FSP Project Y051218:

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

Technical Report #3:

Strategic Road Network Projection

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1. Introduction

Spatial harvest scheduling models are becoming more common for use as strategic planning tools. Even though many of these models can use road networks, roads are rarely included because of the enormous effort required to manually project roads and the lack of confidence associated with most computer programs used to generate road networks. The Linear Features Projection Model (LFPM) was developed specifically to build on existing roads and create complete networks for strategic models. The objective of the program is to quickly and cheaply develop a road network with enough detail to allow managers to have confidence in the results. The long time periods and high uncertainty associated with strategic road plans means that they will not necessarily be implemented exactly where laid out and that the operational feasibility of the road network is not the main concern. At the strategic level the main roads or the framework of the network is most important because it will guide the forest development.

The objective of this part of the project is to use LFPM to project a complete road network for the Fort Nelson Timber Supply Area that is suitable for strategic planning. The report outlines the methods, then presents the results and finally makes conclusions and recommendations.

2. Methods

The methods are divided into five sections:
1. creating a network from the existing road file and developing a dataset
2. projecting roads to complete the road network
3. simplifying the network for use in the planning model
4. description of the inputs
5. description of the parameters used

2.1. Creating a network from the existing road file

A road network requires that all road segments have the preceding (mill side or loaded) segment identified. Once each road segment has the preceding segment, a timber supply model can route wood through the network back to the start of the network. The start of a network is generally a mill, sort yard, dump or in this case simply the city of Fort Nelson. Most road data received from licensees are in the form of lines that need to be transformed into a network. Most road line files have problems that make creating road network difficult, so the road file has to be cleaned. Three data problems need to be addressed while cleaning a road network:

1. road segment not connected to the network
2. multiple line segments representing one road
3. loops within a road network

LFPM is designed to deal with these problems during the development of the road network. LFPM uses a shortest path algorithm (Dijkstra, 1959) to
determine the shortest distance from every link in the road file to the start point of the network. This process identifies the preceding link, and splits any loops in the road network. LFPM then identifies roads that are not connected to the road network and adds a segment that will connect the end points of road to previously cleaned network. The additional segment is restricted to 100 m. This process will not connect all the existing road system to the network because some road segments are too far from the rest of the network. These roads are addressed by manually adding road segments in a commercial GIS package.

After the existing roads are cleaned and transformed into a network LFPM splits long road segments and assigns attributes so that the network can be imported into a dataset. The reader is referred to other publications for the steps involved in developing a dataset (Anderson, 2003; Anderson and Nelson, 2004).

2.2. Road network generation

The following is a brief overview of the methods used by LFPM to create a road network, more information can be obtained from other publications (Anderson, 2003; Anderson and Nelson, 2004).

A shortest path algorithm is used to project roads (Dijkstra, 1959). The land base is covered with a specified density of points that are connected by links. LFPM selects a point to be the start of a new road and then uses penalties to guide the algorithm as it connects the point to the existing road network. Once the point is connected to the existing road network the program adds it the network and selects another point. This process is continued until all the points are within a specified buffer distance from a road.

Control over the projected roads is achieved by assigning penalties to undesirable road segments. For example, a road segments with a stream crossing may receive a penalty of 1000 or a steep section of road might be assigned a penalty of 2 times the road segment length. The algorithm is attempting to find the shortest route back to the existing network, so a penalty of 1000 would represent an extra 1000 m of road, and 2 times the length of low gradient road is equivalent to the steep section. Theoretically, the penalties reflect the relative costs of each road segment; however, the road projections have to be inspected over the ground to make sure they are acceptable. Often penalties can combine to cause the program to behave unexpectedly and the penalties have to be adjusted accordingly. Penalties are used to control road standards such as alignment, grade and switchbacks, and the road location as affected by physical features such as, side slope, riparian zones, stream crossings, terrain type, sensitive soils, productive/non-productive areas, and seismic lines.

The road standards vary with road class (e.g. mainline or operational) so roads are projected in stages. During each stage a different buffer width is specified, and roads are projected until all of the productive area is within the buffer. For the first stage the buffer length is wide (e.g. 5000 m) and mainline standards are used. The program continues adding roads for this first stage until all available land bases are within 5000 m of a road. During the next stage, the
buffer width is decreased and the road standards are relaxed. For the Fort Nelson TSA the final buffer width is 2000 m.

2.3. Simplifying the Road Network

LFPM requires that each road segment be 10 – 75 m in length during road projection, which makes the network too large to be efficiently used in a harvest scheduling model. However, the network has extra information and can be simplified. Once the harvest areas are linked to the network, the spatial information is no longer required. The program then merges adjacent road segments between junctions and points where timber enters the road network. The result is a table that contains the cost of each road segment and the identification number of the appropriate preceding road segment. Other information can be included if required.

2.4. Input Files

Input files obtained from Canadian Forest Products Ltd. in Fort Nelson were used to assign attribute information to points and links, which make up the dataset. This information is then used to determine attributes such as road grade, side slope, and productive area, which are then subsequently used to control the road projections using penalties. This section describes the input files and the respective attributes.

2.4.1. Elevation, Side Slope and Aspect

A contour coverage was used to make a Triangular Irregular Network (TIN) that was then used to determine the elevation, side slope, and aspect of the points. The elevation of the points was then used to determine the grade of each link.

2.4.2. Riparian

Riparian was considered to be within 100 m from polygon water features (river, lake, marsh) and 50 m away from any single line stream. The polygons were obtained from the provided forest coverage. A stream-line coverage was also provided.

