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Economic impact of enhanced forest inventory information and merchandizing yards in the forest product industry supply chain

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ABSTRACT

Forest products industry should maximize the value of timber harvested and associated products in order to be competitive in global markets. Enhanced forest inventories and merchandizing yards can help in maximizing value recovery in the forest products supply chain. This study develops an optimization model to analyze the economic impact of enhanced forest inventory information and merchandizing yard operations in the forest products supply chain. The application of the model is demonstrated by using a case study of a hypothetical forest industry in northwestern Ontario, which obtains four log assortment grades from the surrounding eight forest management units. The model analyzes five different scenarios with 0%, 25%, 50%, 75%, and 100% certainty of tree quality in forest inventory information. The results of the study show that with full certainty of tree quality information, it is possible to gain 49% in gross profit in comparison with a scenario with no certainty. The usefulness of enhanced forest inventory and merchandizing yard in the entire supply chain of forest products industry is recognized by maximizing total value of wood fiber (by allocating right log to the right product), reducing fluctuations in raw wood fiber supply, and minimizing inventory carrying costs and lost sales.

1. Introduction

Canadian forest products industry, which has traditionally produced commodity products is facing challenges of increased production costs, shifting of input factors to other sectors of the economy, lack of coordinated and integrated supply chains, and decline in capital available to improve existing facilities or build new ones [9,17]. To be competitive in global markets, the Canadian forest products industry must maximize the value recovered from timber and other associated forest products, and supply chains need to be improved [17,29]. The integration of an enhanced forest inventory, containing information on the variability of species, stem quality attributes and fiber quality, with merchandizing yards will potentially allow for value creation along the forest products supply chain [25,27]. The forest inventory information should provide timely, accurate and consistent information on valuable fiber attributes for sustainable development of forests [8], and is expected to help in obtaining maximum value from each tree harvested [27,28]. However, as many forest inventories were not designed to optimize each link in the forest value chain, the existing tools and methods are unable to support today's needs for accuracy, spatial detail and timely updates [28].

Inaccurate inventory is often related to the problems in technology, where it is difficult to make better measurements, whereas precision in inventory information refers to certainty in tree quality (volume of different log assortments in m^3). Inaccurate and less precise inventory information can lead to incorrect harvest decisions, and affects production planning in the forest products industry [13,15,23,24,26,32]. Borders et al. [5] in their study found that timber management organizations in the southern United States having lack of precision in inventory information are experiencing losses (188 \$ ha^{-1}) in net present value. Most of the studies have tried to address stochasticity in inventory information using different routing methods and direct deliveries [16,23,26]. The multifold benefits from enhanced forest inventory information have also been documented [5,12,14,19,20,34], and some forest-based companies have started using enhanced forest inventory information in their decision making [27].

Traditionally, the forest management planning decisions depend on the accuracy of stand volume, which is obtained from different data acquisition methods, each having certain limitations [19,20]. There is always an economic trade-off between using

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higher-quality data for operational planning and the cost of obtaining such data [12]. The forest industry relies on the cost plus-loss methodology, which takes into consideration the hierarchical structure and iterative nature of planning, to analyze the value and need for better data in the planning process [12]. Ståhl et al. [34] found that forest inventories are most profitable, if they were conducted well ahead of the harvest operations. A posterior distribution of the inventory can be calculated using Bayesian theory, if an inventory is carried out in advance within the forest planning framework [34].

Enhanced forest inventory captures information, which is precise enough for value chain optimization [28]. It enables forest product industries to prepare plan to access, harvest and deliver the right forest products to the right mills and markets, at the right time. It makes the forest products industry economically sustainable for the long term by reducing costs and increasing profitability [27,28]. For example, forest industries in the provinces of Ontario, Quebec, Newfoundland and Labrador, Alberta, and British Columbia have reported substantial savings by using enhanced forest inventory information [35,37,27]. Based on the enhanced forest inventory information, the forest-based companies have reported savings from (i) the construction of efficient and environmentally sound forest road systems, (ii) accurate forest maps produced by automatic mapping algorithms, (iii) substituting high-density balsam fir for black spruce, and (iv) accurate information on tree height, volume and wood properties [37,27]. However, the potential of enhanced forest inventory information is still under-estimated.

Enhanced forest inventory information containing tree quality attributes will be useful only if the right log is used to produce the right product that will ensure maximum total value through optimal product recovery [10,11,18]. This requires the use of log yards for proper log sorting and merchandizing that stabilize wood supply by playing the role of a coordinating entity for raw wood supply. These log yards, commonly known as merchandizing yards, minimize wood inventory holding costs and loss sale costs for all the mills by transferring and minimizing the risks to the mill yard. Merchandizing yards are used as a buffer for the forest industries as they supply right amounts and types of forest products in right time to the mills. Merchandizing yards also provide easy access to the desired logs for small wood-based industry in rural areas. Merchandizing yards also help in generating rural employment and have potential environmental benefits by reducing the impacts of the entire harvest operation. Merchandizing yards have been found to be most successful where the end products are diverse, for example in Western Europe, Scandinavian countries, West coast of US and Canada [22]; Wallowa Resources 1997; [4,10].

