PLANNING FOREST ROADS WITH COMPUTERS

Greg Arnold
LIRO

INTRODUCTION

Traditional methods used in forest road planning have relied largely upon the individual skill of the forest engineer to draw roadlines on a contour map. The forest engineer then calculates the road costs for a harvest plan based on experience (eg. average roading cost per kilometre). However, the roadline sketched on the topographical map is usually not exactly the same as the gradeline marked in the field due to features in the terrain to enable shortcuts (ie. cut to fill) or areas that need to be avoided. In addition, the exact volume of earthworks is unknown making it difficult to produce a accurate road costing for comparing alternatives.

In difficult mountainous areas, a sketch on a map may not be sufficient to determine if a proposed road and landing locations are feasible. Ridges may be to tight and narrow to allow construction of a curve around the ridge at a radius that trucks are able to negotiate. In addition it may not be possible to construct a landing of sufficient size on some narrow ridges.

To overcome these constraints, various companies now undertake a full road survey, design and setout to determine earthwork quantities for accurate costing and to ensure the correct construction of a engineered alignment. This level of design requires a large commitment in time and resource. Therefore other alternative routes are not surveyed and then designed to determine the best and cheapest option. Effectively the planning finishes when the road is sketched on the map and the road design is just part of the construction process to ensure a proper engineered alignment.

For planning purposes the road and landing locations do not need to be surveyed on the ground for design. The terrain information can be extracted from a GIS or digitized from a topographical map into a road design package. This reduces the surveying time considerably and a larger area is covered to enable the design of several different routes for comparison. However, the terrain information is not of sufficient accuracy to use the road design for setting out construction and should be limited to planning only.

Becker and Jaeger (1992) have extracted a DTM from a Geographical Information System (GIS) into a computer aided road design package for road design. They could quickly design several different road locations. Engineering drawings and earthwork quantities were produced to aid in determining the best (cheapest) road location. This level of planning is a step above a simple sketch on a map and is discussed in this paper.

It is possible to easily extract digital terrain data from a GIS for use in most civil engineering software packages for design and eliminating the need for field surveying. SDR is a road design software package that will be used to demonstrate this procedure. There are many other surveying and engineering software packages available and used throughout the world. Other packages similar to SDR that are used in New Zealand are GEOCOMP and CIVILCAD. In addition, ROADENG which is used by several forestry companies can design roads from a digital terrain model at a limited scale.

CURRENT FOREST ROAD PLANNING

There has been an increasing trend by the forest industry to implement a Geographical Information System (GIS) for planning and management of their forests. Large investments in time and money have been made to obtain accurate digital terrain data from topographical maps and aerial photographs. A GIS is simply a large spatial database to enable data on the forest resource to be retrieved and stored easily. Additional software and skills are needed to use the data stored in the GIS system for planning.

Often the GIS is used to produce a contour map, so that traditional techniques to plan landing and road locations can be employed. The map is placed on a digitise tablet to obtain a series of profiles for PCLOGGER (a program used for payload analyses of hauler settings) and roadlines are simply sketched by pencil on the map. After the harvest plan has been sketched on the map it is placed on another digitise attached to the GIS to update the new road and landing locations in the spatial database.

Clearly, it should be unnecessary to extract digital terrain data onto paper from the GIS which is then read by another software package to store the data digitally for processing. Software should be written to extract digital data from the GIS for direct importation into other software packages. This will utilise more fully the large investment in resources that ensured sufficient and accurate data was stored within the GIS. Some companies have written routines to produce a DTM from a GIS that can be read directly into PLANZ (a program used to analyse landing locations for cable logging using digital terrain data). This is quicker and more accurate than digitizing a contour map produced by a GIS into PLANZ for processing.

ROAD DESIGN (SDR)

The road design process requires a series of steps and is similar for most road design packages used (SDR, GEOCOMP, CIVILCAD). SDR is the most commonly used surveying and civil engineering design package used in New Zealand and will be used as an example to illustrate the road design procedure. First, the DTM needs to be created by either digitising a contour map or extraction from a GIS. This DTM is then imported into an appropriate road design package for design to produce earthwork quantities and engineering drawings for the landing and road construction. Once satisfied with a design the new road and location, complete with finished elevation, can be imported back to the GIS to update the spatial database.

