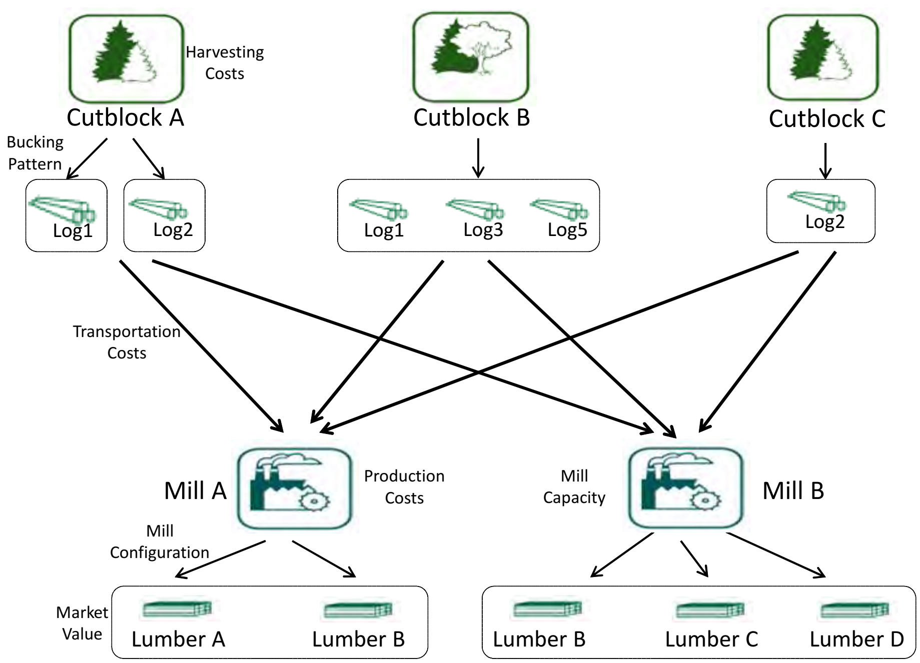

Fig. 1. Forest supply chain divergent processes.

Producing a tactical plan involves dozens of possibilities and combining these possibilities can lead to an exponential number of solutions.

Many decision-support models have been developed in the last decades (see D'Amours et al. (2008) for a review). Some were designed for specific activities such as skidding (Carlsson et al. 1998) and transportation (Wrightman and Jordan 1990; Weintraub et al. 1996), while other research projects have integrated several activities in a single model to capture possible synergies between them.

The idea of making all decisions (harvesting operations, wood allocation and lumber production) at once is very appealing. However, forest companies do not have the required information to supply such a global model. This is why a manager's decisions are highly based on his experience and intuition. Of course, experience and rational thinking are essential elements of an accurate and profitable tactical plan. An experienced tactical planner can help improve his company's results by correctly selecting harvesting, transportation, wood allocation and production options. On the other hand, an opportunity could be lost when different options are analyzed only by hand. Problems are characterized by a large number of possible scenarios but the planner usually reduces its analysis to a limited number of possibilities.

Software simulation tools have been developed in Canada to help the forest industry make better decisions based on more detailed information. For example, FPInterface and Optitek simulation software developed by FPInnovations research centre allows forest companies to evaluate different harvesting and sawing scenarios. These two simulators evaluate costs and productivity levels. Moreover, they predict the lumber products which can be obtained depending on the wood resource, their physical characteristics and the technologies used at the sawmill for wood transformation.

Until now, these tools have been used in order to evaluate the profitability of a plan established manually. What we now propose is a framework linking two simulators, FPInterface and Optitek, to a mathematical model producing in the end an integrated and optimized plan. All possible elementary operations of a tactical plan are simulated individually. Using FPInterface, we have access to 3D scans of stems that are considered a representative sample of each cutblock. For each valid bucking pattern, this system generates 3D profiles of logs that could be obtained. Optitek can also perform sawing simulations for each sawmill of the network. These results are then supplied to the optimization module, which provides an optimal tactical plan. This module takes into account sawmill capacity and the fact that the source of the raw material has a direct influence on lumber produced.

The rest of this paper is divided as follows. In Section 2 we will look at how optimization has been used to make the forest value chain more effective and we will also see which simulation tools are available. Section 3 presents our simulation–optimization framework with its mathematical optimization model. Section 4 presents our experiments that were carried out using data from a large Canadian forest company. The optimized plan is compared with plans obtained using a heuristic simulating manual planning. Section 5 concludes this paper.