Merchandizing yards are of different types depending on the purpose of log sorting and merchandizing, and their location. These include mill yards, concentration yards, log reload yards, remote log processing yards, and log sort yard [11]. In the mill yard, logs are stored for several weeks to several months before feeding into the mill. A concentration log yard is a central point for receiving logs and supplying them to the mill yards using long-distance transport [36]. Log reload yards are transfer points between different modes of transportation, namely truck, rail or barge. Remote processing log yards are used to feed satellite chip mills. A log sort yard is a place to sort logs for short periods at a landing with low capital costs. In addition to sorting, log grading, bucking and scaling can also be done at a sort yard [4,10,11]. A typical merchandizing yard has advanced log sorting facilities with storage, equipped with modern machinery for further processing of logs and chips production [4,18,33]. The main role of the merchandizing yard is to capture the highest value of forest products depending on their availability in the forests and market demands [10,18,21]. The financial feasibility of a log sort yard mainly depends on product prices and revenues [18]. Therefore, maximizing the revenues will realize the direct benefits of these merchandising yards.

Research on merchandizing yards is still sparse, with the majority of studies focusing only on the location problem of the yard [4]. Combined log inventory and process simulation models have also been developed that can monitor and update the status of logs in the merchandizing yard [25,30,31]. A few studies have also focused on optimizing the operations and transportation costs of merchandizing yards [6,21]. Developing an optimization model by linking the combinatorial sets of merchantable tree attributes distributed over a forest area with detailed operations of merchandizing yards to produce logs and biomass for each end product is a big challenge. At present, the Canadian forest products industry seems to have minimal use of enhanced forest inventory information and merchandizing yards in the supply chains. This study, therefore, analyses the role of advanced forest inventory information system and merchandizing yards for enhancing the value chains in the forest products industry with optimization modeling techniques. In particular, we consider different levels of certainty in tree quality information (0%, 25%, 50%, 75%, and 100%) to compare gross profits from different grades of logs (high, medium and low quality logs, and fuelwood). A case study is taken in northwestern Ontario (NWO) to see the usefulness of enhanced forest inventory information in a forest products industry supply chain utilizing a merchandizing yard.

The purpose of this study is to develop an optimization model that can analyze the economic impact of enhanced forest inventory information and a merchandizing yard in the forest products industry supply chain. The specific objectives are: (i) to develop an optimization model that maximizes gross profit of a merchandizing yard, (ii) to compare gross profit from this model using five different scenarios having 0%, 25%, 50%, 75%, and 100% certainty in tree quality in forest inventory information, and (iii) to compare per unit profit from each log grade in order to understand the contribution of each product in the gross profit.

2. Research area

Fig. 1 shows a snapshot of eight forest management units (FMUs) in NWO used for this study, namely Crossroute Forest, Dryden Forest, English River Forest, Kenora Forest, Lac Seul Forest, Sapawe Forest, Wabigoon Forest and Whiskey Jack Forest, surrounding a hypothetical forest products industry in Dryden. In Ontario, the Crown forests are divided into geographic planning areas, which are known FMUs. The FMUs are under the jurisdictions of provincial governments of Canada. Under a sustainable forest licence (SFL), individual forest companies manage most of these FMUs [2]. The simplified forest products industry in Dryden uses four categories of log grade: (i) log grade A is high quality logs, (ii) log grade B is medium quality logs, (iii) log grade C is low quality logs, and (iv) log grade D is fuelwood. The four types of log assortments are collected from FMUs, sorted and stored at the merchandizing yard, which is located between the FMUs and the forest products industry in Dryden. The forest area of each of the eight FMUs is divided into forest cells of 1 km^2 size. The forest cells are further classified based on the percentage of harvested cell area (forest depletion % over the years 2002–2009) as shown in Fig. 1. Alam et al. [2] describe in detail about the research area and its classification into depleted forest cells. The depletion layer of the FMUs is prepared using ArcGIS. To prepare this depletion layer, the percent occurrence method is used [3]. Depending on the depletion percentage, a code number is assigned to the grid cell in this method (percent of the cell area harvested, where, 1 is 100%, 2 is from 80% to 100%, 3 is from 60% to 80%, 4 is from 40% to 60%, 5 is from 20% to 40%, 6 is from more than 0%–20% depletion and 7 is no

