Gowlland

Haida Gwaii Timber Supply Analysis

Memo 3.1: Modelling and Assessing Operational Road Costs and Dynamic Stand Values

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1 Purpose of modelling stand values

This memo presents and evaluates an approach developed for the Haida Gwaii TSR process to represent the effects of road costs and differential stand values. This memo extends memo 3 on this topic to include an evaluation of the road cost modelling using harvest data.

Modelling of road costs and differential stand values was designed in a strategic manner to reflect the effects on timber supply. A previous memo (Memo 1: Options for Modelling Operational Road Costs) reviewed previous methods used on the mainland coast, and provided a start point for adaptation to Haida Gwaii.

The goal of the road cost aspect is to model relative differences in construction and maintenance costs based on geophysical attributes (e.g. slope, land cover). A road cost surface was developed, which was used to develop a full build-out potential road network that can provide access to the entire THLB via a relative lowest-cost layout. The underlying cost of each road segment is retained during timber supply analysis, where segment cost is the relative cost/km multiplied by road segment length.

The goal of the stand value aspect is to model relative differences in stand values per cubic metre of merchantable volume by species. Relative values were derived using log market prices. As these market prices vary by year, scenarios can apply average values, or higher/lower market values. Stand values in can be computed dynamically as value/m^3 multiplied by merchantable stand volume, and can be summed at various scales, such as grid cell, block or woodshed.

Limits can be defined for the maximum average unit of road cost per unit of stand value (cost/km to value/m^3 ratio) that can be incurred during a period within each woodshed for road building and maintenance. These limits influence the order in which stands may be harvested (and hence the resulting timber supply). When limits are reached, further harvesting is constrained to the active road network at that point. For remote stands, the effect may be to cause rotations to be extended (e.g. to allow further stand growth that will lower the cost:value ratio to within acceptable limits), and in extreme cases may lead to a stand never being harvested (e.g. stand “isolation” may occur for a small stand of low volume/poor value that would require high road construction costs to access).

The base parameters derived for the modelling of operational road costs was evaluated using harvest block data to compare the relative road costs associated with these blocks against average expected road costs in merchantable timber, and against the parameters derived based on this analysis. Overall, the parameters proposed for base case analysis performed reasonably.

2 Relative Road Costs

Relative road costs were developed and will be applied as described in memo 1. This was based on the approach used in the GBR on the mainland coast, and adapted from the Woodflow Gap Analysis done by the Joint Solutions Project. This approach applied the following steps:

(a) Create a road cost surface based on relative costs to construct or maintain roads;
(b) Create a full build-out road network based on existing/proposed roads, THLB and the cost surface;
(c) Calculate costs for individual sections of road from the road cost surface – that is the relative cost of each segment is the sum of underlying relative costs from cost surface over the length of the road segment;

2.1 Road cost surface

The relative road cost layer ranges from 1 to 10, where a value of 1 represents the lowest cost condition (e.g. flat areas through forest). Higher values represent the relative increase in cost (e.g. a value of 10 represents a 10-fold increase in cost, or alternatively, a road segment of length 1 km across an area with cost 10 has the same cost as a segment of length 10 km through an area with cost 1). The same cost factors were applied as in the mainland coast analysis, where cost values were computed as (Figure 1):

- Maximum cost (10) for glaciers, lakes, rivers, salt water, tide flats, rivers, mud and swamps.
- Elsewhere: function of slope in percent: slope/10 (rounded up to next highest integer and bounded to range between 1 and 10)

