Computer-Assisted Forest Road Planning—A Proposed Interactive Model with Special Emphasis on Private Forest Land

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ABSTRACT

Calculating the benefit of a forest road where a number of factors must be considered is a complicated operation. The undertaking becomes even more complex when several forest owners are involved, as the incurred costs must be divided according to the benefit that each estate will be able to draw from the road. Today, a great deal of this work is done by skillful people who, based on long experience, have set their own rules-of-thumb. This paper suggests that an interactive model which utilizes spatial data and simplifies the comparison of different alternatives would improve the planning situation, but still take advantage of the skills developed by planners. The model is based on spatial data in a digital raster format. Complementary information like forest inventory, growth models, cost functions and prices must also be available. The planned road may be entered either with a digitizer or a mouse. The likely benefit of the planned road is effectively calculated and the result also includes information about presumed forest operations and estimated development for each forest estate. One of the most important features of the model is a complete transparency; all the preconditions, assumptions and calculations must be easy to retrieve. The results have to be simple to understand, an important issue for private forest land where people of different backgrounds are involved. The suggested model could also serve as a framework for future automated optimization of a forest road network layout

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INTRODUCTION

Forest roads are essential for all forest operations, whether it be harvesting or silvicultural practice. They most certainly affect the economy, but may also be crucial to get access to forest areas at all. A forest road has, at least, two principally separate functions, one longitudinal and one lateral [5]. The longitudinal (length-wise) is the most obvious one: to serve as a base for transport along the road. The lateral (cross-wise) function is to serve as the terminal point for terrain, or off-road, transportation of wood, machines and workforce for the surrounding forest area. A forest road decreases the amount of off-road transport, compared to a situation where there is no road. As on-road transportation is more efficient than off-road, the roads in a forest area are important for the economy of forest operations. However, roads are costly to build, and too many roads in an area would cost more than the benefit. Therefore, it is crucial to balance the investment of building forest roads against the decreasing off-road transport cost. Furthermore, not only the length, but also the location of a road determine the amount of off-road transport.

The benefit from a forest road can be defined as the difference in net income (total income minus total cost) from the forest land influenced by the road, during the estimated life of the road, compared with the net income from a forest that is not accessible by a road. The profitability of a road is the benefit set in relation to the cost of building and maintaining the road.

Where the forest land influenced by a road project encompassess several forest estates, the Swedish rules state that the investment cost should be shared among the landowners according to their benefit from the road. Hence, the difference in net income must be calculated for each forest estate. The rules also state that the cost of maintenance should be shared proportionally to the estate's use of a road. This is not the same as benefit; an owner could have very little benefit of a road, but once it is there, use it quite a lot.

The National Board of Forestry in Sweden, which handles many of the Swedish forest roads built each year, especially where there are several forest owners involved, has published a handbook for calculating the total benefit of a road as well as the shares of different owners [1]. However, it is quite an effort to produce these calculations for a road, and to make calculations for several alternatives for the sake of comparison is most often not possible. Facilitating these calculations could be worthwhile for this reason alone. Still, there are often considerations to be made in a road project which are not easily included in an algorithm that attempts to make a complete road plan. Furthermore, the planners usually have obtained great skills, and it would be a major advantage to use an interactive model that could incorporate these non-formalized skills.

As mentioned above, the spatial distribution of forest and roads is of utmost importance. Hence, maps are the most important tool for a road planner. The manual interpretation of maps, assuming the weighed central point of compartments and estimating off-road transport distance, is not an easy task. Here, digital maps could be used as a source of information. Several studies have shown promising results in using a geographic information system (GIS) for solving a forest road network planning problem [3, 4, 7]. However, to optimize the road network layout is outside the scope of this paper.

A system that uses digital data would be a major improvement in several ways. Firstly, it would be less error prone than a manual one. Secondly, if calculations were automated, several different alternatives could be compared with less effort. Thirdly, information about the alternatives, i.e., consequences for different owners and different harvesting plans, would be generated during the calculations and thus easy to present. This is of great importance when dealing with private forest owners.