2. Literature Review

2.1. Optimization in the Forest Sector

Various optimization methods have been employed to optimize certain aspects of the forest products industry supply chain. Detailed literature reviews regarding supply chain planning and optimization in the forest and agricultural sector are available in D'Amours et al. (2008), Rönnqvist (2003) and Weintraub and Romero (2006).

Regarding transportation costs specifically, some models were developed to minimize production, transportation and distribution costs, see Pirkul and Jayaraman (1996). Other research tried to integrate production and transportation planning, see Chandra and Fisher (1994). Cohen and Lee (1988) tried to integrate production and distribution in a supply chain network. Martin et al. (1999) integrated production, inventory and distribution variables using linear programming.

Regarding sawmilling operations, Singer and Donoso (2007) presented a tactical sawmill optimization model applied to the Chilean sawmill industry. Gaudreault et al. (2010) proposed different operational planning models for lumber sawing, drying and finishing operations.

Looking more specifically at mathematical optimization applied to forest operation planning, Falk (1988) suggested the use of operations research at the International Paper Company. Richards and Gunn (2003), and Richards and Gunn (2000) worked on forest road networks issues while Andalaft et al. (2003) employed an optimization method applied to both harvesting and road building operations. Karlsson et al. (2004) proposed a mixed integer programming (MIP) model to solve a multi-element planning problem while Karlsson et al. (2003) presented a model to integrate transportation and product storage. Maness and Adams (1993) proposed a one-period, one-sawmill MIP model to integrate bucking and sawing process optimization. In Maness and Norton (2002), the authors conceived a multi-period version of their previous model. Ouhimmou et al. (2009) proposed an optimization-based approach for coordinating operations in the wood supply chain using decomposition. Liden and Rönnqvist (2000) developed an integrated optimization system taking into account bucking, sawing, drying, planing and grading processes.

All of this research focuses on some part of the forest supply chain, but none focuses on its four main components together: harvesting, transportation, wood allocation and sawing. The challenge for such global optimization is where to get the data needed in order to supply the mathematical model. Simulation could possibly provide such data.

2.2. Simulation

Many tools have already been built to help tactical planning. Simulation is a set of techniques used to generate and experiment with numerical models using a computer. Simulation can imitate operations, system processes and real-world facilities in order to analyze them. Thus, these techniques provide a way to describe complex relations among system components (Law 2006). Since forest supply chain planning is a complex process, simulation software has proven to be a helpful tool to deal with this complexity.

Simulators can be classified into two main categories, namely deterministic or stochastic. Deterministic simulations do not have a degree of randomness and mostly contain equations with no random variables. With stochastic simulations, probability distributions are used to estimate the uncertainty of events (Ballou 2004). For a problem which includes stochastic elements such as demand and market price, stochastic simulations should be favoured.

In the forest products industry, a great amount of research has been done on modelling the supply chain using simulation (Reeb and Leavengood 2003). For instance, Reeb and Massey (1996) developed a deterministic simulation model to determine the financial feasibility of producing different proprietary grades. Gatchell et al. (1999) developed a deterministic simulator to determine processing scenarios in rough mills. Howard (1988) used a deterministic simulation model to estimate costs and profits for sawmill production. Some simulation tools have been developed to integrate some optimization tools in Lendermann et al. (2001), and Baumgaertel and John (2003).

Over the years, many software planning tools have been created in Canada, such as HSG Wood Supply (Lockwood and Moore 1990), FOREXPERT (Laliberté and Lussier 1997), Woodstock-Stanley (Remsoft Inc. 1996), GISFORMAN (Baskent and Jordan 1991), Strategic Forest Management Model (Kloss 2002), and WPPT (Valeria et al. 2003).

FPInnovations, the research and development centre of the Canadian forest industry, developed FPInterface© (FPInnovations 2013) and Optitek© (Goulet 2006). FPInterface is a platform performing simulations of forest operations. It models the forest supply chain, harvest areas and wood inventories as well as harvesting and transportation systems. It can also predict productivity and costs. Simulation results are shown on a map of the forest. It provides a variety of controls which enable the user to determine certain simulation details. FPInterface identifies which log types could be obtained using different bucking patterns. Several scenarios can be created by modifying simulation parameters. It can compute costs associated with supplying a mill with a given harvesting area. Figure 2 shows the user interface of FPInterface.

