Procurement Planning of Forestry Industry Supply Chain – A Canadian Application

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Abstract. The Canadian forestry industry plays an important role for the country's economy. In order to overcome economic challenges, and continue evolving its results, the rational use of resources in forestry products supply chain is required. We propose in this paper a mixed integer programming model describing the wood fibre network procurement of the supply chain of a pulp and paper mill, located in Québec, Canada. The raw material comes from a distance radius of 350 km, including suppliers from Canada and USA. The model aims to minimize costs encountered during this stage, such as transport, handling and stockyards opening costs for a planning horizon of one year. The presented model considers the effects of the weight restriction zones, imposed during the thawing periods by the Quebec's government and the reduction of the wood moisture caused by the air drying effect, on the transportation costs.

Keywords: forestry planning; procurement stage; supply chain; linear programming.

1 Introduction

The forest industry has a big set of products which can be subdivided, in general, in wood and non-wood forest products. One can understand the first group by the consumption of wood itself, both in form of solid wood or wood particles. The non-wood products can be defined as any biological material (other than raw wood) that can be extracted from the natural environment or managed, and used for home or business use, for example the use of plants for food the use of ecosystems for recreation among others, see Wickens [1]. Besides such wide variety of products, the forestry supply chain unlike most industries, can be classified as divergent, i.e. the number of products multiplies along the chain, see Vahid et al., D'Amours et al. and Rönnqvist [2–4] making its management quite difficult. .
Throughout the supply chain planning matrix (SCP-Matrix) different attached to the various activities carried out may be found. According to Fleischmann et al. [5] the SCP-Matrix planning tasks can be classified in the two dimensions "planning horizon" and "supply chain process". It is possible to decompose the forest planning horizon in hierarchical levels: strategic, tactical and operational; ranging from forest

management to distribution of the finished product. These levels are linked to each other, i.e. the operational decisions have constraints imposed by tactical planning, which in turn has restrictions by the strategic level D'Amours ate al. [3]. When it comes to the supply chain processes one can split it in procurement, production, distribution or sales (Fleischmann et al.) [5].

According to Fleischmann et al. [5], the procurement supply chain includes the sub processes that provide resources necessary for production, the procurement to sawmills, as seen in Helstad [6], can comprise purchasing, logging, transportation, and planning and managing those processes.

In Rix [7], the author proposes two approaches to improve the procurement stage of the wood supply chain, one concerned with the harvest team scheduling problem and the log-truck scheduling problem. The first one was solved using a branch-and-price based heuristic and the last was solved by column generation. Helstad [6] also studied the procurement process of the forestry industry but in a qualitative way, based on 46 in-depth interviews, providing four key strategic dimensions of the process and suggesting a general conceptual model of wood procurement to purchasing sawmills. Gautam et al. [8] in their study tries to contextualize the concept to wood procurement systems in order to identify opportunities to improve the ability of a firm to detect changing demands and efficiently respond to them. The authors conclude after a long literature search that future studies should focus on determining the optimal levels of investment required toward enablers of agility to maximize profitability for the forestry supply chain. Palander and Väätäinen [9] describe two different timber-flow models for planning the procurement management, one as a one-way transportation situations and other with backhauling situations. The use of backhauling decreased transportation costs and the total wood procurement costs when comparing with the one-way transportation situations.

This paper presents a mathematical formulation that aims to optimize the tactical procurement stage of the wood supply chain where the network flow of the raw material of a pulp and paper industry is designed.

Québec has a harsh climate with temperature ranging almost 60°C between winter and summertime. During the winter the ground freezes in depth among 1.2 m and 3 m during four months which might lead to temperature drift of 25°C only in a few hours. That event can be very stressful for the pavement, decreasing its resistance in 30% - 70%. In order to avoid the rupture of the road the Québec's Government creates three restriction zones, which are activated in different moments, where the weight load admitted are decreased in 12 - 20%%, see the report from the Ministère des Transports du Québec [10]. The moisture content is defined as the weight of water in a wood piece expressed as a percentage of that piece oven-dry. When a log is freshly sawn it may have a moisture content greater than 100%, because some wood species can contain more water the wood itself [11]. The material loses moisture until it reaches an equilibrium moisture content that depends of the wood moisture content and the relative humidity and temperature of the surrounding air, see Hor [11]. The air drying is more active during seasons where the temperature is higher and the air humidity is lower, besides that, its efficiency and speed depends of the air movement between the wood piles [12]. This paper contributes with the planning of the wood procurement supply chain by adding the wood drying effect and the constraints caused by the weight restrictions imposed by the Québec Provincial Government during the thaw period in the model construction, which haven't been studied yet. The remainder of this paper is organized as follows. First we describe the procurement stage problem and define the variables and parameters used followed by the mathematical construction of the problem and its validation process. Finally its conclusion remarks.

2 The Procurement Stage Planning Model

In this section introduces the procurement stage planning model that will be used to analyze the effects caused on the supply network design by the weight restrictions imposed during the thawing period and the wood drying.