This paper proposes a computer-based model to estimate the profitability of a forest road project and to allocate the potential benefit among different forest estates. The model would utilize digital spatial information and have an interactive graphical user interface, which makes it possible to incorporate the skill developed by experienced planners. It should also be possible to use the model as a framework for future optimization of forest road location.

ORGANIZING DATA SPATIALLY

Spatial data are represented mainly in two forms, vectors or grids, although there are other forms. In this model the grid or raster form has been chosen, primarily because it can be easily transformed into matrices which are suitable for calculations. The calculations demand information about a number of different factors, each representing a value of an area that can be transformed into a matrix.

Forecasting Forest Operations

When dealing with privately owned forest land, it might be more appropriate to use model-based harvesting plans than actual harvest plans. Private forest owners do not always behave according to rules of strict economical rationality. Private economies and needs are at least as important, especially for smaller estates where the forest is not a main source of income. As these factors are impossible to include in any model, it is more useful to presume a schematic model for management.

Operations that have to be foreseen and scheduled for Swedish conditions are clearcutting, thinning and silvicultural operations. A growth model has to be linked to the data to capture the dynamics of the forest. Time for clearcutting and harvested volume may be estimated from age, site index, species and standing volume. Thinning regimes may be estimated from species composition and site index. Silvicultural operations, i.e., regeneration and precommercial thinning, are predicted from site index, age, volume and species composition. The aim of the management model is to estimate the future transport demand to and from each gridcell.

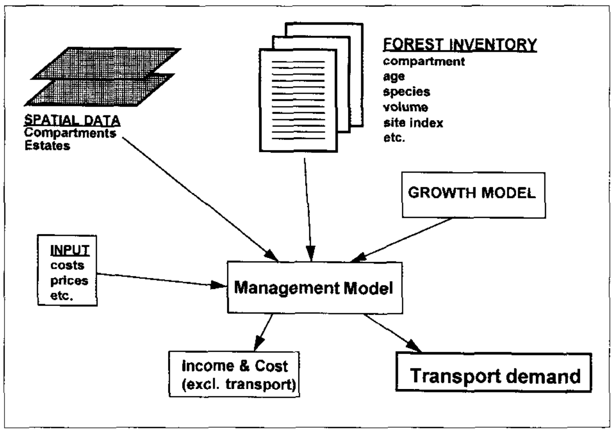

Figure 1. Schematic diagram of model for estimating the transport demand.

Forest Owner Boundaries

The boundaries of separate forest estates in the area must be included as digital data to estimate the cost and benefit correctly for the different owners.

Terrain Transport Cost

The main benefit of a new road is decreased terrain transport. Consequently, the cost of terrain transport is a very important factor in calculating the benefit of a road. If the conditions on a site do not vary too much, it can often be satisfactory to use an average figure for the terrain transport cost. If, however, there is a large span in accessibility, the need arises to differentiate the cost over the area. The factors that are most likely to be of importance are different ground conditions, like soil type, smoothness and moisture. Moreover, the topography plays an important role in most cases. Inclines and declines, their direction and steepness, are important in estimating the terrain transport routes and costs. Information about soils and ground moisture is most usable in the form of digitized maps, which may be converted into grids. The ground smoothness is rarely found in such a form, but might be recorded together with compartment descriptions. If so, it may be extracted from the compartment list and transformed into a grid.

The topography may be accessed from different sources. In Sweden there is a national database covering the whole country with altitude figures in a 50-m grid, which is usually sufficient for this purpose. However, if there are important features in topography which are not captured by the grid, like smaller canyons, these must be included manually.

By combining the factors mentioned above with estimates on how they affect the transportation cost, it is possible to create a grid where each cell value represents the cost for terrain transport across the grid.

