FSP Project Y051218:

Planning Methods to Reduce Costs and Enhance Value Recovery in Sustainably Managed Forests

Technical Annual Report #1:

Strategic Timber Allocation Methodology Integrating Road, Harvest, Environmental and Industrial Planning

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1. Project Objectives

- To improve the efficiency and quality of strategic planning
- To achieve integrated planning of harvest, road lay-out, industrial wood consumption and ecological imperatives
- To transfer the technology to forest and industry planners through published papers and workshops

2. Introduction and Background

This report describes the work accomplished in the first of a two year project on planning methods to reduce cost and enhance value in managed forests. The focus in the first year has been to design decision algorithms and data support systems that will allow a manager to increase his scope and efficiency in strategic planning.

Requirements to meet environmental and social criteria, as part of sustainable forest management (SFM), have greatly increased the complexity in both strategic and operational planning. At the same time, wood supply has increased world wide, preventing real long term increases in wood product prices. Therefore, forest and industry managers need to extract the maximum product value from the forest at the least possible cost. Integrated and optimized decision systems such as what have been researched and developed in this and earlier projects, offer the potential of mastering today’s complex planning environment and maximizing the value derived from converting standing trees into wood products.

2.1. Project Benefits

The decision support tool developed this year will allow forest and industrial planners to answer a number of questions relatively quickly, such as:

- predicting the effects of different silvicultural prescriptions and SFM plans on harvest and plant production
- specifically, investigating SFM scenarios, particularly the effect of varying seral stage targets on timber supply volume and log class distributions to be allocated to manufacturing plants and the resultant costs and benefits
- developing wood products manufacturing strategies that are consistent with the types of timber available given different SFM plans
- specifically, determining the optimum mix of sawmill and plywood plant technologies in response to a given timber supply projection
- gauging the overall impact of new product ideas and value added processing in the region while meeting SFM criteria
• analyzing financial issues, particularly plant up-time and operating margins in response to scenarios for product pricing, one of which might be a return to historic price levels for OSB and plywood products

2.2. State of Planning Technology

Optimization of specific areas of forestry, such as harvest scheduling, stem merchandising, and annual allowable cut determination have been approached in the past as piecemeal tasks. Manufacturing facilities have planning strategies that optimize profits from the conversion of stock in the mill yard into the most valuable mix of products. SFM planning has focused on goals at the forest level, integrating sustainable development of harvesting with ecological and social criteria. The recent interest in ecological and social criteria has relegated many timber objectives to residuals in the forest planning process, with harvesting occurring at rates and in stands specified by secondary objectives rather than specific manufacturing requirements. However, common forest-level economic indicators such as even-flow volume are too coarse to be useful in mill-level optimizations. We have in this project focused on an integrated approach that allows for the determination of where, when and how to harvest while both meeting SFM goals and specific plant timber requirements by manufacturing plants that need to supply the product market place.

The methodology developed in this project was built on research carried out by Dr. Thomas Maness in the Invermere Timber Supply Area in the period 2002-2004, in which methods to balance the timber harvest against the need to consider environmental and societal criteria were evaluated. Dr. Maness previously developed the Forest to Product Manufacturing Optimization model which have been implemented in the decision support system as part of this project (Maness and Norton 2002). Techniques developed in that work will, with modifications, be brought to bear on present research.

Also, the methodology was built on prior work by Dr. John Nelson whose timber harvest model ATLAS, A Tactical Landscape Analysis System (Nelson 2003), was evaluated, along with other similar means such as FORECAST to predict timber growth and connected to a new harvest scheduling module developed by Dr. Mark Boyland (2005).

Manufacturing optimization models are usually single objective linear programming (LP) models that maximize profit. Early models that used LP to optimize log bucking decisions are described in Mendoza and Bare (1986) and Eng et al. (1986). Maness and Adams (1991) added an embedded sawing optimization model and product demand functions to simulate the market environment. This allowed for flexible modeling of widely different sawmills. More recently an operational multi-period production planning model using LP with decomposition was developed that optimizes the flow of logs from potential harvest blocks through manufacturing and to the final customer (Maness and Norton 2002). This Forest to Product Optimization Model is used by sawmills to
plan the operational cutting cycle and schedule the production through the mill once the set of harvest blocks is determined.

