FSP Project Y062218:

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

Final Report:

Strategic Timber Allocation Integrating Road, Harvest, Environmental and Industrial Planning: Methodology and Estimated Base Case and Scenario Results for OSB, Plywood and Sawmill Operations

Prepared for:
Canadian Forest Products Ltd., Fort Nelson Division

Author:
Thomas Maness and Catalin Ristea
University of British Columbia

Date:
October 2006

TABLE OF CONTENTS

List of Tables

List of Figures

1. Project Objective

To improve the efficiency and quality of strategic planning by:

1. developing models for integrated planning of harvest, road lay-out, industrial wood allocation and ecological constraints
2. testing the log allocation and process models at Canfor's Fort Nelson Division
3. transferring the technology to forest and industry planners through published papers and workshop

Note that the testing activity used fictitious data with the base case closely corresponding to 2005 relative values. Therefore, the test results serve to demonstrate the model functions, not the actual planning results from utilizing the most accurate data for this Canfor division. As well, we did not compare the financial results from the analyzed strategies as we used assumptions and methodology that possibly would differ from those of Canfor.

We refer those seeking a relatively short summary of the technical advancements achieved in this work to Section 5, General Discussion and Conclusions.

2. Introduction and Background

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.

This report describes the work accomplished over a two year project on planning methods to reduce harvest and product manufacturing costs and enhance value in managed forests. The focus in the first year was to design decision algorithms and data support systems that would allow a manager to increase his or her scope and efficiency in strategic planning. The foci in the second year were to complete design and testing work that had fallen behind schedule in the first year and to apply the methodology in a set of strategic analyses that would illustrate the functionality of the models.

2.1. Project Benefits

The decision support tools developed in this project will allow forest and industrial planners to:

1. predicting the effects of different silvicultural prescriptions and SFM plans on harvest and plant production
2. 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
3. developing wood products manufacturing strategies that are consistent with the types of timber available given different SFM plans
4. determining the optimum mix of sawmill and plywood plant technologies in response to a given timber supply projection
5. gauging the overall impact of new product ideas and value added processing in the region while meeting SFM criteria
6. 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

Section Four of this report shows results from experiments designed to demonstrate these benefits.

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 (SA) 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. As discussed in Section Three of this report, we encountered problems with the SA technique, and set out, in the second year of the project, to modify our approach. We did not fully achieve a workable modification.

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 for the entire timber harvesting area.

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. Forest products are characterized by unit value that to a great extent increases with product quality, i.e. grade designation. Furthermore, volume demands also vary with product grade. Therefore, forest stand value varies by product and product grade as much by stocking volume. Likewise, manufacturing plants generate product specifications by species and sizes which, in turn, constrain the log volumes acceptable to a specific plant.

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 value derived from the processing of its tree and log classes into veneer, lumber and OSB products. These 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.

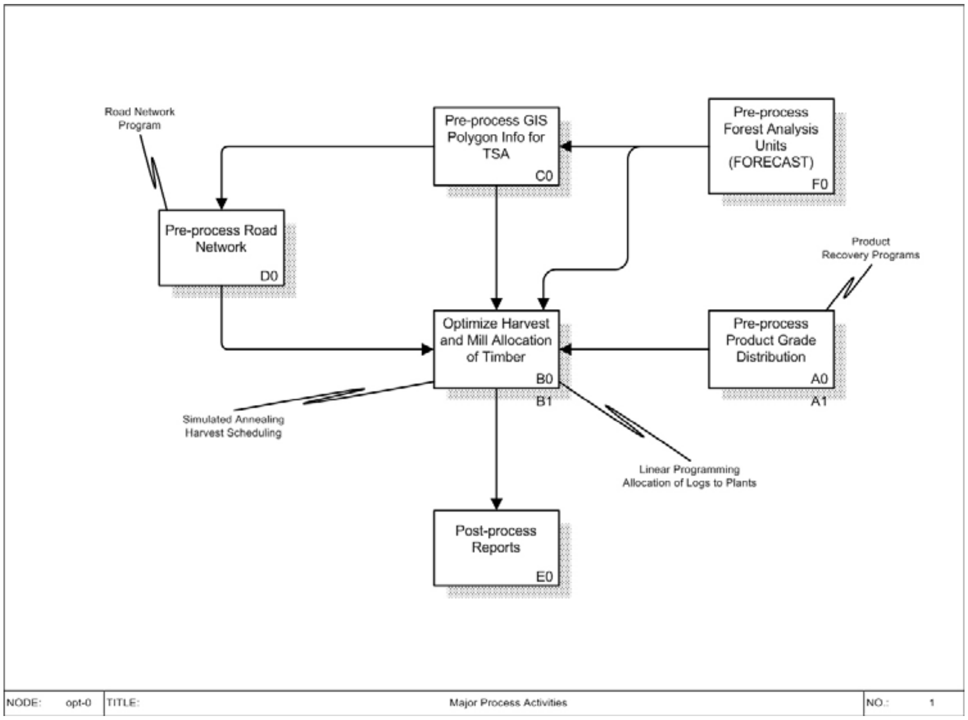

Figure 1. Major Process Activities in the Integrated Planning Framework

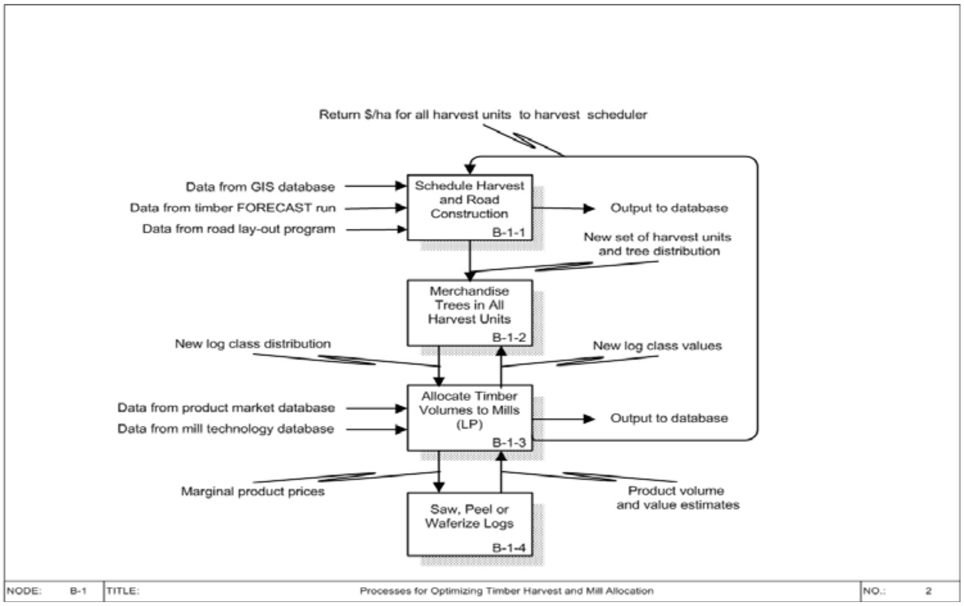

Figure 2. Harvest, Road and Plant Process Overview

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.

Technical Report #1 (Aune and Maness, 2005) describes this process in more detail.

The above approach did not work as planned due to the unconstrained initial selection of harvest units by the Simulated Annealing algorithm. Section 3.6 describes this problem in more detail.

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 FORECAST 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 defined branch data)
- Rot class (rot with defined stain or no rot)

These tree size and quality factors were used to generate 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.

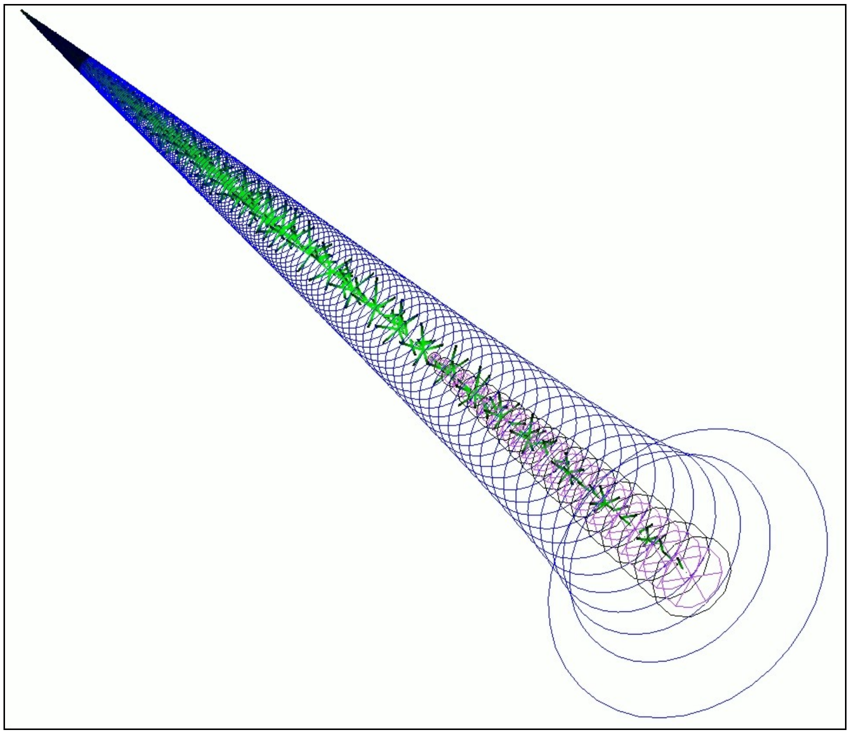

Figure 3. Example of a computer generated tree

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.

1. Height above stump for the first dead branch to the “south”
2. Diameter of the first dead branch to the “south”
3. Height above stump for the first live branch to the “south”
4. Diameter of the first live branch to the “south”
5. Height above stump for the first dead branch to the “north”
6. Diameter of the first dead branch to the “north”
7. Height above stump for the first live branch to the “north”
8. 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 1. Spruce Branch Data by Tree Clear Class

Clear Class	Dead South Height	Dead South Diameter	Live South Height	Live South Diameter	Dead North Height	Dead North Diameter	Live North Height	Live North Diameter
	[m]	[in]	[m]	[in]	[m]	[in]	[m]	[in]
CC0	0.3	0.5	11.4	1.3	1.0	0.4	14.6	1.0
CC1	2.3	0.5	13.6	1.6	4.6	0.5	15.6	1.3
CC2	4.5	0.5	14.7	1.8	9.2	0.7	17.5	1.5

Table 2. Aspen Branch Data by Tree Clear Class

Clear Class	Dead South Height	Dead South Diameter	Live South Height	Live South Diameter	Dead North Height	Dead North Diameter	Live North Height	Live North Diameter
	[m]	[in]	[m]	[in]	[m]	[in]	[m]	[in]
CC0	1.3	0.9	10.0	2.1	1.4	0.7	11.0	1.8
CC1	3.0	0.7	11.5	2.8	4.2	0.7	13.2	2.1
CC2	9.2	1.0	11.5	2.8	14.0	1.1	21.5	2.3

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 Table 1 for each ten-year age- class between 60 and 300 years. The aspen data in Table 2 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 3. Tree volume distribution by dbh and tree clear classes [%]

Dbh Class [cm]	Spruce, Age=150			Aspen, Age=90		
	CC0	CC1	CC2	CC0	CC1	CC0
15	85	15	0	11	42	47
20	80	20	0	10	40	50
25	75	22	3	9	38	53
30	70	24	6	8	36	56
35	65	26	9	7	34	59
40	60	28	12	6	32	62
45	55	30	15	5	30	65
50	50	32	18	4	28	68
55	45	34	21	3	26	71
60	40	36	24	2	24	74
65	35	38	27	1	22	77
70	30	40	30	0	20	80

The volume distribution in Table 3 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 logged cut-blocks yielded the following relationships between heart rot diameter (RD) at the stump and estimated dbh;

$$RD = 0.010344426 * dbh * dbh \text{ (spruce)}$$

$$RD = 0.007613 * dbh * dbh \text{ (aspen)}$$

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 member ship 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 harvest 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.

The intent with this profit function was to discourage 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. This did not work out due to the randomness of the SA technique, which, early in the selection process would allow HU selection all over the landscape. The cost of road construction across substantial distances would then be paid for by the first HU. Subsequent HU selections close to the first one would then be very profitable as road cost would be very low. This resulted in clusters of HU selections all over the landscape and a higher than normal road cost in the first few years of the analysis period. Regrettably, project time ran out before we could remedy this anomaly. However, the average un-discounted road cost over a 20-year period came reasonably close to actual road cost for 2005.

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 specifications; 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 BC log grade definitions. Each graded log is also classified by a two-centimetre diameter class and a ten-centimetre length class. Log grade definitions are shown in Table 4 for peeler logs and in Table 5 for the saw logs.

Table 4. Peeler Grade Definitions

	All Species			Conifers	Deciduous
Peeler Grade	Clear Veneer Volume	Clear Depth	Max Knot Diameter	Max Rot Diameter	
	[%]	[% of radius]	[mm]	[mm]	
D	50	25	9999	100	25
F	25	13.4	9999	100	25
H	0	0	12.7	100	25
I	0	0	63.5	100	25

Table 5. Saw Log Grade Definitions

Saw Log Grade	Minimum Log Diameter, cm	Clear Lumber Volume, %	Minimum Clear Depth, mm	Max Knot Diameter, mm	Max Rot Volume, %
	[cm]	[%]	[mm]	[mm]	[%]
D	61	50	179	25.4	0
F	51	25	78	25.4	25
H	38	0	0	63.5	50
I	38	0	0	101.6	50
J	10	0	0	63.5	50
U	10	0	0	152.4	50
Y	10	0	0	9999	50

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 preceding 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 processed 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 iterations.

The original intent, as described earlier, was to use the final marginal RTLs from this iterative process to calculate new values for all Harvest Unit and to start anew the harvest/road optimization. This primary iteration between the forest and manufacturing complex and the secondary iteration between tree merchandising and plant processes would continue until the overall maximum profit for the combined forest and plants had been reached. The optimum schedule of harvest and roads and the allocation of log volumes to plants would then be achieved. This scheme did not work as intended, primarily due to the simulated annealing process not being sufficiently responsive to changes in marginal tree class values. Instead, the harvest solution was determined by sum of tree class RTTs (Return To Tree) as the weight for HU Net Revenue.

4. Results

4.1. Study Problems

There are a number of problems related to the one to one comparison of model and real life production data. Most such problems can be solved whereas some, such as tree quality, would require extensive further studies to obtain accurate data.

4.1.1. Raw material volume input

Generally, mills have insufficient data describing the raw material consumed in any given period. Records may show consumed and produced volumes at each mill and perhaps the short log volume distribution by diameter classes, but data that relate log classes to product grade outturns are generally not available. Furthermore, there is overlap in species consumption and diameter classes between plants and no log yard records are present that describes input volumes to plants by species, log grades and diameter distributions. Finally, there is no audit trail that leads back to forest cut blocks apart from the total volume records from truck scaling.

As specific input/output studies along the log supply chain are expensive, the WoodFlow model includes adjustment factors that reconcile specific inputs and outputs. Plan product volume recovery is generally also used in the OSB model, and model log throughput in all plants is adjusted by the respective downtime percentage to equal plan log throughput.

4.1.2. Raw material quality

Data that describes log quality are generally not available. WoodFlow sampled a number of spruce and aspen trees for quality indicators and applied those data to tree classes in estimating lumber and veneer grade outturns. The sample may have been too small to represent the variability in the resource across the TSA in which case the value recovery in the model would differ from the actual value recovery in the plant. An approximation of reality may be obtained from adjusting the relative volumes of tree classes in the TSA. However, theses tree classes are presently applied equally to all forest Analysis Units and adjustments were not done for this base case calculation. The long term solution to this particular problem is to cruise all new cut blocks for quality parameters as specified for the WoodFlow model, thus slowly accumulate quality data by tree classes and Analysis Units.

4.1.3. Model Optimization

It is the purpose of the model to optimize the cut block selection and log volume allocation to plants whereas the plants most often do not work in their optimal state. This will lead to an overestimation of operating profit by the model relative to the base case. The profit difference can usually be reconciled by recognizing and adjusting the underlying fundamental factors.

All data reported in this section are manufacturing operating estimates and, in case of costs, exclusive of overhead, depreciation and special items.

4.2. Scenario Analysis

The following seven scenarios were conducted in the strategic analysis:

Scenario 1 (base case):

- The harvest and allocation models were run for 20 years into the future. The purpose of this scenario was to calibrate the model to reproduce the actual activity of Canfor's operations as per year 2005
- The sawmill plan was set to consume about 190,000 m^3 of conifers annually.
- Plywood consumed 539,000 m^3 with about 413,000 conifers and 126,000 deciduous, according to the plan
- OSB consumed a total of 910,000 m^3 including plywood cores. Plan for OSB product volume was 650,000 Msqft3/8
- Total log volume delivered to plants was approximately 1,598,000 m^3. This figure represents only the actual delivered log volume, after breakage and other logging operations losses. The actual target volume of harvested timber will be somewhat higher - 1,670,000 m^3 (1,035,000 deciduous and 635,000 coniferous).