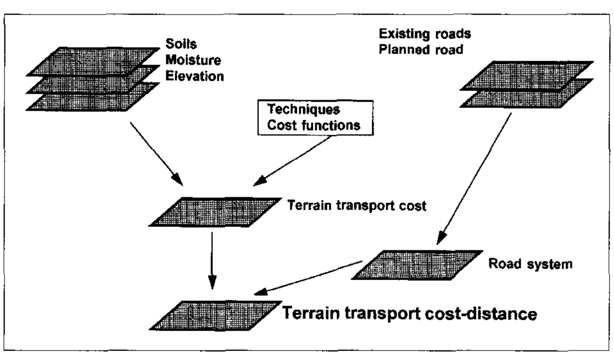

Figure 2. Schematic diagram of model for estimating the terrain transport cost.

Road Construction Cost

For many forest owners, it is quite a large investment to build a road, an investment which must be carefully compared to its benefit. The available techniques of building roads are usually well-established and factors influencing the cost may be estimated. The road construction cost depends mainly on two things: ground conditions, i.e., soil, rocks and water properties, and topography. The topography determines the amount of material that has to be moved, often one of the most costly operations in road building. Streams are another factor that have to be included. Crossing water is costly even if it is only a small creek, and special attention has to be drawn to this. A grid can be constructed where each value represents the cost of building a road of the same length as the grid size.

Forest Road Network

The existing roads in the planned area must also be considered, as they are alternative terminal points for terrain transportation and as new roads should connect to the existing road network. The road network must be digitized and, if in vector format, converted to a grid.

The layout of the projected road, for which benefits and costs are to be calculated, could be drawn on a map and then put into digital form with a digitizer, or it could be drawn directly on the computer screen with some sort of pointing device (like a mouse). Either way, it is important that the layout of the road may be easily altered with a pointing device to emphasize the interactive way of working. This puts demands on how the user interface should be designed. This is discussed below.

CALCULATION MODEL

Terrain Transport

The cost of terrain transport must be estimated, as it is the most crucial factor in determining the profitability of a forest road. The terrain transport not only includes the transportation of the wood from harvesting, but also the transportation of men and machines for harvesting as well as for silvicultural operations. Here is one of the greatest strengths in using a spatial model, as when the basic cost functions are established, the model utilizes the spatial information to calculate the total terrain transport cost.

There are several ways to calculate the total cost of terrain transport. The simplest is to first define a number of possible landings, located on existing and planned roads. The closest landing point to each cell can be determined. The distance between these points, with a correction factor for terrain transport not being straight, is used to estimate the total terrain transport cost. This procedure is sufficient if the terrain transport cost is similar over the whole area. Otherwise the terrain transport cost grid described in the previous chapter has to be used. Starting from a set of defined landings or from the road network (assuming every roadgrid is a potential landing), the cost-distance to every forest grid adjacent to the starting points is equated, using the terrain transport cost grid. The operation is iterated for the next adjacent grids, including the result from the previous operation. Thus, the cost-distance will spread from the landings out to the periphery. This is similar to the command FocalProximity of ROADGRID spreading in TERRAIN-TRANSPORT-COST-GRID as defined by Tomlin [8] in the Map Algebra language. The resulting cost-distance grid should then be multiplied with the transport demand grid to give a total terrain transport cost grid.

Road Building Cost

The calculations of the road-building cost are more straightforward. The layer of the projected road is combined with the road-building cost grid. The values from the latter which coincide with a road cell are summed, giving the total road building cost.

Total Cost and Benefit

Finally the total cost is calculated. In a situation where the same amount of wood is to be harvested and the same operations are to be performed in all alternatives, there is no need to estimate the income, as it will sum up to the same number. However, if forest operations (like harvesting) would not be profitable without a road, the default alternative to compare with is not to carry out these operations without a road, but to do nothing at all. In such a case the income has to be included as well in the calculations to give a correct comparison.