Terrain Data Extraction

Data defining the terrain needs to be imported into SDR before a road design can begin. The data that is imported into SDR is a series of points located on a grid with a known co-ordinates (northing, easting and elevation), there will also be additional points identifying features (boundaries, existing roads etc). SDR will then form its own DTM for interpolating cross sections and displaying contours at set intervals. SDR readily reads and writes data from and to a wide variety of sources, and some of these include:

- ASCII file, with the ability to customise the format accepted.
- DXF (common format accepted by drawing packages such as Autocad).
- Arcinfo points file (commonly used Geographical Information System).
- Contour map from a digitise.

There are a large number of other formats available and there should not be any difficulty in reading in the required digital terrain data sourced from a GIS or contour map. After importation, the map displayed within SDR is similar to the display within the GIS, as shown in Figure 1.

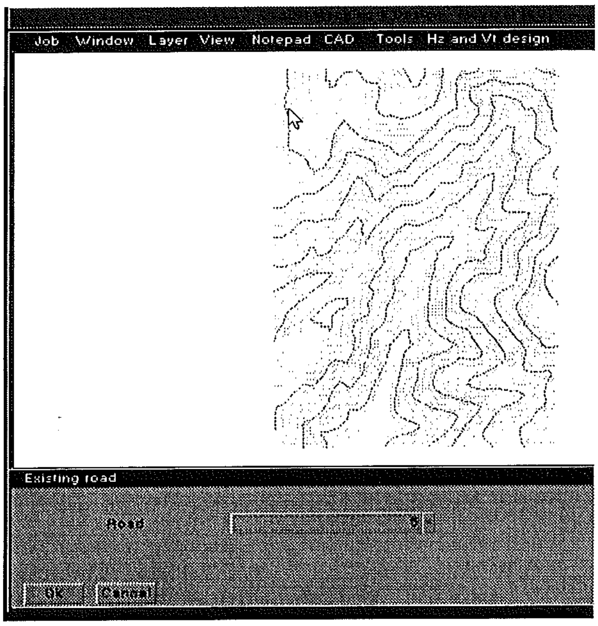

Figure 1 - Plan view of terrain data displayed in SDR.

Horizontal and Vertical Alignment Design (SDR)

Within SDR, the horizontal and vertical alignments are designed. For an experienced user of SDR, the design process is very straight forward, with some routines automated. It is important to realise that computer road design software packages like SDR are a tool only. These design packages do not automatically produce a design that will work and minimise earthwork quantities. The final design is only as good as the users expertise in geometric road design. A sound knowledge on how combinations of grade and curve radii could restrict the trucks manoeuvrability is required. If the user does not know the maximum grade for various curve radii, then it is quite possible to design a road that trucks will be unable to negotiate.

However, SDR does include features that will ensure a proper engineered alignment even by people with little knowledge in geometric road design. There are look up tables within SDR listing the curve radius and transition length required for a particular design speed. These are incorporated in the horizontal alignment design section and all that is required to design the curve is the design speed. The curve radius is automatically calculated or a message will be displayed on the screen that a curve to match the design speed is not possible between the two straights. Alternatively a curve radius can be entered and the design speed will be calculated. Figure 3 shows the horizontal alignment design screen.

The vertical alignment design is also automated, the user specifies the maximum grade and the minimum sight distance allowable. SDR then computes the vertical alignment automatically. This alignment can be edited if required but it is usually acceptable. After the horizontal and vertical alignments are designed, the new road cross section shape is defined to generate the design cross sections (Figure 2).

