CUT TO LENGTH WOOD PROCUREMENT PLANNIG MODEL: EXACT AND HYBRID APPROACHES

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ABSTRACT

In this paper we develop three MIP models for a real life wood procurement-planning problem based on cut-to-length (CTL) bucking system, for the eastern Canadian context of operations, where bucking patterns are not determined by on-board computers. This important problem in forest management is difficult to solve since it integrates the stem bucking problem and the multi-commodity supply planning problem. This problem is characterized by the simultaneous minimization of a combined non-linear harvesting cost (i.e., the harvesting cost increases non linearly with the number of harvested products) and an aggregated transportation cost, and the maximization of the value of bucking products (i.e., profit maximization). Each model was used to evaluate a different harvesting scenario: the first scenario aims to apply one bucking pattern to each stand; the second scenario aims to apply a bucking pattern for each sector (i.e., a group of stands predefined by the forest company); and the final one aims to apply a bucking pattern for each species. The aim of these scenarios is to explore the effects of the harvesting system structure on the harvesting cost. These scenarios allow investigating the gains and losses that could arise from the use of bucking sectors aggregation. The first two problems were solved using a linearized mathematical model. For the third model, we develop a hybrid approach based on Large Neighbourhood Search, Tabu Search heuristic and Linear Programming. In tests and comparisons between the developed methods, we found that bucking sectors aggregation significantly reduces the forest company's profit.

Keywords: Cut to length bucking, wood procurement planning, Mixed Integer Programming, Large Neighbourhood Search, Tabu Search.

INTRODUCTION

(Uusitalo 2005) defines the wood procurement as a set of distinct activities (technical, commercial and logistical) included in the process of supplying wood manufacturing mills with wood raw material, and considering at the same time the most crucial characteristics of the conversion process and the final product. Adopting the definition of (Chauhan and al. 2009), we also present the cut-to-length wood procurement planning problem addressed in this paper as a combination of two classic problems: The multi-commodity supply planning problem with multiple supply sources and demand destinations and the cut-to-length based bucking problem. The cut-to-length based bucking is the operation of cutting tree stems into smaller logs so that they can be used in further industrial process (Arce 2002, kevinin 2007, Pickens and al. 1997), using the cut-to-length harvesting procedure. This later is a harvesting system where tree stems are cross-cut directly at the stump. It is widely used for wood procurement by forest companies since it facilitates the handling of logs, but it is a divergent process since only one raw material produces (tree stem) a variety of sub-products (logs) at forest stands. A better fit between the mills' demand and the supply of logs (the output of the bucking operation) has been shown as an even more important target in wood procurement development than the harvesting and transportation cost minimization objective. In fact, a good bucking has a direct impact on the end products, so on the profit of wood mills. It is also an irreversible process, as it is impossible to correct a poor bucking output at any subsequent step of a forest supply chain (kevinin 2007, Usenius 1986). In addition, when the tree bucking and the wood supply planning are considered separately, some of the supply plans may be infeasible due to the heterogeneity of the forest (Chauhan and al. 2009). In this paper we try to better coordinate the activities involved in the wood procurement planning. The content of this article is organized as follows. We begin with an overview of the literature. Then, we describe the problem and we present its formulation for each scenario. We end with some concluding remarks and we propose some research perspectives.

LITERATURE REVIEW

Based on the decomposition of the wood procurement planning problem into the bucking optimization problem and the multi-commodity supply planning problem, presented by (Chauhan and al. 2009), we will present briefly these problems in this section.

Bucking optimization problems

Stem and stand level bucking optimization problems
(Laroze 1999) classified the bucking optimization problems into three categories: the stem level, the stand level and the forest level bucking optimization problems.