Optitek (Figure 3) is a simulator for sawmill operations. Since 1994, this simulator has been used across Canada. Optitek is able to simulate all operations in a softwood conversion mill, including bucking and trimming (Goulet 2007). Using this simulator, each machine in the production line is modelled

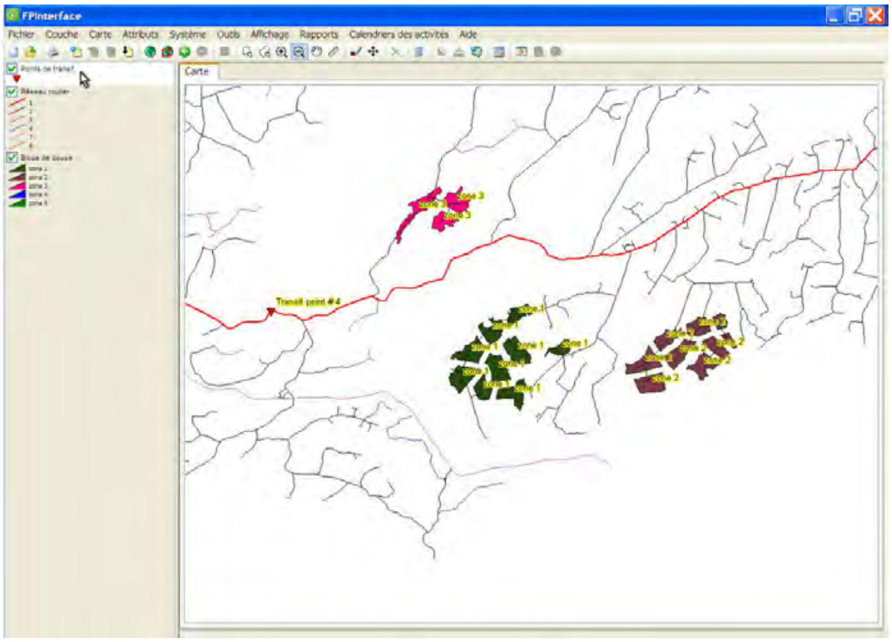

Fig. 2. FPInterface user interface.

through different modules. A log description (either a three-dimensional model or a parametric description) is provided to Optitek. Afterward, it forecasts the lumber production which could be obtained at the sawmill (Hebert et al. 2000). In other words, Optitek can compute the sawmill performance according to its physical configuration. It can also assess the effect of a change in the log supply (Zhang and Tong 2005).

Researchers at FPInnovations have already used the opportunity to combine data from FPInterface and Optitek. This combination allows anticipating the economic value generated by a harvesting area to be allocated to a sawmill (net worth value). To do this, FPInterface determines: the type of logs (3D profiles) that will be obtained from a given cutblock according to sample stems (3D profiles), the selected bucking pattern, as well as the computed harvesting and transportation costs. Using Optitek, it is then possible to compute sawmill processing costs, lumber products that will be generated, and revenues. Therefore, the combination of FPInterface and Optitek simulates the entire supply chain, evaluates a plan and allows the user to assess the economic value of this specific plan. However, this system has several limitations:

1. The user must specify a plan manually.

2. It is only possible to evaluate a single plan per simulation.

3. Developing a plan/scenario is based on the decision maker's experience and intuition.

4. Reconfiguration of the system can be quite long and trying all possible solutions is impractical.

5. Decision makers may disregard certain solutions, because they do not seem to have enough potential, while in reality, they would have been a good choice.

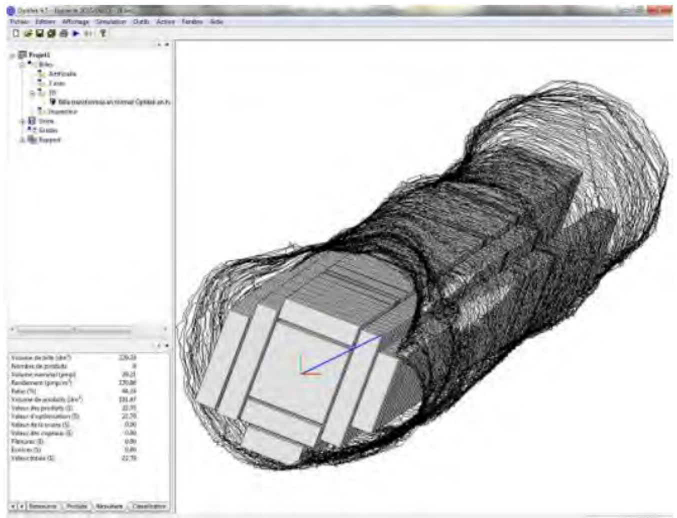

Fig. 3. Optitek user interface.

6. There is no indication about the income gap that separates the plan from what would be the optimal solution.

7. It is also very difficult to assess the impact of a change (real or potential) that may occur in the network (e.g., mill shutdown).