2.1 Problem Description

The model considers the transportation of the raw material (logs) in full truckloads of logs. The decision horizon has one year range and is divided into periods (e.g. weeks). At the beginning of the planning horizon there will not be any open stockyards. Backhauling will not be considered for the construction of the model. If a truckload arrives at an open stockyard it must stay there at least for one period.

The model aims to redesign the product flow network on the supply chain procurement stage of a pulp and paper industry. For that we consider direct transportations, i.e. transportation between suppliers (e.g. forests, secondary mills) and the pulp mill, also the transportation between the suppliers and the stockyards and those made from the stockyards to the mill. The transportation to the stockyards and from it only occurs if the model decides to open it. Concerning with the raw material transportation two aspects should be emphasized: 1) the presence of the weight constraints imposed by the Quebec Province Government; 2) the wood inherent feature of moisture loss caused by the air-drying in the log piles at the stockyard. Both of them influence in the raw material transportation costs, the first raising it when the weight restriction is activated, and the last generating costs savings.

Suppliers and stocks have a limited capacity, avoiding that way that all raw material have come from a unique supplier, or that the logs will be sent to only one stockyard. Besides the storage and supplying capacity, the stocks also have a handling limitation.

2.2 Model Formulation

This section shows the Mathematical formulation used to tackle the Procurement Planning of Forestry Industry problem. Tables 1-3 show the sets, variables and parameters notation used in the mathematical model.

Table 1 Sets description

Notation	Description
T = {1,…,|t|}	Sets of periods
T' = {1,…,|t|}(t')	Set of periods'
I = {1,…,|i|}	Set of suppliers
L={1,…,|l|}	Set of stock yards
F={1,…,|f|}	Set of factories (mills)

Table 2 Parameters description

Notation	Description
d_{ft}	Demand of the mill (full truck-load) *f* during period *t*.
k_{it}	Capacity of supplier *i* on period *t (*full truck-load).
k_i	Total capacity of the supplier *i* (full truck-load)
s_{lt}	Stockyard's handling *l* capacity on period *t* (full truck-load).
s_l	Total stockyard's *l* capacity (full truck-load)
C_{ift}	Transport unit cost between supplier *i* and factory *f* on period *t* ($/full truck-load).
C_{ilt}	Transport unit cost between supplier *i* and stockyard *l* on period *t* ($/full truck-load)
$C_{lft't}$	Transport unit cost between stockyard *l* and the mill *f* of the products that arrived on period *t'* and have left during period *t* ($/full truck-load)
O_l	Fixed cost (annual) to open and operate the stockyard *l.*
M_{lt}	Handling cost at the stockyard *l* on period *t* (full truck-load).
β_{it}^{zone}	Penalty for trespassing the active constraint zones when in supplier *i* on period *t*.
β_{ft}^{zone}	Penalty for trespassing the active constraint zones when in mill *f* on period *t*.
β_{lt}^{zone}	Penalty for trespassing the active constraint zones when in stock *l* on period *t*.
$\alpha_{t't}^{drying}$	Advantage gained caused by the wood drying effect by staying *t'* periods in stock on period *t*.

Table 3 Decision variables definition

Notation	Description
x_{ift}	Amount of product (full wood truckload) that goes from the supplier *i* to the factory *f* at period *t*.
ψ_{ilt}	Amount of product (full wood truckload) that goes from supplier *i* to the stockyard *l* at period *t*.
$\varphi_{lft't}$	Amount of product (full wood truckload) that goes from stockyard *l* to the factory *f* stored at *t'* and leaves the stock at moment *t*.
$w_{lt't}$	Amount of product (full wood truckload) at stock *l* stored at *t'* in period *t*.
y_l	$\begin{cases} 1, \text{if a stock yard } l \text{ is opened} \\ 0, \text{otherwise} \end{cases}$

We assume in the model construction that the wood logs arrive at a node in the beginning of the period and leave at the end of the period. The model is therefore formulated as follows.

$$\boldsymbol{Minimize} \; = C^{sup-fac} + C^{sup-stock} + C^{stock-fac} + C^{open} + C^{handling} \, . \qquad \textbf{(1)}$$

Where:

$$C^{sup-fac} = \sum_i \sum_f \sum_t \left(C_{ift} x_{ift}\right) \times (1 + \beta_{it}^{zone}) \times \left(1 + \beta_{ft}^{zone}\right).$$

$$C^{sup-stock} = \sum_i \sum_l \sum_t (C_{ilt} \psi_{ilt}) \times (1 + \beta_{it}^{zone}) \times (1 + \beta_{lt}^{zone}) \, .$$

$$C^{stock-fac} = \sum_l \sum_f \sum_{t'} \sum_t (C_{lft't} \varphi_{lft't}) \times (1 + \beta_{lt}^{zone}) \times \left(1 + \beta_{ft}^{zone}\right) \times \left(1 - \alpha_{t't}^{drying}\right) \, .$$

$$C^{open} = \sum_l O_l y_l \, .$$

$$C^{handling} = \sum_l \sum_t M_{lt} w_{lt't} \, .$$

Our objective function contains five components which aim to minimize the solution's total cost. The first three are associated with transportation costs. The $C^{sup-fac}$ represents the transportation cost from the supplier directly to the factory, similarly, $C^{sup-stock}$ deals with transportation costs from the supplier to the stockyard while the transportation cost of the stockyard to the factories is represented by the component $C^{stock-fac}$. The fourth (C^{open}) element computes the opening costs of the stockyards, and the last component ($C^{handling}$) represents the handling costs in the stocks. It is important to mention that if the product distribution occurs during a period that a restriction zone is activated the transportation costs ($C^{sup-fac}, C^{sup-stock}, C^{stock-fac}$) are increased by a β factor, as a penalty for crossing the zones during weight restriction imposed on roads. Besides, if a truck load stays at least one period at the stockyard, the transportations costs would decrease by an α factor, caused by the moisture loss of wood.