At stem level, the objective is to find the bucking pattern that maximizes the single stem value. As cited by (Kevinin 2007), the dynamic programming (DP) approach is used for stem-level bucking optimization in general. But, an optimal bucking for individual stems does not lead necessarily to the same result at the stand level where we consider a large set of tree stems (Laroze 1999, Arce and al. 2002, Pickens and al. 1997), In fact, this earlier does not necessarily consider the diversity of trees in each stand, nor does it fulfil all the market constraints (desired volumes, qualities, length and minimum average small end diameter (SED) of logs). Therefore, the stand level bucking optimisation problem aims to maximize the whole production value taking into account the resources availability of the stand and the customers' needs. In order to solve the stand level bucking optimization problem, (Eng and al. 1986, Mendoza and Bare 1986, Nasberg 1985, Pickens and al. 1997) used a two stage models. In their general framework, the constrained timber procurement problem is usually modelled in the master problem and the stem bucking problem in the sub-problem. The link between the two problems and the constraints considered in each problem differ from one model to another. This method is theoretically correct and computationally efficient (Laroze 1993, Marshall 1998). But, the solution produced a large numbers of cutting instructions, which are difficult to implement by the operators of the harvesters (Laroze 1993, Martell and al 1998, Sessions and al. 1989). Heuristic approaches were proposed by (Laroze 1997, Sessions and al. 1989) to solve the same problem. (Laroze 1997) proposed a Tabu Search (TS) heuristic for each stand to generate rule-based bucking pattern for each stem class.

Forest level bucking optimization problems

At forest level, the bucking algorithms maximizing the global fit should be determined for each stand. Considering the three levels of the bucking optimization problems, the forest level is the least studied one. As an extension of his work done in 1997, (Laroze 1999) used the TS heuristic method for generating bucking rules with LP formulation to solve the forest-level bucking optimization. (Kivinen 2006) presented an extension of his work done in 2004. He found that adjusting the value and demand matrices prior to the harvesting operation was advantageous in stand level bucking. For the forest-level bucking problem, no improvement in the cumulative apportionment degree was reported by the pre-control of the price matrix.

The multi-commodity wood distribution problem

In the general theory, the multi-commodity distribution problem involves many decision problems ranging from long to short term planning. In the Strategic level, decisions on locating facilities sources are considered. Allocating customers to the supply points is an example of the decisions taken in the tactical planning level. For short term level, transportation flows and inventory levels are dressed taken into account the specific demand of each customer, the cost of transportation and inventory and others restrictions. Even there is a lot of similarities between the wood procurement planning problem and the multi-commodity supply planning problem. Similarly some differences must be taken into account: in the forest context, there is no fixed cost to the location of facilities sites (forest stand) as it is the case for others contexts. For a review of multi-commodity supply network planning, the reader is referred to (Melo and al. 2009). (Arce and al. 2002) formulated the log product allocation problem including transport activities as a Mixed Integer Linear Programming (MIP) problem. They generated the bucking pattern for this upper level MIP problem through a simple heuristic rules. Their objective aimed to maximize the total net revenue at the forest level. (Chauhan and al 2009) proposed a short term supply network planning problem in which decisions on what timber assortment should be produced in a pre-selected stands in order to fulfil the demand of some sawmills are taken. They did not address the bucking problem in their work.

PROBLEM DESCRIPTION

In the cut-to-length harvesting system considered in this project, trees are processed into the final log products at the stump, considering the demand of a set of geographically distributed mills (buck-to-order bucking problem). Two combined costs must be minimised. It is not desirable to cut many products from the same stand, mainly because it implies a reduction of the harvester productivity by 1–4% and forwarder productivity by 3–7% (Arce and al. 2002, Brunberg and Arlinger 2001, Gingras and Favreau 2002). Therefore, a non linear unit harvesting cost is considered. This cost increases according to the number of different product-mix bucked per stand and depends on the volume harvested for each product type and the bucking patterns used. The unit transportation cost, which is a significant portion of the total cost, increases linearly with the volume of transported product and depends on the distance between blocks and mills as well as the species of the product. This problem was used with three different harvesting strategies: the first one aims to apply one bucking pattern to each stand; the second aims to apply a bucking pattern for each sector (i.e., a group of stands predefined by the forest company); and the final one aims to apply a bucking pattern for each species. For each of these problems, the main question is to choose which bucking pattern to be applied to each harvesting block and in what quantities each product type (i.e., species, length) should be transported from each block to satisfy the demand of a number of different wood mills.

The main goals of this paper are, first, to analyse and propose a mathematical model for this complex problem that meets the current forest industry practice in eastern Canada, and, second, to develop solution methods that can solve large real-life problem instances in reasonable computational times. Also, we investigate the effects of the different bucking aggregation level on the harvesting cost. This is done by comparing the results of the three addressed scenarios.