Additionally, Optitek and FPInterface do not take into account each individual sawmill's capacity. Sawmill capacity can be either *time capacity* (how much time during a specific period a sawmill can operate), *cubic metre capacity* (how much wood a sawmill can process during a specific period), or *Foot Board Measure* (FBM) *capacity* (how much lumber a sawmill can output).

On the other hand, the FPInterface–Optitek combination offers a perfect basis to perform mathematical optimization, since practically all needed data is made available or computed by these tools. This situation led us to develop a simulation and optimization framework aimed at optimizing the forest value chain, from wood harvesting to sawing. We will detail this framework in the next section.

3. Proposed Simulation–Optimization Framework

Regarding FPInterface–Optitek limitations, an optimization module called *LogiOpt* is proposed to be added to these two simulation tools. All possible "elementary operations" that can be included in a tactical plan are simulated individually. Forest data and harvesting simulation results (from FPInterface), as well as sawing simulation results and revenue (from Optitek), are supplied into the optimization module which generates an optimal tactical plan. Consequently, LogiOpt can evaluate all possible and allowed scenarios (valid combinations of "elementary operations") and compute the optimal solution. In the end, the plan is returned to FPInterface to be displayed to the user.

Figure 4 shows a schematic representation of proposed interconnections between the two simulation tools and the optimization module, as well as data flows between them. These interactions, as well as the mathematical programming optimization model, are detailed in the next subsections.

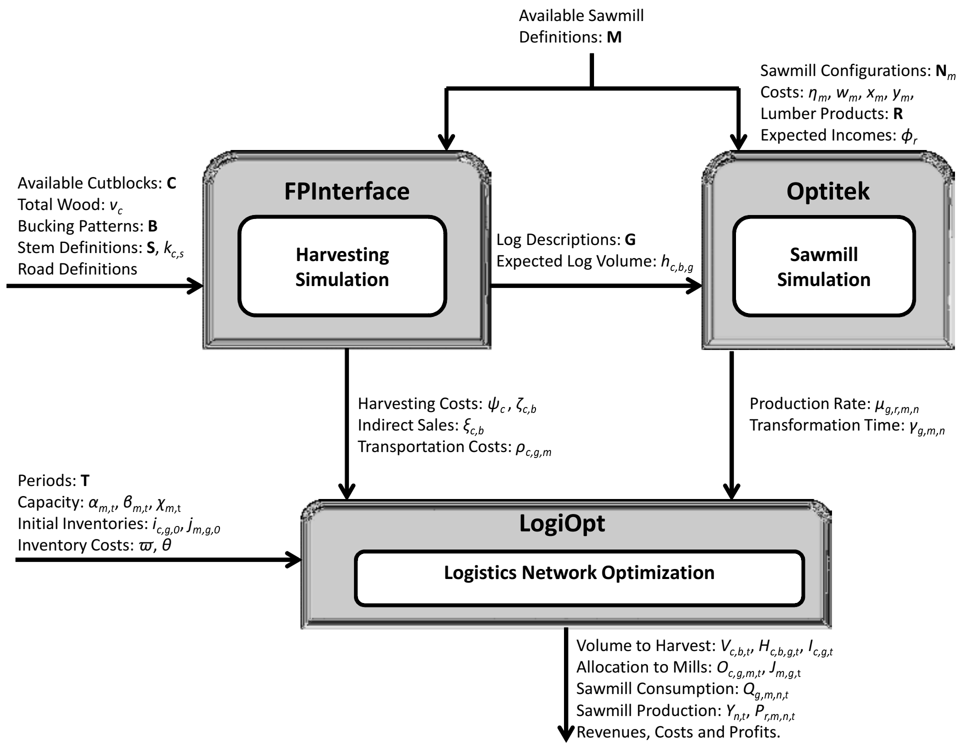

Fig. 4. Interactions between FPInterface–Optitek and LogiOpt.

3.1. FPInterface Harvesting Simulations

By knowing available cutblock capacity and the 3D profiles of sample stems, FPInterface can compute log production and costs according to available bucking patterns. It also computes transportation costs as FPInterface knows cutblock and sawmill locations as well as transportation systems.

Harvesting Simulation Inputs

- **C** Set of cutblocks ($c \in$ C).
- **B** Set of bucking patterns ($b \in$ B).
- **S** Set of sample stems ($s \in$ S) for which 3D profiles are provided.
- **M** Set of sawmills ($m \in$ M) and their location.
- v_c The total wood volume (in m^3) which can be harvested from a cutblock c.
- $k_{c,s}$ Ratio of wood volume at cutblock c that can be related to stem $s \in$ S (according to forest inventory).