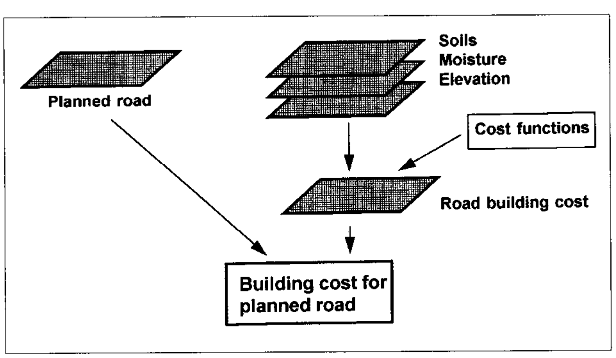

Figure 3. Scheme of estimating road-building cost.

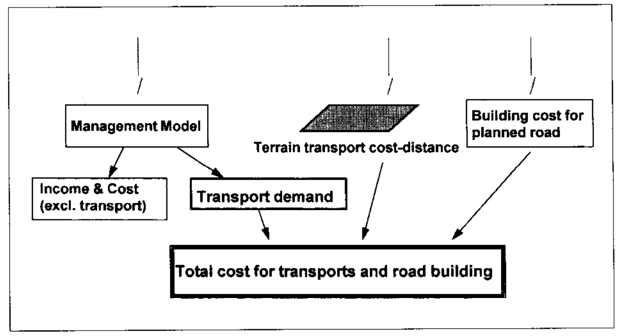

Figure 4. Scheme of estimating the total cost associated with a road project.

User Interface

The user interface is of crucial importance. The interface usually determines whether a model will be used or just become yet another dust collector. There are certain features that the interface must include to be useful in this context. It should be easy to draw a planned road, and it should be equally easy to modify the plans to compare different alternatives. Furthermore, underlying data and assumptions, like terrain transport costs and harvesting plans, must be easily displayed and modified. This is essential for a planner dealing with private forest owners. The planning material will be used for discussion, and it is of great importance that the model has a transparency and the results have a clarity that enables everybody involved, despite different backgrounds, to understand and hopefully accept the work of the planner.

DISCUSSION

There are two major issues that need to be solved to make the proposed model suitable for planning private forest land: transparency and flexibility. The model has to be transparent for the people involved, owners and others, to validate the model. All data, assumptions and functions must be accessible. This brings us to the other crucial issue, flexibility. The first plan of a forest road project could be considered as a starting point for further discussions with the forest owners. The owners might have additional information that should be incorporated into the model. One of the aims of a planner would be to reach consensus about the project, or at least as great an acceptance as possible among the forest owners. Hence, it is necessary to be able to easily show different alternatives, or modify existing ones, to reach a final agreed solution. Thus, the fundamental property of the model is the interactive working concept, which allows transparency and flexibility.

The user interface could be custom made for an application using the proposed model, but this is not a prerequisite, and may not even be desirable. The model could be programmed as an addition to an existing GIS, utilizing the interface of that program. There are several GIS's that are either programmable in a propriority or macro language or where newly written program modules can be added to the system. One benefit of using an existing system is that it usually has interfaces to a wide range of GIS file formats. Hence, it is possible to utilize spatial data from a variety of sources, which is often a necessity in a road project.

One issue not mentioned so far in this paper is how to determine the best layout of a new road. Here we have discussed how to calculate the cost and benefit of a road and comparing different alternatives. Where a larger area is to be served by a new road and there are quite a few optional locations it might be necessary to start with an estimation of where to put the road. This could be accomplished in several ways. One is to calculate the optimal road spacing [6]. There are also several optimizing algorithms proposed for this purpose, like local-search [3], maybe combined with some heuristics [7] or a more stochastic approach as outlined in [2]. C oupled with one of these optimizing algorithms, the proposed model could serve as a framework for optimizing the road network.

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