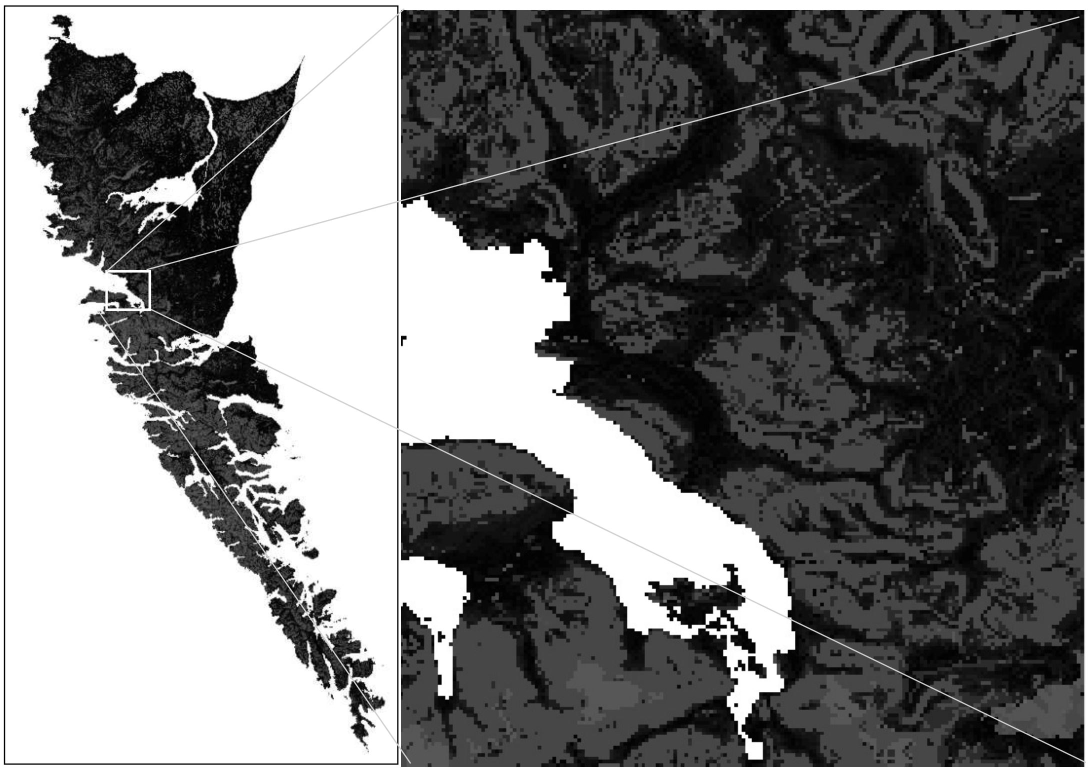

Figure 1. Relative road cost surface in Haida Gwaii: lighter shades indicate higher relative cost.

2.2 Full build-out road network

A "full build-out" road network is defined here as a road network consisting of existing and potential future road segments for which all THLB stands are within 1 km of road (existing or future) or water access. To create a road network that can be applied in both pre-LUO and LUO scenarios, the network is developed with an aim to minimize traversing conservancies and other no-harvest areas. Note that the objective is to make a plausible road network to capture the effects of road access on timber supply, not to predict the exact placement of future roads.

"Exit points" were identified from log handling site information (which are generally at existing road access points from water). Since log handling sites were polygons, an overlay was done with the existing road network, and a single grid cell was selected as the road network exit point.

To generate a full build-out, a location requiring access is stochastically selected, with probability increasing with distance from network roads. The least cost path across the road coast surface is then found to join the site to the road network.

Distance and cost to network information is updated and the process is repeated iteratively until all target areas are within 1 km of a road.

The reason for preferentially selecting sites further from road is that this creates segments that follow the cost surface and avoid lots of short, angular segments (which look more like spurs than the longer segments, which have a pattern more comparable to mainline roads). Conversely, the reason for not simply selecting the furthest site from the road network is that this creates a road network that is more linear than the actual existing network.

The road network was then decomposed into segments, with segment breaks at forks, where roads change from existing to future, and at woodshed boundaries. The average length of segments in the LUO scenario was about 300m.

Information for each road segment is stored in a table that includes the length and cost of each road segment, as well as information on connections with other segments in the network.