Harvesting Simulation Outputs

- **G** Set of log types ($g \in$ G).
- $h_{c,b,g}$ The expected volume of log g that will be generated per cubic metre harvested from cutblock c using bucking pattern b
- ψ_c Harvesting fixed costs associated with cutblock c.
- $\zeta_{c,b}$ Harvesting variable costs which are generated when harvesting one unit (m^3) from cutblock c using bucking pattern b.
- $\xi_{c,b}$ The value of indirect sales (in dollars) generated when harvesting wood at cutblock c using bucking pattern b. Indirect sales correspond to products that are sold to a third-party and which do not need to be transported to a sawmill in order to generate revenues.
- $\rho_{c,g,m}$ Transportation costs of a unit (m^3) of log g from cutblock c to sawmill m.

3.2. Optitek Sawmilling Simulations

Using log definitions (3D profiles) generated by FPInterface and having a physical model of each sawmill (available machinery, sawing processes, etc.), Optitek generates a basket of lumber products and resulting quantities that would be obtained. This simulation is performed for each valid combination of log, sawmill and sawmill configuration. Productivity information is also computed.

Sawmilling Simulation Inputs

- **M** Set of sawmills ($m \in$ M) and their detailed physical model.
- $\mathbf{N}_m$ Set of alternative sawmill configurations $n \in \mathrm{N}_m$ for each sawmill $m \in$ M. In most sawmills, production lines can be configured using different sawmilling configurations. For each configuration, there is a different basket of products associated to it. This gives some control over the finished products which could be obtained.
- **G** Set of logs ($g \in$ G) and their physical definitions, generated by FPInterface.

- **R** Set of lumber products ($r \in$ R) that could be produced.
- η_m Sawmill *m* fixed costs of operation. Fixed costs do not vary with the quantity of lumber produced. Sawmill fixed costs typically include insurance, licenses, leases, property taxes, etc.
- w_m Sawmill *m* variable costs per m^3 processed.
- x_m Sawmill *m* variable costs per FBM produced.
- y_m Sawmill *m* variable costs per time unit.
- ϕ_r Expected incomes (in dollars) per FBM of a lumber product *r* produced.

Sawmilling Simulation Outputs

- $\mu_{g,r,m,n}$ The quantity (in FBM) of lumber product *r* produced when one cubic metre of log *g* is consumed by sawmill *m* using sawmill configuration *n*.
- $\gamma_{g,m,n}$ The time required to transform a cubic metre of log *g* at sawmill *m* using sawmill configuration *n*.

3.3. LogiOpt Optimization

In addition to the already defined inputs/outputs from FPInterface and Optitek, the LogiOpt optimization model uses the following sets and parameters as inputs:

Sets

T Number of periods in the planning horizon (t = 1,. . . ,T)

Parameters

$\alpha_{m,t}$ The maximum consumable wood volume (in m^3) by sawmill *m* at period *t* (sawing capacity).

$\beta_{m,t}$ The maximum production capacity (in FBM) of sawmill *m* at period *t* (production capacity).

$\chi_{m,t}$ The number of time units available for sawmill *m* at period *t* (time capacity).

$i_{c,g,0}$ The quantity (m^3) of log type *g* in inventory at cutblock *c* at the beginning of the planning horizon.

$j_{m,g,0}$ The quantity (m^3) of log type *g* in inventory at sawmill *m* at the beginning of the planning horizon.

ϖ Costs for holding one cubic metre of logs in inventory at a cutblock for one period.

ϑ Costs for holding one cubic metre of logs in inventory at a sawmill for one period.

All of this allows computing an optimal tactical plan integrating harvesting, allocation and sawing decisions.

Decision variables

$V_{c,b,t}$ The total volume in m^3 harvested at cutblock *c* using bucking pattern *b* at period *t*.

$H_{c,b,g,t}$ The volume in m^3 of log *g* obtained from cutblock *c* using bucking pattern *b* at period *t*.

$O_{c,g,m,t}$ The volume in m^3 of log *g* transported from cutblock *c* to sawmill *m* at period *t*.

$Q_{g,m,n,t}$ The volume in m^3 of log *g* sawed at sawmill *m* using sawmill configuration *n* at period *t*.

$P_{r,m,n,t}$ The volume in FBM of lumber product *r* produced by sawmill *m* using sawmill configuration *n* at period *t*.

$I_{c,g,t}$ The volume in m^3 of logs *g* in inventory at cutblock *c* at period *t*.

$J_{m,g,t}$ The volume in m^3 of logs *g* in inventory at sawmill *m* at period *t*.

