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A Network Design Approach for Improving the Value-Creation Potential of Strategic Forest Management Plans

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Abstract

To be credible at the operational level, strategic forest management plans need to include financial performance indicators. Otherwise, trying to harvest the entire allowable annual cut (AAC) leads to a wood supply of unknown profitability for the industry. We apply a previously-developed methodology to disaggregate any subset of species-wise AAC into wood products, insert financial performance indicators and estimate the net value-creation potential of the AAC using a network flow optimization model. This model enabled us to link the optimal solution of a strategic forest management optimization model with the transformation capacity of a network of primary production factories. We considered the uncertainty of timber prices as the most unpredictable value chain driver. We applied our planning system on a large mixed-wood forest management unit in Quebec, Canada. Consuming the entire AAC led to lower simulated profit. Fulfilling timber licences lowered the profit margin. Results also revealed that a weak demand for one wood product was a serious impediment to achieving the full value-creation potential. We therefore simulated the implementation of a new hardwood pellet mill which improved the net value-creation potential, and demonstrated the insights provided by strengthening the link between strategic and tactical planning, with the concept of value-creation potential.

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Introduction

In many jurisdictions, a hierarchical planning framework is used to achieve sustainable forest management (Tittler et al. 2001). Hierarchical forest management divides forest management into strategic, tactical and operational planning phases. Yet, objectives and constraints at one level may not properly account for the objectives and constraints at another level (Gunn 2009).

In Canada, the strategic planning phase essentially consists in allocating timber licences to industrial fiber consumers. Provincial government authorities are responsible for this on public land. Timber licenses depend on the annual allowable cut (AAC). The AAC is the species-wise amount of wood that can be harvested within a defined area on a sustainable basis and is determined by maximizing the volume harvested (Canadian Council of Forest Ministers 2005). However, neither financial nor economic indicators are considered when computing AAC. Strategic forest management plans may therefore overestimate future forest yield supply and lead to uneconomical periods for the forest industry (Mathey et al. 2009, Paradis et al. 2013).

We propose to strengthen linkages between strategic and tactical planning, with the concept of value-creation potential, by simulating the fiber consumption of the strategic forest management plan during the process of tactical planning, using a methodology adapted from Paradis and LeBel (2017a, 2017b, 2018a, 2018b). The term value-creation potential (VCP) describes the maximum benefit achievable with the timber available for harvest in a forest management unit to supply an industrial network. As a case study, we used a forest management unit (FMU) located in Quebec, Canada, and the industrial network from this area.

The main objective of this paper is to estimate the VCP of different fiber consumption scenarios using outputs of strategic forest management optimization models as input to a network flow optimization model that optimized potential profit from fiber consumption. The specific objectives are: (1) to simulate fiber consumption with different industrial network behavior (central management versus no collaboration), (2) estimate potential improvements in network profits from a change in the network configuration.

Methodology

Data set and case study description

The availability of stands for harvest was obtained from the harvest schedule of a strategic forest management model developed by government planners for FMU 064-51 in Quebec, Canada (Figure 1) for the planning period 2013-2018 (Bureau du forestier en chef 2014). Forest strata included in the harvest schedule are composed of 40% hardwood strata, 39% mixed-wood strata and 21% softwood strata, corresponding to 653 518 m^3 of softwood per year and 745 822 m^3 of hardwood per year, respectively 125% and 115% of the official AAC values.