The following figure is a snapshot of an area that shows the current existing road network and modelled potential future roads overlain on the road cost surface.

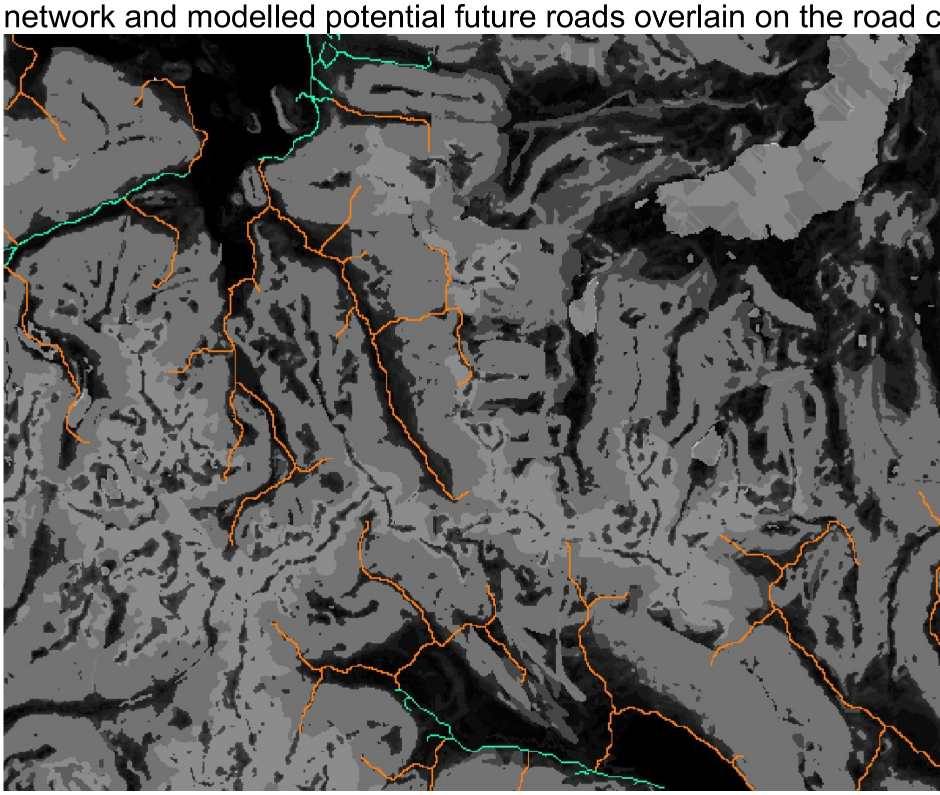

Figure 2. Example of full build-out road network. Shades of grey represent relative road costs, where lighter shades represent higher cost. Cyan represents existing roads and orange represents potential future modelled roads.

3 Relative stand values

3.1 Sources of information for stand values

The goal was to quantitatively derive value factors per cubic metre for each major species. Two sources of information were explored for deriving relative stand values:

(a) Harvested stands in Haida Gwaii
(b) Log market prices

Information for harvesting in Haida Gwaii was available by timbermark, in which information was available on the percent by species of each harvested unit. Given an overall value for the harvested area, as well as the total volume harvested, factors for the value of each species could be derived via a least-cost-fit (i.e. minimizing the sum of the square of the differences between the actual values of the harvested units and the estimated values using the species factors, prorated by the percent of each species in the harvest unit). Direct information on harvest unit value was not available by timbermark, and so explorations were made on potential surrogates for value (in particular stumpage rate). Unfortunately, it was evident that no adequate surrogates were available in the data set.

3.2 Developing stand value parameters based on log market prices

Log market prices provide information for various grades and types of timber based on species, product, etc. These vary by year.

Standard lumber prices are available for Cedar, HemBal, and Spruce. Processed 2x4 prices are available for all species, so these prices were used for this analysis[1].