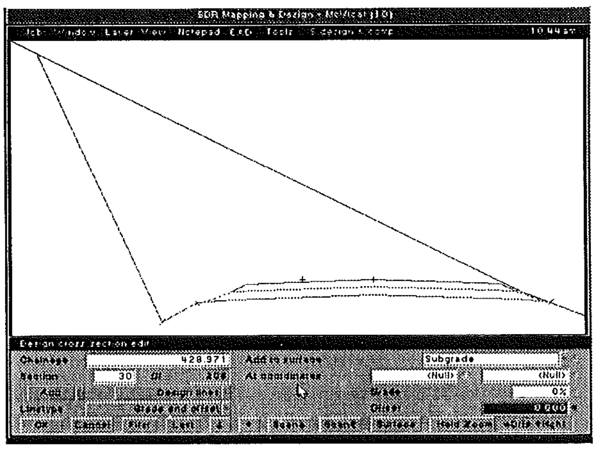

Figure 2 - Example design cross section produced in SDR.

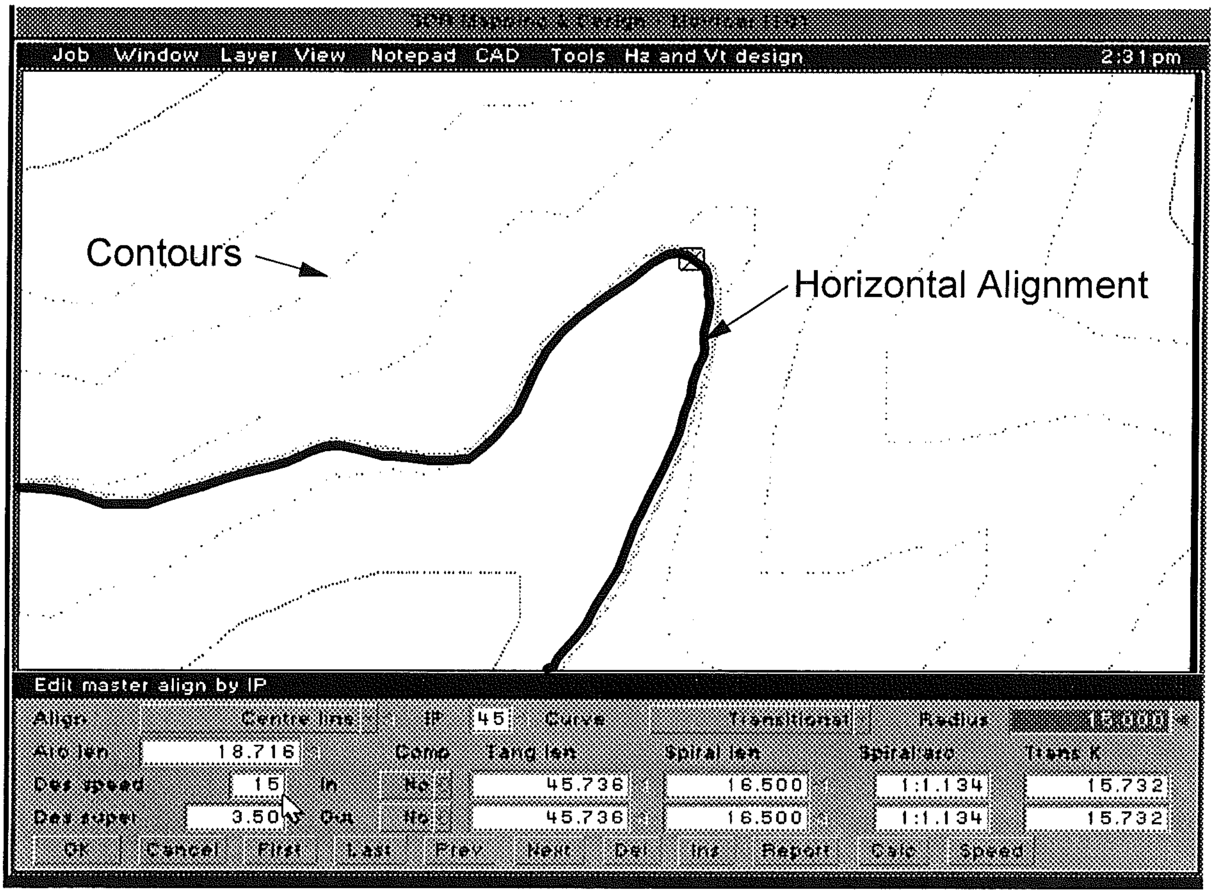

Figure 3 - Horizontal alignment design screen, displaying the required inputs when designing a curve (the user inputs the design speed and curve radius and the rest is automatically calculated or the user is prompted that the combination of design speed and curve radius is not possible).