Techniques for linking the *Forest to Product Optimization Model* to secondary manufacturing were added recently by Farrell and Maness 2003. This allows planners to look at the economic and environmental impacts of adding secondary manufacturing plant to the production mix. Many companies are considering this in the face of reductions in timber supply and the associated changes in raw material species, size and quality.

The *Forest to Product Optimization Model* operates on a pool of pre-approved harvest blocks. Developing a comprehensive harvest plan has been the role of a forest-level planning model such as *ATLAS* (Nelson 2003), which looks strategically at the forest and schedules the harvests to meet a wider array of objectives. Recently, planning techniques have been developed for multi-criteria optimization that have expanded forest level planning models to include goals for stand structure (Liu *et al.* 2000) as well as a complex set of SFM criteria and indicators (Maness and Farrell 2003).

These two planning functions have been executed separately in the past. Linking forest-level planning to manufacturing models is very difficult because of the enormous level of complexity and the different goals and objectives of land management and manufacturing. However, division of the planning problem into strategic, tactical and operational levels is useful because the objectives and the level of detail required are quite different in each. Hierarchical planning (HP) techniques have been developed to deal with optimization of two more subsystems at different levels of detail or temporal scales. A thorough review of HP techniques applied to forest management can be found in Weintraub and Davis (1996).

Most of the HP applications developed to date divide the planning problem spatially, for example between levels of an organization such as headquarters and division, or stands and forest level (examples are Hof and Baltic 1991, Schreier *et al.* 1993, Palander 1997). Jamnick and Robak (1996) describe an integrated forest planning system that looks at tactical and operational decisions that sequentially optimize decisions made in selecting harvest areas, building harvest blocks, and planning harvest operations. Ogweno (1994) also developed a 3 level hierarchical planning model for the production of logs. These models do not find global optimal solution to the overall problem as they operate in one only direction - from the top down. Paredes (1996) describes a mathematical framework for a two level HP model that could be used to solve such problems to optimality by passing dual values between the two levels, but did not actually develop the model.

Solving these large problems can be a very challenging problem. Research in the field of operations research has led to specialized linear, integer and dynamic programming techniques to find the optimal solution for such large problems. Simulated annealing offer heuristic optimization techniques that have
been used to find solutions very close to the optimal in similar projects (Boyland 2003a, 2003b) and were explored for this project.

2.3. Fort Nelson Timber Supply Area

Canadian Forest Products Ltd. in Fort Nelson, B.C., meets all its timber requirements from the Fort Nelson Timber Supply Area (TSA). This TSA has a total productive Crown forest land base of 5.6 million ha and a current timber harvest land base of 1.4 million ha with a tree species inventory of about 280 million m$^3$ (Niziolomski 2004). Anderson (2005) and Boyland (2005) implemented a substantial and largely automated data reduction to create a feasible set of road links and harvest units for the purpose of planning roads, harvests and industry timber consumption for periods from one to 30 decades into the future.

The approximate consumption of timber by the Canfor sawmill, plywood and OSB plants in Fort Nelson adds up to about 1.5 million m$^3$ per year, of which about 60% is Aspen. The sawmill processes small-diameter conifers, the plywood plant peels large-diameter, sound conifers and aspen, and the OSB plant consumes all other scaled volumes.

3. Methodology

The description below of our strategic integrated planning approach start with general block diagrams to show how the model components interact both as data-flows and as maximum-value search processes. This is followed up by documentation of each component. The documentation of work in sections that are supported by a separate technical report is relatively general.

The concept of wood product value brought back to the tree stump to impact on forest stand value is an essential component in the methodology that follows. The section on tree quality classes describes how tree value properties, such as branches and rot, have been used to define tree classes. The section on log classes describes how log grades are defined. Log classes, in turn, are linked to wood product size and grade distribution determined through processing models. In this project, each harvest unit in the forest is assigned a marginal value derived from the processing of its tree and log classes into veneer, lumber and OSB products. These marginal values drive the processes that allocate log volumes to manufacturing plants.