CASE STUDIES

Tree species are not similar in geometry and structure. Therefore, it is inappropriate to apply the same bucking pattern to different tree species. Similarly, each forest stand represents a unique internal composition of trees in terms of species, number, size, and quality. Again, forest stands differ from one another in terms of area, density and species mixture. Consequently, applying the same bucking pattern to a group of stands may lead to a sub-optimal use of the wood source and a mismatch between demand and supply, although it simplifies the general management the harvesting operations. Therefore, in the three harvesting scenarios presented in this paper, particular attention was paid to exploring the effects of the bucking sectors aggregation level on the harvesting cost.

In this section, a mathematical formulation for each harvesting scenario is presented. The premise for theses three models is the availability of a set of bucking patterns and their corresponding product-specific timber yields. The procedure for generating these bucking patterns and their corresponding wood yields is discussed in the section 4.1. The limited number of the generated bucking patterns and the availability of the simulation tools provided by the institute of forest research in Canada (FPInnovations) are some of the criteria that motivated the choice of the following mathematical formulations of the problems. For the MIP formulation of all the problems, we consider:

$\boldsymbol{B}$ Set of harvesting blocks
$\boldsymbol{U}$ Set of mills
$\boldsymbol{P}$ Set of log/product types
$\boldsymbol{E}$ Set of species
$\boldsymbol{E_b}$ Set of species in block b
$\boldsymbol{d^L_{p,e}}$ Minimum demand (m^3) of sawmill *u* for log type *p* of species *e*
$\boldsymbol{d^L_{p,e}}$ Maximum demand (m^3) of sawmill *u* for log type *p* of species *e*
$\boldsymbol{C^t_{b,u,e}}$ Unit transportation cost between *b* and *u* for log species *e* ($dollar/m^3$)
$\boldsymbol{C^h_b}$ A crude cost for harvesting stand *b*
$\boldsymbol{V^u_p}$ The sawmill *u* unit price for log length *p*
$\boldsymbol{l_p}$ The length of product type p
$\boldsymbol{M^{b,c}_{p,e}}$ Volume of the product *p* available when bucking the species *e* of block *b,* according to the bucking pattern *c* , it is previously obtained during the simulation phase
$\boldsymbol{\gamma}$ A number < 1

Simulation of the generated Bucking Patterns

A bucking pattern is defined in our problem as a combination of at most 5 length types products from the longest to the smallest (as defined by the Canadian forest research institute *FPInnovations*). This assumption generates easy to implement bucking patterns. Table.1 shows two examples of typical bucking patterns.

Table 1: Example of bucking patterns

PatternID	StepOrder	Product	MinLen	MinDiameter
1	1	16	502	17
	2	14	440	15
	3	12	380	12
	4	10	320	10
	5	8	100	4
2	1	16	502	17
	2	14	440	15
	3	12	380	12
	4	10	320	10

The generation of the bucking pattern was done in an exhaustive way since their number is limited. *FPInterface* is used to carry out bucking simulations of the generated patterns on the considered forest data set. This software tool is specifically designed to simulate all activities in the forest supply chain. The harvesting module of this platform can predict the amount of timber assortments obtained from the application of a given pattern on a sample of trees from the cutting blocks. For the bucking pattern1 (shown in Table.1), the simulators tries to obtains as many products as possible from the first product type (1) before moving to the second one and so on. These simulations are always done once a year before the beginning of the harvesting operations, even if the output will not be used for further applications.

Scenario(1): Stand oriented bucking

For this scenario, we consider only one bucking pattern per stand (cutting site). According to this assumption, the harvesting cost can be pre-calculated. A linearized mixed integer mathematical formulation of the stand oriented wood procurement problem follows. In this formulation, the following coefficients and variables are used:

$x_{p,e}^{b,u}$ Flow of product type *p*, species *e* from block *b* to mill *u* ($dollar/m^3$)

y_c^b Binary variable: takes value *1* if pattern *c* is applied to block *b*; otherwise *0*

$K_{p,e}^{b,c}$ Binary variable: takes value *1* if the volume of product p of species e when pattern *c* is applied to block *b* is under *10%* of the total volume obtained from the bloc; otherwise 0

$C_{b,c}^h$ The unit harvesting cost if pattern *c* is applied to block *b* ($dollar/m^3$). Using the formulation giving by *FPInnovation*s, it is pre-calculated for each block *b* and pattern as follows:

$$C^{h}_{b,c} = C^{h}_{b} \cdot \left[\delta^{Y}_{c,b} \cdot \left(\sum_{p\in P} \sum_{e\in E} \sum_{c\in C} M^{b,c}_{p,e} \cdot l_{p} \; / \sum_{p\in P} \sum_{e\in E} \sum_{c\in C} M^{b,c}_{p,e} \right) \right]$$

where

δ^{Y}_{c} A correction factor addressing the number of different assortments in each block b, when using the bucking pattern *c*.