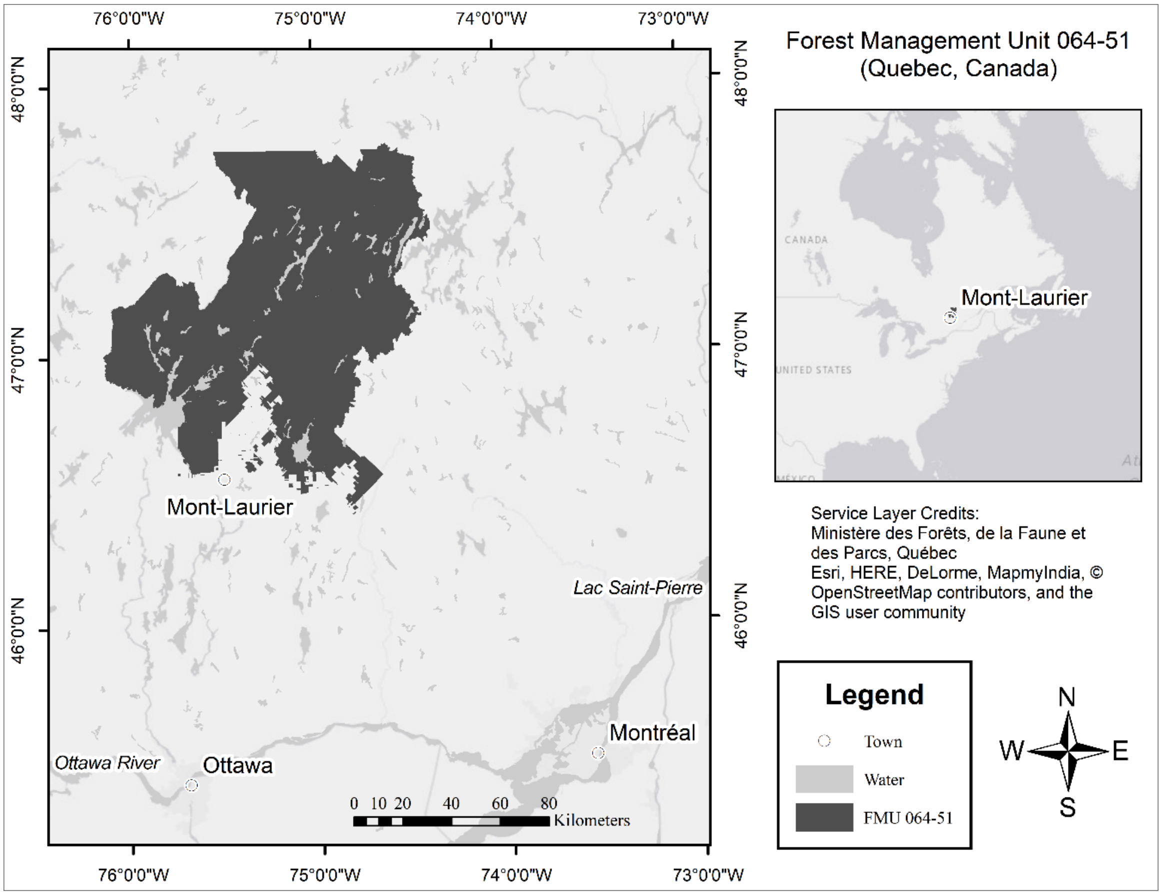

Figure 1. Map showing the location of FMU 064-51 in Quebec, Canada

In our case study, the industrial network is composed of 10 softwood sawmills, 2 hardwood sawmills, 2 hardwood veneer mills, 2 softwood roof shingle mills, 2 board mills and 2 hardwood pulp mills. All mills are within a 30 km radius from Mont-Laurier, except for the pulp mills located at 150 and 400 km south and south-east of Mont-Laurier.

Compiling financial revenue and cost data for harvest nodes and wood flow

Solutions of strategic forest management optimization models provide aggregated timber volumes values that cannot be used as such to estimate expenses and revenues from the harvest and primary transformation of timber. We used and adapted methodology from Paradis and LeBel (2017a, 2017b, 2018a) to disaggregated volume from the strategic forest management plan outputs and derived costs and revenues from the MERIS database compiled by the Quebec government (Bureau de mise en marché des Bois 2015) to form the harvest nodes of the network flow optimization model.

Supply costs are composed of harvest costs, transportation costs, road construction and maintenance costs, and stumpage fees. Sales profits include sales income minus transformation and transportation costs (from the mills to the markets). All presented prices are in CAD.

To simulate price uncertainty, we used price index time series from Statistics Canada (2018). Commodity prices tend to converge to a long-run mean price (Bessembinder et al. 1995). We used the geometric Ornstein-Uhlenbenck process suggested by Dixit and Pindyck (1994) to generate a thousand price simulations.

Network flow optimization model

The network flow optimization model simulates fiber flows through the value chain during the tactical phase. Fiber flow begins with the harvest of forest stands scheduled in the strategic forest management plan. Logs are then transported to a primary processing mill. Primary wood products are sold, and process by-products such as chips are sold to a pulp mill. The total VCP for the value chain is the sum of all sales minus supply and transformation costs and is maximized with the network flow model shown in Figure 2. We reformulate the network flow optimization model from Paradis and Lebel (2018b) to simulate the fiber consumption at a tactical level with implementation of an additional mill.