Scenario 2 (improved sawmill):

- The objective of this scenario was to analyze a modern sawmill replacement. Grade recovery data were rerun to cover increased diameters to sawmill; OSB and plywood same as for scenario 1; time horizon was 20 years
- Sawmill data:
    - Two lines: DDM-6 and canter/quad operating as a 10-foot stud mill for two shifts per day
    - Sawmill log volume 700,000 m^3 of conifers, an increase of 510,000 m^3 over the base case's 190,000 m^3
    - Max. sawmill short log SED was increased to 16 inches
- Target volume of harvested timber was 2,180,000 m^3 (1,035,000 deciduous and 1,145,000 coniferous).

Scenario 3 (no sawmill):

- In this scenario only the plywood and OSB plants were operating (no sawmill)
- The log volume targets were 539,000 m^3 for the plywood plant, and 910,000 m^3 for the OSB plant. The proportion of coniferous and deciduous log volumes changed as follows: the quantity of 190,000 m^3 of saw log conifers (previously consumed by the sawmill) was added to the OSB intake volume, and the deciduous was decreased by the same volume

- Total harvested timber volume was 1,480,000 m^3 (845,000 deciduous and 635,000 coniferous).

Scenario 4 (base case 300 yrs):

- In this scenario, the base case (scenario 1) was run for 300 years
- All other model inputs were identical to scenario 1 (base case)
- The purpose was to determine if the base case figures (profit, harvest volumes by plant allocation) were sustainable over a 300-year period.
- The rationale for choosing a 300 year length was to allow approximately three rotations required for steady state seral stage class composition

Scenario 5 (base case 300 yrs and old growth retention):

- This was a modified version of scenario 4 with the characteristic that 20% of the old growth timber area was preserved in each year
- The aim was to determine if the base case numbers were sustainable over 300 years while preserving 20% of the old growth timber in each year of the period

Scenario 6 (improved sawmill 300 years):

- This scenario represents scenario 2 run for 300 years
- The purpose was to determine if the modernized sawmill scenario was sustainable over 300 years, in terms of profits log volumes allocated to plants.

Scenario 7 (improved sawmill 300 years and old growth retention):

- This is scenario 6 with the addition that 20% of the old growth area was preserved in each year
- The objective of this analysis was to determine if the improved sawmill scenario was sustainable over 300 years while showing feasibility of preserving 20% of the old growth timber in each year

Scenarios 1-3 might be considered short term (20 years) investment analyses of industrial plant configurations. Scenarios 4-7 may best be considered timber supply analyses in support of the investment alternatives under two SFM criteria: With and without a 20% old growth retention.

4.3. Model settings and input data

While much of the model settings and inputs were scenario specific, some were constant throughout the analyses and they are summarized in this section.

Sales price for conifer chips from the sawmill was set at $25 per oven dried ton (ODT). Conversion to the solid wood equivalent requires the basic density (OD weight of one cubic foot of green wood) which for white spruce is 22.45 lbs/cu.ft. As one BC Interior Unit represents 1.2 ODT and weighs 2400 lbs, there are 107 cu.ft. of green solid wood per BC Interior Unit or 3.03 m3 per ODT which results in a chip price of $8.25 per m3 solid wood equivalent.

The shipping cost for lumber was considered to be $12/Mfbm, for plywood products $1.25/Msqft, and for the OSB product $2.60/Msqft.

Table 6 shows the unit costs applied to harvest/logging operations, hauling, stumpage, and reforestation respectively.

Table 6. Harvest (logging), haul, stumpage, and reforestation costs by species

Species Group	Harvest cost	Haul cost	Stumpage cost	Reforestation cost
	[$/m3]	[$/km]	[$/m3]	[$/m3]
Coniferous	16.00	0.067	variable*	9.00
Deciduous	17.00	0.097	0.50	1.00

*The stumpage cost calculation for coniferous species is variable and depends on the haul distance, and it was calculated as follows: base stumpage cost is set at $30/m^3 within the first 20km, after that it is reduced by a factor of $0.166667/km.

4.4. Scenario 1 (Base Case)

Base case studies are necessary steps to give confidence to model results when future scenarios are evaluated. Although there does not need to be a perfect one to one relationship in all manufacturing facets between the model and the real world, there is the expectation, as well as the necessary condition for future scenario analyses, that knowledgeable Canfor staff would recognize the model's input/output ratios as factors representing their manufacturing environment.

The base case study portion of this work presents data that compare the WoodFlow allocation and process model output to Canfor Fort Nelson comparable plan data for the OSB, plywood and sawmill for the year 2005. The reader should refer to descriptions of the model methodology to understand how the models operate and interact.

4.4.1. Harvest Data

The time period considered for scenario 1 (base case) was twenty years. The road and harvest model was run for the entire twenty years, and individual results were obtained for each year. Table 7 shows the harvest model data summary results. Both coniferous and deciduous volumes performed well in all years, being virtually identical to the targets of 635,000 m^3 and 1,035,000 m^3 respectively.

Table 7. Scenario 1 (base case) wood cost factors

Year	Road Cost	Conifer Stumpage*	Conifer Haul	Deciduous Haul	Conifer Volume	Deciduous Volume	Conifer Log Cost**	Deciduous Log Cost**
	[$]	[$/m3]	[$/m3]	[$/m3]	[m3]	[m3]	[$/m3]	[$/m3]
1	20,246,749	5.94	11.19	16.67	634,531	1,034,988	42.13	35.17
2	13,063,250	3.49	12.40	14.67	634,861	1,034,974	40.89	33.17
3	13,503,008	9.20	9.81	12.84	634,920	1,034,886	44.01	31.34
4	15,609,045	4.75	11.62	13.46	634,925	1,034,964	41.37	31.96
5	12,704,535	8.27	10.19	10.82	634,999	1,034,955	43.46	29.32
6	12,514,127	9.59	9.60	11.79	634,981	1,034,933	44.19	30.29
7	11,304,940	8.25	10.31	21.21	634,365	1,034,946	43.57	39.71
8	13,249,069	8.79	10.17	10.86	634,962	1,034,989	43.96	29.36
9	13,272,504	5.42	11.73	14.13	634,978	1,034,934	42.15	32.63
10	15,710,185	7.37	10.52	12.22	634,972	1,034,955	42.90	30.72
11	10,658,691	8.43	10.22	18.72	634,865	1,034,822	43.65	37.22
12	16,480,181	11.96	8.61	10.45	634,922	1,034,838	45.56	28.95
13	14,691,107	5.10	11.86	12.72	634,860	1,034,978	41.96	31.22
14	14,635,926	10.49	9.23	10.50	634,907	1,034,955	44.72	29.00
15	13,433,372	5.66	17.13	9.14	634,913	1,034,954	47.80	27.64
16	17,735,584	10.38	9.32	9.60	634,978	1,034,974	44.70	28.10
17	11,803,482	7.02	15.04	10.72	634,993	1,034,979	47.06	29.22
18	17,178,517	9.11	9.80	10.67	634,973	1,034,989	43.91	29.17
19	15,633,739	10.93	8.99	11.11	634,955	1,034,977	44.91	29.61
20	17,115,682	8.68	9.94	10.87	634,921	1,034,957	43.62	29.37
Avg	**14,527,185**	**7.94**	**10.88**	**12.66**	**634,889**	**1,034,947**	**43.83**	**31.16**
Min	**10,658,691**	**3.49**	**8.61**	**9.14**	**634,365**	**1,034,822**	**40.89**	**27.64**
Max	**20,246,749**	**11.96**	**17.13**	**21.21**	**634,999**	**1,034,989**	**47.80**	**39.71**
StDev	**2,429,227.44**	**2.29**	**2.07**	**3.12**	**159**	**47**	**1.73**	**3.12**

* The deciduous stumpage cost is not shown above, as it is a constant 50¢/m^3

**Exclusive of road costs which cannot be apportioned by species

The total annual road building and maintenance cost averaged $14,527,185 with year 1 showing a much higher value, due mainly to the model characteristic of initially locating a large number of HU blocks at random all over the TSA. The average road cost, based on the above average totals, was $8.70 per m^3. Average delivered wood cost, weighted by species volumes, was $44.68 per m^3 for the 20-year period.

As described in section 3.9 above, the harvest solution was determined by sum of tree class RTTs (Return To Tree) as the weight for HU Net Revenue. We set a HU Net Revenue value of $22,000,000 for this scenario based on experimental runs. The HU Net Revenue is a measure of the value of the timber in the HU, i.e. a higher HU Net Revenue value is associated with larger diameters and/or higher quality trees and delivered wood cost.

Table 8. Scenario 1 (base case) model harvest solutions

Year	Coniferous	Deciduous	HU Net Revenue
	target: 635,000 m3	target: 1,035,000 m3	target: $22 million
1	634,531.32 (99.92%)	1,034,987.79 (99.99%)	11.6 mil (52.86%)
2	634,861.45 (99.97%)	1,034,974.38 (99.99%)	22 mil (100.09%)
3	634,920.30 (99.98%)	1,034,885.83 (99.98%)	22 mil (100.04%)
4	634,924.50 (99.98%)	1,034,964.48 (99.99%)	22.2 mil (101.02%)
5	634,999.14 (99.99%)	1,034,955.43 (99.99%)	22.1 mil (100.63%)
6	634,980.92 (99.99%)	1,034,933.12 (99.99%)	22 mil (100.25%)
7	634,365.32 (99.90%)	1,034,946.32 (99.99%)	15.1 mil (68.77%)
8	634,961.90 (99.99%)	1,034,988.95 (99.99%)	22 mil (100.3%)
9	634,978.25 (99.99%)	1,034,934.31 (99.99%)	22 mil (100.01%)
10	634,972.20 (99.99%)	1,034,955.42 (99.99%)	22.3 mil (101.38%)
11	634,865.30 (99.97%)	1,034,821.64 (99.98%)	22 mil (100.15%)
12	634,922.01 (99.98%)	1,034,838.24 (99.98%)	22 mil (100.17%)
13	634,860.00 (99.97%)	1,034,978.21 (99.99%)	22 mil (100.05%)
14	634,907.37 (99.98%)	1,034,954.60 (99.99%)	22 mil (100.23%)
15	634,913.24 (99.98%)	1,034,954.35 (99.99%)	22 mil (100.00%)
16	634,977.80 (99.99%)	1,034,974.27 (99.99%)	22.1 mil (100.86%)
17	634,992.95 (99.99%)	1,034,979.08 (99.99%)	22.1 mil (100.47%)
18	634,972.81 (99.99%)	1,034,989.03 (99.99%)	22.1 mil (100.58%)
19	634,955.30 (99.99%)	1,034,977.21 (99.99%)	22 mil (100.14%)
20	634,920.81 (99.98%)	1,034,957.09 (99.99%)	22 mil (100.42%)

Table 8 above shows the target values and results for coniferous and deciduous volumes and HU Net Revenue. Target achievement levels are shown in brackets, as compared to the target value of 100% achievement. As seen, the target values are achieved in most years.

The plant allocation model was run on a yearly basis, e.g. for only one year at a time. As the process of preparing the allocation model, running it and validating the results was a time consuming process, and as the results of individual years were presumed to be highly similar for comparable HU Net Revenue levels, only one year was chosen to be used for analysis. We chose the first year of the twenty based on the general assumption that the timber profile and costs would be nearly the same for each year in the period given a constant revenue target. This was subsequently shown to create a bias and overestimate road cost in the accounting for the first year due to the aforementioned initial HU selection.

Table 9 and Table 10 show the plan and model, respectively, harvest volumes of logs that were directed to the OSB, plywood, and sawmill plants.

Table 9. Scenario 1 (base case) plan harvest volumes [m^3/year]

Species Group	Total	OSB[*]	Plywood	Sawmill
Coniferous	672,520	69,520	413,000	190,000
Deciduous	925,480	799,480	126,000	0
Total	1,598,000	869,000	539,000	190,000

[*] Log volumes shown above consumed by the OSB plant do not include the core volume produced by the plywood plant (41,000m^3). Actual OSB consumed log volume is shown in the respective results section below.

Table 10. Scenario 1 (base case) model harvest volumes [m^3/year]

Species Group	Total	OSB[*]	Plywood	Sawmill
Coniferous	658,720	54,273	412,982	191,465
Deciduous	919,760	793,742	126,018	0
Total	1,578,480	848,015	539,000	191,465

[*] Again, log volumes shown above consumed by the OSB plant do not include the core volume produced by the plywood plant (41,000m^3). The core volume was consumed by the OSB plant; it is just not shown here so that the plant volumes total correctly.

A comparison of results in Table 9 and Table 10 shows that the harvest model finds a combination of cut blocks in the Fort Nelson TSA that matches well the set targets for the plants for the first year of the twenty year period.

The average species specific wood cost per cubic meter of logs included harvesting (logging), stumpage, haul, and reforestation costs and are shown in Table 11.

Table 11. Scenario 1 (base case) wood cost exclusive of road costs by species

Species	Average cost over the 20 years, $/$m^3$	Cost for year 1, $/$m^3$
Coniferous	43.83	42.13
Deciduous	31.16	35.17

Figure 4 shows that the road cost varied significantly from year to year as the model tried to access high-value timber stands that yielded higher revenue. The model tried to optimize for profit by evaluating higher revenues generated by high-valued timber against the higher expenses, particularly road building, to reach far away timber.

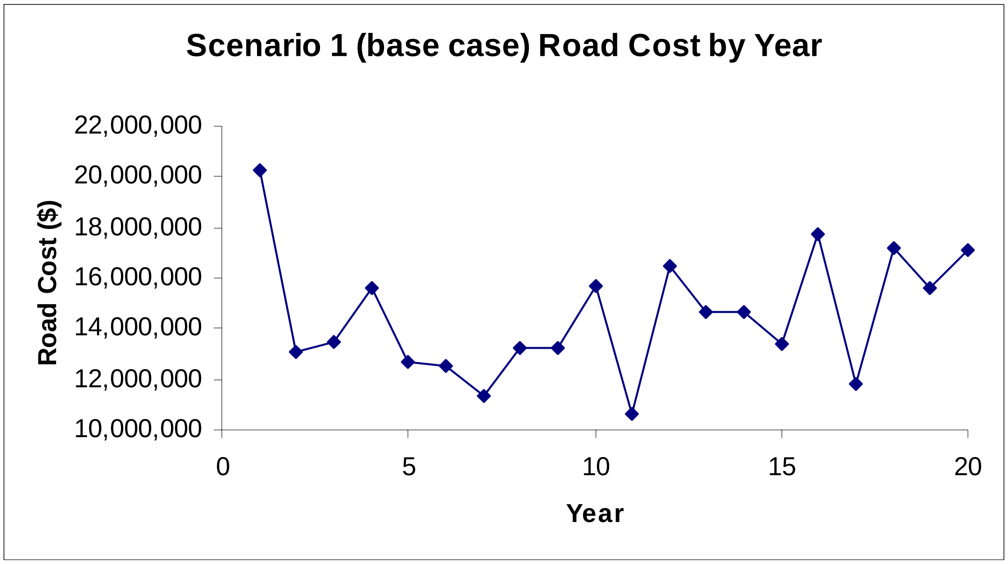

Figure 4. Scenario 1 (base case) road costs by year

The graph in Figure 5 shows average wood costs per cubic meter by species exclusive of road costs.

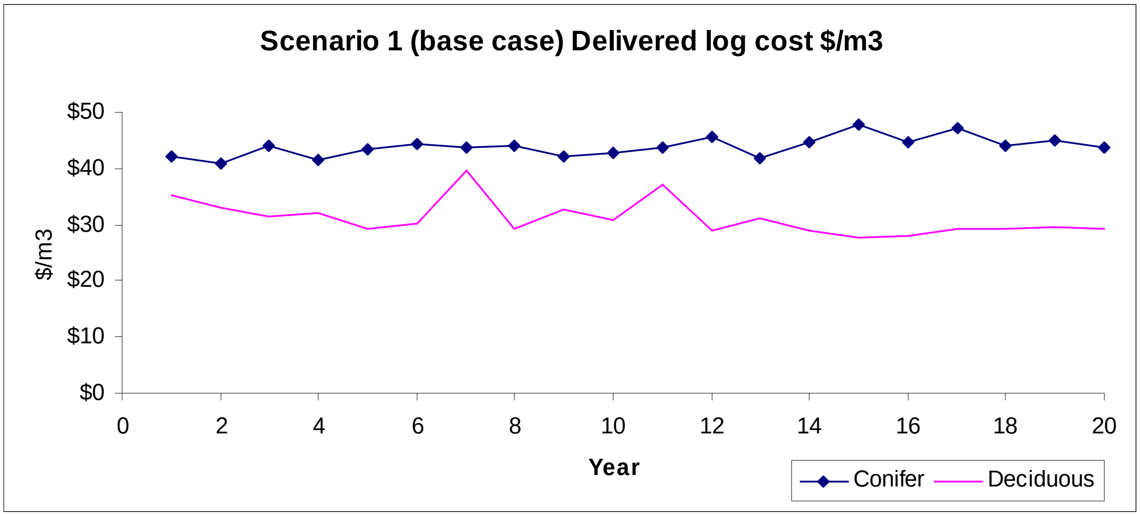

Figure 5. Scenario 1 (base case) wood costs exclusive of road costs by year and species

Conifer cost showed a small gradual increase over the years as higher haul costs were mitigated by lower stumpage when haul distance increased. Deciduous costs spiked in years seven and eleven were due to sudden increases in haul costs for those years. Again, the somewhat arbitrary HU selection relative to haul distance from the mills caused these spikes.