(P1) ***Maximize*:**

$$\sum_{b\in B} \sum_{e\in E} \sum_{p\in P} \sum_{c\in C} \sum_{u\in U} \left[V^{u}_{p} \cdot x^{b,u}_{p,e} - \left(C^{h}_{b,c} \cdot M^{b,c}_{p,e} \cdot y^{b}_{c} + C^{t}_{b,u,e} \cdot x^{b,u}_{p,e} + C^{c}_{b} \cdot y^{b}_{c} + P_{p} \cdot M^{b,c}_{p,e} \cdot K^{b,c}_{p,e} \right) \right]$$

subject to

$$\sum_{c\in C} y^{b}_{c} = 1 \qquad \forall\, b \in B \qquad (1)$$

$$d^{L}_{p,e,u} \leq \sum_{b\in B} \sum_{c\in C} x^{b,u}_{p,e} \leq d^{U}_{p,e,u} \qquad \forall\, u \in U, e \in E_{b} \text{ and } p \in P \qquad (2)$$

$$\sum_{u\in U} x^{b,u}_{p,e} \leq \sum_{c\in C} M^{b,c}_{p,e} \cdot y^{b}_{c} \qquad \forall\, b \in B, e \in E_{b} \text{ and } p \in P \qquad (3)$$

$$x^{b,u}_{p,e} \geq 0 \qquad \forall\, b \in B, e \in E_{b}, u \in U \text{ and } p \in P \qquad (4)$$

$$y^{b}_{c}, K^{b,c}_{p,e} \in \{0,1\} \qquad \forall\, b \in B, c \in C, e \in E_{b} \text{ and } p \in P \qquad (5)$$

The problem's objective function consists in maximizing the global profit. In this objective, the first term presents the net profit of the total harvested products. The second terms gives the sum of respectively: the harvesting cost, the transportation cost, the cost of using a giving bucking pattern *c* on a giving block *b*, and a penalty term which will be described below. *Constraints (1)* says that we use only one bucking pattern per stand to harvest it. *Constraints (2)* means that the flow of product *p* of species *e*, out of stand *b* and into mill *u* must be between the lower $(d^{L}_{p,e,u})$ and the upper bound $(d^{U}_{p,e,u})$ of the demand. *Constraints (3)* states that the flow of product *p* of species *e*, out of stand *b* and into mill *u*, must respect the total supply of that product available in this stand. *Constraints (5)* is a non-negativity constraint and *Constraints (6)* states that the variables are limited to being 0/1 variables.

In practice, it is not desirable to harvest a volume of a product p, species e from a block b, that is under a certain percentage *(Ptg)* of the total volume harvested in this block. We allow this, but we penalize it using binary variables $K^{b,c}_{p,e}$. This increases the complexity of the model, since the number of binaries variables increases and the problem becomes non linear. As a first formulation, we added *constraints (6)*, which is a logical constraint supported by the commercial LP package CPLEX v12.1 to the MIP formulation (P1) and the binary variables $K_{p,e}^{b,c}$ to this constraint, as follows:

$$if((M_{p,e}^{b,c}.y_c^b \leq Ptg.\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c}.y_c^b)\ and\ (y_c^b \geq 0))\ then\ (K_{p,e}^{b,c} = M_{p,e}^{b,c}) \qquad (6)$$