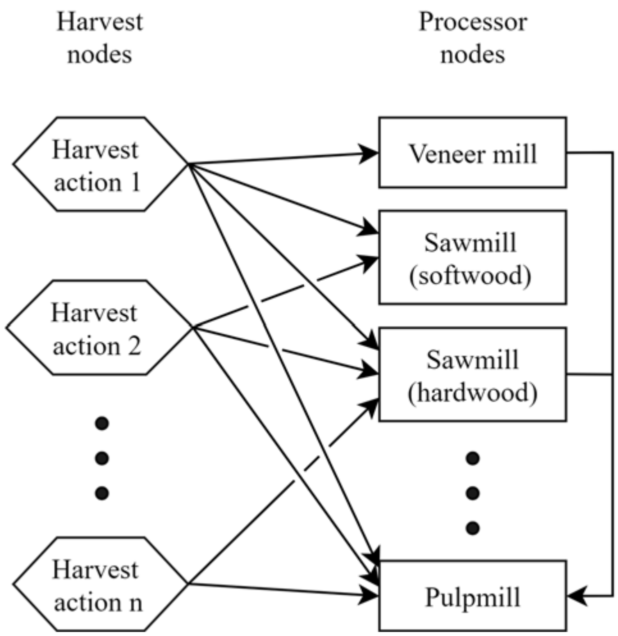

Figure 2. Schematic representation of the network flow model

Timber licences were used as proxies for market demands. We constrained the model to fulfill a minimum of 80% of the timber licences. We hypothesized that the full harvest of AAC from one FMU would not saturate the industrial network as the mills also procure from other FMU.

Experimental design

We simulated eight scenarios, which varied in terms of industrial network configurations, price for wood pellets and constraints. Scenarios are numbered 1 to 4, with two variants for scenario 1 (1.1 and 1.2) and scenario 2 (2.1 and 2.2). Scenarios 3 and 4 have three variants.

In Scenario 1.1, we repeatedly solved the model to optimality for a range of harvest areas between 0 and 100% of the scheduled for harvest area. MERIS database was used for the prices. AAC could not be exceeded and timber licences were not considered. Without timber licence constraints, the industrial network will seek to maximize the VCP, implying that profits are optimized for the whole network (central management).

Scenario 1.2 is identical to scenario 1.1, except that we set a high penalty if the timber license volume was not delivered. This scenario represents the case where each mill wants to increase its own profit by fulfilling its timber licences (no collaboration).

With scenario 2 we start the premises of scenario 1.2. We solved the network flow model to optimality for all price simulations. This is a control scenario. Scenarios 3 and 4 are based on scenario 2, adding a hypothetical hardwood pellet mill located near Mont-Laurier.

The differences between the scenario parameters are shown in Table 1. We used data from Barrette et al. (2017) and Boukherroub et al. (2017) for data on wood pellet production cost and revenue. Return on capital employed (ROCE) was used to determine if implementation of the pellet mill was worth the investment for the entire network. The ROCE is calculated by dividing the net profit by the investment. For the industry, the net profit represents the increase of VCP when implementing a pellet mill. The government net profit represents the increase on stumpage paid by the industry. In case 1, the pellet mill was entirely financed by the industrial network. In case 2, the government financed a portion of the mill to reach the same ROCE as the industry.

Table 1. Pellet mill parameters for scenarios 3 and 4

Simulation scenario	Pellet mill capacity (BDMT/year)	Pellet prices ($/BDMT)
3.1	50 000	200
3.2	50 000	210
3.3	50 000	220
4.1	100 000	200
4.2	100 000	210
4.3	100 000	220

Results and Discussion

All 10 forest products were aggregated into three commodity groups to make it easier to present the results. The three groups are: Fir-Spruce-Pine-Larch (FSPL), hardwood pulp, and other products.

In scenario 1.1, a highly collaborative industry prioritizes the harvest of forest strata with positive VCP values for the entire network. The optimal VCP is 11.4 M$ for the 5-year period (Figure 3a). It is reached by harvesting 56% of the area scheduled for harvest. This result indicates that 44% of the scheduled area has a negative global value-creation potential. Figure 3b shows that the curve of harvested area for hardwood pulp commodity group has a convex function shape, meaning that lower-value hardwood-rich forest strata are avoided to optimize VCP.