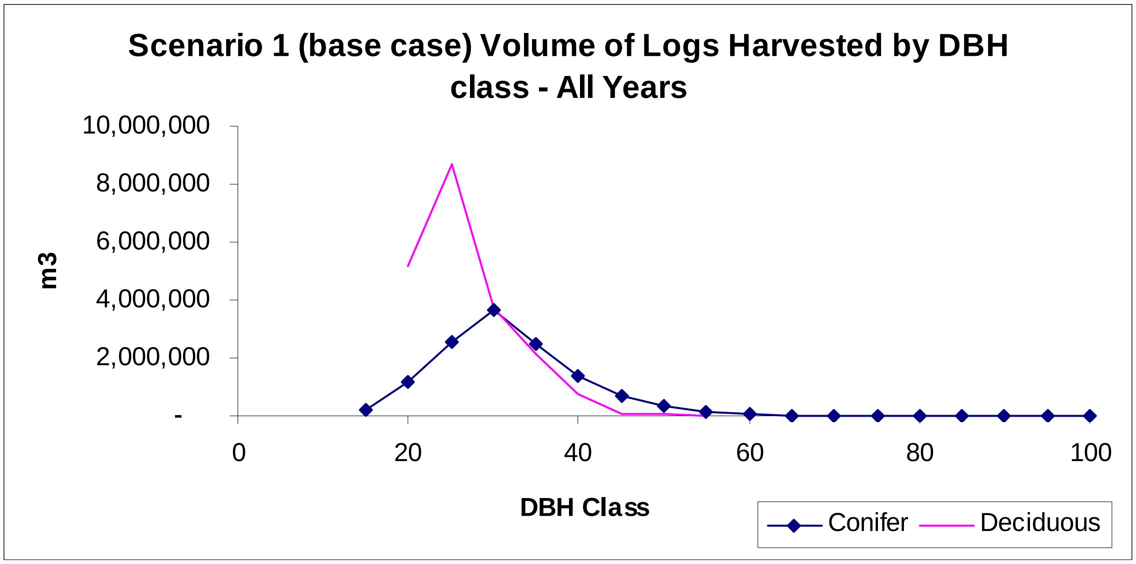

Figure 6. Scenario 1 (base case) distribution of total harvested volumes by 5 cm DBH class over all 20 years

The volume distribution by DBH class shown in Figure 6 varied somewhat from year to year albeit in a minor way. We did not pursue this variation as the overall volume requirement was satisfied in all years.

Table 12. Scenario 1 (base case) consumed average small end diameter (SED) and species mix by species and plants

Plant	**SED, cm**			**Species Mix**	
	Coniferous	Deciduous	Overall	Coniferous	Deciduous
Sawmill	18.28	--	18.28	100.0%	0.0%
Plywood	29.06	28.75	28.99	76.6%	23.4%
OSB	17.87	18.04	18.03	6.4%	93.6%

We could not relate these SED values to actual plant values as reliable data were not available. However, the amount of heart rot estimated for the deciduous OSB logs will affect the allocation away from the plywood plant to the OSB plant in that heart rot increases in large diameter logs.

Table 13. Scenario 1 (base case) average annual gross operating profits

Plant	Plan			Model		
	[m3]	[$/m3]	[$]	[m3]	[$/m3]	[$]
Sawmill	190,000	43.54	8,273,156	191,465	(17.84)	(3,415,690)
Plywood	539,000	75.80	40,856,000	539,000	42.00	22,640,647
OSB	910,000	102.77	93,522,362	910,000	57.64	52,448,334
Total	1,639,000	87.04	142,651,518	1,640,465	43.69	71,673,291

The average gross profit for each plant, shown in Table 13, compares less favourably between plan and model than volume consumption. Virtual identical data for the OSB plant follow from identical coefficients in both the plan and the model; there is no attempt to calculate OSB log yield by log size classes. However, plywood and sawmill RTL values are calculated based on recovery model estimates for veneer and lumber grades which, in turn, relate directly to defect distributions in the tree classes. The model's estimate for the sawmill log conversion is significantly lower than plan values whereas the model plywood log conversion is somewhat higher. As seen below, there are specific reasons for this.

4.4.2. Sawmill Data

The sawmill plant annual operating hours used in the model were 2,000 hrs for one shift, and the manufacturing cost applied was $1,484.75/hr.

Table 14. Scenario 1 (base case) plan vs. model sawmill cost and revenue results

Sawmill	Plan			Model		
	[Mfbm]	[$/Mfbm]	[$]	[Mfbm]	[$/Mfbm]	[$]
Lumber production sales	56,000	265.79	14,884,156	49,987	259.07	12,950,220
Manufacturing cost		106.05	5,939,000		118.81	5,939,000
Shipping		12.00	672,000		12.00	599,844
	[m3]	[$/m3]	[$]	[m3]	[$/m3]	[$]
Chip Production	n/a	incl.	incl.	73,022	8.25	602,432
Revenue by log volume	190,000	78.34	14,884,156	191,465	70.78	13,552,651
Sawmill RTL		43.54	8,273,156		36.63	7,013,807
Volume recovery, [Mfbm/m3]		0.295			0.261	
Haul, stumpage, harvest and reforestation costs						8,066,420
Road costs						2,363,076
Gross operating profit						(3,415,690)

*Volume recovery coefficient is expressed in Mfbm/m^3

The sawmill RTL dollar value calculation in Table 14 includes lumber sales and chips values, less the manufacturing and shipping costs. The manufacturing cost is essentially the same in the model as in the plan, as the model ran the plant for the maximum number of scheduled hours, and all hours were used for production.

Table 15. Scenario 1 (base case) plan vs. model lumber product distribution

SPF Grade	Cross-Section	Plan		Model	
	[in x in]	[Mfbm]	[%]	[Mfbm]	[%]
J Grade	2x4	728	1.3	6,872	13.7
Super Stud	2x4	7,224	12.9	2,480	5.0
Stud Grade	2x4	25,312	45.2	5,934	11.9
Stud Grade	2x3	560	1.0	8,022	16.0
#3	2x4	18,480	33.0	12,772	25.6
#3	2x3	616	1.1	12,791	25.6
Mill Run	1x4	3,080	5.5	1,116	2.2
Total		**56,000**	**100.0**	**49,987**	**100.0**

The sawmill recovery model estimated lumber volume recoveries and product grades directly from tree models with defects. The reason for this, as opposed to using a historical product volume and grade distribution, was to reflect changes to lumber sizes and grades when harvesting stands with both smaller timber and more and larger defects and knot sizes.

In the above comparisons, the cost of operating the sawmill remained the same for the plan and the model. Therefore, the RTL variance was entirely due to the lumber value difference. As seen from the lumber product distribution table, #3-grade lumber 2x3 was 25.6% in the model vs. 1.1% in the plan which goes a long way towards explaining the difference in average lumber price between plan and model. This implies either a high expectation in the plan or a higher than actual estimation of knot sizes in the trees. As historical data are the basis for the former and the sample size for the latter was limited, we conclude that the latter is the case.

Whereas the model input data may be modified to reflect a higher percentage of small knotted trees, this trial and error approach serves only to cover up for the lack of TSA wide estimates of tree quality factors. Once such data have been obtained, the variance between plan and model will diminish.

4.4.3. Plywood Plant Data

The model considered 5,280 annual operating hours for the plywood plant over two shifts, and the manufacturing cost applied was $5,210.89/hr. The two lathes had each 5,280 operating hours available. This calculation was based on 330 working days per year.

Table 16. Scenario 1 (base case), plan vs. model plywood cost and revenue results

Plywood Plant	**Plan**			**Model**		
	[Msqft]	[$/Msqft]	[$]	[Msqft]	[$/Msqft]	[$]
Plywood prod. sales (3/8)	286,000	335.26	95,883,000	297,445	347.11	103,247,231
Manufacturing cost		192.40	55,027,000		185.00	55,027,000
Shipping		1.25	357,500		1.25	371,806
	[m3]	[$/m3]	[$]	[m3]	[$/m3]	[$]
Core Production (transferred to OSB)	41,000		2,166,638	61,985		3,275,587
Revenue by log volume	539,000	177.89	95,883,000	539,000	191.55	103,247,231
Peeler RTL		75.80	40,856,000		89.46	48,220,231
Volume recovery, [Msqft/m3]		0.531			0.552	
Haul, stumpage, harvest and reforestation costs						21,830,983
Road costs						6,652,381
Gross operating profit						22,640,647

Note: The core production $ value is the recovered core volume delivered cost, further deferred to the OSB plant

The total manufacturing cost is the same in the model as in the plan, as the model ran the plant for the maximum number of scheduled hours, and all hours were used for production.

Table 17. Scenario 1 (base case) plan plywood volume distribution by grade (%)

Plan		**Panel Grade**					
Thickness	Production	Select	Ind. Sand.	Standard	Shop	Degrade	Cull
	[%]						
3/8	0.14	1.40%	0.00%	11.80%	0.00%	0.70%	0.10%
1/2	0.36	3.60%	0.00%	30.20%	0.00%	1.80%	0.40%
5/8	0.24	6.00%	0.00%	16.60%	0.00%	1.20%	0.20%
3/4	0.24	12.00%	0.00%	10.60%	0.00%	1.20%	0.20%
Ind. 7/8	0.02	0.00%	1.60%	0.00%	0.30%	0.10%	0.00%

Table 18. Scenario 1 (base case) model plywood volume distribution by grade (%)

		Panel Grade					
Thickness	Production	Select	Ind. Sand.	Standard	Shop	Degrade	Cull
	[%]						
3/8	0.14	1.40%	0.00%	11.76%	0.00%	0.70%	0.14%
1/2	0.36	3.60%	0.00%	30.24%	0.00%	1.80%	0.36%
5/8	0.24	6.00%	0.00%	16.56%	0.00%	1.20%	0.24%
3/4	0.24	12.00%	0.00%	10.56%	0.00%	1.20%	0.24%
Ind. 7/8	0.02	0.00%	1.58%	0.00%	0.30%	0.10%	0.02%

The veneer peeling and plywood lay-up model took the plan data as input and ensured that the plywood product distribution were not exceeded or under-produced. One might think of this distribution as the expected demand for plywood products. It does not mean that the product grade distribution reflects the quality of the timber resource; high quality face veneer may be used as face veneer in a lower grade product, as backing veneer and as core veneer. The veneer data showed that substantially higher volumes of Select grade plywood could have been produced had there been a greater demand for this grade.

Plywood production data above showed that the peeler model generated a substantially lower volume recovery factor than the plan assumption. The difference in the recovery values explains the lower volume production and RTL value in the model. The factors impacting on recovery are core volumes, defect trimming and log taper (round-up). In this case, optimum model defect trimming based on veneer grade price differentials may have contributed to lower production. One way of dealing with this variance would be to introduce a volume recovery adjustment factor that aligns planned and model recoveries without affecting the veneer quality distribution.

4.4.4. OSB Plant Data

The total operating time considered in the model assumed 330 working days per year, or 5,280 operating hours per year over two shifts. The manufacturing cost applied in the model was $10,435.80/hr and this was extracted from the "plan" figures. Table 19 summarizes the comparison results between the "plan" and the "model" OSB production.

Table 19. Scenario 1 (base case), plan vs. model OSB cost and revenue results

OSB Plant	**Plan**			**Model**		
	[Msqft]	[$/Msqft]	[$]	[Msqft]	[$/Msqft]	[$]
OSB prod. sales (3/8)	650,000	234.58	152,480,000	649,740	235.29	152,880,000
Manufacturing cost		84.77	55,101,000		84.80	55,101,000
Shipping		2.60	1,690,000		2.60	1,689,324
	[m3]	[$/m3]	[$]	[m3]	[$/m3]	[$]
Core Consumption (from plywood plant)	41,000		2,166,638	61,985		3,275,587
Revenue by log volume	869,000	175.47	152,480,000	848,015	180.28	152,880,000
OSB RTL		102.77	93,522,362		101.99	92,814,089
Volume recovery, [Msqft/m3]		0.748			0.714	
Haul, stumpage, harvest and reforestation costs						32,410,050
Road costs						11,231,292
Gross operating profit						52,448,334

As there is no recovery sub-model in the OSB manufacturing model, the resulting plan will always show identical results provided the harvest/road model finds the necessary timber volumes.

The total manufacturing cost value is the same in the model as in the plan, as the model ran the plant for the maximum number of scheduled hours, and all hours were used for production.

4.5. Scenario 2 (improved sawmill)

The objective of this scenario was to analyze the feasibility of a modern sawmill replacement. The new improved sawmill had a maximum short log SED of 16 inches, and the grade recovery data set was rerun to cover these increased diameters to the sawmill. The new sawmill would have two lines, a DDM-6 and a canter/quad, operating as a 10-foot stud mill for two shifts per day. The volume of logs processed by the new sawmill was increased to 700,000 m^3 of conifers, an increase of 510,000 m^3 over the scenario 1 (base case) value of 190,000 m^3. OSB and plywood mills had the same characteristics and parameters as in scenario 1 (base case). The target volume of harvested timber was 2,180,000 m^3 (1,035,000 deciduous and 1,145,000 coniferous), and the time horizon for the analysis was 20 years.

4.5.1. Harvest Data

The combined road and harvest model was run for the 20-year period and Table 20 shows the target values and results for coniferous and deciduous volumes and HU net revenue. Target achievement levels are shown in brackets. The HU net revenue achievement is lowest in year number one on account of the aforementioned road building cost that year.

Table 20. Scenario 2 (improved sawmill) harvest solutions

Year	Coniferous	Deciduous	HU Net Revenue
	target: 1,145,000 m3	target: 1,035,000 m3	target: $25 million
1	1,143,689.69 (99.88%)	1,034,993.55 (99.99%)	14.3 mil (57.28%)
2	1,144,842.02 (99.98%)	1,034,824.37 (99.98%)	25 mil (100.0%)
3	1,144,986.22 (99.99%)	1,034,964.98 (99.99%)	25 mil (100.26%)
4	1,144,141.21 (99.92%)	1,034,947.23 (99.99%)	25 mil (100.05%)
5	1,144,737.53 (99.97%)	1,035,014.23 (100.0%)	25 mil (100.02%)
6	1,144,740.11 (99.97%)	1,034,832.92 (99.98%)	25 mil (100.17%)
7	1,144,945.03 (99.99%)	1,034,968.44 (99.99%)	25.4 mil (101.92%)
8	1,144,710.34 (99.97%)	1,034,866.61 (99.98%)	25 mil (100.12%)
9	1,144,894.34 (99.99%)	1,034,982.33 (99.99%)	25 mil (100.05%)
10	1,144,906.83 (99.99%)	1,034,780.12 (99.97%)	25 mil (100.01%)
11	1,144,982.93 (99.99%)	1,034,897.83 (99.99%)	25.3 mil (101.24%)
12	1,144,991.74 (99.99%)	1,034,956.69 (99.99%)	25.2 mil (101.0%)
13	1,144,985.56 (99.99%)	1,034,939.45 (99.99%)	25 mil (100.02%)
14	1,144,933.4 (99.99%)	1,034,983.76 (99.99%)	25 mil (100.09%)
15	1,144,969.14 (99.99%)	1,034,926.71 (99.99%)	25.1 mil (100.64%)
16	1,144,974.99 (99.99%)	1,034,955.2 (99.99%)	25 mil (100.05%)
17	1,144,950.81 (99.99%)	1,034,975.78 (99.99%)	25.1 mil (100.43%)
18	1,145,012.96 (100.0%)	1,034,998.97 (99.99%)	25 mil (100.12%)
19	1,144,945.87 (99.99%)	1,034,849.64 (99.98%)	25 mil (100.03%)
20	1,144,996.4 (99.99%)	1,034,836.0 (99.98%)	25 mil (100.22%)

The results in Table 20 were that the harvest model was able to meet the target volumes in all years, while maintaining the target HU Net Revenue. The exception was the first year of the analysis, which can be attributed, at least in part, to the much higher road cost of year one.

The harvest data summary results, run for the first year of the twenty-year period, are shown in Table 21. The annual road costs, while averaging $13.3 million, were again higher in year one of the analysis, for the same reasons as in the previous scenario.