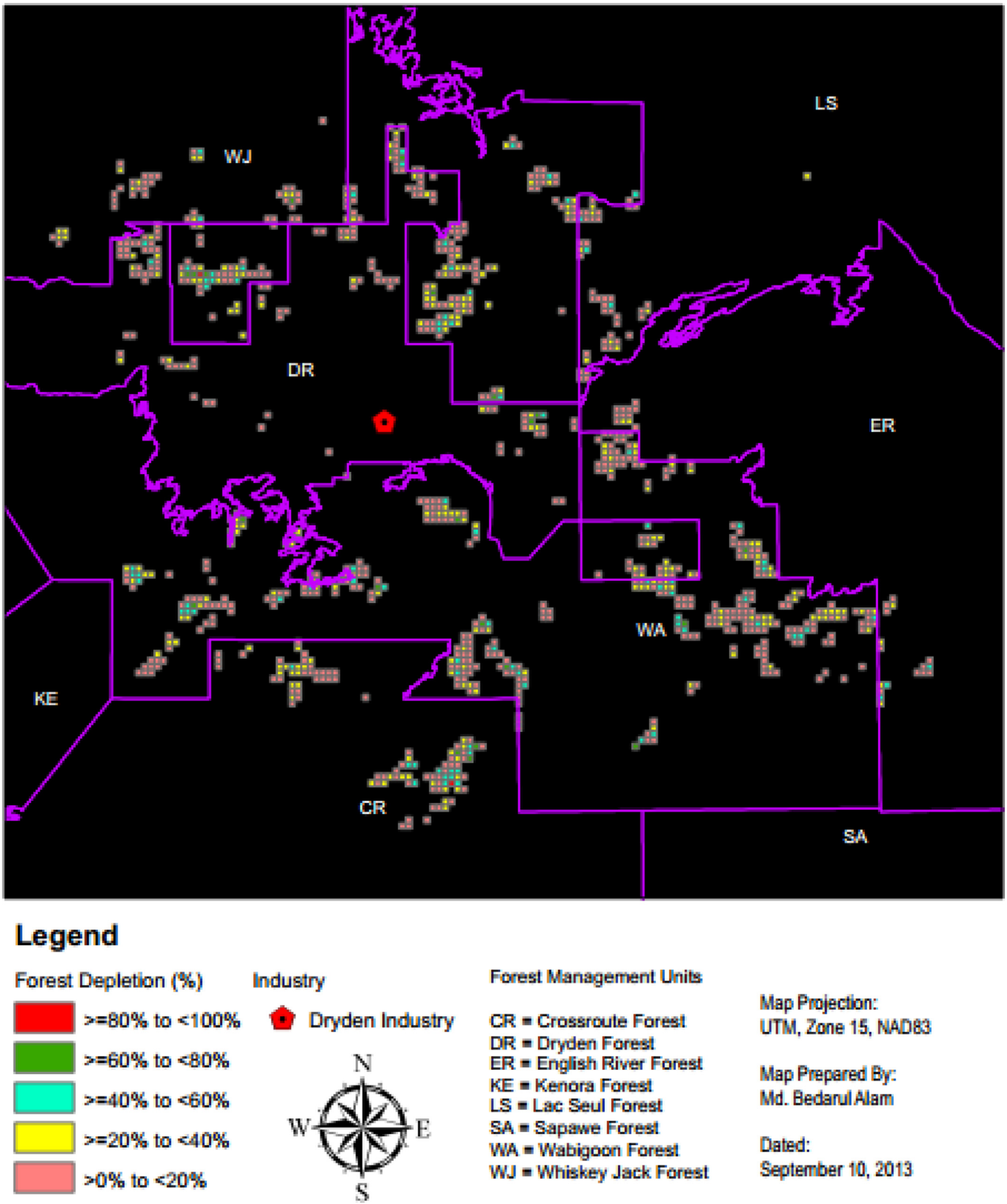

Fig. 1. Snapshot of the research area surrounding a hypothetical forest products industry in Dryden.

depletion) [2,3]. For the purpose of this study only 2500 depleted forest cells surrounding the Dryden forest industry are considered (Fig. 1). The depleted forest cells are divided into 50 forest zones based on the transportation time between the forest cells and forest industry in Dryden. Table 1 shows average percentage availability of each forest product in a forest cell. It is assumed that the maximum availability of each product in a forest cell is 100 m^3 ha^{-1}. In addition, Table 1 also shows a hypothetical weekly demand, gross profit, inventory carrying cost and lost sales cost for each log grade. Inventory carrying cost is the cost of holding inventory, which is related to the capital tied up in inventory, storage, insurance and obsolescence. Inventory carrying cost is often expressed as an annual percentage rate of the total cost of inventory [1]. Lost sales cost is the profit foregone for failing to fulfill the orders [7].