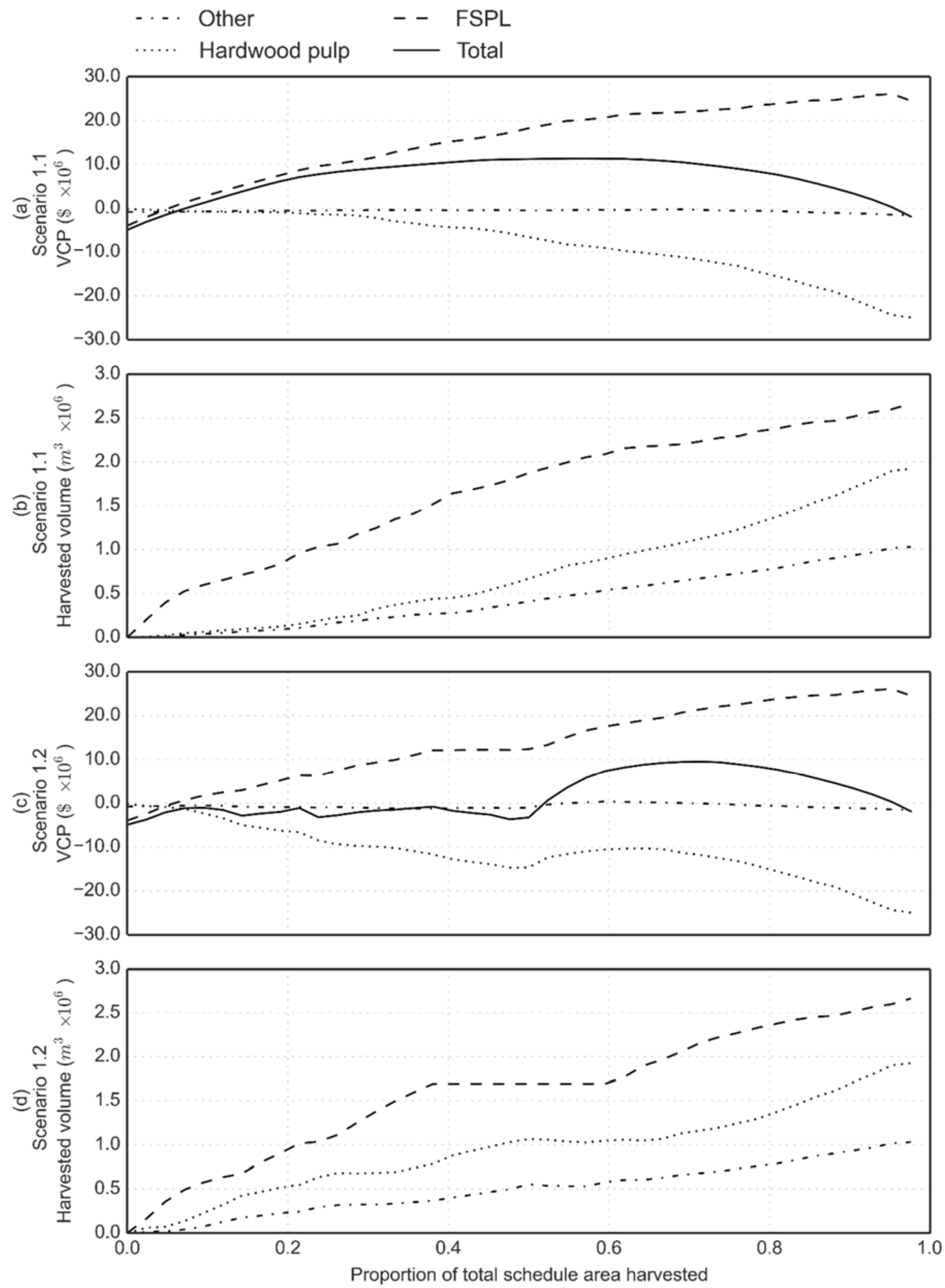

Figure 3. Value-creation potential and harvested volume for scenarios 1.1 and 1.2

In scenario 1.2, the optimal VCP is 9.6 M$ and requires harvesting 71% of the area scheduled for harvest. A larger share of hardwood-rich forest strata is harvested (Figure 3d) when compared to scenario 1.1 (Figure 3b). Timber licences are fulfilled when approximately 54% of the scheduled volume is harvested. Beyond that point, the model can then seek strata that will increase the VCP without accounting for balance between individual mill allocation. VCP increases more quickly beyond this point. Figure 3d shows a change in convexity (from concave to convex) for hardwood pulp commodities once timber licences are fulfilled, meaning that this commodity group needs, once again, to be avoided when optimizing VCP.

Total integration between business units in the network (scenario 1.1) leads to increased profit margins for the whole network. Our model predicts that AAC volume will not be entirely harvested with actual prices. Optimal VCP peaks when harvesting between 56% and 71% of the available area.

Implementation of a hardwood pellet mill increases the VCP and the harvested volume for all scenarios (Table 2). FMU 064-51 is composed of a high proportion of mixed-wood forest, forcing the network to harvest hardwood. Adding a pellet mill decreases the median unit loss ($/m^3) for hardwood pulp commodities. Higher pellet prices (scenarios 3.3 and 4.3) and an increased capacity at the pellet mill (scenarios 4) increase the volume harvested for the three commodity groups. A diversified value chain network has more options to adapt its productive process to available market opportunities.