Table 21. Scenario 2 (improved sawmill) harvest data summary results

Year	Road Cost	Conifer Stumpage	Conifer Haul	Deciduous Haul	Conifer Volume	Deciduous Volume	Conifer Log Cost	Deciduous Log Cost
	[$]	[$/m3]	[$/m3]	[$/m3]	[m3]	[m3]	[$/m3]	[$/m3]
1	23,160,700	2.25	13.81	14.38	1,143,690	1,034,994	41.05	32.88
2	13,034,837	2.24	13.60	15.56	1,144,842	1,034,824	40.85	34.06
3	13,186,134	4.97	11.95	14.46	1,144,986	1,034,965	41.92	32.96
4	11,223,448	3.85	12.50	14.94	1,144,141	1,034,947	41.35	33.44
5	10,680,373	9.36	9.65	13.56	1,144,738	1,035,014	44.01	32.06
6	9,829,916	7.16	10.57	13.93	1,144,740	1,034,833	42.73	32.43
7	12,743,021	4.64	12.07	12.97	1,144,945	1,034,968	41.70	31.47
8	14,381,205	3.33	12.68	15.75	1,144,710	1,034,867	41.01	34.25
9	10,889,386	3.35	12.41	15.00	1,144,894	1,034,982	40.76	33.50
10	12,159,410	8.20	10.14	12.58	1,144,907	1,034,780	43.34	31.08
11	12,167,845	7.47	10.41	12.26	1,144,983	1,034,898	42.88	30.76
12	13,307,854	9.14	10.01	10.58	1,144,992	1,034,957	44.15	29.08
13	11,694,501	9.02	9.82	11.70	1,144,986	1,034,939	43.84	30.20
14	14,689,101	6.61	11.44	11.24	1,144,933	1,034,984	43.06	29.74
15	13,394,147	9.94	9.57	10.92	1,144,969	1,034,927	44.51	29.42
16	13,653,962	5.60	12.34	11.58	1,144,975	1,034,955	42.94	30.08
17	12,207,763	5.59	11.63	18.60	1,144,951	1,034,976	42.22	37.10
18	17,390,782	8.67	10.01	9.81	1,145,013	1,034,999	43.68	28.31
19	13,453,014	8.78	9.92	11.04	1,144,946	1,034,850	43.70	29.54
20	13,999,861	6.30	10.88	14.53	1,144,996	1,034,836	42.19	33.03
Avg	**13,362,363**	**6.32**	**11.27**	**13.27**	**1,144,817**	**1,034,925**	**42.59**	**31.77**
Min	**9,829,916**	**2.24**	**9.57**	**9.81**	**1,143,690**	**1,034,780**	**40.76**	**28.31**
Max	**23,160,700**	**9.94**	**13.81**	**18.60**	**1,145,013**	**1,035,014**	**44.51**	**37.10**
StDev	**2,841,516**	**2.49**	**1.34**	**2.19**	**329.60**	**69.17**	**1.20**	**2.19**

The average road costs were slightly lower in this scenario in spite of the substantially larger harvested log volumes compared to the base case. Again, this underpins the conclusion that the HU selection was biased towards the road development across the entire TSA thus obliterating the cost differences expected between two significantly different harvest volumes.

Table 22. Scenario 2 (improved sawmill) model harvest volumes [m^3/year]

Species Group	Total	OSB[*]	Plywood	Sawmill
Coniferous	1,056,957	72,373	313,237	671,347
Deciduous	896,991	789,210	107,781	0
Total	1,953,948	861,583	421,018	671,347

[*] Again, log volumes shown above consumed by the OSB plant do not include the core volume produced by the plywood plant (48,417m^3). The core volume was

consumed by the OSB plant; it is just not shown here so that the plant volumes total correctly.

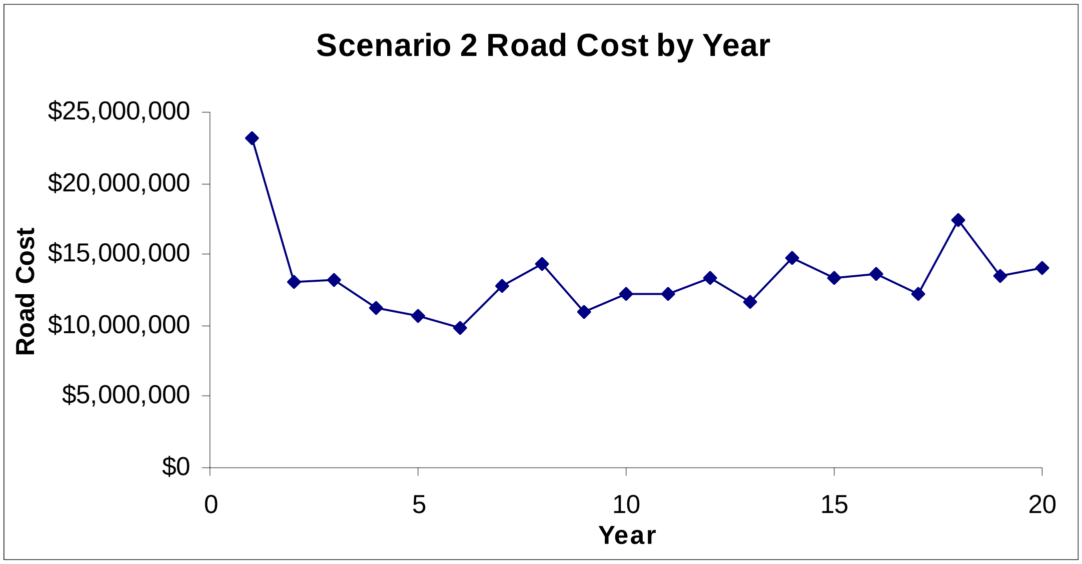

Figure 7. Scenario 2 road costs by year

The annual road costs, as shown in Figure 7, show an increasing trend towards the later years, likely due to the fact that a more extensive road network needs to be maintained, and timber may be hauled from further away distances from the mill. As these data and those presented in Figure 8 and 9 have not been analyzed further, comments are not warranted.

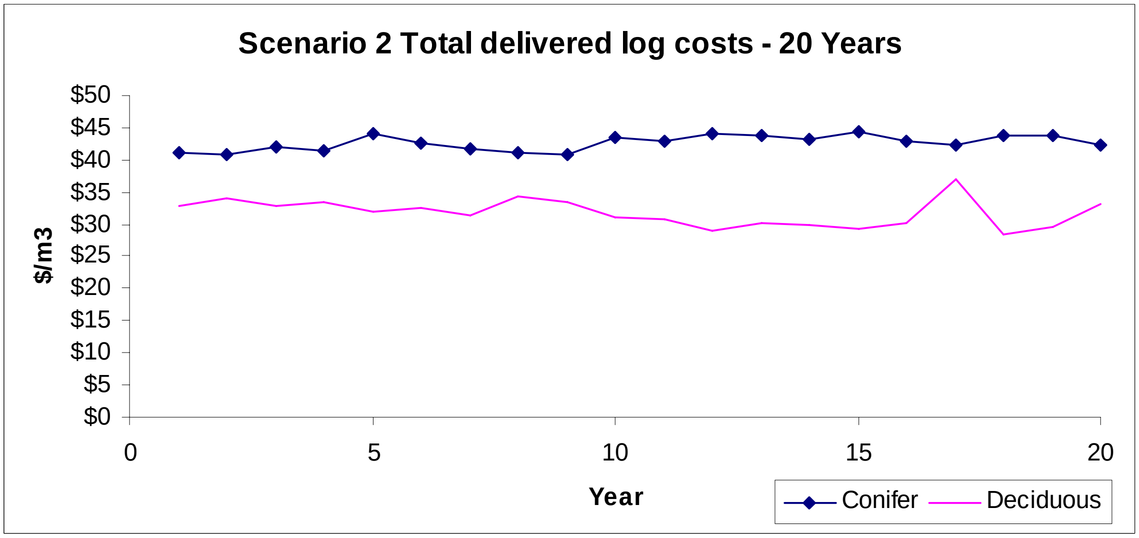

Figure 8. Scenario 2 wood cost by year excluding road cost

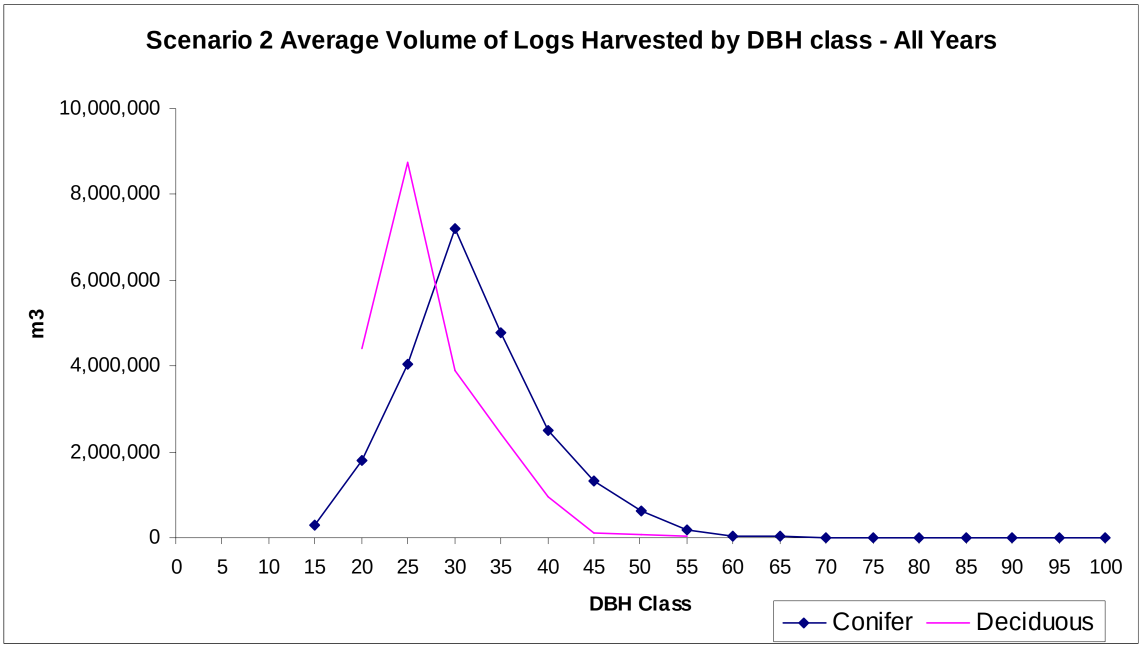

Figure 9. Scenario 2 distribution of harvested volumes by DBH class, all years

Table 23. Scenario 2 (improved sawmill) consumed average small end diameter (SED) and species mix by species and plants

Plant	**SED** [cm]			**Species Mix**	
	Coniferous	Deciduous	Overall	Coniferous	Deciduous
Sawmill	22.54	--	22.54	100.0%	0.0%
Plywood	26.81	29.39	27.47	74.4%	25.6%
OSB	18.02	18.70	18.64	8.4%	91.6%

As the sawmill in this strategy consumed substantial additional softwood volumes, the average softwood SED increased from 18 to 23 cm and that of veneer logs decreased from 29 to 27 cm. The sawmill section below explains the reasons.

Table 24. Scenario 2 (improved sawmill) average annual gross operating profits

	Model		
	[m3]	[$/m3]	[$]
Sawmill	671,347	0.09	58,522
Plywood	421,000	10.95	4,608,876
OSB	910,000	60.46	55,018,689
Total	2,002,347	29.81	59,686,087

Whereas the sawmill operating profit increased relative to base case, it remained insufficient to support a sawmill rebuild. We provide further comments in the next section. As well, loosing larger logs had a large negative effect on the plywood plant.

4.5.2. Sawmill Data

The improved sawmill plant had two operating lines, a DDM-6 and a canter/quad as a 10-foot stud mill operating two shifts. The maximum short log SED was set at 16 inches, increased from the base case. The target log volume to be consumed by the sawmill was increased to 700,000 m^3 from the base case volume of 190,000. The manufacturing cost applied was $2,140/hr for each processing line. The canter/quad line was set to accept a minimum small end diameter of 6 in to a maximum of 20 in butt. The DDM-6 line allowed a 3 in minimum SED and a maximum of 6 in SED. Table 25 shows the lumber production summary.

Table 25. Scenario 2 (improved sawmill) model sawmill cost and revenue results

Sawmill	Model		
	[Mfbm]	[$/Mfbm]	[$]
Lumber production sales	167,344	312.50	52,294,283
Manufacturing cost		102.30	17,120,000
Shipping		12.00	2,008,128
	[m3]	[$/m3]	[$]
Chip Production	268,656	8.25	2,216,412
Revenue by log volume	671,347	81.20	54,510,695
Sawmill RTL		52.70	35,382,567
Volume recovery, [Mfbm/m3]		0.249	
Haul, stumpage, harvest and reforestation costs			27,558,794
Road costs			7,765,251
Gross operating profit			58,522

The DDM line consumed all of the 4,000 available annual hours (over two shifts). However, the large-diameter line (canter/quad) used only 1987 hours of the 4,000 available. This resulted in a smaller consumed log volume of 671,347 m3, compared to the target of 700,000 m3. Whereas the sawmill was allocated log classes that had a higher RTL than the plywood plant, there was not a sufficient volume of these mid-size logs to run the sawmill the full two shifts all year.

The overall volume recovery of 0.249 Mfbm/m3 was lower than the 0.261 value from the base case due to a larger share of the smallest logs. In contrast with the base case where there was a negative profit, this scenario showed a positive but very small profit of $58,522.

Table 26. Scenario 2 (improved sawmill) model lumber product distribution

SPF Grade	Cross-Section	Model	
	[in x in]	[Mfbm]	[%]
#2 COM	1x4	13,523	8.1
#2 & BTR	2x3	19,886	11.9
Utility	2x3	6,974	4.2
#2 & BTR	2x4	7,240	4.3
Stud Sq.	2x4	22,261	13.3
Utility	2x4	16,932	10.1
#2 COM	2x6	25,457	15.2
#3	2x6	14,529	8.7
Stud Sq.	2x6	40,541	24.2
Total		**167,344**	**100.0**

4.5.3. Plywood Plant Data

The plywood plant settings for this scenario were identical to the base case scenario. The model had 5,280 available annual operating hours over two shifts, and the manufacturing cost applied was $5,210.89/hr. The two lathes had each 5,280 operating hours available. This calculation was based on 330 working days per year.

Table 27. Scenario 2 (improved sawmill) model plywood cost and revenue results

Plywood Plant	**Model**		
	[Msqft]	[$/Msqft]	[$]
Plywood prod. sales (3/8)	226,857	347.11	78,745,170
Manufacturing cost		242.56	55,027,000
Shipping		1.25	283,571
	[m3]	[$/m3]	[$]
Core Production (transferred to OSB)	48,417		2,446,276
Revenue by log volume	421,018	187.04	78,745,170
Peeler RTL		56.34	23,718,170
Volume recovery, [Msqft/m3]		0.539	
Haul, stumpage, harvest and reforestation costs			16,402,221
Road costs			4,869,777
Gross operating profit			4,608,876
note: the core production $ value is the recovered core volume delivered cost, further deferred to the OSB plant			

The results in Table 27 above show that the veneer and plywood operations were not as efficient as in the base case. While consuming all the available hours, the plywood plant used only 421,018 m3 of logs, compared with 539,000 in the base case. One reason for this was that the model was not able to find the larger log diameters to increase plant productivity. The volume recovery for the plywood plant was 0.539 Msqft/m3, value which was lower than the 0.552 of the base case. The lower quantity of logs consumed also translated in a lower sales revenue value, which ultimately produced a much lower operating profit of $4.6 million vs. $22.65 million in the base case.

4.5.4. OSB Plant Data

The OBS plant settings for this scenario were identical to the base case. The total operating time considered in the model assumed 330 working days per year, or 5,280 operating hours per year over two shifts. The manufacturing cost applied in the model was $10,435.80/hr. Table 28 summarizes the results for the OSB production.

Table 28. Scenario 2 (improved sawmill) model OSB cost and revenue results

OSB Plant	**Model**		
	[Msqft]	[$/Msqft]	[$]
OSB prod. sales (3/8)	649,740	235.29	152,880,000
Manufacturing cost		84.80	55,101,000
Shipping		2.60	1,689,324
	[m3]	[$/m3]	[$]
Core Consumption (from plywood plant)	48,417		2,446,276
Revenue by log volume	861,583	177.44	152,880,000
OSB RTL		102.90	93,643,400
Volume recovery, [Msqft/m3]		0.714	
Haul, stumpage, harvest and reforestation costs			30,545,315
Road costs			10,525,672
Gross operating profit			55,018,689

The results for the OSB plant were very similar to the ones obtained in the base case. The only notable differences were the smaller delivered log and road costs, which led to a higher profit value of $55 mil vs. $52.5 mil in the base case.

4.6. Scenario 3 (no sawmill)

The objective of this scenario was to have only the plywood and OSB plants operating while maintaining the total harvested timber volume at 1,480,000 m^3 consisting of 845,000 m^3 deciduous and 635,000 m^3 coniferous volumes.

The log volume targets were 539,000 m^3 for the plywood plant, and 910,000 m^3 for the OSB plant. The proportion of coniferous and deciduous log volumes changed as follows: the quantity of 190,000 m^3 of saw log conifers (previously consumed by sawmill) was added to the OSB intake volume, and the deciduous was decreased by the same volume.

4.6.1. Harvest Data

The combined road and harvest model was run for the 20-year period and the results are shown below. Table 29 shows the target values and results for coniferous and deciduous volumes and HU Net Revenue. Target achievement levels are shown in brackets, as compared to the target value of 100% achievement. The HU Net Revenue achievement was lowest in year number one as before.