2.4.3. Stream crossings, River Crossings, and Seismic Lines

The data format used by LFPM only allows one stream crossing, seismic or river crossing per link. If one link has two attributes the following hierarchal system is used.

1. River crossings are always retained. Rivers are determined from the polygon coverage and streams are determined from line coverage
2. Next, stream crossing are retained based on the highest order stream
3. Finally, seismic line information

For example, if a link had both a stream crossing and a seismic line attribute the stream crossing information would be retained.
2.4.4. Productive Area

Productive area was assigned to each point using the provided forest coverage.

2.4.5. Road Costs

Road costs for each link were not calculated at this stage. The length of seismic line and the total length of each road segment were output for the harvest-scheduling model.

2.5. **Road Projection Penalties and Stages**

The description of the rules that the penalties represent are presented in this section. The rules can either prevent a road from using a link (prohibitive limit), or can be used to discourage a link (favoured limit). The Fort Nelson TSA was projected in two stages. The first used a 5 km buffer and the second stage used a 2 km buffer. The rules are explained in two sections; 1) constant rules are penalties that applied to all stages of network development and 2) variable rules are penalties that are different for each stage.

2.5.1. Constant rules

The constant rules are applied to both stages of the road projection.

1. Roads are discouraged from crossing water bodies (swamps, lakes, or rivers) and all other non-productive areas. River crossings represent bridges and if needed lake crossings represent a barge crossing. Where possible and required it is best to manually determine the location of barge crossings and major river crossings using local knowledge.
2. Roads with a side slope less than 10% are favoured, and roads with a side slope of greater than 35% are further discouraged.
3. Roads within 100 m of water bodies (polygons) and 50 m of streams (lines) are discouraged.
4. Stream crossings are discouraged. The higher order streams have larger penalties.
5. Roads are discouraged in areas already accessed by roads. This is achieved by identifying and penalizing points that are within the buffer distance.
6. Seismic lines are favoured over other areas.

2.5.2. Variable rules

The varying rules are used to control the road standards for each stage. These values were modified from rules for other projects. Although the road standards have operational significance the values are higher than operational design parameters because the confidence in the digital data is low. The road standard parameters for stage 1 and 2 are in Table 1 and Table 2, respectively.

Two limits are used to control the standards. The first limit is the upper bound of the standard (prohibitive). The second limit is the favoured limit above which
roads are highly discouraged. In addition to the limits, LFPM is designed to always favour better road standards.

Table 1. Rules used to control the standards for stage 1 (5 km buffer).

<table>
<thead>
<tr>
<th>Stage 1 Standards</th>
<th>Prohibitive limit</th>
<th>Favoured limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favourable Grade (%)</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Adverse Grade (%)</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Vertical Alignment (Grade Change % / 10m)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Horizontal Alignment (Radius of Curve m)</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Switchback Radius of curve (m)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Distance Between Switchbacks (m)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Junction Angle</td>
<td>70°</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Rules used to control the standards for stage 2 (2 km buffer).

<table>
<thead>
<tr>
<th>Stage 2 Standard</th>
<th>Prohibitive limit</th>
<th>Favoured limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favourable Grade (%)</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Adverse Grade (%)</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Vertical Alignment (Grade Change % / 10m)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Horizontal Alignment (Radius of Curve m)</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Switchback Radius of curve (m)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Distance Between Switchbacks (m)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Junction Angle</td>
<td>90°</td>
<td></td>
</tr>
</tbody>
</table>

3. Results

Table 3 has the kilometres of road and the number of links for each stage. Note the decrease in the number of links when the network is simplified. Figure 1 is a map of the completed road network. Roads were not projected into southwest portion of the TSA because this planning exercise excluded this area from harvesting. Figure 2 shows an example of road projected in the mountainous topography. Figure 3 shows roads projected in gentle topography, and also shows how stage 2 (5 km buffer) builds on stage 1 (2 km buffer).
Table 3. Kilometres of road and number of links for each stage.

<table>
<thead>
<tr>
<th></th>
<th>Length of roads in network (km)</th>
<th>Length added during stage (km)</th>
<th>Total number of links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original roads</td>
<td>17,409</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaned Network</td>
<td>17,773</td>
<td>364</td>
<td>865,749</td>
</tr>
<tr>
<td>Stage 1 (5 km buffer)</td>
<td>22,332</td>
<td>4,559</td>
<td>9776,853</td>
</tr>
<tr>
<td>Stage 2 (2 km buffer)</td>
<td>32,711</td>
<td>10,379</td>
<td>1,222,972</td>
</tr>
<tr>
<td>Simplified network</td>
<td>23,143</td>
<td>N/A</td>
<td>24,513</td>
</tr>
</tbody>
</table>

Figure 1. Map of the complete road network for the For Nelson TSA. The black lines are existing roads, red lines are added roads, green polygons are the non-timber, or excluded from harvesting land-base in this project, and blue polygons are water bodies.
4. Conclusions

This portion of the project was a success in that a road network was developed for the Fort Nelson TSA and simplified for use in a harvest scheduling model. This road network could be improved by using the local knowledge that
the managers possess. A meeting to obtain feedback would be recommended to improve the road network if future projects require a better network.

The ability to add road networks to spatial strategic plans raises some questions. The main roads of a network have the potential to affect the economical, environmental, and social indicators predicted by a model. This is especially true if a plan has policies that limit the amount of active road per time period or the amount of road constructed in a time period. Very little work has been done to determine which types of land bases are sensitive to the road network design. Projects designed to address this sensitivity could help managers decide how much consideration to give to the development of their road network.

5. References