$Y_{n,t}$ Binary variable, equals to 1 if sawmill *s* is configured using sawmill configuration *n* at period *t*; 0 otherwise.

Objective function

The objective function consists in maximizing incomes (lumber value and indirect sales from harvesting) while subtracting bucking, transportation, production and inventory holding costs respectively.

Maximize

$$\begin{aligned}
&\sum_{c\in C}\sum_{b\in B}\sum_{t=1}^{T}\xi_{c,b}V_{c,b,t} && +\sum_{r\in R}\sum_{m\in M}\sum_{n\in N_m}\sum_{t=1}^{T}\phi_r P_{r,m,n,t} \\
&-\sum_{c\in C}\sum_{b\in B}\sum_{t=1}^{T}\zeta_{c,b}V_{c,b,t} && -\sum_{c\in C}\psi_c \\
&-\sum_{c\in C}\sum_{g\in G}\sum_{m\in M}\sum_{t=1}^{T}\rho_{c,g,m}O_{c,g,m,t} && -\sum_{g\in G}\sum_{m\in M}\sum_{n\in N_m}\sum_{t=1}^{T}w_m Q_{g,m,n,t} \\
&-\sum_{r\in R}\sum_{m\in M}\sum_{n\in N_m}\sum_{t=1}^{T}x_m P_{r,m,n,t} && -\sum_{g\in G}\sum_{m\in M}\sum_{n\in N_m}\sum_{t=1}^{T}y_m\gamma_{g,m,n}Q_{g,m,n,t} \\
&-\sum_{m\in M}\eta_m && \\
&-\sum_{c\in C}\sum_{g\in G}\sum_{t=1}^{T}\varpi I_{c,g,t} && -\sum_{m\in M}\sum_{g\in G}\sum_{t=1}^{T}\vartheta J_{m,g,t}
\end{aligned} \tag{1}$$

Constraints

Constraint 2 specifies the maximum possible harvest volume in each cutblock.

$$v_c \geq \sum_{b\in B}\sum_{t=1}^{T}V_{c,b,t} \qquad \forall c\in C \tag{2}$$

Constraint 3 specifies the maximum harvest volume of each log type in each cutblock.

$$h_{c,b,g}V_{c,b,t} = H_{c,b,g,t} \qquad \forall c\in C, \forall b\in B, \forall g\in G, \forall t=1,\dots,T \tag{3}$$

Constraint 4 specifies the maximum m^3 volume that can be sawed at each sawmill, constraint 5 specifies the maximum FBM production rate and constraint 6 specifies the maximum time available at a sawmill. Normally, only one of those capacities should be used, since they should be equivalent.

$$\sum_{g \in G} \sum_{n \in N_m} \alpha_{m,t} \geq Q_{g,m,n,t} \qquad \forall m \in M, \forall t = 1, \dots, T \tag{4}$$

$$\sum_{r \in R} \sum_{n \in N_m} \beta_{m,t} \geq P_{r,m,n,t} \qquad \forall m \in M, \forall t = 1, \dots, T \tag{5}$$

$$\sum_{g \in G} \sum_{n \in N_m} \chi_{m,t} \geq \gamma_{g,m,n} Q_{g,m,n,t} \qquad \forall m \in M, \forall t = 1, \dots, T \tag{6}$$

Constraint 7 sets the relationship between a sawmill wood consumption and its lumber production.

$$\sum_{g \in G} \mu_{g,r,m,n} Q_{g,m,n,t} = P_{r,m,n,t} \qquad \forall r \in R, \forall m \in M, \forall n \in N_m, \forall t = 1, \dots, T \tag{7}$$

Constraints 8 and 9 specifies that a sawmill can be configured using only one sawmill configuration at a time.

$$\sum_{n \in N_m} Y_{n,t} = 1 \qquad \forall m \in M, \forall t = 1, \dots, T \tag{8}$$

$$Q_{g,m,n,t} \leq \alpha_{m,t} Y_{n,t} \qquad \forall g \in G, \forall m \in M, \forall n \in N_m, \forall t = 1, \dots, T \tag{9}$$

Constraints 10 and 11 calculate log inventory at each cutblock and balance flows.

$$i_{c,g,0} + \sum_{b \in B} H_{c,b,g,1} - \sum_{m \in M} O_{c,g,m,1} = I_{c,g,1} \qquad \forall c \in C, \forall g \in G \tag{10}$$

$$I_{c,g,t-1} + \sum_{b \in B} H_{c,b,g,t} - \sum_{m \in M} O_{c,g,m,t} = I_{c,g,t} \qquad \forall c \in C, \forall g \in G, \forall t = 2, \dots, T \tag{11}$$