Table 29. Scenario 3 harvest model achievement solutions

Year	Coniferous	Deciduous	HU Net Revenue
	target: 635,000 m3	target: 845,000 m3	target: $16 million
1	634,980.85 (99.99%)	845,569.49 (100.06%)	4.9 mil (30.57%)
2	634,676.14 (99.94%)	1,230,802.54 (145.65%)	16 mil (100.03%)
3	634,322.40 (99.89%)	844,758.03 (99.97%)	16 mil (100.24%)
4	635,005.65 (100.0%)	844,807.45 (99.97%)	16 mil (100.08%)
5	634,988.99 (99.99%)	845,006.17 (100.00%)	16.1 mil (100.66%)
6	634,934.32 (99.98%)	855,072.59 (101.19%)	16 mil (100.04%)
7	634,977.25 (99.99%)	844,894.89 (99.98%)	16 mil (100.39%)
8	635,031.87 (100.0%)	844,875.66 (99.98%)	16.2 mil (101.83%)
9	635,001.21 (100.0%)	844,995.31 (99.99%)	16.1 mil (100.93%)
10	634,976.31 (99.99%)	844,939.08 (99.99%)	16 mil (100.55%)
11	635,002.82 (100.0%)	844,825.94 (99.97%)	16.1 mil (101.06%)
12	634,982.72 (99.99%)	844,996.68 (99.99%)	16 mil (100.32%)
13	634,977.57 (99.99%)	845,016.37 (100.00%)	16 mil (100.56%)
14	634,951.45 (99.99%)	845,019.73 (100.00%)	16 mil (100.33%)
15	635,000.87 (100.0%)	844,906.30 (99.98%)	16.4 mil (102.55%)
16	634,951.96 (99.99%)	844,991.06 (99.99%)	16 mil (100.52%)
17	635,004.98 (100.0%)	845,003.69 (100.00%)	16 mil (100.20%)
18	634,988.55 (99.99%)	844,902.94 (99.98%)	16 mil (100.05%)
19	634,999.51 (99.99%)	845,009.76 (100.00%)	16 mil (100.24%)
20	634,878.06 (99.98%)	845,004.27 (100.00%)	16 mil (100.55%)

The results in Table 29 show that the harvest model was able to meet the target volumes in all years, while maintaining the target HU Net Revenue except for the first year of the analysis, with the same observation that this can be attributed at least in part to the much higher road cost of year one.

The HU Net Revenue target was set at $16 million per year. This value is lower than scenario 1 (base case), mainly due to the lower gross value of the annual total timber volume harvested.

The harvest data summary results, run for the first year of the twenty-year period, are shown in Table 30. The annual road costs, while averaging $14.7 million, were again much higher in year one of the analysis, for the reasons stated in the base case.

Table 30. Scenario 3, harvest data summary results

Year	Road Cost	Conifer Stumpage	Conifer Haul	Deciduous Haul	Conifer Volume	Deciduous Volume	Conifer Log Cost	Deciduous Log Cost
	[$]	[$/m3]	[$/m3]	[$/m3]	[m3]	[m3]	[$/m3]	[$/m3]
1	24,241,873	4.32	11.91	14.57	634,356	844,997	41.22	33.07
2	12,203,660	5.80	11.25	15.58	634,897	844,908	42.05	34.08
3	12,006,485	5.31	11.33	12.44	634,937	844,942	41.64	30.94
4	14,221,874	8.41	10.03	10.26	634,908	844,982	43.44	28.76
5	13,674,628	9.00	9.89	13.67	634,967	844,932	43.89	32.17
6	11,092,039	9.45	9.62	11.82	634,989	844,889	44.07	30.32
7	16,294,133	3.14	12.72	14.00	634,925	844,933	40.86	32.50
8	13,692,533	5.71	11.60	12.79	634,980	844,955	42.32	31.29
9	14,722,119	5.09	12.60	14.01	634,976	844,998	42.69	32.51
10	12,755,392	8.81	9.87	13.27	634,996	844,998	43.69	31.77
11	12,502,854	4.34	12.16	15.14	634,873	844,957	41.50	33.64
12	14,485,945	5.82	11.79	14.00	634,815	844,894	42.61	32.50
13	11,444,359	5.95	11.46	14.93	634,812	844,906	42.41	33.43
14	10,279,955	4.64	12.12	14.36	634,972	844,877	41.77	32.86
15	16,939,840	5.32	11.77	10.69	634,961	844,971	42.09	29.19
16	14,752,102	6.54	11.00	14.29	634,944	844,988	42.54	32.79
17	18,845,265	8.38	10.58	10.55	635,001	844,901	43.96	29.05
18	18,237,069	10.36	9.27	9.48	634,996	844,870	44.62	27.98
19	17,062,800	10.99	8.96	7.96	634,951	844,892	44.96	26.46
20	14,252,417	8.38	10.95	14.49	634,981	844,853	44.33	32.99
Avg	**14,685,367**	**6.79**	**11.04**	**12.91**	**634,912**	**844,932**	**42.83**	**31.41**
Min	**10,279,955**	**3.14**	**8.96**	**7.96**	**634,356**	**844,853**	**40.86**	**26.46**
Max	**24,241,873**	**10.99**	**12.72**	**15.58**	**635,001**	**844,998**	**44.96**	**34.08**
StDev	**3,257,958**	**2.24**	**1.11**	**2.11**	**142**	**47**	**1.20**	**2.11**

Compared with scenario 1 (base case), the annual road costs in Scenario 3 had an average value nearly identical to the one in the base case. The average conifer stumpage was lower than the base case while both coniferous and deciduous haul costs were higher.

Table 31. Scenario 3 model harvest volumes (m^3/year)

Species Group	Total	OSB	Plywood
Coniferous	597,001	184,019	412,982
Deciduous	790,014	663,996	126,018
Total	1,387,015	848,015	539,000

Table 32. Scenario 3 wood cost excluding road cost by species

	Average wood cost over 20 years [\$/m^3]	Wood cost for year 1 [\$/m^3]
Coniferous	42.83	41.22
Deciduous	31.41	33.07

The coniferous wood cost (excluding road cost) was lower (vs. \$43.83 in the base case) while the deciduous delivered log cost was slightly higher (vs. \$31.16).

Table 33. Scenario 3 small end diameters and species mix consumed, by species and plants

Plant	**SED, cm**			**Species Mix**	
	Coniferous	Deciduous	Overall	Coniferous	Deciduous
Sawmill	N/A	N/A	N/A	N/A	N/A
Plywood	26.5	28.3	26.9	76.6%	23.4%
OSB	14.7	18.5	17.7	21.7%	78.3%

The diameter distribution of scenario 3, displayed in Table 33, shows that generally the average log diameters consumed by the mills were smaller than in the base case, except for the deciduous logs of the OSB plant. Coniferous plywood logs were 29.1 cm in the base case, and deciduous plywood logs were 28.8 cm. Coniferous OSB logs were 17.9 cm in the base case, and deciduous OSB logs were 18.0 cm.

Table 34. Scenario 3 average annual gross operating profits

	Model		
	[m3]	[\$/m3]	[\$]
Plywood	539,000	35.30	19,024,601
OSB	910,000	54.02	49,162,231
Total	1,449,000	47.06	68,186,831

The gross operating profit for the plywood plant ($35.30/m3) was lower than in the base case ($42.00/m3) and this resulted in a lower net profit for this plant, $19 million vs. $22.6 million in the base case. This can be explained by the smaller timber processed by the mills in Scenario 3 vs. the base case, as shown by the diameter distribution in Table 33 and Table 12, respectively.

Figure 10. Scenario 3 road cost by year

The annual road costs data series, shown in Figure 10, exhibits the same trend of slightly escalating road costs towards the latter years.

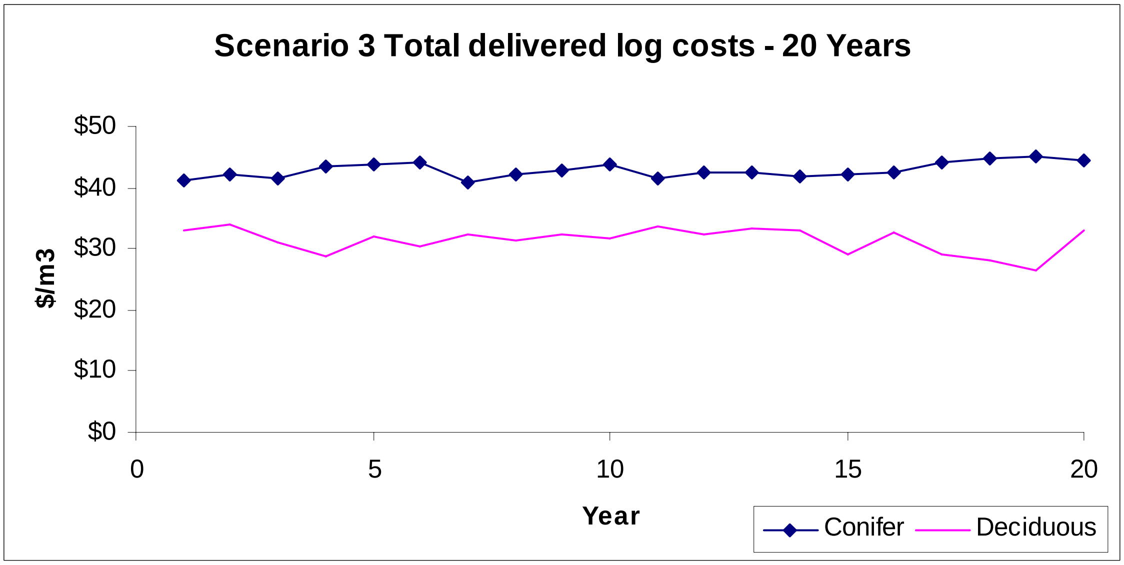

Figure 11. Scenario 3 wood cost by year not including road cost

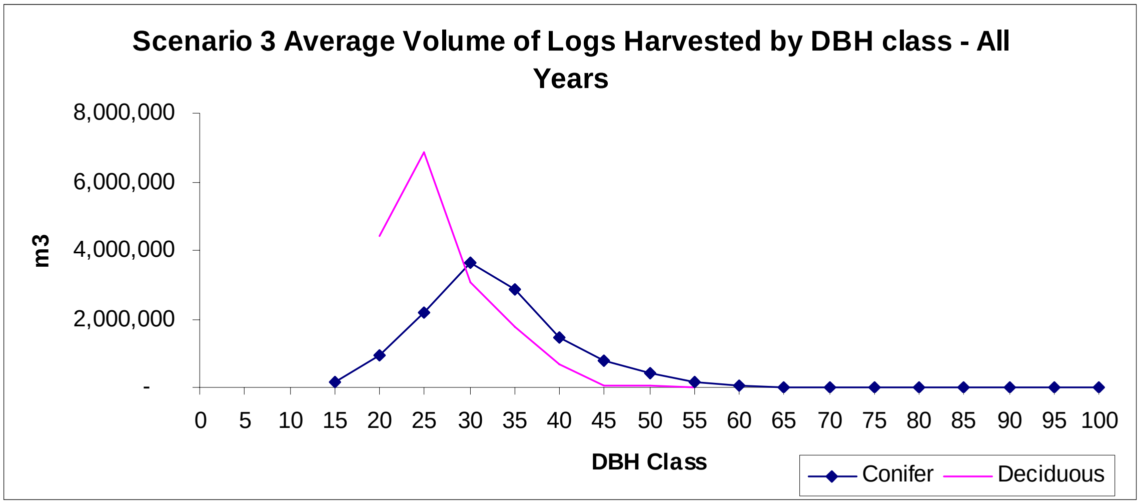

Figure 12. Scenario 3 distribution of harvested volumes by DBH class, all years

4.6.2. Plywood Plant Data

Table 35. Scenario 3 (no sawmill) model plywood cost and revenue results

Plywood Plant	**Model**		
	[Msqft]	[$/Msqft]	[$]
Plywood prod. sales (3/8)	291,403	347.11	101,149,970
Manufacturing cost		188.83	55,027,000
Shipping		1.25	364,254
	[m3]	[$/m3]	[$]
Core Production (transferred to OSB)	61,985		3,473,925
Revenue by log volume	539,000	187.66	101,149,970
Peeler RTL		85.57	46,122,970
Volume recovery, [Msqft/m3]		0.541	
Haul, stumpage, harvest and reforestation costs			21,190,532
Road costs			9,017,508
Gross operating profit			19,024,601

Table 36. Scenario 3 (no sawmill) model plywood volume distribution by grade, (%)

Model		**Panel Grade**					
Thickness	Production	Select	Ind. Sand.	Standard	Shop	Degrade	Cull
3/8	0.14	1.40%	0.00%	11.76%	0.00%	0.70%	0.14%
1/2	0.36	3.60%	0.00%	30.24%	0.00%	1.80%	0.36%
5/8	0.24	6.00%	0.00%	16.56%	0.00%	1.20%	0.24%
3/4	0.24	12.00%	0.00%	10.56%	0.00%	1.20%	0.24%
Ind. 7/8	0.02	0.00%	1.58%	0.00%	0.30%	0.10%	0.02%

4.6.3. OSB Plant Data

Table 37. Scenario 3 (no sawmill) model OSB cost and revenue results

OSB Plant	**Model**		
	[Msqft]	[$/Msqft]	[$]
OSB prod. sales (3/8)	649,740	235.29	152,880,000
Manufacturing cost		84.80	55,101,000
Shipping		2.60	1,689,324
	[m3]	[$/m3]	[$]
Core Consumption (from plywood plant)	61,985		3,473,925
Revenue by log volume	848,015	180.28	152,880,000
OSB RTL		101.78	92,615,751
Volume recovery, [Msqft/m3]		0.714	
Haul, stumpage, harvest and reforestation costs			31,703,081
Road costs			15,224,365
Gross operating profit			49,162,231

The first three scenarios all represented 20-year investment analyses. Graphs 13-18 present some of the trends for these scenarios.