The actual dollar values are not what is important for this application, but rather the relative differences between species and between years. It is, however, important that the prices used for each species are comparable.

Table 1 shows summary information for each species group over the timeframe 2008 to 2017.

Table 1. Summary 2x4 annual average lumber prices for Cedar, HemBal and Spruce from 2008-2017

[1] On the Madison site: madisonsreport.com

Species type	$/thousand board feet		
	Min	Max	Mean
Cedar (WRC Green Din R/L Std 2&Btr S4S)	622.50	1307.08	860.08
HemBal (Hem/Fir KD Coast Srd&Btr)	182.76	424.76	307.00
Spruce (WSPF KD 2&Btr 2x4)	181.85	414.93	292.08
Overall	181.85	1307.08	483.05

For each species group, monthly prices were averaged across each year (2008-2017; 2018 was excluded since it is not a complete year). Average yearly price values were then divided by the minimum yearly price across all years and species, to put prices on a relative scale (Table 2).

Table 2. Relative value/unit by year for Cedar, HemBal and Spruce

Year	Cedar	HemBal	Spruce	All
2008	3.7	1.2	1.2	2.0
2009	3.4	1.0	1.0	1.8
2010	3.6	1.4	1.4	2.1
2011	3.5	1.5	1.4	2.1
2012	4.2	1.7	1.7	2.5
2013	4.9	2.1	2.0	3.0
2014	5.3	2.1	1.9	3.1
2015	5.4	1.7	1.5	2.9
2016	5.5	1.9	1.7	3.0
2017	7.2	2.3	2.3	3.9
Average	4.7	1.7	1.6	2.7

The relative values/unit by species group can be used to compute total relative stand values by multiplying these relative values by volume proportional to the percent of each species in the stand. The base scenario can use the average for each species group across all years.

Sensitivity analyses can apply high/low values by year and/or species. To facilitate this, years were classified into low, mid and high market years by species group and overall based on equal percentiles (Table 3), and then the mid-point value/unit for each percentile class was calculated (Table 4).

Table 3. Year value class for Cedar, HemBal and Spruce

Year	Cedar	HemBal	Spruce	All
2008	Mid	Low	Low	Low
2009	Low	Low	Low	Low
2010	Low	Low	Mid	Mid
2011	Low	Mid	Low	Low
2012	Mid	Mid	Mid	Mid
2013	Mid	High	High	Mid
2014	Mid	High	High	High
2015	High	Mid	Mid	Mid
2016	High	Mid	Mid	High
2017	High	High	High	High
Low percentile	3.66	1.49	1.39	2.14
Mid percentile	5.31	1.92	1.76	3.00

Table 4. Relative value/unit for each value class for Cedar, HemBal and Spruce

Year	Cedar	HemBal	Spruce	All
Low	3.5	1.2	1.2	2.0
Mid	4.5	1.7	1.6	2.6
High	6.3	2.1	2.0	3.5
Average	4.7	1.7	1.6	2.7

3.3 Projecting stand values

The Spatial Timber Supply Model (STSM) projects stand ages, analysis units, road network and other attributes. A minor modification will be made to the STSM to expand the timber analysis unit (AU) input table to include the percent of the three leading species expected in typical stands for the AU. The merchantable volume in a grid cell will then be pro-rated by species using these percentages, and the relative value will be computed as the sum across all species:

$$\text{Total Stand value} = \text{StandVolume} * \sum_{i=1,n} \text{SppPercent}_i * \text{SppValue}_i$$

where (i) *StandVolume* is the total merchantable volume in the stand;
(ii) There are *n* species types (in this case Cedar, HemBal and Spruce, so *n=3*);
(iii) Each species type has a relative value/m^3 *SppValue*; and
(iv) Each species has a percentage in the stand *SppPercent* (which sum to 100%).

4 Developing and applying cost:value ratios

The relative road costs and relative stand values are used to influence stand availability and preference, in combination with other factors in the timber supply model (e.g. cover objectives).