3.1. A Strategic Integrated Planning Framework

Figure 1 shows how the major dataflow components of the framework interact. The pre-processing models are what make the optimization feasible within a reasonable time period. For example, product grade distribution within each log class is assumed not to change materially with sawing patterns; thus, there is no need to saw repeatedly each log class with respect to product grade as marginal lumber prices change. Likewise, by assuming that an overall road
lay-out for the TSA is acceptable for strategic analyses spanning decades, there is no need for infinitely variable road paths weighed by proximity to old growth harvest units. This is particularly true when we look ahead to analyzing the optimum construction of permanent roads of a higher class that will end up serving most of the TSA in the future, versus the annual rebuilding of winter roads.

Figure 1. Major Process Activities in the Integrated Planning Framework

Figure 2. Harvest, Road and Plant Process Overview
Figure 2 shows the iterative approach to reaching the optimum harvest and allocation to manufacturing plants. An iteration of the process creates a new marginal dollar value per hectare for every HU in the TSA. Initially, the value per hectare may lead to harvest volumes that are lower than plant capacities. Thus, the marginal values of these particular log types will increase and drive the harvest solution towards HUs with more volumes that fill the gap. Likewise, as wood product demands are not met initially, the marginal prices for these products will increase and, in turn, increase the value of log classes that fill the product volume gap, thus impacting on tree merchandising and log class allocation to plants.

Data from the process activities enters the objective function for the optimization. This objective function represents the standard overall business result from manufacturing the allocated timber volumes into forest products. The objective function value has been proven in the past (Maness and Farrell, 2003) to steadily increase to a maximum as the HU selection and log allocation improves.

3.2. Harvest Units: The Polygon Aggregation Approach

Project Report #2 (Boyland 2005, pp 7) describes briefly this method and refers to a more detailed publication for aggregating polygons into harvest units (HUs) in which fuzzy simulated annealing is described in more detail (Boyland and Nelson 2005). A more accessible publication is Polygon Aggregation and Generation of Harvest Units with Fuzzy Sets and Simulated Annealing prepared for FII Project R04058 (Boyland 2004). The method is flexible in its application in that each HU indicator, such as size, shape, age, harvest method, etc., may be given stepwise linear values across the indicator value range. For example, if the spruce rotation age is 90 years, then all spruce polygons of an equal and older age may be given the maximum value of 1.0 whereas younger spruce polygons would be given a lower value, say 0.5 at age 70 and 0.0 at age 60. This would drive the polygon aggregation algorithm towards a stand consisting of age 90 and older while accepting adjacent younger polygons if those, in turn, would create a bridge to new and older polygons. Simultaneously, adjacent younger polygons would aggregate into their own uniform HU and “compete” for boundary polygon so as to increase their area. This process has been found to be a reasonable way of creating a workable HU-set.

3.3. Forest Growth Analysis

Dr. Brad Seely authored Technical Report #4: Projection of temporal sequences of stand table data for analysis units within the Fort Nelson TSA, utilizing the FORECAST model. FORECAST works on defined analysis units and Dr. Seely obtained the Analysis Unit (AU) definitions from Forest Ecosystem Solutions Ltd., a company contracted by Canfor to develop basic data for the Fort Nelson timber supply review (TSR3). Species growth for each AU was tabulated
to show projected dbh distribution and average tree height for natural and managed stand ages ranging from zero to 300 years.

Each species in each polygon in each HU was assigned an AU identifier that allowed the retrieval of expected stand volume at any harvest age for use by the harvest/road scheduler. Once harvested, the new stand was set to a managed stand with slightly higher growth rate for the next rotation.

3.4. Tree Class Definitions

The number of combinations of wood species, dbh, tree height, branch morphology and biological defects for trees in a forest is infinitely high. For this reason, it became necessary to classify trees so as to obtain a manageable number of classes for the purpose of predicting product outturns.

The AU data from the FORECAST runs classify trees based on species, ten-year age classes and five cm dbh classes, and each dbh class has an average tree height. Additionally, we have added the following to represent tree quality:

- Clear surface area class (with attendant branch data)
- Rot class (rot with attendant stain or no rot)

These tree size and quality factors were used to generated a tree data set for each tree class and were carried forward through log merchandizing, mill bucking and product manufacturing resulting in product outturns described by standard grades.