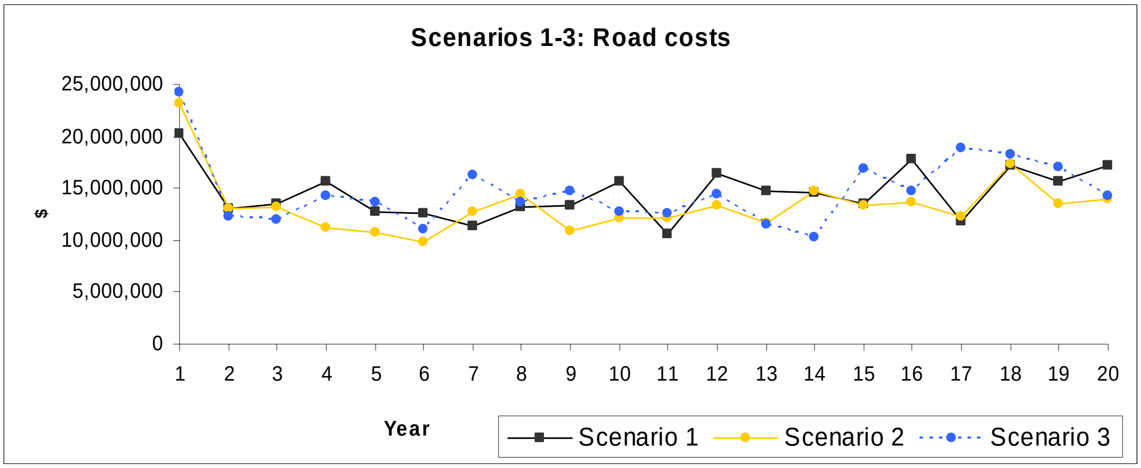

Figure 13. Comparison of Scenarios 1-3 road costs

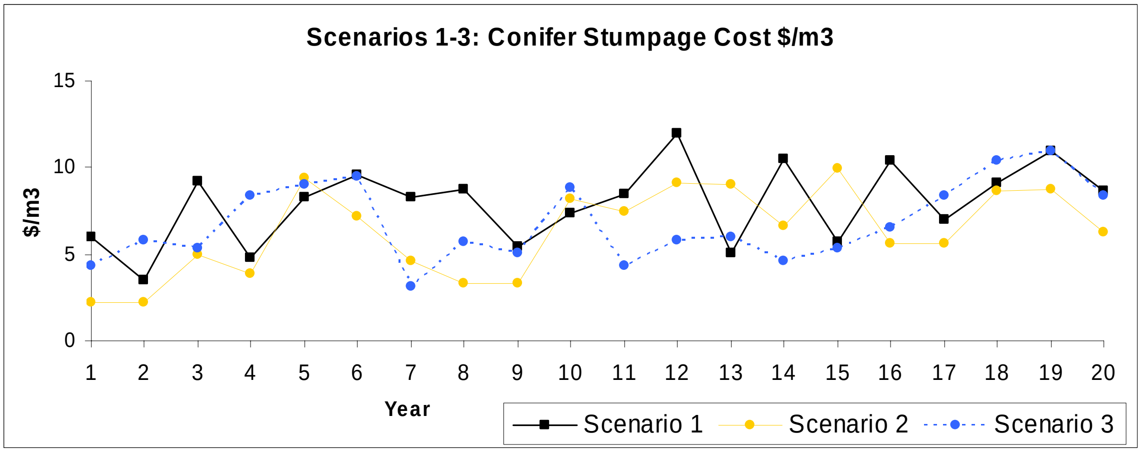

Figure 14. Comparison of Scenarios 1-3 coniferous stumpage cost

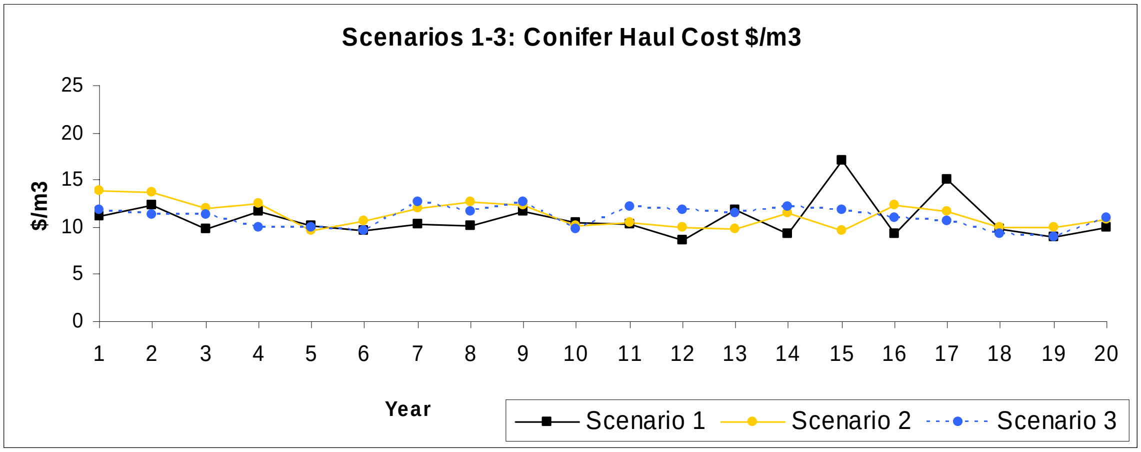

Figure 15. Comparison of Scenarios 1-3 coniferous haul costs

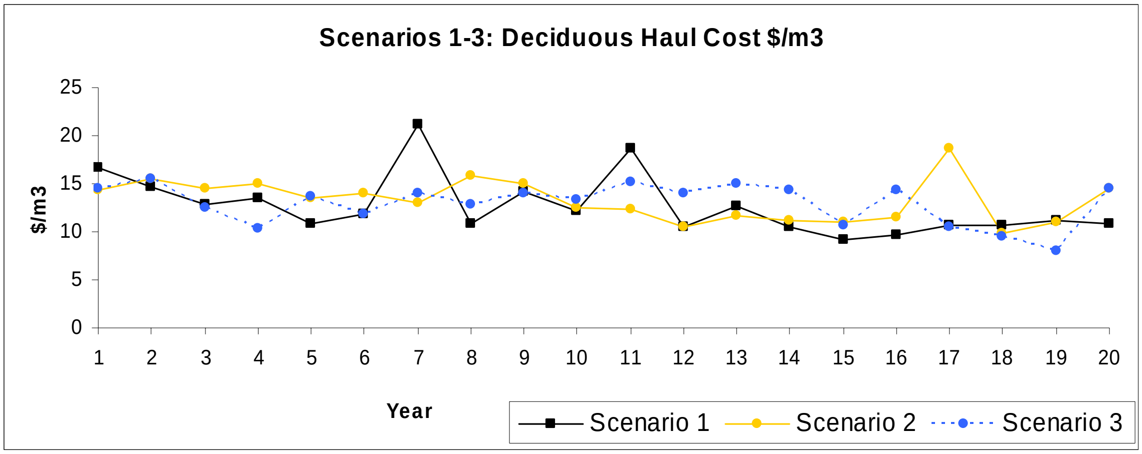

Figure 16. Comparison of Scenarios 1-3 deciduous haul costs

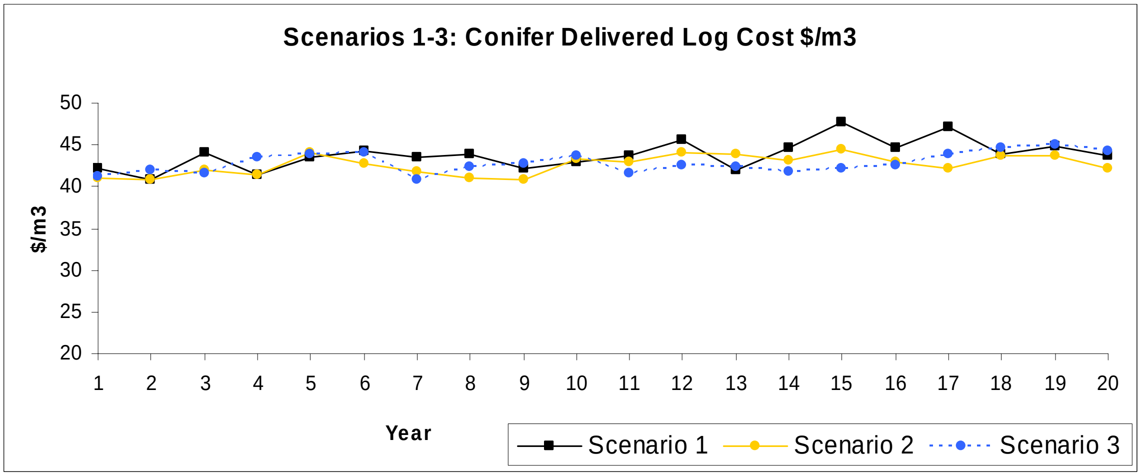

Figure 17. Comparison of Scenarios 1-3 coniferous wood costs

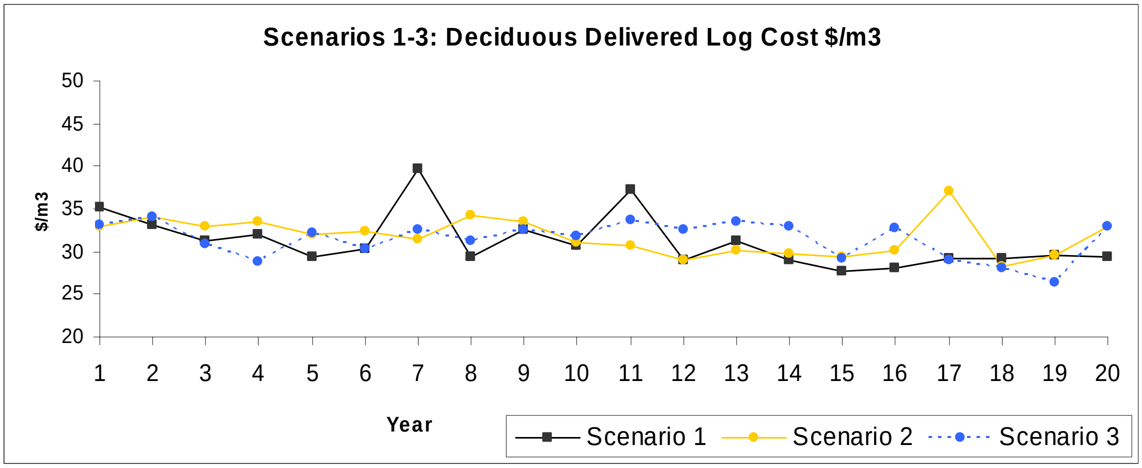

Figure 18. Comparison of Scenarios 1-3 deciduous wood costs

4.7. Scenario 4 (base case 300 yrs)

This, and the subsequent three scenarios, represent timber supply analyses with tradeoffs between the available timber supply and the cost of delivered logs, particularly the road and haul cost components. The tradeoffs are achieved by reducing the requirement to net operational profit, thereby enabling increasing costs to access smaller and more distant HUs. As the SA analysis method has higher penalties for underachieving profit relative to underachieving log volumes, it follows that in a trade-off situation the search for higher profits will not allow HUs with a negative profit contribution to be selected just so that the volume requirement can be met. Although the timber supply will fall short of demand in some years, the volumes in specific years are largely a random result and not a result of temporal decisions.

The data show clearly that, given specific requirements to return to capital employed (ROCE) and conservation of old growth, there will be a corresponding fall down in the timber supply in future years. We also conclude that the higher the requirement to profit, the sooner this will happen given that all other economic factors stay constant. This project was not designed to answer these temporal questions, but the technique is capable of doing so through repeated runs in which the analytical period is increased, say by ten years at the time.

Here, we replaced ROCE by HU Net Revenue which is a pseudo-value to drive the SA analyses.

Scenario 4 represented a 300-year run of the base case (Scenario 1). The settings for both road/harvest and plant allocation models were kept at the same values as for the base case. The purpose was to determine if the base case figures (mill profit, harvest volumes by plant allocation) were sustainable over a 300-year period.

4.7.1. Harvest Data

The combined harvest and road model was run initially with a target HU Net Revenue of $22 million as in the base case. Figures 19 and 20 illustrate that neither the deciduous volume nor the HU Net Revenue met their respective annual targets. Given the base-case harvesting and plant operating conditions, this type of operation is not sustainable for a period of 300 years.

Subsequently, we decreased the HU Net Revenue target value to $10 million and then to $5 million with the objective to obtain sufficient timber volumes and corresponding HU Net Revenue levels. Figure 21-24 show the respective results.

4.7.2. Scenario 4 Discussion

The conclusion from these analyses were that only at the HU Net Revenue level of $5 million, the target levels for the annual volume harvested were met reasonably well, i.e. for coniferous all the years and for deciduous in more than 96.5% of the years. The timber allocation result and profitability analysis (not presented) showed that the investment at these levels of manufacturing technology, revenue and cost were not sustainable.

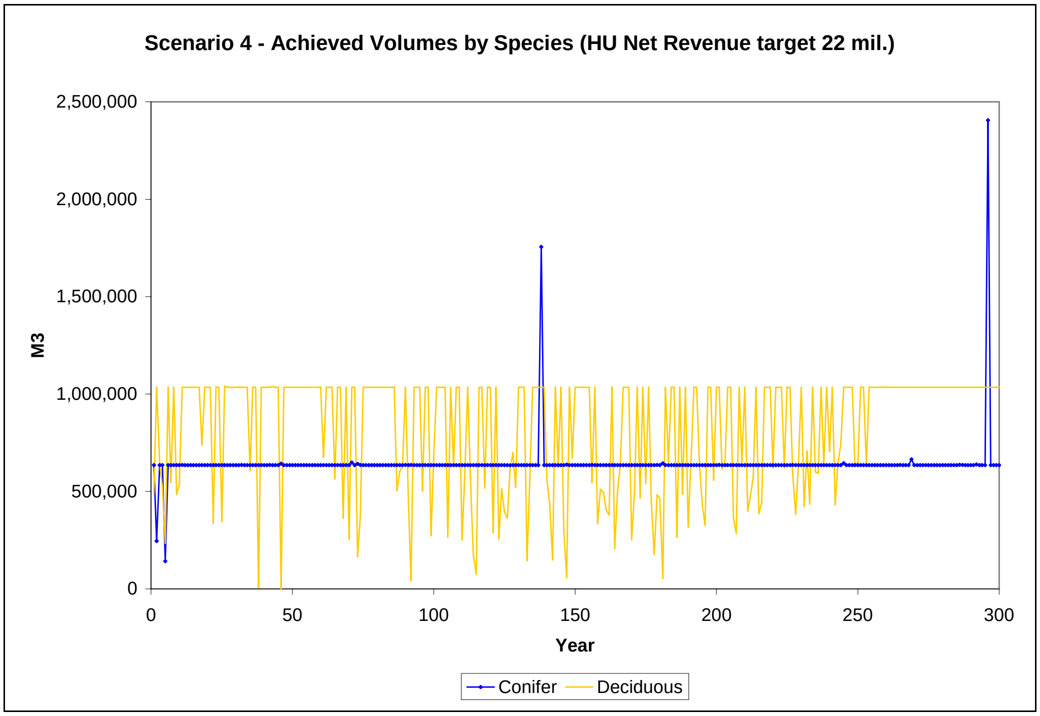

Figure 19. Scenario 4 annual volume harvest by species with HU Net Revenue target of $22 million

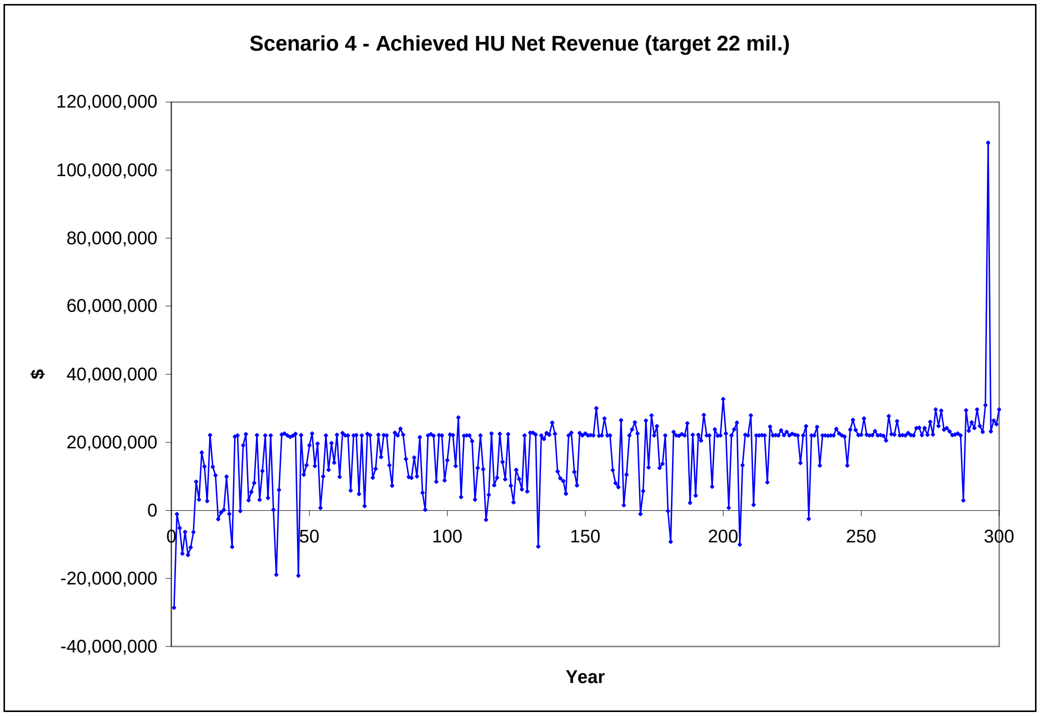

Figure 20. Scenario 4 HU Net Revenues with HU Net Revenue target of $22 million

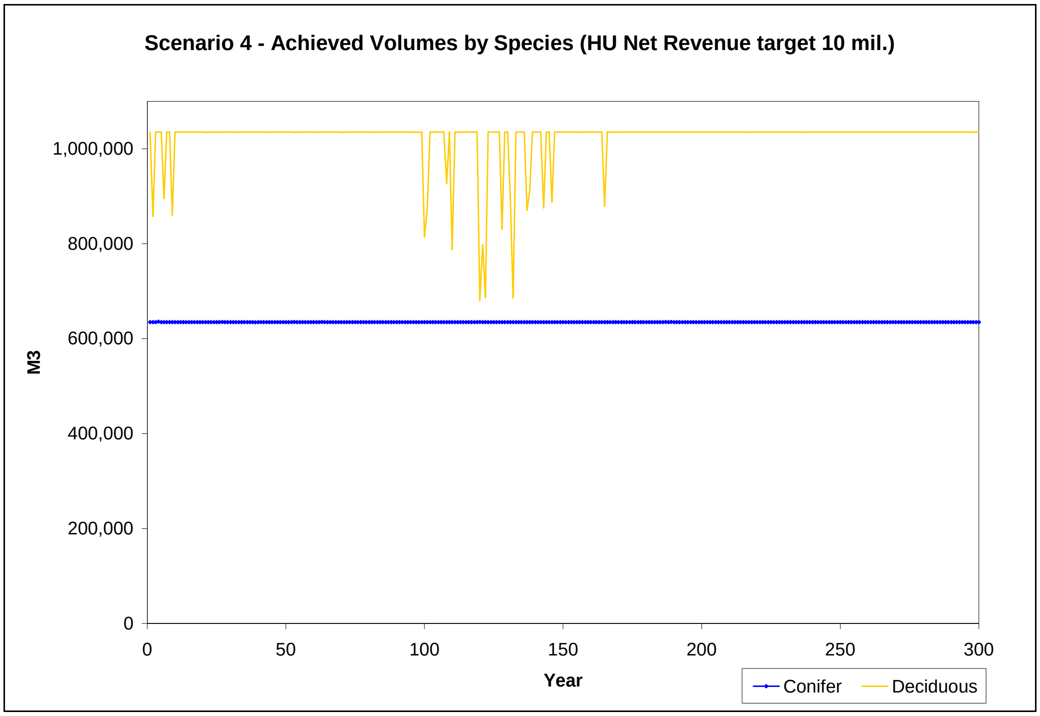

Figure 21. Scenario 4 annual volume harvest by species with HU Net Revenue target of $10 million