Finally a quantities report is printed for a cost estimate of the proposed route (Table 1). Other possible routes can then be designed to compare costs.

Table 1 - Cost estimate printed from SDR on a proposed route

Item	Description	Quantity	Unit	Rate	Cost
1	Cut volume	24940.34	cu m	2.00	$49881
2	Fill volume	67.23	cu m	4.00	$268.92
3	Basecourse	3240.56	cu m	10.00	$32405.60
	Total				$82555.52

ROAD DESIGN (ROADENG)

ROADENG is a forest engineering software system developed by Softree in Canada. It operates within Microsoft Windows, which is easy to use and learn. Because of its simplicity, the occasional user can design a forestry road, producing drawings, earthwork quantities and set out data in very little time. Facilities include field note entry, map generation, digitising, digital terrain modelling, contouring, road design and cable logging analysis. These facilities are available in five modules; Survey Notes, Map View, Terrain, Cable Analysis, and Location Design.

Terrain Data Extraction

The TERRAIN module provides facilities for assembling and manipulating topographic and other map features. Information can be entered either from a topographical map, using a digitising tablet, or directly from an external file. ROADENG can accept data in DXF (Data Exchange File) or ASCII formats (x,y,z co-ordinates of points). ROADENG can accept a wide range of ASCII file formats and importing data is relatively straight forward. However, only 8000 points can be imported into ROADENG in comparison with the more elaborate packages like SDR which can accept a total of 500,000 points. This limits the terrain area to 1.8 square kilometres if a 20 m grid spacing were used.

Horizontal and Vertical Alignment Design

Similar to using a pencil and a ruler to sketch the road location on a topographic map, the road location is drawn using a digitiser or a mouse in the plan view (Byng *et al*, 1994) of the Terrain module. As the road is being drawn the profile is calculated and displayed in a separate window. This allows the road location to be adjusted to stay within grade limitations (eg. ± 10%). The road location can be adjusted by dragging points with the mouse. In the Terrain module there are no facilities to design the road alignment and determine earthwork quantities. Therefore cross sections are created at set intervals along the sketch roadline which are used in the Location Design module to design the horizontal and vertical alignments. Engineering drawings, cross sections, quantities and set out data can then be produced for a complete design.

To design the alignment using ROADENG, the cross sections, profile and plan windows are displayed concurrently. By viewing the cross sections, adjustments to the road alignment that will minimise the earthworks are determined. These adjustments can be lowering, raising or moving the road left or right. Lowering or raising the road is achieved by dragging the appropriate point with the mouse in the profile window. Similarly, moving the road left or right is achieved in the plan window. For very fine adjustments the arrow keys can be used to move the point to be changed. Figure 4 shows that at Station 719 m (as shown by the arrows) this road needs to be raised up and shifted to the left to minimise earthworks.

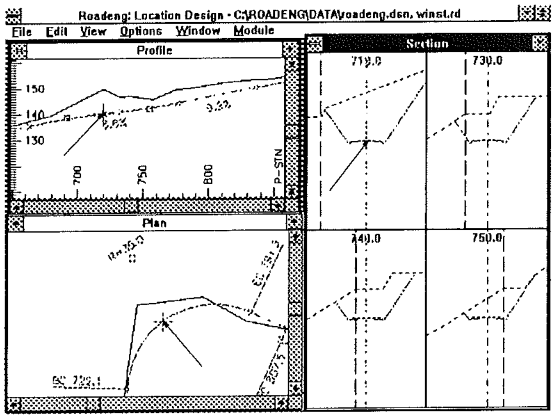

Figure 4 - Interactive road design within ROADENG.