In the second formulation, we added binary variables $K_{p,e}^{b,c}$ in constraints (7) , (8) and (10) as well as $L_{p,e}^{b,c}$ in constraints (8) and (9), to the MIP formulation (P1) as follows:

$$Ptg.(\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c}.y_c^b) - M_{p,e}^{b,c}.y_c^b \geq Z.(K_{p,e}^{b,c} - 1) \qquad \forall\, b,c,e\ and\ p \qquad (7)$$

$$Ptg.(\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c}.y_c^b) - M_{p,e}^{b,c}.y_c^b \leq Z.(K_{p,e}^{b,c} + L_{p,e}^{b,c}) \qquad \forall\, b,c,e\ and\ p \qquad (8)$$

$$L_{p,e}^{b,c} \leq 1 - y_c^b \qquad \forall\, b,c,e\ and\ p \qquad (9)$$

$$K_{p,e}^{b,c} \leq y_c^b \qquad \forall\, b,c,e\ and\ p \qquad (10)$$

where

$L_{p,e}^{b,c}$ Binary variable used for modelling purpose, takes *1* if pattern *c* is applied to block *b*
Z Big number

Scenario(2): Sector oriented bucking

In this case, we consider only one bucking pattern per sector (a predefined set of stands). Assuming that the unit harvesting cost for each stand in the sector is pre-calculated as in Scenario1 (paragraph 4.3). The linearized formulation for the sector remains the same as in (P1), we added to it constraint (1a) only as follows:

$$\sum_{c\in C} y_c^b = |B_s| y_c^b \qquad \forall\, s \in S, b \in B_s, c \in C \qquad (1a)$$

where

S Set of sectors (a group of stands)
B_s The set blocks included in the sector s
This constraint specifies that the bucking pattern chosen for a sector must be the same for all stands of that sector.

Scenario(3): Species oriented bucking

For the third scenario, we consider only one bucking pattern per species of each block. In this case, the aggregated harvesting cost ($C_{b,c}^{h,e}$) is:

$$C_{b,c}^{h,e} = C_b^h.\left[(\sum_{e\in E}\sum_{c\in C}\delta_c.y_c^{b,e})^{\gamma}.(\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c}.l_p.y_c^{b,e} / \sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c}.y_c^{b,e})\right]$$

In this scenario, it is no more possible to pre-calculate the harvesting cost as we did for the first and the second scenarios. The following formulation (P3) for the species-oriented bucking wood procurement problem is non linear. We consider:

$y_c^{b,e}$ Binary variable: takes value *1* if pattern *c* is applied to block species *e* of block b; otherwise *0*

(P3) Maximize:

$$\sum_{b\in B}\sum_{e\in E}\sum_{p\in P}\sum_{c\in C}\sum_{u\in U}[V_p^u . x_{p,e}^{b,u} - (C_{b,c}^{h,e} . M_{p,e}^{b,c} . y_c^{b,e} + C_{b,u,e}^{t} . x_{p,e}^{b,u} + C_{b,e}^{c} . y_c^{b,e} + P_p . M_{p,e}^{b,c} . K_{p,e}^{b,c})]$$

$$\sum_{c\in C} y_c^{b,e} = 1 \qquad \forall\, b \in B \text{ and } e \in E_b \qquad (1e)$$

$$d_{p,e,u}^{L} \leq \sum_{b\in B}\sum_{c\in C} x_{p,e}^{b,u} \leq d_{p,e,u}^{U} \qquad \forall\, u \in U, b \in B\ e \in E_b \text{ and } p \in P \qquad (2)$$

$$\sum_{u\in U} x_{p,e}^{b,u} \leq \sum_{c\in C} M_{p,e}^{b,c} . y_c^{b,e} \qquad \forall\, b \in B, e \in E_b \text{ and } p \in P \qquad (3e)$$

$$x_{p,e}^{b,u} \geq 0 \qquad \forall\, b \in B, e \in E_b, u \in U \text{ and } p \in P \qquad (4)$$

$$y_c^{b,e},\ K_{p,e}^{b,c} \in \{0,1\} \qquad \forall\, b \in B, e \in E_b, c \in C \qquad (5e)$$

As in (P1) and (P2), the objective function of the problem (P3) consists in maximizing the global profit. *Constraints (1e)* says that we use only one bucking pattern per species for each stand to harvest. *Constraints (2)* and *Constraints (4)* are common to the three models. *Constraints (3e)* states that the flow of product *p* of species *e*, out of stand *b* and into mill *u*, must respect the total supply of that product available in this stand (when we apply a bucking pattern to every species of a block). We Maintain the same penalties when we harvest a volume of a product p, species e from a block b, that is under certain percentage *(Ptg)* of the total volume harvested in this block as done in (P1) and (P2). We add to (P3), *Constraints (6e)* as a first formulation approach. For the second formulation, we also add to (P3) the same *Constraints(7e)* to *Constraints (10e)* which have the same meaning as the constraints *Constraints(7)* to *Constraints (10)* respectively in (P1).