The dbh distribution in a forest stand is mostly the result of an unknown stand density history. Therefore, we have assumed that the tree class quality distribution by dbh for a given species and age class is constant for the entire TSA. The prohibitive cost of sampling prevented us from gathering extensive data representative of the TSA and to verify or reject this assumption. However, we sampled sufficient data to demonstrate the application of the tree class concept and use of the data in the model.

Figure 3 shows an example of a spruce tree generated with live and dead branches, rot and stain. Diameters were drawn every 100 mm of tree height (26 m) and flows taper equation for white spruce. Branch (knots), rot and stain generation are described below. The tree is straight with circular cross sections. Trees may also be generated with real shape data; however, we have not, as of yet, sampled trees to determine out of round cross sections, the extent of pistol grip butts, and incidents of sweep and crook. However, our observations from the ground were that the spruce trees in the regions were generally straight.
3.4.1. Clear surface area class and branch data estimation

We defined tree clear surface area classes (CC0, CC1, and CC2) as CC0<25%, 25%<=CC1<=50%, and CC2>50% as calculated for the first 10 meters of stem height starting at the stump. We sampled a total of 83 spruce trees at an estimated stand age of 150 years and 50 aspen trees at an estimated stand age of 90 years, determined the “south” and “north” side of each tree and estimated the visible branch data listed below. The “south” and “north” side should be understood to mean the opposite sides of the tree that have, over time, had the least and most self-pruning, respectively, and do not necessarily refer to compass directions.

- Height above stump for the first dead branch to the “south”
- Diameter of the first dead branch to the “south”
- Height above stump for the first live branch to the “south”
- Diameter of the first live branch to the “south”
- Height above stump for the first dead branch to the “north”
- Diameter of the first dead branch to the “north”
- Height above stump for the first live branch to the “north”
- Diameter of the first live branch to the “north”

This data served to calculate the tree clear class as the average of north and south dead heights divided by ten. As well, the average branch data by tree
clear class were calculated and used to populate each tree clear class with dead and live branches. The measurements clearly indicate that “south” side branches are closer to the ground (by definition) and have the larger diameter for the same height in the tree.

Table I. Spruce Branch Data by Tree Clear Class (Heights in meters; diameters in inches)

<table>
<thead>
<tr>
<th>Clear Class</th>
<th>Dead South Height</th>
<th>Dead South Diameter</th>
<th>Live South Height</th>
<th>Live South Diameter</th>
<th>Dead North Height</th>
<th>Dead North Diameter</th>
<th>Live North Height</th>
<th>Live North Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC0</td>
<td>0.3</td>
<td>0.5</td>
<td>11.4</td>
<td>1.3</td>
<td>1.0</td>
<td>0.4</td>
<td>14.6</td>
<td>1.0</td>
</tr>
<tr>
<td>CC1</td>
<td>2.3</td>
<td>0.5</td>
<td>13.6</td>
<td>1.6</td>
<td>4.6</td>
<td>0.5</td>
<td>15.6</td>
<td>1.3</td>
</tr>
<tr>
<td>CC2</td>
<td>4.5</td>
<td>0.5</td>
<td>14.7</td>
<td>1.8</td>
<td>9.2</td>
<td>0.7</td>
<td>17.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table II. Aspen Branch Data by Tree Clear Class (Heights in meters; diameters in inches)

<table>
<thead>
<tr>
<th>Clear Class</th>
<th>Dead South Height</th>
<th>Dead South Diameter</th>
<th>Live South Height</th>
<th>Live South Diameter</th>
<th>Dead North Height</th>
<th>Dead North Diameter</th>
<th>Live North Height</th>
<th>Live North Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC0</td>
<td>1.3</td>
<td>0.9</td>
<td>10.0</td>
<td>2.1</td>
<td>1.4</td>
<td>0.7</td>
<td>11.0</td>
<td>1.8</td>
</tr>
<tr>
<td>CC1</td>
<td>3.0</td>
<td>0.7</td>
<td>11.5</td>
<td>2.8</td>
<td>4.2</td>
<td>0.7</td>
<td>13.2</td>
<td>2.1</td>
</tr>
<tr>
<td>CC2</td>
<td>9.2</td>
<td>1.0</td>
<td>11.5</td>
<td>2.8</td>
<td>14.0</td>
<td>1.1</td>
<td>21.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Dead and live branch diameters were assumed to decrease linearly with tree height between the “south” and “north” side. Spruce nodal radial locations in the tree were allocated to one of sixteen cross-section “pies” selected at random within each of five or six sectors of the cross section, respectively. The nodal location along stem height followed a growth curve with single, inter-nodal branches located every 10 cm. Aspen branches were selected at random radial orientation and limited to one major branch at the base of each annual increment with a second branch located 10 cm below the first.