Table 2. Value-creation potential and harvested volume for each scenario over a 5-year period.

Scenarios	Median of optimal VCP ($\$\times10^6$)				Median of volume harvested ($m^3\times10^6$)			
	FSPL	Hardwood pulp	Other	Total	FSPL	Hardwood pulp	Other	Total
2	19.6	-11.9	-0.3	7.8	2.11	1.16	0.68	3.95
3.1	21.5	-12.1	-0.5	9.6	2.30	1.31	0.73	4.34
3.2	21.7	-10.0	-0.6	11.6	2.30	1.32	0.74	4.36
3.3	22.0	-7.8	-0.6	14.3	2.34	1.42	0.78	4.54
4.1	23.9	-13.0	-1.3	9.6	2.54	1.72	0.92	5.17
4.2	23.9	-9.0	-1.3	13.6	2.54	1.72	0.92	5.17
4.3	24. 0	-4.8	-1.5	17.6	2.54	1.72	0.92	5.17

Capital investments and ROCE are shown in Table 3. Implementing a pellet mill increases VCP and stumpage paid to the government. Consequently, government involvement in financing the pellet mill is not unreasonable. We set the minimum acceptable ROCE at 6% for the industry since the average ROCE of Canada's forest industry sector was 6.2% between 2010 and 2016 (Statistics Canada 2017). In case 1 (pellet mill entirely financed by the industry), neither of the scenarios reached an acceptable ROCE. In case 2 (pellet mill co-financed by government and industry), scenarios 3 and 4 had an acceptable ROCE. Implementing a medium pellet mill (scenarios 4) funded by the industry and the government (case 2) seems to be the best option due to a higher and more stable ROCE.

It can be argued that the goal of the government is not only to increase its revenues but also to contribute to job creation and ensure better access to a diversity of forest resources (Boukherroub et al. 2017b). Implementation of a pellet mill can contribute to these objectives. For example, in scenario 4.2 (a medium pellet mill and average pellet price) the median amount invested by the industrial network to construct and maintain roads increased by 23% compared to scenario 2. In absolute terms, this is 1,87 million dollars per year, creating jobs, and providing access to the forest for wood production and recreation.

Table 3. Investments and ROCE for scenarios with the implementation of a pellet mill. Median VCP and median increase of paid stumpage are given for the entire FMU for all commodities.

Scenario	Increase of VCP ($/year)[a]	Increase of paid stumpage ($/year)[a]	Case	Industry investment ($)	Government investment ($)	Industry ROCE	Government ROCE
3.1	376 080	288 468	1	10 000 000	-	3.76%	-
			2	5 659 180	4 340 820	6.65%	6.65%
3.2	414 014	378 797	1	10 000 000	-	4.14%	-
			2	5 222 105	4 777 895	7.93%	7.93%
3.3	469 202	411 166	1	10 000 000	-	4.69%	-
			2	5 329 609	4 670 391	8.80%	8.80%
4.1	853 029	923 293	1	16 000 000	-	5.33%	-
			2	7 683 555	8 316 445	11.10%	11.10%
4.2	853 029	925 031	1	16 000 000	-	5.33%	-
			2	7 676 043	8 323 957	11.11%	11.11%
4.3	864 743	1 028 696	1	16 000 000	-	5.40%	-
			2	7 307 280	8 692 720	11.83%	11.83%

[a] Compared to scenario 2

Most biomass value chain studies have a narrow focus on energy feedstock and fail to address the possible synergies and impacts on traditional forest products (Cambero and Sowlati 2014). Our methodology focuses on the entire value chain rather than on only one mill. It can be useful to adopt a system view of the impact of changes in the value chain, such as implementing a bioenergy production facility.

Conclusion

Forest management plans must consider cash flow otherwise they could lead to an economically unsustainable industry (Gunn 2011). We adapted a previously-developed methodology to estimate the financial costs and revenues of the outputs of a strategic forest management plan for a forest management unit in Quebec, Canada. We used a network flow optimization model to simulate the fiber consumption at a tactical level. We showed that strong collaboration between the value chain network leads to a higher value-creation potential by avoiding the harvest of unprofitable forest strata. We also showed that addition of a pellet mill could improve value creation potential and may constitute a worthy investment for the industry if supported by the government.

We tested our proposed methodology, adapted from Paradis and LeBel (2017a, 2017b, 2018a, 2018b), on a large and diversified FMU in Quebec, Canada. We kept using easily accessible data so that our methodology could also be applied to any other FMU in Quebec, Canada.

Acknowledgements

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