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Modelling hierarchical planning process using a simulation-optimization system to anticipate the long-term impact of operational level silvicultural flexibility

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Abstract: Hierarchical approach is used for forest management planning as opposed to a monolithic approach for its capability to better handle such a complex problem. However, in the approach, certain decisions are fixed at upper hierarchies and enforced upon operational level managers. The approach debilitates supply chains faced with uncertainty in both supply and demand. This study proposes an approach to provide greater flexibility to operational level managers and a mechanism to anticipate its impact on the upper level plans. Application of the approach to a case-study demonstrated that profit improvements of 2-4 % can be realized without an impact on upper level constraints.

Keywords: Agility, flexibility, Forest product industry, wood procurement system, hierarchical planning, value-adding.

1. INTRODUCTION

Forest management planning is a complex task due to the stochastic and dynamic nature of the forest systems, social constructs and economic parameters. The process is carried out using a top-down hierarchical approach aggregating and disaggregating information at the various levels to reduce complexity (Bettinger et al. 2008). A long-term strategic plan is first devised taking into consideration ecological and social concerns to determine the annual allowable cut. Subsequently, the volumes calculated at the strategic level are spatially allocated at the tactical level. In the process, forest stands are aggregated to form cutblocks. A silvicultural treatment is then prescribed to each individual cutblock allowing volume estimation by assortment. A cutblock is a contiguous piece of forest land that forms the basic unit of forest management plans for which harvesting and regeneration schedule is prescribed. Silvicultural treatments are different approaches in which cutblocks can be harvested, and regenerated. Next, an annual plan is formulated from this pool of cutblocks, attempting to match supply with the forecast of demand. Once the annual plan has been established, a schedule is developed for the supply chain to fulfil prevailing demand from within this annual pool of cutblocks using the silvicultural treatments already prescribed.

Even if the prevailing demand differs significantly from forecast, altering silvicultural treatments to better align supply with demand is not contemplated (Gunn 2009). The problem is exacerbated by imprecise knowledge of inventory. Strictly constraining the short-term planning process in a hierarchical planning framework impedes value-creation potential (Paradis et al. 2013).

Due to the natural variability of forest ecosystems, a multitude of operational level plans may allow achieving objectives set at an upper hierarchy (Gunn 2009). Thus, there are a number of different silvicultural treatments that can be prescribed without impacting long-term sustainability. Thus, devising a credible plan and allowing flexibility to readjust could improve convergence between planned and executed activities. Such an approach generates value adding opportunity for wood procurement systems (WPS) through an improved agility to satisfy supply chain's timber demand. The WPS links forests with markets; the activities of the system include identifying cutblocks, scheduling harvesting activities, harvesting, bucking the logs into different specifications, sorting the logs, managing inventory, and finally transporting products to different industrial systems. Agility is the ability of wood procurement systems to responds promptly and effectively to unexpected short-term fluctuation in the demand (Gautam et al. 2013). Practitioners could be provided with an array of ecologically feasible silvicultural treatments for a cutblock from which a selection can be made to satisfy market demand. Such a practice allows better alignment of supply with emerging demand considering that silvicultural treatments dictate the array of assortments and their quantities produced from cutblocks (Lussier 2009; Gautam et al. 2014).

Exercising silvicultural flexibility requires postponement of the final decision-making rights to the operational level. Postponement has been identified as an effective strategy to improve supply chain agility

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(Christopher 2000). However, considering that forest management planning is carried out using a top-down hierarchical approach, it leads to a situation of distributed decision making as described by Schneeweiss (2003). When silvicultural treatments are altered at the operational level, there is a risk that the executed plan could jeopardize sustainable harvest levels. Thus, amendments in the operational level plan have to be evaluated in terms of its impact on the long-term wood supply. A coordination mechanism is required to make such an evaluation.

A number of studies have proposed iterative procedures to ensure inter-level consistency (Davis and Martell 1993; Beaudoin et al. 2008; Marinescu and Maness 2010). However, to our knowledge, the impact of allowing flexibility in the choice of silvicultural treatment at the operational level on long-term wood supply has not been studied. This study proposes a system to examine the impact of operational level silvicultural flexibility on long-term wood supply. The system is validated using a hypothetical case study from Quebec, Canada.