3. Optimization model

Fig. 2 shows the flow chart of a non-linear dynamic optimization model developed for supplying four types of log grades, through a merchandizing yard, from eight FMUs to the forest products industry in Dryden. The log grades are weekly harvested over a one year (50 weeks) planning horizon in the optimization model. The harvesting schedule of 50 weeks is selected in such a way that the same forest area is not revisited more than once for harvesting in the planning horizon of one year.

The optimization model, which uses a non-linear dynamic programming method, maximizes gross profit for four log grades harvested from eight FMUs surrounding the hypothetical Dryden forest products industry, using varying levels of certainty of tree quality in forest inventory information. All the log grades are routed through the merchandizing yard, which is used to merchandize the trees and sort/store the products after harvesting and before supplying to the industry. The sets, indices, parameters and variables used in the optimization model are described below.

Sets/Indices:
- i = production time in weeks ($i = 1, 2, 3, \ldots, 50$), the planning horizon being 1 year = 50 weeks
- j = log grades ($j = 1, 2, 3, 4$), represent products A, B, C, D, respectively

Parameters:
- DLG_{ij} = demand of jth log grade in ith week (m^3)
- GP_j = gross profit from log grade j ($\$/m^3$)
- IC_j = inventory carrying cost of yard for jth log grade in ith week ($\$/m^3$/week)
- SC_j = lost sales cost of yard for jth log grade in ith week ($\$/m^3$/week)

Variables
- XLG_{ij} = harvested volume of jth log grade in ith week (m^3)
- TGP = total annual gross profit of merchandizing yard ($)
- XEI_{ij} = end inventory of jth log grade in ith week (m^3)
- XBI_{ij} = beginning inventory of jth log grade in ith week (m^3)
- XSA_{ij} = sales volume of jth log grade in ith week (m^3)
- XLO_{ij} = lost sales volume of jth log grade in ith week (m^3)

The objective function of the optimization model is specified by Equation (1) that maximizes total annual gross profit ($) of the merchandizing yard. The right hand side of Equation (1) represents the total revenue from the sale of log grades minus total inventory carrying cost and total lost sales cost.

$$\text{Maximize TGP} = \sum_{i=1}^{50}\sum_{j=1}^{4}(XSA_{ij}{*}GP_j) - \sum_{i=1}^{50}\sum_{j=1}^{4}(XEI_{ij}{*}IC_j) - \sum_{i=1}^{50}\sum_{j=1}^{4}(XLO_{ij}{*}SC_j) \tag{1}$$

Subject to the constraints specified by Equations (2)–(8).

$$\sum_{i=1}^{50}\sum_{i=1}^{4}XLG_{ij} \geq \sum_{i=1}^{50}\sum_{i=1}^{4}DLG_{ij} \tag{2}$$

$$XSA_{ij} \leq DLG_{ij} \tag{3}$$

$$XBI_{(i+1)j} = XEI_{ij} \tag{4}$$

$$XBI_{1j} = 0 \tag{5}$$

$$XEI_{ij} = XBI_{ij} + XLG_{ij} - XSA_{ij} \tag{6}$$

$$DLG_{ij} - XSA_{ij} = XLO_{ij} \tag{7}$$

$$XLG_{ij}, XSA_{ij}, XEI_{ij}, XLO_{ij} \geq 0 \tag{8}$$

Equation (2) ensures that the total volume of all log grades harvested is greater than total volume of log grades demanded. Equation (3) determines that weekly sales volume of log grades is less than the total volume demanded of each grade. The constraint in Equation (4) confirms that the beginning inventory of next week is the same as end inventory of current week for each product. Equation (5) specifies that there is no beginning inventory in the first week. Equation (6) ensures that the end inventory of a week is the beginning inventory of that week plus volume harvested in that week minus sales volume in that week. Equation (7) determines the lost sales (if positive) in each week, which is the demand minus sale in each week. Finally, Equation (8) is the non-negativity constraint on decision variables.

The optimization model is used to conduct five scenario analyses, specifying different inventory information. In scenario 1 (base scenario), it is assumed that there is no prior inventory knowledge of the quality of trees in each forest cell. However, in scenarios 2, 3, 4 and 5, the certainty in quality attributes in the forest inventory in each forest cell is assumed to be 25%, 50%, 75%, and 100%, respectively.

4. Results and discussion

Table 2 shows the number of forest cells selected by the optimization model for supplying four log grades to the forest industry

Table 1
Average supply, demand and merchandizing yard parameters.