$$if((M_{p,e}^{b,c} . y_c^{b} \leq Ptg. \sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c} . y_c^{b}) \text{ and } (y_c^{b} \geq 0)) \text{ then } (K_{p,e}^{b,c} = M_{p,e}^{b,c}) \qquad (6e)$$

$$Ptg.(\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c} . y_c^{b}) - M_{p,e}^{b,c} . y_c^{b} \geq Z.(K_{p,e}^{b,c} - 1) \qquad \forall\, b, c, e \text{ and } p \qquad (7e)$$

$$Ptg.(\sum_{p\in P}\sum_{e\in E}\sum_{c\in C} M_{p,e}^{b,c} . y_c^{b}) - M_{p,e}^{b,c} . y_c^{b} \leq Z.(K_{p,e}^{b,c} + L_{p,e}^{b,c}) \qquad \forall\, b, c, e \text{ and } p \qquad (8e)$$

$$L_{p,e}^{b,c} \leq 1 - y_c^{b,e} \qquad \forall\, b, c, e \text{ and } p \qquad (9e)$$

$$K_{p,e}^{b,c} \leq y_c^{b,e} \qquad \forall\, b, c, e \text{ and } p \qquad (10e)$$

TABU BASED LARGE NEIGHBOURHOOD SEARCH

A Large Neighbourhood Search (LNS) is an iterative improvement approach where we modify an existing solution to the problem by making large changes. As it was reported by... , LNS is based on the fix/optimize technique (destroy/repair technique) where the fix operation corresponds to fix a subset of the solution at its current value while the rest remains variable, and the optimize method tries to improve the current solution with respect to the fixed values.

The Fix method

At each iteration, a subset of stands is chosen. All variables presenting the allocation of the bucking pattern to the species included in these stands are fixed to their current values. The fixing procedure stops when a given number of stands is selected. This number is randomly chosen at each iteration, but it cannot exceed a given number.

The repair methods

The choice of the repairing strategy is based on solution time, solution quality and diversification attributes. In this project, The optimize (repair) methods is based on a Tabu Search heuristic methods.

The Tabu Search heuristic

The Tabu Search which was proposed by Fred Glover en 1986 (Fred Glover 1986), is well performing heuristic for solving a wide variety of combinatorial optimization problems including forest management ones (Bettinger 2008 , Laroze 1999). It uses a neighbourhood search procedure to iteratively improve the initial solution, until some stopping criterion has been satisfied. Tabu list is used to direct future moves. In fact, this short term memory prevents cycling when moving away from local optima through non-improving moves. It forbids some moves likely to drive us back to recently visited solutions. The TS method range from simple designed ones to more complicated, depending on the design elements such as the nature of the Tabu tenure, the algorithm used to find initial solution and the diversification technique.

In this paper, the TS algorithm is invoked for two reasons. First, it rapidly calculates the new profit obtained from the fix step and improves it randomly and makes diversification so that the repair method does not give the same solution at each iteration. It starts with an initial solution which is the solution of the first scenario (stand oriented bucking), and tries to improve it during a total number of iterations. We consider a neighbourhood structure based on changing the allocation of a bucking pattern to every species in every move. The search is allowed to visit only feasible solutions in order to restrain the search space. At each iteration, many solutions have to be evaluated and it is important to perform this computation in an efficient way. For every new best solution in the neighbourhood found, an LP is solved to have the new transportation cost.

DESCRIPTION OF DATA

The material used for testing and evaluating each of the three scenarios consisted of 30 heterogeneous real stands in Canada. Each of these stands contains at least two of these five species: white Birch, black spruce, populus, pinus banksiana, abies balsamea (Table 2).