Constraints 12 and 13 calculate the log inventory at each sawmill and balance flows.

$$j_{m,g,0} + \sum_{c \in C} O_{c,g,m,1} - \sum_{n \in N_m} Q_{g,m,n,1} = J_{m,g,1} \qquad \forall g \in G, \forall m \in M \tag{12}$$

$$J_{m,g,t-1} + \sum_{c \in C} O_{c,g,m,t} - \sum_{n \in N_m} Q_{g,m,n,t} = J_{m,g,t} \qquad \forall g \in G, \forall m \in M, \forall t = 2, \dots, T \tag{13}$$

The following defines non-negativity constraints:

$$V_{c,b,t} \geq 0 \qquad \forall c \in C, \forall b \in B, \forall t = 1, \dots, T \tag{14}$$

$$H_{c,b,g,t} \geq 0 \qquad \forall c \in C, \forall b \in B, \forall g \in G, \forall t = 1, \dots, T \tag{15}$$

$$O_{c,g,m,t} \geq 0 \qquad \forall c \in C, \forall g \in G, \forall m \in M, \forall t = 1, \ldots, T \tag{16}$$

$$Q_{g,m,n,t} \geq 0 \qquad \forall g \in G, \forall m \in M, \forall n \in N_m, \forall t = 1, \ldots, T \tag{17}$$

$$P_{r,m,n,t} \geq 0 \qquad \forall r \in R, \forall m \in M, \forall n \in N_m, \forall t = 1, \ldots, T \tag{18}$$

4. Experiments

This section reports experiments that were carried out using data from a large Canadian forest company. The optimized plan is compared with the plans obtained using a heuristic simulating manual planning.

4.1. Industrial Case

FPInnovations provided us with industrial data from a large Canadian forest company. We had access to historical data for the year 2010 and for three sawmills. Each sawmill is located at a relatively equivalent distance from all of the different cutblocks. The optimal solution is therefore not trivial, since transport costs between cutblocks and sawmills are equivalent. Using this test bed, we had data regarding:

- 341 cutblocks (1 504 870 m^3);
- 2 bucking patterns: shortwood and longwood;
- 3 sawmills (total capacity of 1 075 000 m^3);
- 156 log types coming from 53 different sample stems (only counting softwood; hardwood is computed as indirect sales, since wood is sold to clients external to the network);
- 160 types of lumber products, each sawmill generating its own different set of products which differs according to the log supply.

4.2. Optimization with LogiOpt

Our mathematical model was fed using FPInterface and Optitek. We used IBM ILOG CPLEX Optimization Studio© 12.4, to generate the LogiOpt optimal plan. Using a 2.3GHz Intel Core i7 machine, the model is solved in an average time of 35 seconds. However, generating simulation results with FPInterface and Optitek to supply the model takes several hours. LogiOpt solutions were reviewed with the project stakeholders to assess that the model described the system accurately.

4.3. Comparison with the plans obtained using a heuristic simulating manual planning

We compared the optimal solution obtained using our model with other solutions generated using a heuristic simulating what a human planner could have done. Human planners often allocate cutblocks on the basis of transportation costs. This means that each sawmill will be supplied with cutblocks which are the closest to it. Because we had access to all transportation costs between each sawmill and each cutblock, and because we were aware of each sawmill capacity (both in m^3 and FBM), we could estimate a close to reality tactical plan. We simply had to allocate to each sawmill cutblocks that are the closest to it, until we reached the sawmill capacity.

The heuristic goes as follows:

- Randomly select a sawmill;

- Assign the nearest unallocated cutblocks to the selected sawmill, until sawmill maximum capacity is reached;
- Select another sawmill and apply the same process.

Using this heuristic, we get different plans depending on the sequence in which we select sawmills. Since we have three different sawmills, named *B*, *L* and *T*, there are six different plans (3! = 6) that can be generated. The possible sequences are: BLT, BTL, TLB, TBL, LTB and LBT. To assess the value of these plans, we send heuristic plans data to LogiOpt and we use special constraints. LogiOpt then computes costs, revenues and the objective function value associated with those plans. This ensures that the solution value is evaluated in the same way, whether it is provided by a heuristic or computed by LogiOpt.

4.4. Results

Objective function value (revenues minus expenses) for the optimal plan computed with LogiOpt, as well as for the six plans obtained using the heuristic, are provided in Table 1. Results are in millions of dollars, for one operation year. The LogiOpt plan is on average 55.6% better than the ones obtained using the heuristic.