Road construction and maintenance constraints are applied by “roadshed”. Within each roadshed, limits are placed on the maximum cost that can be incurred within a period on road construction and maintenance relative to value harvested (i.e. road cost : stand value ratios).

4.1 Roadsheds

A roadshed is defined as a group of one or more adjacent exit points (log handling sites), and all the road segment that are connected to those sites. Analogous to a watershed, wood harvesting in a roadshed flows from further inland to these exit points.

In the mainland coast application, roadsheds had to be derived. In Haida Gwaii, a layer of 13 woodsheds was available (Figure 3; left). This layer was used as a basis for roadsheds. Fragmented portions of woodsheds were merged with adjacent roadsheds or placed in a separate roadshed, and each roadshed had at least one exit point. This resulted in 14 roadsheds Figure 3; right).

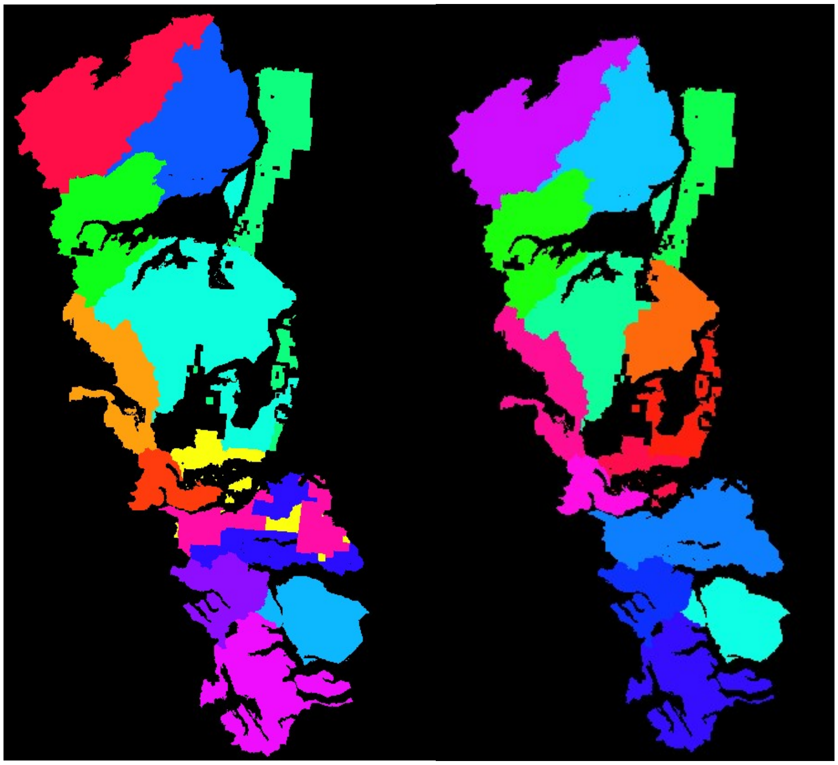

Figure 3. Woodsheds (left) and roadsheds (right)

4.2 Roadshed information tracked in timber supply analysis

The SELES Spatial Timber Supply Model tracks information for both individual road segments and entire roadsheds. The net relative cost of each road segment was computed using the road cost surface (represented as the sum of cost values across the length of each segment). During harvest, the volume and relative value of stands harvested, and the length and cost of road segments that are built by the model ("activated" from the road network) is tracked by roadshed. Also, the model tracks the length and cost of previously built segments that are maintained (accessed for the first time in the period). At present, roads are built once, and maintained up to once per period. In addition hauling effort is tracked as sum of haul distance for each m^3 (volume-weighted haul distance).