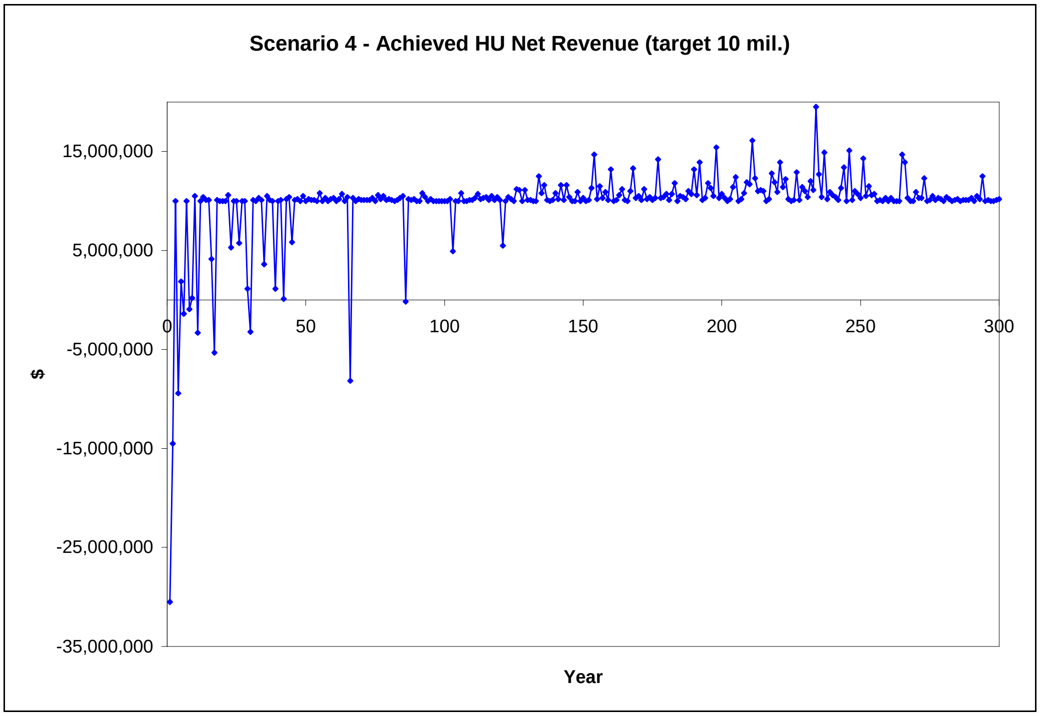

Figure 22. Scenario 4 HU Net Revenue with HU Net Revenue target of $10 million

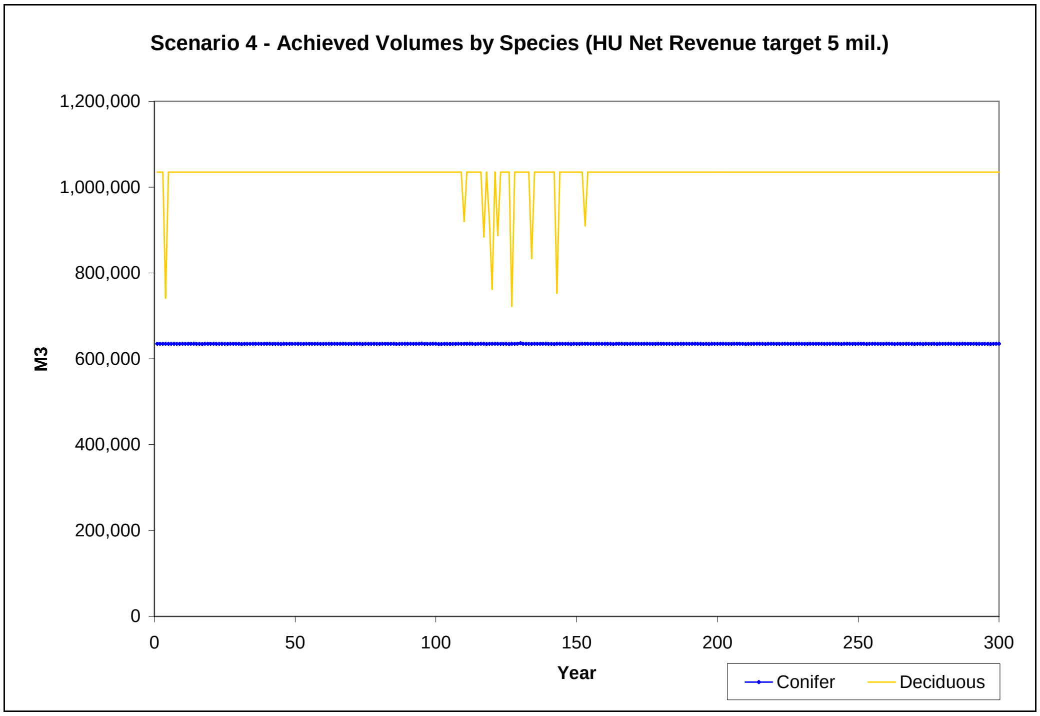

Figure 23. Scenario 4 annual volume harvest by species with HU Net Revenue target of $5 million

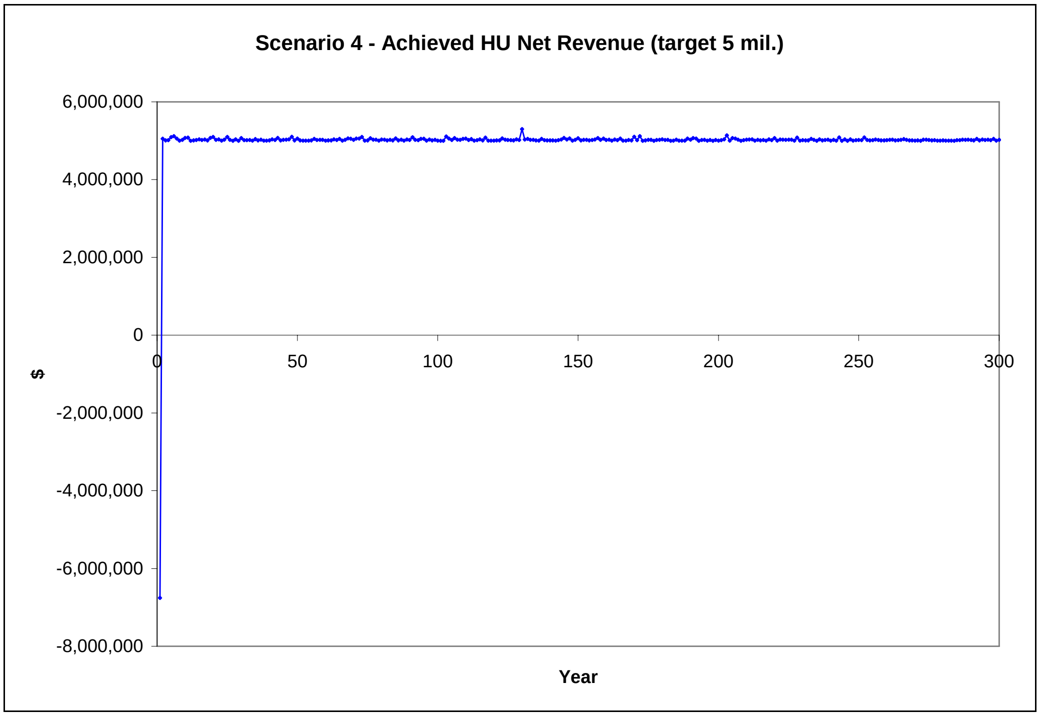

Figure 24. Scenario 4 HU Net Revenue with HU Net Revenue target of $5 million

4.8. Scenario 5 (base case 300 yrs and old growth retention)

Scenario 5 is based on Scenario 4 (with the additional assumption that 20% of the old growth timber area be set aside to be preserved in each year. The aim was to determine if the base case numbers were sustainable over 300 years while preserving 20% of the old growth timber in each year.

4.8.1. Harvest Data

Given that the results for scenario 4 showed that the combined harvest and road model was barely able to find the timber volumes for the mills at HU Net Revenue target of $5 million, we ran Scenario 5 with the HU Net Revenue target of $5 million, as well.

The result from this run, shown in Figure 25, illustrated that the deciduous volume did not achieve the target of 1,035,000 m3 in about 10 of the 300 years, while the conifers volume target was met in all years. The HU Net Revenue, shown in Figure 26, achieved the annual targets, except for year 1.

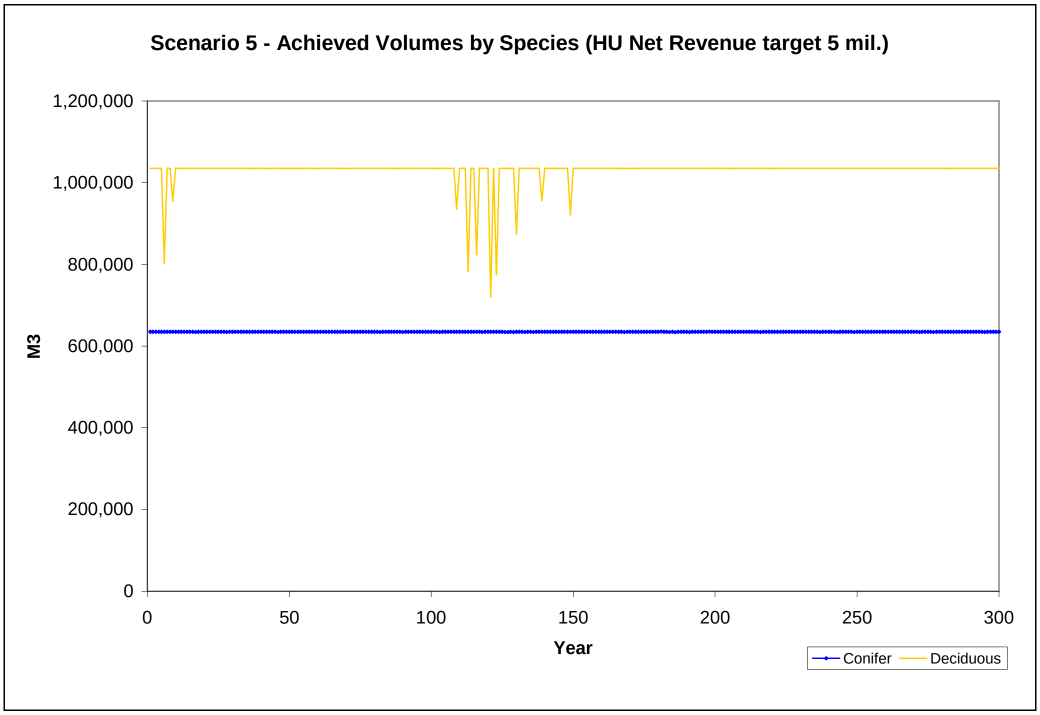

Figure 25. Scenario 5 annual volume harvest by species with HU Net Revenue target of $5 million and 20% old growth retention

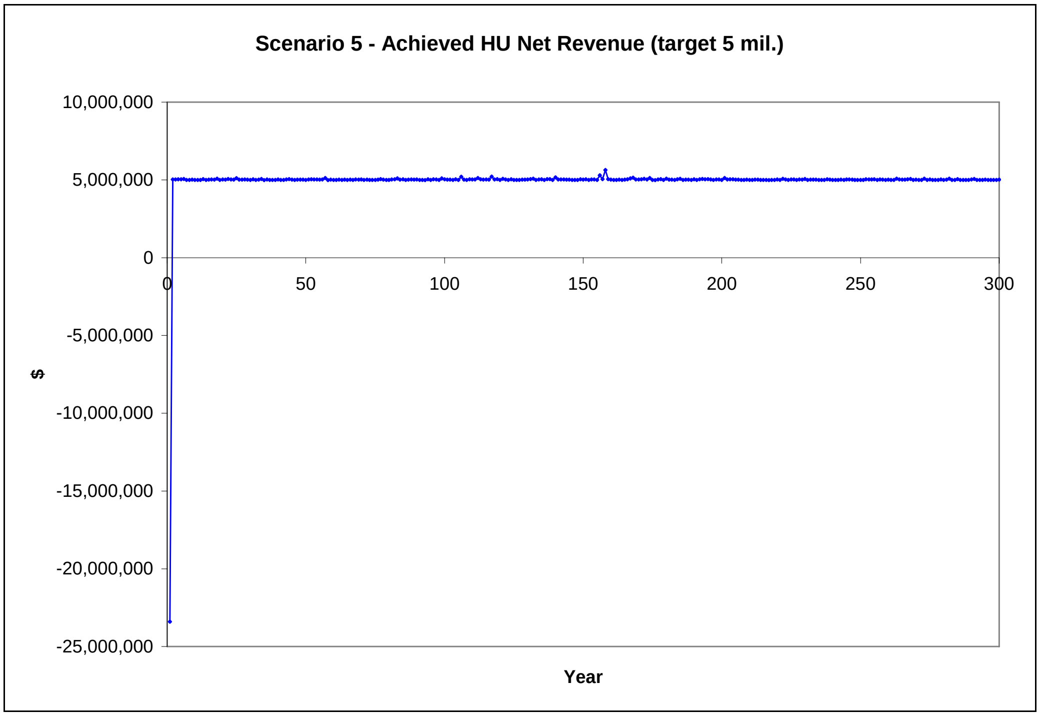

Figure 26. Scenario 5 HU Net Revenue by year with HU Net Revenue target of $5 million

4.8.2. Scenario 5 Discussion

The outcome of this scenario was similar to that of Scenario 4. The “old growth” characteristic of the deciduous timber appeared not to affect the general availability of timber to the mills. There was no shortage of the conifer volume.

The low HU net revenue of $5 million in this scenario likely caused a smaller diameter distribution to be sufficient for finding a solution, which meant that the timber volume for this scenario was not impacted by preserving the old growth.

4.9. Scenario 6 (improved sawmill 300 years)

Scenario 6 is based on Scenario 2. The HU Annual Net Revenue level was set at $22 million as in Scenario 2. Results depicted in Figures 27 and 28 show insufficient conifer volumes with a positive contribution to profit to meet the increased demand for wood by the improved sawmill operation.

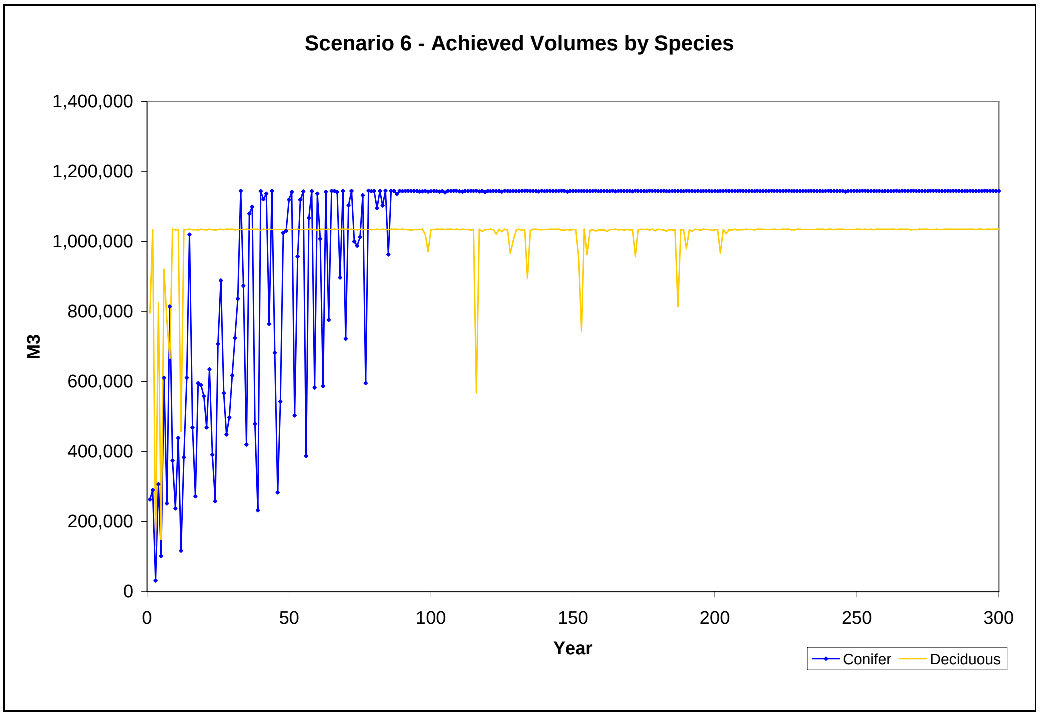

Figure 26. Scenario 6 annual volume harvest by species with HU Net Revenue target of $22 million