	LogiOpt	**BLT**	**BTL**	**LBT**	**LTB**	**TBL**	**TLB**
Objective function (in millions)	$12.78	$5.56	$6.03	$5.56	$5.58	$6.03	$6
Difference	-	-56%	-53%	-56%	-53%	-56%	-53%

Table 1. Objective function value for LogiOpt and heuristic plans.

Table 2 shows the percentage of the available sawing processing capacity (m^3) used by each plan. Table 3 shows the production capacity (FBM) used by each plan. Generally, LogiOpt uses less wood (Table 2) in order to reach maximum production capacity (Table 3). This is explained by LogiOpt allowing wood transportation on longer distances in order to bring the right logs to the right sawmill (i.e., logs that fit well with the production line characteristics).

Sawmill	**LogiOpt**	**BLT**	**BTL**	**LBT**	**LTB**	**TBL**	**TLB**
B	88%	95%	95%	95%	95%	95%	95%
L	97%	100%	100%	100%	100%	100%	100%
T	87%	100%	97%	100%	100%	100%	97%

Table 2. Percentage of processing capacity (m^3) used.

Sawmill	**LogiOpt**	**BLT**	**BTL**	**LBT**	**LTB**	**TBL**	**TLB**
B	100%	100%	100%	100%	100%	100%	100%
L	100%	98%	97%	98%	98%	97%	97%
T	100%	99%	100%	99%	99%	100%	100%

Table 3. Percentage of production capacity (FBM) used.

An interesting point is the number of cutblocks harvested in each plan among the 341 possible ones. This can be seen in Table 4. On average, LogiOpt harvests in 26 fewer cutblocks than the heuristic plans (a 12% difference). This also explains in part the 55% difference between LogiOpt objective function value and the heuristic plans. Some cutblocks with extremely interesting logs are discarded by every heuristic plan, while they are entirely harvested in the LogiOpt solution. Indeed, the cutblock of origin of a log makes a significant difference to the resulting quantity and type of lumber produced and on the revenues generated.

LogiOpt	BLT	BTL	LBT	LTB	TBL	TLB
220	244	245	244	250	245	248

Table 4. Number of cutblocks harvested.

This situation is made possible as the total available wood volume is greater than the total sawmilling capacity. Thus, we can assume that a part of the value increase we observed using LogiOpt is explained by a better cutblock selection, and another part is a consequence of a better wood allocation between sawmills. In a LogiOpt plan, wood from a cutblock can be allocated to two different sawmills which is not the case in a heuristic plan. Both of these factors can explain such a huge difference between the LogiOpt plan and heuristic plans.

We weighed this up by running an additional experiment. We identified the cutblocks consumed by the best heuristic plan (TBL) and we made it mandatory for LogiOpt to only harvest in these specific cutblocks. With this additional constraint, profits with LogiOpt dropped from $12.8 million to $11.7 million. Therefore, 15% of the original gain is explained by a better “global” cutblock selection, and 85% by a better allocation of wood between sawmills. This indicates that allocating logs to the sawmill where equipment will generate the highest lumber value will greatly impact the resulting profits.

5. Conclusion

Our proposed framework allows integrating wood harvesting, transportation, allocation and production together in a single decision process. Although the idea of global optimization is not entirely new, the challenge is always to get the needed data. This is why we proposed a framework integrating optimization and simulation as a group. Simulation of forest and sawing operations allows obtaining the required data in order to perform this global optimization. Simulation additionally allows assessing a log value from its cutblock of origin up to the sawmill where it will become lumber.

By rethinking the tactical planning process and making it focus on value rather than on costs, we provide an optimal solution to the tactical planner, helping him make better decisions. This optimization method could possibly give forest products companies a considerable opportunity to become more efficient and to reevaluate the way they traditionally perform tactical planning.

Experiments carried out using industrial data from a large Canadian company indicate that many opportunities are lost because the tactical planner focuses more on cost-related considerations. Although the numerical results are specific to this industrial case and data, it illustrates well why the forest supply chain needs to be considered as a whole rather than by its individual components (e.g., focusing on transportation costs or one specific sawmill).

Finally, even though LogiOpt can give tactical planners an optimal solution, we do not seek to replace their job—just improve it. The optimal plan should be viewed as a suggestion—as the most profitable option—but not necessarily as the most appropriate one. A planner can have many intangible constraints. The sawmill could be bound by contract with clients to make a specific product quantity. A client might ask for a product basket for a specific period, including good and poor-value lumber. This situation could be overcome with new constraints in the model, but for now, it still remains to be done.

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