Branch lengths were determined following the equation \( y = b x^2 \), where \( x \) is height from the ground or the top and \( y \) equals branch length. The coefficient \( b \) was estimated for each “pie” from the ground both to the dead branch height and live branch height, and from the top of the tree down to the bottom green branch. All branch lengths at their respective branch heights were clipped by tree radius. Thus, overgrown “live” knots would have a “live” length followed by an overgrown dead tip.

Branch diameter was estimated in the same manner, but given a minimum value of three mm (pin knot).

As we did not have the tabulated branch values for the range of age classes represented in this planning model, we used an increment of 0.1 meter.
per year for the advance of self pruning on the “south” side and 0.2 meter per year on the “north” side and a value of 0.01 cm per year for the changes to branch diameters to generate Tables I for each ten-year age-class between 60 and 300 years. The aspen data in Table II change only between 60 and 90 years.

The collected data showed the following distribution of trees by dbh and clear class after linear smoothing by dbh class:

Table III. Tree volume distribution by dbh and tree clear classes, %

<table>
<thead>
<tr>
<th>Dbh Class, cm</th>
<th>Spruce, Age=150</th>
<th></th>
<th></th>
<th>Aspen, Age=90</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC0</td>
<td>CC1</td>
<td>CC2</td>
<td>CC0</td>
</tr>
<tr>
<td>15</td>
<td>85</td>
<td>15</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
<td>20</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
<td>22</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
<td>24</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>35</td>
<td>65</td>
<td>26</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>28</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>45</td>
<td>55</td>
<td>30</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>32</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>55</td>
<td>45</td>
<td>34</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>36</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>65</td>
<td>35</td>
<td>38</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>0</td>
</tr>
</tbody>
</table>

The volume distribution in Table III was modeled to change linearly with time for all dbh classes: At age class 60, the spruce distribution for dbh-class 15 is 100% CC0, and at age-class 200, dbh-class 50 is 0, 67 and 33 for CC0, CC1 and CC2, respectively.

3.4.2. Rot probabilities, rot diameter and stain

A small data sample taken from a logged cut-block yielded the following relationships between heart rot diameter (RD) at the stump and estimated dbh;

\[
RD = 0.010344426 \times \text{dbh} \times \text{dbh} \text{ (spruce)}
\]

\[
RD = 0.007613 \times \text{dbh} \times \text{dbh} \text{ (aspen)}
\]

An accurate representation of rot distribution in the Fort Nelson TSA will require substantial additional research and not part of this project. However, as rot is prevalent in the wood supply and not recorded in any forest database, we modeled its shape in trees with rot according to the function:
RH = bRot * RD * RD, where RH equals rot height in the tree measured from the ground.

As the extent of rot up the tree will increase with rot diameter, we made the assumption that rot height will increase with RD from 3m to 18 m for spruce and 6m to 24 m for aspen for RD values ranging from 10cm to 100 cm. The coefficient bRot was calculated as bRot = b0 + b1 * rotRadius, where b0 = 357 for spruce and 726 for aspen, and b1 = -570 for spruce and -1260 for aspen. Finally, we imposed the condition that sound wood shell thickness would be greater or equal to the sound wood shell at dbh.

Presently, the frequency of rot was modeled with two percent for trees of dbh class 15 increasing to 12 percent for dbh class 70. These data need to be investigated further to estimate values representative of the range of Analysis Units in the TSA. For example, observations by Canfor staff suggest that mixed aspen and spruce stands have a higher incident of rot compared to single species stands. Rot originating through a branch and extending vertically, but not showing as heart rot at the stump, was not modeled.

Generally, all rot was accompanied by a band of stain about five centimetres in width.

3.5. Road Planning

Axel Anderson, a former M.Sc. student of Dr. John Nelson, prepared the strategic network projection utilizing software he developed for his thesis work. He wrote Technical Report #3: Strategic Road Network Projection, included in the project report packet. It describes the strategic network projection methodology.