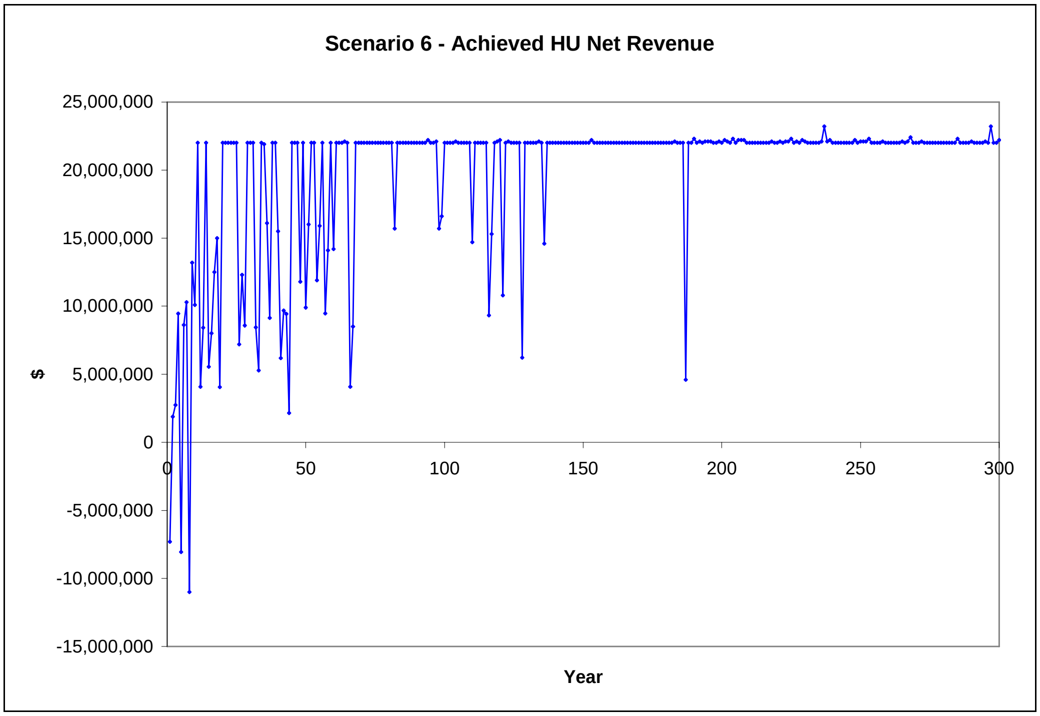

Figure 28. Scenario 6 HU Net Revenue by year with HU Net Revenue target of $22 million

4.9.1. Discussion of Scenario 6

The general conclusion of the Scenario 6 analysis is that it is not feasible to operate the mills and the attendant harvest volumes with the settings from Scenario 2 (improved sawmill) for a period of 300 years. Neither the volumes nor the HU net revenue targets were met in many of the years of the analysis.

4.10. Scenario 7 (improved sawmill 300 years and old growth retention)

This scenario is based on Scenario 6 (improved sawmill 300 years) with the addition that 20% of the old growth timber area was set as a target to be preserved in each year. The aim was to determine if the targeted level of harvest volumes were sustainable over 300 years while preserving 20% of the old growth timber in each year of the study period.

4.10.1. Harvest Data

The combined harvest and road model was run with a HU Net Revenue target of $22 million, the same as the previous scenario 6. The results of this run, illustrate that, while the deciduous volume did achieve the target of 1,035,000 m3 in all years, the conifers volume targets were not met in many years of the analysis, particularly in the first 100 years. The HU Net Revenue did not achieve the annual targets in almost half of the years, especially in the first 150 years.

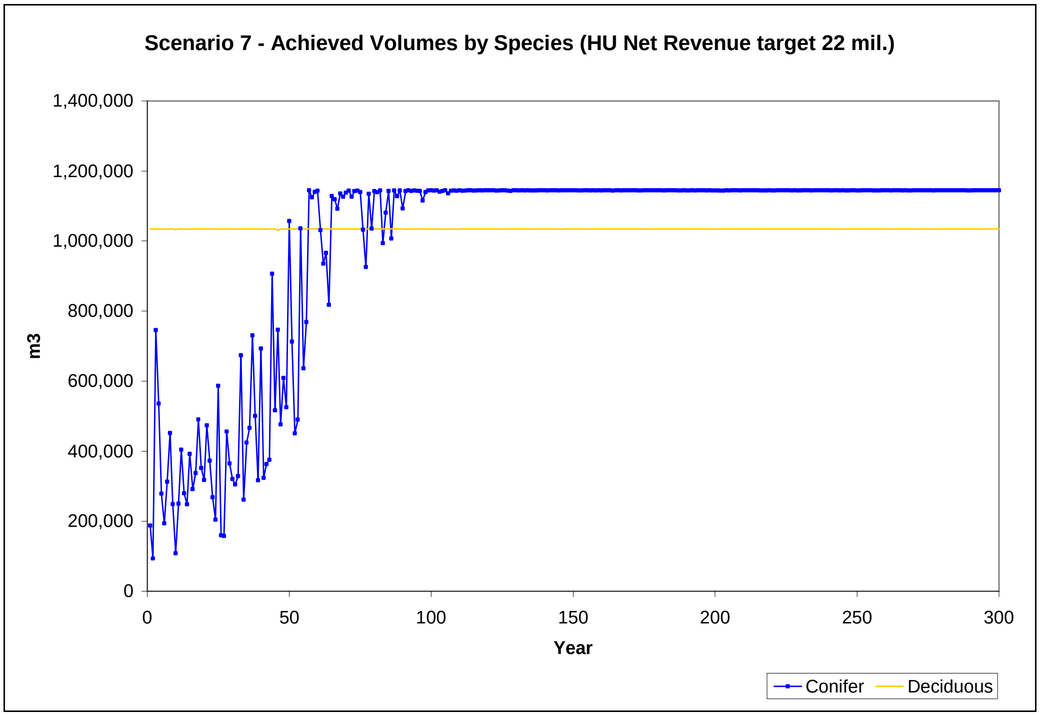

Figure 27. Scenario 7 annual volume harvest by species with HU Net Revenue target of $22 million and 20% old growth retention

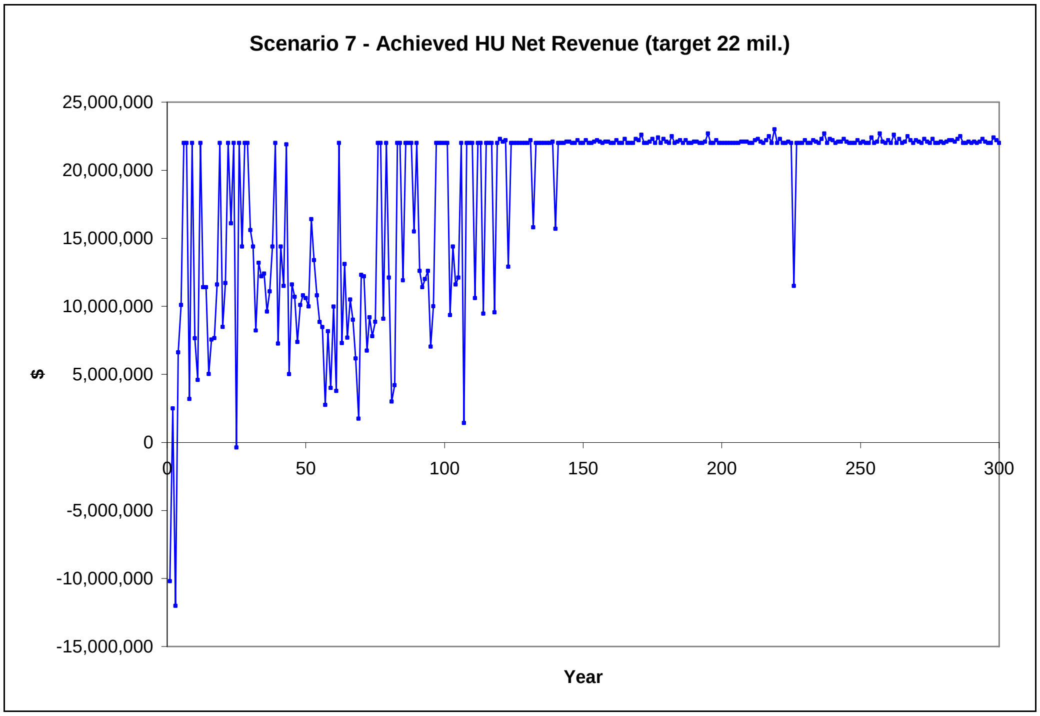

Figure 30. Scenario 7 HU Net Revenue by year with HU Net Revenue target of $22 million

4.10.2. Discussion of Scenario 7

The results depicted in Figure 29 are similar to the ones from Scenario 6. Increased volumes of smaller size logs replaced those with "old growth" characteristic.

The broad conclusion of scenario 7 analysis is that it was not feasible to operate the mills with the settings from Scenario 2 (improved sawmill) for a period of 300 years with the additional constraint that 20% of the old growth timber area to be preserved in each year. Neither the volumes nor the HU Net Revenue targets were met in many of the years of the analysis.

5. General Discussion and Conclusions

The methodology applied in this research represents an innovation in integrating known operations research techniques. Whereas many components worked as expected, a few did not and must be rethought. Yet others will require further research to overcome present deficiencies. We discuss this work in two parts: Methodology and Analyses. In the former we spell out what went right and what were the flaws and how to remedy these; in the latter we discuss what may been learned from the analysis results.

5.1. Methodology

5.1.1. Forest characterization

At the time of we started the project the Simulated Annealing (SA) technique to determine HU size, uniformity and boundaries from the available GIS data represent seemed to represent the best analytical tool available, short of ground surveys, for this analytical purpose. It requires that all available cruise and harvest data be applied to a company's GIS files so as to provide an updated GIS database at all times.

The descriptors used to characterize trees were applied without problems and the recovery programs for lumber and veneer executed as planned. Whether the descriptors took on values representative of the Fort Nelson wood supply is highly uncertain. The surveys forming the basis for knot and rot representation in trees were limited and should be repeated through their inclusion in standard cruise specification.

Plywood recovery in the model and production recoveries need to be better reconciled. This is a relatively easy task accomplished with a recovery adjustment factor. When the tree model has advanced to include parameters for crook, sweep, shake or splits, the adjustment factor can be adjusted.

5.1.2. Optimum log allocation

Given a specified timber supply, the dynamic programming (DP) used in the log merchandising and the linear programming (LP) used to allocate log classes to plants worked as expected. Particularly, the nested DP allowed us to identify bush bucked log lengths which, in turn, were bucked into saw logs or veneer bolts. This feature is required for operations that trade logs to others with their own log specifications.

5.1.3. Road network

Our road network program worked as specified and remains a cornerstone of the analysis technique. It solved the road layout problem and ensured that each harvest unit was associated with a road segment no further away than two kilometres. Furthermore, each road segment had an associated cost of construction varying with the forest type, slope and soil. The road network would take off from the end of existing roads, but does not presently include any road classification. We hope to embed an optimum road classification (temporary, permanent, etc.) model as part of the present methodology.

5.1.4. Forest harvest unit selection

The SA technique did not work as well as we hoped it would for this purpose, primarily because the first harvest unit (HU) selections along main roads formed HU clusters which became impossible to dislodge in a random trade until another HU seeded a cluster further away from the plants along the same road. Thus, the entire TSA was covered in road construction from the first year. More likely, a gradual road development, building the next few kilometres of road and harvesting the closest HUs along the way, would represent a more rational strategy. Therefore, the SA algorithm is not a good fit for this particular project and much more work needs to be done on the harvest selection algorithm.

5.1.5. Harvest/allocation optimization

We planned on iterating the harvest and allocation solutions to maximize the RTL for all the plants. The problem with the SA technique prevented this.

5.1.6. Revenue Targets

The SA technique used included a revenue target to guide the harvest selection process. It turned out that the revenue target was an important mechanism to get the SA algorithm to behave properly, but a revenue target doesn’t make sense from an operational perspective. This is another reason why the SA algorithm needs to be modified or replaced in further research.

5.2. Analyses

The analyses fell into two categories: Investment analyses with a time horizon of 20 years and sustainable timber supply analyses which, in this case, had a time horizon of 300 years.

5.2.1. Investment analyses

Scenarios 1-3 belong in this category. We believe this is the most accurate ROCE estimation available through any available technique as it reflect the change in timber supply volume and quality over time and at the same time provide the short term plan for both harvest and road construction.

5.2.2. Timber supply analysis

The SA technique, once modified, provides the best available tool for extensive analysis of the long term timber supply including the detailed short log profile (diameter, length and quality) to each processing plant. In the present analyses we put forward data showing how the requirement to profit impacted on timber availability. Another, more familiar, way of viewing this problem formulation is how the increasing costs of harvesting a particular log volume and the reducing productivity of smaller log diameters would impact on profit over time.

6. Literature Cited

Anderson, A. 2005. Strategic road network projection. Technical Report #3, Forest Science Program Project Y051218. Vancouver, Canada. 11 pp

Aune, J.E. and T.C. Maness 2005. Strategic timber allocation methodology integrating road, harvest, environmental and industrial planning. Technical Report #1, Forest Science Program Project Y051218. Vancouver, Canada. 19 pp.

Boyland, M. 2003a. Creating forest management zones with the Simulated Annealing algorithm. ATLAS/SIMFOR Project Technical Report, 10 pp.

Boyland, M. 2003b. Hierarchy planning in forestry. ATLAS/SIMFOR Project Technical Report, 7 pp.

Boyland, M. 2005. A criteria and indicators strategic decision support system for combined harvest and road planning. Technical Report #2. Forest Science Program Project Y051218. Vancouver, Canada. 11 pp.

Eng, G., H.G. Dallenbach, and A.G.D. Whyte. 1986. Bucking tree-length stems optimally. Canadian Journal of Forest Research. 16:1030-1035.

Farrell, R. and Maness, T.C. 2003. A relational database approach to a linear programming based DSS for production planning in secondary wood products manufacturing. Decision Support Systems. In-press

Hof, J.G. and T. Baltic. 1991. A multi-level analysis of production capabilities of the national forest system. Operations Research. 39(4):543-552.

Jamnick, M.S. and E.W. Robak. 1996. An integrated forestry planning system. In: Proceedings of a Workshop on Hierarchical Approaches to Forest Management in Public and Private Organizations. Natural Resources Canada. Information Report PI-X-124. Toronto, Canada.

Liu, G., J.D. Nelson and C.W. Wardman. 2000. Target oriented approach to forest ecosystem design – changing the rules of forest planning. Ecological Modelling. 127(2000)269-281.

Maness, K. 2005. GIS data management. Technical Report #5. Forest Science Program Project Y051218. Vancouver, Canada. 7 pp.

Maness, T.C. and D.M. Adams. 1991. The combined optimization of log bucking and sawing and strategies. Wood and Fiber Science. 23(2):296-314.

Maness, T.C. and R.A. Farrell. 2003. Sensitivity Analysis for SFM Criteria and Indicators Using Multi-criteria Optimization. Symposium Proceedings: Systems Analysis in Forest Resources, October 7-9, Stevenson, WA.

Maness, T.C. and S.E. Norton. 2002. Multiple period combined optimization approach to forest production planning. Scandinavian Journal of Forest Research. 17:460-471

Maness, T.C., and S. E. Norton. 2002. A multiple period combined optimization approach to forest production planning. Scandinavian Journal of Forest Research. 17:460-471

Mendoza, G.A. and B.B. Bare. 1986. A two-stage decision model for log bucking and allocation. Forest Products Journal. 36(10):70-74.

Nelson, J. 2003. FPS-Atlas database manual ver. 6. University of British Columbia, Vancouver, Canada. 79 pp.

Ogweno, D.C.O. 1994. Integrated Optimization of Operational and Tactical Planning for Log Production. Ph.D. thesis, University of Canterbury

Palander, Teijo. 1997. A local DLP-GIS-LP system for geographically decentralized wood procurement planning and decision making. Silva Fennica. 31(2):179-192.

Paredes, G.L. 1996. Design of a resource allocation mechanism for multiple use forest planning. In Proceedings of a Workshop on Hierarchical Approaches to Forest Management in Public and Private Organizations, Toronto, Ontario, Canada, 25–29 May 1992. Edited by D.L. Martell, L.S. Davis, and A. Weintraub. Can. For. Serv. Petawawa Natl. For. Inst. Inf. Rep. PI-X-124. pp. 67–82.

Schreier, H., W.A. Thompson, C.G. van Kooten and I Vertinsky. 1993. A decomposed hierarchical system for forest land use allocation decisions with public participation. FEPA Working Paper 175. University of British Columbia. Vancouver, BC.

Seely, B. 2005. Projection of temporal sequences of stand table data for analysis units within the Fort Nelson TSA. Technical Report #4. Forest Science Program Project Y051218. Vancouver, Canada. 19 pp.

Weintraub, A. and L Davis. 1996. Hierarchical planning in forest resources management: defining dimensions of the subject area. In: Proceedings of a Workshop on Hierarchical Approaches to Forest Management in Public and Private Organizations. Natural Resources Canada. Information Report PI-X-124. Toronto, Canada.

END OF REPORT