Subjected to:

$$w_{lt't} = \sum_i \psi_{ilt} \quad \forall \, t, l, t' = t \, . \qquad \textbf{(2)}$$

$$w_{lt't} = w_{lt'(t-1)} - \sum_f \varphi_{lft't} \quad \forall l, t' < t, t \ . \tag{3}$$

$$\mathrm{w}_{\mathrm{lt}'\mathrm{t}} = 0 \quad \forall\, \mathrm{l}, \mathrm{t}' > \mathrm{t}\,. \tag{4}$$

$$\varphi_{lft't} = 0 \quad \forall\, l, t < t'. \tag{5}$$

$$\sum_i x_{ift} + \sum_l \sum_{t'} \varphi_{lft't} \geq D_{ft} \quad \forall\, f, t\,. \tag{6}$$

$$\sum_{t'' \leq t} \left(\sum_f x_{ift''} + \sum_l \psi_{ilt''} \right) \leq k_i \quad \forall\, i \tag{7}$$

$$\sum_f x_{ift} + \sum_l \psi_{ilt} \leq k_{it} \quad \forall\, i, t \tag{8}$$

$$\sum_{t'' \leq t} \sum_{t'} w_{lt't''} \leq s_l y_l \quad \forall\, l \tag{9}$$

$$\sum_{t'} w_{lt't} \leq s_{lt} y_l \quad \forall\, l, t \tag{10}$$

$$w_{lt't} \leq BigMy_l \quad \forall\, t \tag{11}$$

$$\varphi_{lft't} \leq BigMy_l \quad \forall\, t', t, f \tag{12}$$

$$x_{ift} \in \mathbb{R} \tag{13}$$

$$\psi_{ilt} \in \mathbb{R} \tag{14}$$

$$\varphi_{ift't} \in \mathbb{R} \tag{15}$$

$$w_{lt't} \in \mathbb{R} \tag{16}$$

$$y_l \in \mathbb{B} \tag{17}$$

The set of constraints (2) to (4) are flow conservation constraints, where the first ensures that all the wood quantity at the stockyard l is equal the amount of product that went from the suppliers *i* on period *t* to the stockyards. The equation (3) guaranties that the amount of wood stocked at depot *l*, for all *t' < t*, is equivalent to all the wood that arrives in period *t* at the stockyard l minus the sum of product that leaves the depot stored to the mill *f*. Constraint (4) ensures that there isn't any inventory at stock *l* for all *t'* greater than *t*. Constraint (5) ensures that any product will leave the stockyard, unless it stays stored for more than a period. Expression (6) ensures that the demand of the factory will be satisfied. Expressions (7) and (8) guarantee, respectively, that the suppliers' total and per period capacities will not be exceeded. The same is applied in relation to the stockyards at constraints (9) and (10), ensuring the stock's total capacity and handling capacity are respected. Constraints (11) and (12) impose that wood will arrive or leave the stockyards only if it's opened. Finally, the domain restrictions are described on equations (13) through (17).

After the model formulation, the validation process was made. To this end, we created a small instance, with two suppliers, a stock, one pulp mill and two periods and we adjusted the supplier's and stock's capacity to the mill's demand. Thereupon, we force the opening of the stockyard by inputting negative opening costs, then to send raw material to the open depot the supplier-mill transporting cost on period *0* was increased. With the depot open and receiving wood we readjusted its capacities as well the transportation costs on period *0* and increasing the cost on the period *1*. Validating therefore, the model. It is important to emphasize that for the capacities on the period $t = 0$, the demand must be smaller than the total wood availability ($D_0 < K_0$). For the periods thereafter the demand follows the following pattern in order to keep the model valid.

$$D_0 + D_1 \leq K_0 + K_1$$
$$D_0 + D_1 + D_2 \leq K_0 + K_1 + K_2$$
$$D_0 + D_1 + D_2 + D_3 + D_n \leq K_0 + K_1 + K_2 + K_3 + K_n$$

3 Conclusion

In this work, we proposed a mathematical formulation to model a real-world problem arising in the context of Canadian forestry industry. This scenario was modeled as a network design problem where one must decide how to maintain the wood flow to the pulp mill avoiding the weight restrictions zones and also being benefited for the moisture loss of the raw material which might occur in the stockyards, in order to minimize the industry's total costs. The model responded well in the validation process and computer experiments with real data are being carried out.

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