Axel’s work was built on the GIS database prepared by Katie Maness (2005). The database used in this project represented a subset of the GIS database assembled by Forest Ecosystem Solutions Ltd. for the purpose of a TSR3 review started in 2003. A significant part of Katie’s work was to filter the database and assign an Analysis Unit ID (AU) to each polygon so that a population of trees distributed by DBH classes could be retrieved by a log merchandising program should a particular polygon be selected for harvesting. Map contour and built road data were obtained directly from Canfor’s forestry office in Fort Nelson.

Axel’s computer program generated road segments from Fort Nelson to within 1000 m of a central point of each Harvest Unit (HU) as generated by Boyland (2005). Each HU object included the end road segment ID from the road segment data, the road distance to the mill and a pointer to the next road segment towards the mill. Should the HU be selected for harvesting in a particular year, the necessary road segment that would have to be built that year or had to have been built in a earlier year, could then be retrieved along with both construction and maintenance cost.

Upon the completion of the analysis, the estimated road location, construction cost and maintenance cost may be displayed for any time period.
3.6. Combined Road and Harvest Planning

Dr. Mark Boyland modeled the combined road and harvest planning algorithm utilizing a simulated annealing technique. He authored Technical Report #2 which describes the details of his approach.

The objective of combining road and harvest planning is to maximize “value” of the harvest for a set time period, which in this model might be as high as 300 years, and across any number of defined indicators for which there are data in the GIS database. “Value” is represented by a score which is the sum of values of each individual indicator included in the model. Examples of such indicators are profit, total harvest volume, seral stage areas, adjacency and wildlife. Each indicator has a target value and an achievement percentage. The achievement percentage serves as input to retrieve an indicator score from the indicator membership function. This membership function, in turn, is a defined stepwise linear function which generally awards 1.0 for 1.0 achievement and lower values for achievements above and below the target. Thus, one might give a 1.0 value for harvest volumes ranging from 100% to 110%, but a 0.0 value for harvest volumes ranging from 0% to 99%.

Each indicator also has a weight variable to allow the analyst to assign an importance factor. For example, in the not too distant past, the analyst would assign 1.0 to profit and harvest volume and zero to all other factors. Today, given strict limits on some environmental indicators, profit and harvest may be assigned lower values and some ecological indicators assigned 1.0.

The overall score becomes the sum of weight times the indicator membership function value for all indicators across the set time period. Presently, future scores carry equivalent weights to today’s score. This may have unintended consequences in that a solution may show that today’s harvest should be reduced such as to better meet environmental and economic requirements in the future. The analyst needs to be careful about setting weights to prevent this. We will continue to research techniques to discount future scores relative to present scores so as to ensure that any reduction in harvest volumes and economic activity comes gradually in future years as opposed to a present day shock.

The simulated annealing technique flips harvest units in and out of an overall solution in a random fashion to maximize the score value. Each time a harvest unit is included in or excluded from the solution, the roads required to haul the timber is also evaluated and updated. As roads in the TSA are generally winter roads, the total annual road construction or maintenance costs are adjusted and deducted from the total annual net harvest value to represent achieved profit value. This discourages the building of roads into far flung corners of the TSA unless large volumes of timber are also harvested along the haul route to leverage the road cost.
3.7. **Log Class Definitions**

The definition of log classes allows the value of a short log alternative located anywhere in any tree to be retrieved from a pre-calculated database. The only determination required is to identify the class to which the log belong, i.e. grade the log characteristics against a set of log grade class properties.

The model contains two sets of log classifications: Long logs manufactured in the cut-block or at the landing that may need further bucking at the mill and short logs manufactured from long logs at the mill. OSB logs manufactured in the bush need no further bucking and the short log specifications equal those of the long log; long saw-logs and peelers may contain two or three short saw-logs or peelers, respectively. Long logs have species, log type, diameter and length specification; short-logs have additional grade specifications for grade factors such as knots, rot and percentage clear fibre to determine a short log grade for both peelers and saw-logs. These grades correspond roughly to coastal log grade definitions. Each graded log is also classified by a two-centimetre diameter class and a ten-centimetre length class.

Table IV shows the peeler and Table V the saw-log log grade specifications.