Log grades	Average availability per cell (%)	Weekly demand (m^3/week)	Gross profit ($\$/m^3$)	Inventory carrying cost ($\$/m^3$/week)	Lost sales cost ($\$/m^3$/week)
A	10	500	100	10	50
B	40	2000	75	7	35
C	30	1500	50	5	25
D	20	1000	10	1	0

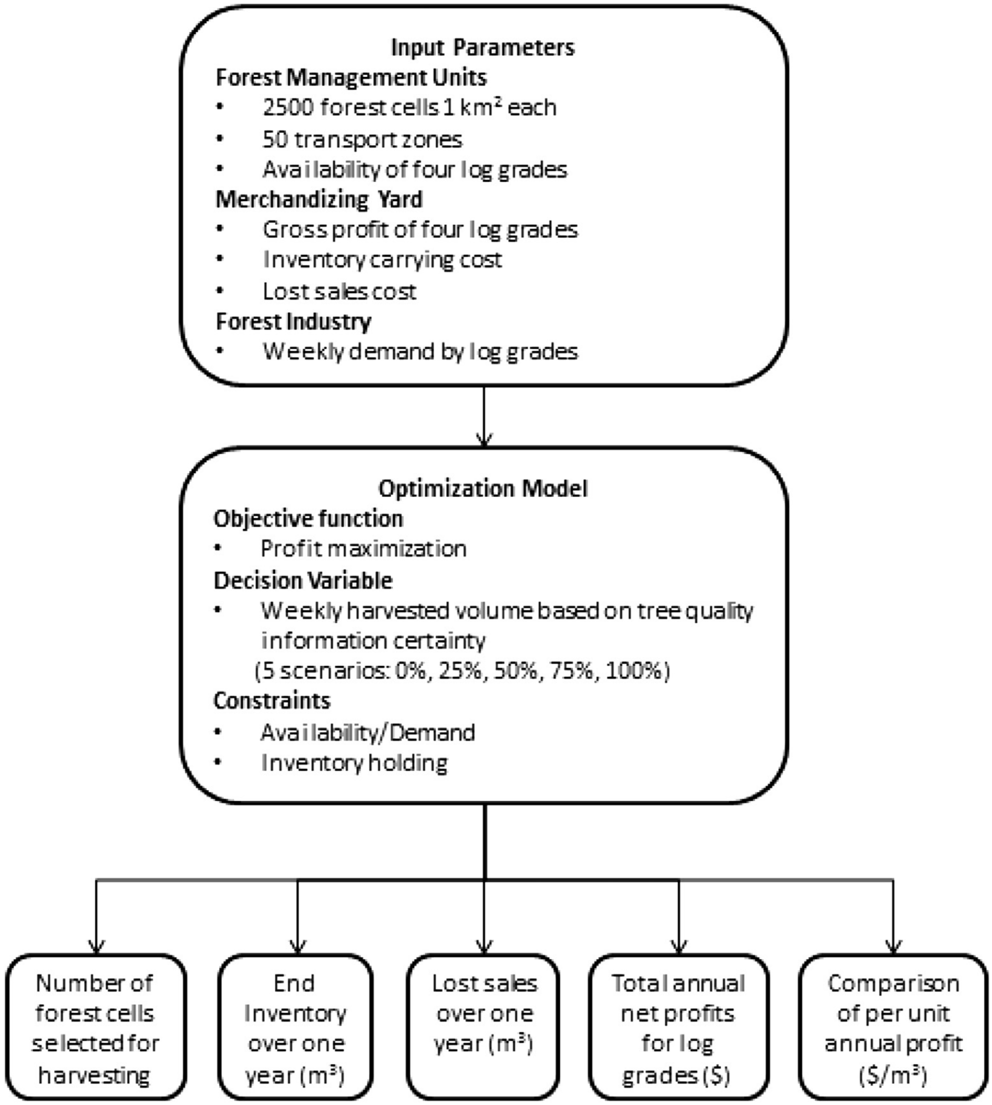

Fig. 2. Flow chart of optimization model.

over one year (50 weeks) planning horizon in five different scenarios, each having different forest inventory information. As expected, the model selects fewer cells to meet the demand for each log grade as the certainty of inventory information of the forest cells increases. When there is no certainty in quality attributes in the inventory information, the model selected 650 cells and with complete inventory information, the model selected only 549 cells. For an illustrative purpose, Fig. 3 shows the distribution of selected forest cells for supplying log grades to the forest industry over one year planning horizon in scenario 3, where 50% log grades are harvested from forest cells having complete inventory knowledge and other 50% are harvested without any inventory knowledge. Therefore, with complete inventory information the model avoids going to 101 extra cells, which represents an area of 101 km^2 in one year, resulting in significant savings for the forest products industry.

Table 2
Forest cells selected for supplying log grades over one year planning horizon.