4.3 Deriving base road cost : stand value ratio parameters

Separate cost:value ratios are derived for road construction and road maintenance. As in the mainland coast analysis, baseline road building and maintenance costs will be estimated by running the pre-LUO scenario with no road cost constraints to produce output by period for each roadshed that included total volume and relative value harvested, and total km and cost of roads built and maintained. This will be done using average stand values (Table 2). Dividing total road building and maintenance costs by the total relative value harvested results in the mean cost per unit value of roads built and maintained.

As in the mainland coast analysis, road building constraints will be derived using the above outputs in each period, and adding 10% to provide some within-period flexibility in stand harvest sequencing[2]. In general, road building declines over time (as the road network reaches buildout), and hence maximum mean cost of roads built per unit value of wood harvested also declines (while maintenance costs do not change over time).

4.4 Evaluating road cost : stand value parameters

Past harvesting information from the timbermark data will be used to assess, and potentially calibrate, the road cost and stand value parameters. Given the location, area and volume harvested, modelled relative road costs and stand values for the past harvest units will be compared the overall distinction of road modelled road costs and stand values for available stands.

4.5 Apply road cost constraints

A *road building constraint* is defined, for each roadshed and in each period, as an upper limit on the mean cost of roads built per unit value of wood harvested in the roadshed. A *road maintenance constraint* is defined as an upper limit on the mean cost of roads maintained per unit value of wood harvested in the roadshed during the period.

At the start of each period, information on the current harvest level, roads built and roads maintained by roadshed is cleared. The volume of “potentially available” timber (merchantable timber not reserved to meet a specific constraint) accessed from each road segment is computed (using a grid of nearest road segments).

During the period, “block initiation” cells are queued using the harvest order criteria (e.g., relative oldest-first with preference increasing with stand value, and declining with distance from road to a maximum distance of 2 km from an existing road for road access and 5km from a road or ocean for heli access). Before harvest, road constraints are tested:

[2] The road cost constraints must be met at all times during a period. In some cases, higher cost/lower value stands must be harvested prior to reaching higher value stands. The additional 10% allows modest overrun of the cost:value during a period. Post-hoc analysis can be done to assess average end-of-period cost:value ratios to ensure that they are not consistently exceeded.

- If the nearest road is not yet built, a test is made as to whether building this segment would exceed the construction constraint limit for the roadshed. Specifically, the test is for whether the net cost (total cost of roads built so far during the period plus the cost for this segment) divided by the net value harvested (the relative value of volume harvested so far during the period plus the relative value of volume available for this road segment) is less than the constraint cost per unit value for road construction.
- If the road has been previously built, but has not yet been accessed in this period, a test is made as to whether maintaining this segment would exceed the maintenance constraint limit for the roadshed. Specifically, the test is for whether the net cost (total cost of roads maintained so far during the period plus the cost for this segment) divided by the net value harvested (the relative value of volume harvested so far during the period plus the relative value of volume available for this road segment) is less than the constraint cost per unit value for road maintenance.

As logging progresses, distance to road information is updated. Further, at the end of each period, the total volume harvested with access from each road segment is "flowed" down the road network to the water access point to supporting computing the total hauling effort.

When applying road constraints, some areas may never be accessed if the cost per length of road is high relative to the available value (which depends on the area of THLB, productivity of stands and relative species value). Some areas will be accessed with delay (compared to not applying road constraints) if available volume must increase to satisfy the road cost requirements. Other areas will be unaffected (e.g. areas with dense, high productivity THLB, with existing road access close to water entry points).

Note that, although the road constraint targets will be derived from the pre-LUO scenario, applying these targets to the pre-LUO scenario may still result in timber supply impacts. This is because, as implemented, the road constraints must be met at all times during a period (i.e. no road segments are permitted to be built or maintained if this would violate the road constraint). However, when running a scenario without road constraints, the net road building and maintenance costs at the end of the period may be less than at some points during the period. For example, a relatively expensive road segment may be built that accesses little timber (increasing cost per unit value), but this may create access to subsequent segments that are relatively lower cost and access more timber (decreasing cost per unit value).