### Table IV. Peeler Grade Definitions

<table>
<thead>
<tr>
<th>Peeler Grade</th>
<th>Clear Veneer Volume, %</th>
<th>All Species Clear Depth (% of Radius)</th>
<th>Max Knot Diameter, mm</th>
<th>Conifers Max Rot Diameter, mm</th>
<th>Deciduous</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
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<td>25</td>
<td>9999</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
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<td>25</td>
<td>13.4</td>
<td>9999</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>H</td>
<td>0</td>
<td>0</td>
<td>12.7</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>63.5</td>
<td>100</td>
<td>25</td>
</tr>
</tbody>
</table>

### Table V. Saw Log Grade Definitions

<table>
<thead>
<tr>
<th>Saw Log Grade</th>
<th>Minimum Log Diameter, cm</th>
<th>Clear Lumber Volume, %</th>
<th>Minimum Clear Depth, mm</th>
<th>Max Knot Diameter, mm</th>
<th>Max Rot Volume, %</th>
</tr>
</thead>
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<td>179</td>
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<tr>
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<tr>
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<td>0</td>
<td>9999</td>
<td>50</td>
</tr>
</tbody>
</table>
3.8. **Tree Merchandising**

The objective of tree merchandising is to maximize the value of valid log length combinations in the tree given a set of short log class values while allocating the total annual harvest to manufacturing facilities. The model searches for a combination of peeler, saw log and OSB log lengths that maximizes value. Each log length derives its value from the product values that may be recovered from its short log classes. As the search progresses from the butt end towards the top, utilizing a two level nested dynamic programming technique, each valid consecutive length alternative is added to its search branch and the corresponding tree segment graded to determine the log classes contained within that length. Should two search branches consume the same tree length, the lower value branch is pruned from further search up the tree. When reaching the tree top, the search branch with the cumulative highest value contains the set of consecutive lengths that will be allocated to their designated manufacturing plants.

3.9. **Optimum Plant Allocation**

The plants sharing the wood basket compete for the logs that maximize the plant profit. Some log classes produce higher Return to Log (RTL) value in one plant than in another; other classes might be acceptable to only one plant and must be consumed or chipped by that plant. In this model, the RTL value for a log class is calculated based on the sum of recovered product volume multiplied by the marginal product value less manufacturing cost.

It follows from the above, that marginal RTL values will increase for plants starved for wood, as well as increase for log classes that generate products required for meeting sales targets and that contributes more than others towards maximizing revenue. In this model, the evaluation of a given wood supply iterates between maximizing the recovered value from each log class through process models, given the marginal product prices, and merchandizing the tree classes, weighed by their volume representation, to arrive at a new log volume distribution between plants. Usually, the generated profit from this iterative analysis will peak after four or five iteration.

The final marginal RTLs from this iterative process results in new values for all Harvest Unit and the harvest/road optimization starts anew. This primary iteration between the forest and manufacturing complex and the secondary iteration between tree merchandising and plant processes continue until the overall maximum profit for the combined forest and plants have been reached. The optimum schedule of harvest and roads and the allocation of log volumes to plants have then been achieved.

4. **Discussion and Conclusions**

The model presented in this report contains a number of new features compared to recent past large scale modeling work in SFMP:
• Two level optimization between harvest/road scheduling and log allocation to manufacturing plants
• Use of simulated annealing to generate harvest units and harvest scheduling
• Branch and rot patterns assigned to tree and log class
• Log sawing and peeling models that consider defects in logs in determining product outturns

The model has been tested in all its parts, but not yet validated. We will attempt to do so in the second year of the project. As well, the formulation of tree defects across the forest analysis units as described here must be considered highly experimental and imprecise until additional data can be collected to test the model assumption.

Next, we intend to validate and calibrate the model through the recreation of the 2003/04 harvest and compare the actual and predicted product outturns. This would represent the base case run. Thereafter we will proceed with the definition of analyses scenarios to document how the model responds to changing SFM and business related conditions.

5. Recommendation

Canadian Forest Products Ltd. should consider investing more in characterizing the forest resource. This might be accomplished at a relatively low cost if cut block cruisers collected and stored the tree measurements used herein under their polygon/analysis unit ID and added a cut block stump survey of rot frequency and size.

6. Literature