Tree quality information certainty	Total number of forest cells selected	Forest cells selected with certainty in log quality inventory information
0%	650	0
25%	634	152
50%	618	293
75%	586	417
100%	549	549

Forest inventory information in each cell also results in profits for the merchandizing yard. Table 3 shows the end inventory and lost sales of log grades in merchandizing yard over one year planning horizon. In Scenario 5 with full certainty in tree quality in the forest inventory information, there is no end inventory or lost sales for any log grade in the merchandizing yard. Although the amount of lost sales decreases with improved inventory knowledge, the end inventory does not decrease in the same order. This may be due to the fact that the inventory carrying cost for three major log grades, assumed in the model, is significantly lesser than their lost sales cost (Table 1). Moreover, the objective function of the optimization model is to minimize cost and not end inventory, and therefore, the model makes a trade-off between end inventory and lost sales to keep the cost minimum.

The total profits over one year from four log grades in different inventory information scenarios are shown in Table 4. It is found

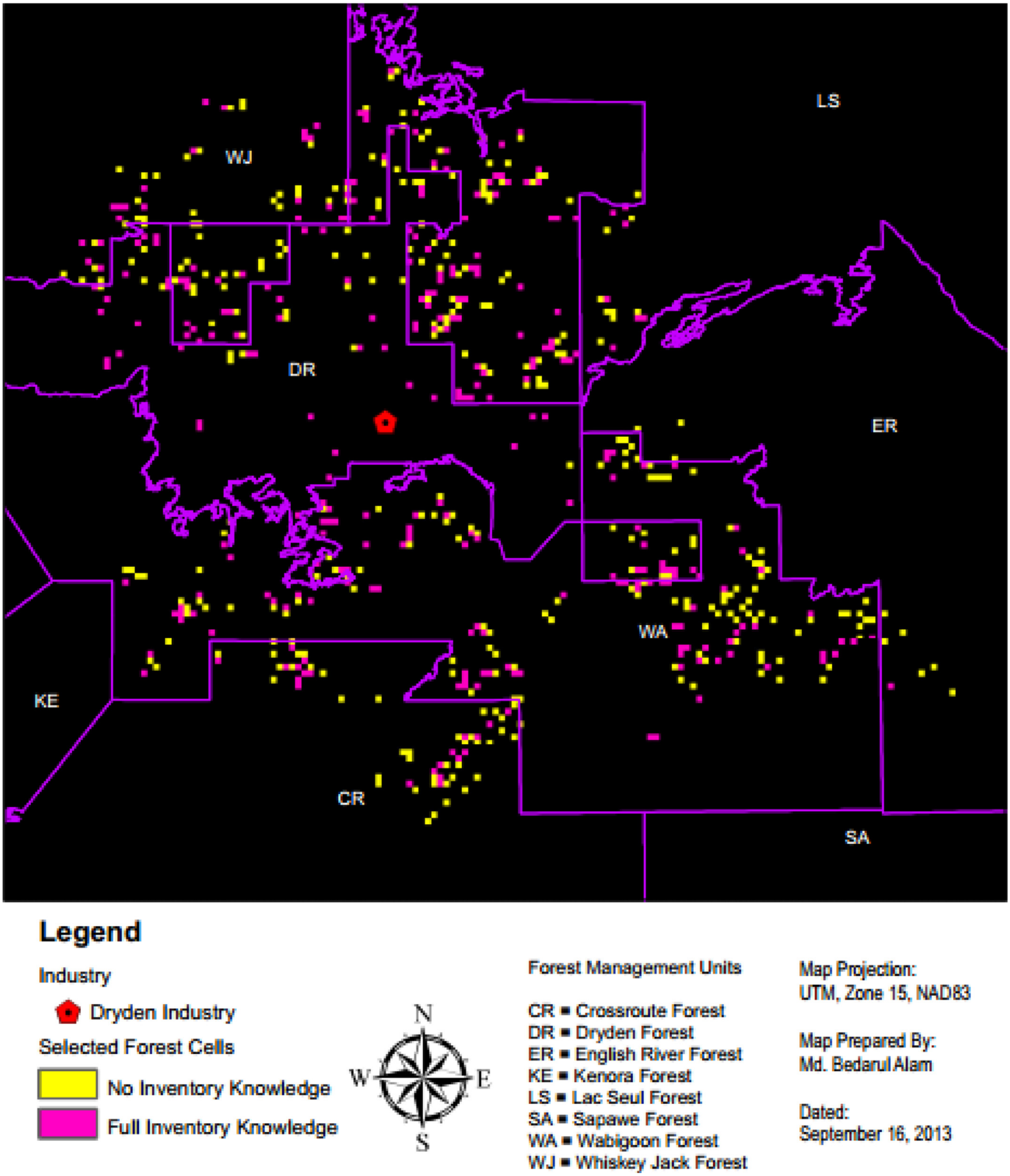

Fig. 3. Forest cells selected for supplying log grades to the forest industry over one year horizon with 50% tree quality certainty in forest inventory information.

that by incorporating a merchandizing yard and having complete inventory quality information results in an additional profit of about $4.7 million over 1 year as compared to a scenario with no quality information contained in the inventory information. Most of this profit comes from log grades (B and C), which are high in demand (Table 1).