5 Evaluating cost:value ratios

The best data available to evaluate these methods and parameters was market cycle harvest blocks (“Market Cycle Blocks”), which was used to assess the parameters derived in the preceding section with recent harvesting.

5.1 Historical harvest scenario

The Market Cycle Block data included information on harvested blocks from 2007-2017, by timbermark, for a range of attribute. The primary attribute for this analysis volume/ha. A grid was generated for the Haida Gwaii TSR data set grids for this attribute to identify a historical spatial harvest scenario.

5.2 Modelled harvest scenarios

Three modelled harvest scenarios were developed to compare against historical harvesting:

- Operational Road Costs: This scenario basically the base case TSR scenario (i.e. all constraints, criteria, etc.) with operational road costs.
- No Operational Road Costs: The same as above, but without operational road costs.
- No Operational Road Costs Randomized: The same as the “No Operational Road Costs”, but also applying a random harvest preference order for stand harvest selection (rather than based on relative to the age at the culmination of mean annual increment. This scenario was intended to represent as close to "random" as possible, but still respecting constraints, min. harvest criteria, etc.

For each of these scenarios, the Spatial Timber Supply Model (STSM) was run for 10 years, with output of grids for areas harvested and volume/ha prior to harvest.

To make comparisons relevant, the rate of harvest was based on the total volume harvested in the Market Cycle Block data. This is because, in general, road costs/unit value will decline with increasing harvest level (with lots of potential for variability), so it is important to compare scenarios at the same (or nearly the same) harvest level.

5.3 Identify roads accessed

For each scenario, the portion of the road network required to access the harvest blocks was identified using a new road flow model adapted from the roading model in STSM. For each harvest cell, the road network was traversed, starting at the nearest road segment, and ending at the “exit” point at the water.

Those road segments were considered as “accessed”. Roads were separated into permanent high-use road (e.g. mainlines) and branch roads.

The data did not allow identification of which road were built primarily to access the Market Cycle Blocks. So this analysis focused on the entirety of roads accessed, and can be interpreted as either assuming all branch roads pre-existed the harvesting (i.e. branch roads were maintained) or all were built for the harvesting.

5.4 Summary road cost metrics

For each scenario, a number of metrics were calculated:

- The "value/ha" in harvested cells was calculated using the stand type value weights derived from log market data (by multiplying volume by relative stand value).
- The total road length and total road cost was summed for the road segments accessed for the harvest.
- The average cost/unit value for the roads accessed (separating permanent high-use roads from branch roads) was calculated by dividing total road cost by total value.

5.5 Normalized Results and Discussion

Average cost/unit values were then normalized by dividing values for each of the modelled scenarios by the historical harvesting scenario:

- Operational Road Costs: 107% for branch roads alone and 98% for all roads
- No Operational Road Costs: 129% for branch roads and 112% for all roads
- No Operational Road Costs Randomize: 161% for branch roads and 147% for all roads

These results show that the modelled operational road costs in the projected 1st decade result in road cost per unit value that are close to, but slightly higher than the Market Cycle Blocks. This is reasonable, since in the first pass, one would expect that road costs per unit value to increase over time as more remote and isolated stands are accessed, which may require more road or more costly road access, and possibly lower volumes per ha.

The results for scenarios without operational road costs show the magnitude of the improvement, which is reasonably significant given the other factors that constrain and direct harvesting.

6 Recommendation for Timber Supply Review Process

This memo is presented as a proposal for both applying operational road costs and stand values in the Haida Gwaii Timber Supply Review process. Simplifications include focusing on relative road costs and stand values (rather than on absolute dollar costs or values). Use of relative stand values instead of volume as the units that can offset road construction or maintenance costs (i.e. cost:value ratios instead of cost:volume ratios) was designed to improve/refine the method.

Parameters for modelling operational road costs were derived and assessed against recent historic logging. Applying operational road costs in the model, using the derived parameters, provided an improved correspondence with historical harvesting.