Table 2: Stands inventories used in the problem

Stand	EPN (/ha)	PIG (/ha)	SAB (/ha)	PEU (/ha)	BOP (/ha)	Stand	EPN (/ha)	PIG (/ha)	SAB (/ha)	PEU (/ha)	BOP (/ha)
1	54,89	112,54	0	17,47	0	**16**	55,11	78,69	2,17	62,35	0,94
2	37,90	135,70	0,9	43,80	0,3	**17**	55,11	78,69	2,17	62,35	0,94
3	57,21	42,68	2,05	12,27	1,17	**18**	55,11	78,69	2,17	62,35	0,94
4	57,21	42,68	2,05	12,27	1,17	**19**	65,88	57,66	2,97	22,82	1,73
5	57,21	42,68	2,05	12,27	1,17	**20**	65,88	57,66	2,97	22,82	1,73
6	57,21	42,68	2,05	12,27	1,17	**21**	52,75	11,39	25,29	6,61	8,12
7	58,27	63,72	0	0	0	**22**	52,75	11,39	25,29	6,61	8,12
8	58,27	63,72	0	0	0	**23**	42,49	118,23	1,02	35,6	1,16
9	58,27	63,72	0	0	0	**24**	68,56	38,42	0,06	15,52	1
10	55,11	78,69	2,17	62,35	0,94	**25**	65,09	27,84	0,03	2,59	0
11	55,11	78,69	2,17	62,35	0,94	**26**	65,09	27,84	0,03	2,59	0
12	55,11	78,69	2,17	62,35	0,94	**27**	62,88	54,06	5,6	74,11	0,67
13	55,11	78,69	2,17	62,35	0,94	**28**	62,88	54,06	5,6	74,11	0,67
14	55,11	78,69	2,17	62,35	0,94	**29**	59,04	0,04	2,54	0	0,17
15	55,11	78,69	2,17	62,35	0,94	**30**	77,85	70,82	0,28	37,23	0,29

There were 25 log-types. These types products vary in terms of species, length and small end diameter. The log specifications for each product used in the problem (for each of the five species) are giving in table3.

Table 3: Specifications of the products

Product ID	Product	Length	MinDiameter
1	16	502	17
2	14	440	15
3	12	380	12
4	10	320	10
5	8	100	4

COMPUTATIONAL EXPERIMENTS AND DISCUSSION

The models were tested with different demand instances, in order to compare the performance of the developed methods. The problems were set up with 30 bucking patterns. The size of the models differs from one scenario to another. In order to accomplish the computational tests, the algorithms were implemented using C++. The MIP and the LP problems are solved using the commercial LP package CPLEX v12.1 via its concert platform. As we deal with an annual planning, a termination criteria of a maximum running time of 24 hours was used if no optimal solution was yet found. The solution gap is fixed to 6%.

Table 4: Results for the Scenario(1)

Instances	HCost *(10⁷)*	TCost *(10⁶)*	Profit *(10⁶)*	Time
1	2,32985	1,76617	5,897	10s
2	2,37959	1,80863	5,509	1849s
3	2,48612	1,83738	4,943	7h72
4	2,68361	1,91501	3,928	22h
5	2,38435	1,79638	5,796	207s

Table 5: Results for the Scenario(2)

Instances	HCost *(10⁷)*	TCost *(10⁶)*	Profit *(10⁶)*	Time
1	2,337257	1,747	5,344	17h
2	2,447723	1,820	4,833	14h
3	-	-	-	-
4	-	-	-	-
5	2,442861	1,795	5,198	6h

Scenario(1) achieved better output (potential increase in the total profit), for all the instances, comparing to scenario(2). This result is not affected by changes in demand level and allocation between sawmills. We are still working on the instances 3 and 4 in (Table5) and the third part (species oriented Bucking), results and more details of the corresponding method will be presented during the conference.

CONCLUSION

The first two models proposed in this paper have achieved our goals of developing a method capable of producing a cut to length-wood procurement plan according to the actual forest practice in eastern Canada. In the solutions provided in the first two scenarios, we have in all our tests on different demand instances, registered a potential savings in harvesting costs, therefore and a substantial increase of profit. This imply that some strategic changes in the harvesting strategies, in form of applying a bucking pattern for each stand instead of sector would be very profitable. These changes will be further investigated with the third part of the project, which is the species based bucking problem. As a future research direction, one can consider an extended version of the problem to treat a (DHB) class-based bucking scenario where we apply a bucking pattern to every (DHB) tree class in each block.

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