The total profit from full inventory information does not give a complete picture of the contribution in gross profit of all log grades.

Table 3
End inventory and lost sales of log grades in merchandizing yard over one year.

Tree quality information certainty	End inventory (m^3)				Lost sales (m^3)			
	A	B	C	D	A	B	C	D
0%	624	1985	1476	1213	5431	22,912	15,950	12,340
25%	13,502	25,559	19,124	7052	2884	15,653	10,643	8580
50%	7061	20,390	15,822	4411	1798	7232	4910	4393
75%	11,595	14,321	2127	0	301	1882	1784	863
100%	0	0	0	0	0	0	0	0

Note: End inventory of a week is the beginning inventory of that week plus volume harvested in that week minus sales volume of the log grade in that week; and lost sale is the demand minus sale of the log grade in each week.

Moreover, each log grade has different supply, demand, gross profit, inventory carrying cost and lost sales cost parameters (Table 1). The per unit savings ($/$m^3$) of each log grade were, therefore, analyzed to get a better picture of the contribution of each log grade in the total profit. The per unit profits ($/$m^3$) from all four log grades in different scenarios are shown in Table 5. In comparison with zero inventory knowledge scenario (scenario 1), the full inventory knowledge scenario (scenario 5) results in the highest per unit profit (51%) for the log grade B and least (33%) for fuelwood (log grade D). The average gain in per unit profit in the complete information scenario is 57 $/$m^3$ more (49%) as compared to no information scenario (Table 5). With 100% tree quality information certainty, there is no inventory carrying cost and lost sales cost (Table 3). Therefore, complete inventory knowledge results in savings, which would otherwise be lost in carrying inventory or as lost sales.

Fig. 4 shows the percentage gross profit gain trend for different levels of tree quality information certainty. The percentage gross profit gain shows an increasing trend from 0 to 50% tree quality information certainty, after which it begins to level off.

Fig. 5 shows gross profit gain ($/$m^3$) for different log assortments at 100% tree quality information certainty. Maximum gain in gross profit with tree quality information certainty is noticed for log grade A, which is the least available (%) in the forest and the least demanded (m^3/week) by the forest industry, and has the highest gross profit per unit ($/$m^3$) (Table 1). Therefore, complete inventory knowledge results in highest profits for high value log grades.

This study clearly shows that enhanced forest inventory information in combination with a merchandizing yard in the supply chain results in significant benefits to the forest products industry. Other studies also support our claim that enhanced forest inventory and merchandizing yard have versatile advantages. Tembec Inc. is saving approximately $2.4 million per year by using enhanced inventory from 650,000 ha of Romeo Malette Forest in Ontario [27,35]. Tembec Inc. saves more than $2 million per year by using accurate information on tree size and product potential, and also saves an additional $400,000 annually by the construction of efficient and environmentally sound forest road systems based on enhanced inventory/terrain information on ground surface and

Table 5
Comparison of per unit profit for merchandizing yard from each log grade.

Scenario	Tree quality information certainty	Per unit profit ($/$m^3$)				
		A	B	C	D	Average
Scenario 1	0%	67.16	49.66	33.95	7.51	38.27
Scenario 2	25%	77.30	55.99	38.08	8.14	43.18
Scenario 3	50%	86.39	65.62	44.04	9.03	49.90
Scenario 4	75%	93.56	71.93	47.39	9.75	54.29
Scenario 5	100%	100.00	75.00	50.00	10.00	57.00

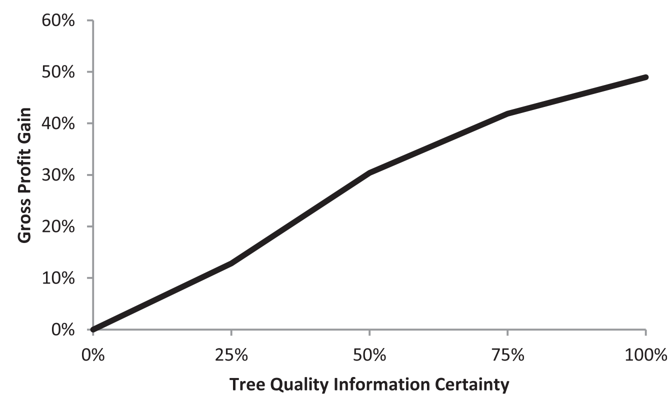

Fig. 4. Percentage gross profit gain with tree quality information certainty.