After the road has been designed reports can be generated showing the volume of cut and fill. Unit rates are then applied to these volumes to estimate the cost of a proposed road location. To determine the cost of other proposed routes the process from sketching the roadline in the Terrains module is repeated.

LIMITATIONS

The process of extracting terrain data from a GIS or topographical map for use in engineering software to design the road alignment should be restricted to planning only. The information produced from the design should only be used for a cost estimate and as a guide in the field to find the road location when marking a gradeline. There should be no attempt to use the design to set out the batter pegs and mark the cut and fill depths due to the inherent inaccuracies of the terrain data, as listed below:

- The producers of topographical maps from aerial photographs report a elevation accuracy at best half the contour interval. Therefore, if the design required a cut depth of 2 m, then in the field this could be any where between a cut depth of 4.5 m or a fill depth of 0.5 m if the terrain data used was derived from 5 metre contour intervals.

- It is difficult to accurately locate the designed road in the field.

- Inaccuracies result in the exporting and importing terrain data. To create a file from a GIS for import into SDR, the GIS calculates the elevations of points in a specified grid interpolating from the contours using its own assumptions. SDR imports these points and then interpolates between them to form its own contours.

If the road design were to be set out to ensure the proper construction of a engineered alignment, then the road line will need to be surveyed manually. The surveyed information, which is typically cross sections at 20 metre intervals is then imputed into a road design package. The alignments are designed to produce accurate setout information from established survey marks.

OTHER COMPUTER PACKAGES USED FOR ROAD PLANNING

There are numerous other computer programs written by university scholars to aid in determining the optimum roading network and density. The following is a summary of programs cited in recently published literature that may be useful. I am not aware that any of these programs are used in New Zealand for planning. Their main limitation is the amount of data required, the difficulty in using the software and some programs are restricted to flat terrain.

ROADPLAN

ROADPLAN is a program that produces a road network plan for a forest area being accessed for the first time (Newnham, 1995). It is based on a raster GIS, for each cell the available merchantable volume and the cost of road construction is known. The transportation cost $/tonne/km is assumed to be constant. For each cutblock, the cost of constructing potential road links to all points on the existing network and the cost of transporting wood over each link and along the network to one of the access points to the area are calculated. At every step the cutblock with the minimum combined construction and transportation cost (in $\$/m^3$) is added to the network.

The model does not produce an optimum or minimum cost solution but can be used as a simulation tool to test different values for construction and transportation costs, and for the constraints. ROADPLAN is only suitable in flat terrain as ground slope would increase the models complexity as a cell could no longer be considered roadable in all directions but only where slope permitted construction.

Liu and Sessions (1993)

Liu and Sessions (1993) suggest a computerised method using data from a digital terrain model to determine the cheapest or most optimum road location. The method computes, (1) a network of possible road segments, (2) the construction, transport, and maintenance cost of each road segment, and (3) a preliminary transportation plan. Road construction is estimated by calculating side slopes and in turn the cut and fill volumes. Maintenance costs are dependent on road gradient and transportation costs are estimated by calculating travel times. For known harvesting areas road segments which minimise the total costs are determined using network analysis.

From the literature it appears that one program that automates the routines outlined above is not available. Liu and Sessions determined a optimal roading network for a example forest using a number of different programs and spreadsheets to calculate the costs for each segment.

ROUTES

ROUTES is part of the integrated preliminary harvest and transportation planning software package, PLANS (Reutebuch, 1988). The program uses a digital terrain model, created by using the MAP computer program in the PLANS package, to produce profile plots and estimates of grades and sideslopes along projected routes. This information can be used to help estimate the road construction costs when evaluating alternative routes.

This program operates in imperial units only, and is a add on to the PLANS package which is in imperial units also (PLANZ which is used to analyse cable logging areas is the metricated version of PLANS).

SUMMARY

The main purpose of this paper was to discuss the concept of using digital terrain data sourced from a topographical map or a GIS in a road design package. Using the features within the road design package the feasibility of a road location and earthwork quantities can be determined. This enables road construction costs to be more accurately determined for evaluating alternative road locations.

There are computer programs available to determine optimal road spacing and road network but they are limited in use.

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