2. METHOD

The system consists of a series of models to support decision making at various hierarchies. The strategic and tactical plans represent the government or land owner's perspective, with a goal of long-term wood supply sustainability. The operational level plans are developed from the perspective of a wood supplier attempting to maximize value-creation opportunity. Development and execution of hierarchical plans in a forest land base on a rolling planning horizon basis is simulated (Figure 1). First, the strategic model determines the annual allowable cut for a time horizon of 150 years. Next, a tactical model spatially identifies cutblocks to be harvested while respecting the annual allowable cut determined at the strategic level. The output of the tactical phase consists of five annual plans with a list of cutblocks allocated for each year and a silvicultural treatment prescribed to each cutblock. At the operational level, the annual plans are optimized to develop monthly schedules to meet the prevailing demand on a rolling planning horizon basis. Once all operational level plans are implemented, the land base inventory is updated followed by subsequent iterations of the process as displayed in Figure 1. The fluctuation in annual allowable cut and WPS' profits were recorded prior to each run of the strategic model.

2.1 Hierarchical planning models

The strategic model was developed as a model II linear program (Johnson and Scheurman 1977) in SilviLab, a modelling platform developed by FORAC research consortium for forest growth simulation and optimization. The objective (equation 1) is to maximize volume harvest h (m³) in each period t. N is the number of periods in the planning horizon.

[1] $$\text{Maximize Volume harvest} = = \sum_{t=1}^{N} h_t$$

The constraints of the model are: (i) area accounting constraints (ii) even flow constraint to limit periodic harvested volume fluctuation to within 5%, and, (iii) non-negativity constraints.

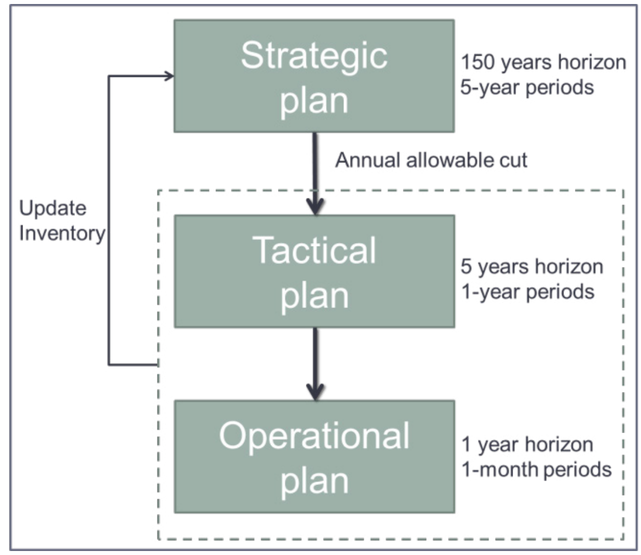

Figure 1. An overview of the hierarchical planning process simulation.

The tactical model minimizes volume allocation to each of the time periods while meeting volume targets set at the strategic level. It is assumed that the cutblocks eligible for harvest in the 5 year horizon have been delineated and the data is available for the tactical model. The objective of the model is to minimize the total volume harvested (equation 2) of assortment a from cutblock h using silvicultural treatment s in period t. Equation 3 forces the model to meet volumes targets set by the strategic model. Equation 4 ensures that only one silvicultural treatment is applied to each of the selected cutblock. Finally, equation 5 prohibits the harvesting of adjacent cutblocks. Generally, harvesting of adjacent cutblocks in the subsequent periods is prohibited, to avoid large openings in the forest.

Sets

T: is the set of time periods t
H: is the set of cutblocks h
S: is the set of silvicultural treatments s
A: is the set of species a

Input Data

V_{hsa}	Volume of species a available in cutblock h when subjected to silvicultural treatment s (m³).
N_h	Set of adjacent cutblocks.
$\nexists_{sat}$	Volume target of species a in period t under silvicultural treatment s.

Decision Variables

O_{hst}	1, if cutblock h is allocated for harvest under silvicultural treatment s in period t. 0, otherwise

Objective Function:

[2] $$\text{Minimize} = \sum_h \sum_a \sum_s \sum_t V_{hsa}\, O_{hst}$$