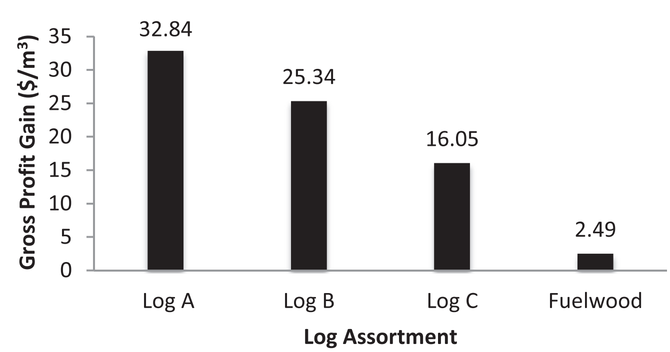

Fig. 5. Gross profit gain for log assortments at 100% tree quality information certainty.

digital elevation [37,27]. The provincial government of Quebec is saving $3 million annually by using enhanced forest inventory in production of forest maps with automatic mapping algorithms efficiently and accurately [37,27]. The Corner Brook Pulp and Paper Ltd. is saving $230,000 per year based on accurate enhanced forest inventory information in Newfoundland and Labrador [37,27]; The West Fraser Timber Co. Ltd. is using enhanced inventory to get accurate information on tree height, volume and wood properties in British Columbia and Alberta [37,27]. Therefore, taking strategic

Table 4
Total annual gross profits of the merchandizing yard for log grades.

Scenario	Tree quality information certainty	Total profit ($)				
		A	B	C	D	Total
Scenario 1	0%	1,679,110	4,965,785	2,546,370	375,387	9,566,652
Scenario 2	25%	1,932,380	5,599,257	2,856,155	407,148	10,794,940
Scenario 3	50%	2,159,690	6,561,750	3,302,640	451,659	12,475,739
Scenario 4	75%	2,338,900	7,192,733	3,554,155	487,559	13,573,347
Scenario 5	100%	2,500,000	7,500,000	3,750,000	500,000	14,250,000
Additional profit with 100% information		820,890	2,534,215	1,203,630	124,613	4,683,348

and operational business decision based on accurate enhanced forest inventory information can result in benefits to both public and private forest sectors in Canada. In order for the forest products industry to be competitive in the global markets, there has to be value addition all along the supply chain of log grades [29,39].

Both enhanced forest inventory information, containing tree quality attributes, and merchandizing yard can help in value addition in the forest products industry supply chain. In future, it is expected that more value-added forest products from small producers requiring specialized wood characteristics will develop. This means that there would be many more log assortments/grades required based on species, position in tree, fiber quality and log form. Developments in airborne laser scanning (e.g. LiDAR) will also assist in developing more detailed quality information in the forest inventories [38]. Eid et al. [14] also supported the use of LiDAR for assessing the inventory information of basal area, dominant height and number of trees per hectare from two sites in Norway, and found that laser scanning provides more precise estimates than traditional photo-interpretation methods.

This optimization model is applicable across Canada and abroad for optimizing the supply of forest products from FMUs based on forest management planning and demand for different types of forest products. This model can be used by forest product industries to make decisions based on profit maximization, and inventory carrying costs and lost sales costs minimization. However, further work on this model that includes refined tree quality data, actual transportation, harvesting and processing costs for each product, and authentic data on demand uncertainty will make this paper highly suitable for real world applications.

5. Conclusions

This study uses optimization modeling techniques to analyze the role of an enhanced forest inventory information system, containing tree quality attributes, in combination with merchandizing yards for value addition in forest products industry supply chains. Even with the simplified situation, with just four log grades, the results of the study show that by having full forest inventory knowledge of tree quality, it is possible to significantly increase the gross profit in comparison to a scenario with little or no certainty of tree quality in the forest inventory. Using a merchandizing yard and complete knowledge of an enhanced forest inventory helps maximize total value of wood fiber by allocating the right log to the right product, reduce fluctuations in raw wood fiber supply, minimize wood inventory holding costs, and reduce lost sales at mills. Both public and private forest sectors of Canada can benefit from accurate enhanced forest inventory information for taking right strategic and operational business decisions. The results of this study can be further improved by incorporating refined tree quality data, and including transportation, harvesting and processing cost for each product. Another limitation of this paper is that we do not consider uncertainty in demand, which can be incorporated in future work on this model to make it more realistic.

Acknowledgments

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