ALIGNMENT AND LOCATING FOREST ROAD NETWORK BY BEST-PATH MODELING METHOD.

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ABSTRACT

The paper is written to explore a modern geographic information systems (GIS) in automated planning process of routing and alignment of the forest road network. GIS is used since it is becoming the mainstream tool in forest road network alignment and location analysis. It is also proved to be beneficial in helping forest managers evaluate alternatives and select the optimal location for forest road network. Theoretical parts of these applications are discussed briefly with emphasis on the general procedure for locating forest roads. In the case study, the results are discussed and examined through the comparison of hypothetical forest road network generated by several different methods, field design, office design, and best-path analysis design. Each method is compared statistically and qualitatively. The results show that the best-path analysis design is the best solution to forest road network placement and provides sensitivity to rule base and input features. Thus constituting an improvement over other designs.

INTRODUCTION

In forest management practices emphasis is being placed not only on timber production but also on forest roads planning. A good forest road network is essential in the intensive management of timber production in any forest area. Even though, forest roads are built to provide short-term access to the forest but such a road network should be designed to minimize the construction and operational costs of the completed network. Other factors such as geographical and environmental impact should also be considered and evaluated in the earliest stage of the planning process.

Engineering practices on forest road building are challenged by the task of minimizing the impact on forest environment. In some studies, there is evidence that improvements in planning and locating forest roads reduce the negative effects on the forest environment. Poorly placed access road can affect forest productivity by taking forest area out of production, damaging residual trees and seedlings, removing nutrients from the site, and by compacting, rutting, and eroding the soil (Blinn et al. 1999). Adjacent areas can be affected by associated changes in the hydrology condition of the site. Water can run in the ruts, loosening and transporting soil particles, which may eventually drain into local streams, potentially increasing the stream turbidity and affecting the water resources. Even though these impacts are unavoidable but their frequency and extent can be significantly reduced by a stable forest road network.

The traditional forest roads planning method, in Peninsular Malaysia, develop road alternatives based on field reconnaissance followed by draftsman's sketch steps along the map between the beginning and ending points. The steps, movement from one contour to the next, were calculated through the difference in elevation between the two points. Traditionally planners try to avoid building roads through recognized environmentally sensitive areas or protection zone by identifying their spatial boundaries. However traditional planners working with road location analysis are faced with problems involving multiple goals, which required them to consider multiple criteria early in the road location analysis. It seems that, the objective of the novel methods is to become more proactive in the reduction of the problems.

Forest road network location analysis is often based on the study of trade offs between different criteria in maps using map overlay technique to provide data and information. Manually this task is difficult and very limited sophisticated analysis can be done. However with the latest GIS technology, advance analysis has become easier through efficient data management and more comprehensive analysis of criteria (Salah, et. al, 2000). This technique also offers the analyst a range of data manipulation possibilities that would be impractical through conventional routines, thus substantially enhancing the realism of location modeling. In addition, the capability of GIS manipulating large amount of spatial data can be documented, retraced and repeated, which lead to the location of more stable forest road network.

Recently, a few models that produce a road network plan was undergone the extensive review common for scientific journals. Many papers describe models that particular based on an economic evaluation of alternative routes. Which most of the computations are quantitative and rely on the most common economic means of evaluation. The second model is based on the identification of broad feasible corridor (Tucek and Pacola 1999). This model is based on the identification of broad feasible corridors that are selected for detailed evaluation of their route potential. Route alternatives are identified within each corridor followed by further analysis involving the synthesis of specific information extracted by aerial photo interpretation, field surveys and integrated DTM data Another model is to find the route, which might best minimize damage to the environment. Their evaluation is done by considering the minimum total score from estimating variable factors related to conservation of land such as evaluating route locations based on digital terrain data and other topographical features (Minamikata, 1984)

In Malaysia, the modeling and implementing of modern Geographic Information System (GIS) technology for developing road alignment and locating model that is capable of taking into account the spatial variation of forest environments and criteria has, as yet, been unexplored. In this paper we addressed an overview of the technology advancement, through gathering information using latest technology e.g remote sensing, topographic maps and other informative data of the site in solving the forest road alignment and locating analysis problem. Initially we outline the successful results obtained from the model.

CONCEPT OF FOREST ROAD ALIGNMENT

Conceptually, procedures for locating forest roads may include many formal steps. The steps can be summarized by six distinct phases as: 1) Analysis and survey, 2) Identify and evaluate road routes, 3) Model building, 4) Simulation, 5) Forecasting evaluation and 6) Improve road route(s) location. The whole process is iterative in that any simulation result has to evaluate and repeated until satisfactory results are achieved.

Analysis and survey step is described as the rule base and input features. This involves simple analysis in defining the planning policies and other factors which will come in to play. The amount of information and detailed needed will vary according to the forest condition. A wrong interpretation of the input features and rule base at this stage may affect the analysis. It is important to identify the definition of the exercise, including its goal, specific objective and the necessary budget at this stage.

Road locating and alignment model will assist road planning managers to determine the optimum location for road network. Once the definition has been made, evaluation such as checking certain critical points on the route is necessary. This task can be done in the office using inexpensive materials, which is quicker, or by doing field survey, which is more costly. The task should answer two important questions. First which are the factors and constrains that should be considered. Second, what information and at what accuracy should it be surveyed (Ellis, 1990). It is clear that the primary issue concerning the locating of forest roads is to make a forecast of the optimum road network in the forest area. Knowledge of forest environment and their relationships to each other are important in locating, designing, constructing, and maintaining forest roads that will sustain use and stay in good condition and to avoid sensitive areas. (Leung, et. al, 1997).

There are three basic models that can be use to produce a road network plan for forest areas. The model basically works by finding the least value pixel each time it moves from one pixel to next from a starting point to a terminus point. This analysis will model the increased value of movement from one cell to another based on the frictions acting on the movement (DeMers, 1997). Values are modeled as a function of both the road standard and the frictions that impede or facilitate movements and resulting in pathways. However the result should be modified to allow for more realistic result. In the evaluation phase, to allow for more realistic simulation, adjustment should be made to the parameter so that, they satisfy the objectives and rules.

ROAD NETWORK LOCATION

Forest management policy in Malaysia was formulated to ensure the continuity of product flow while conserving complex ecosystem and minimizing the negative effect on the environment. While these policies have sound sustainable yield production, alternatives have been sought to improve the aesthetic result of the timber harvest. The most important activity in contributing to the sustainable forest management practices is forest roads building.

Properties of The Case Study Area

Because the study was aimed at generating a package to demonstrate the potential of GIS technique for selecting suitable areas for locating forest roads, it was decided the research use a study area that reflect the real problem in forest road building activities. Sungai Weng is a small area of about 4.5 km x 3.6 km (5^0 52'- 5^0 49.5'N, 100^0 58'- 101^0 0.5'E) located in Ulumuda Forest reserved, Kedah State, Malaysia. The area is hilly, with the minimum and maximum elevation of 1 250 m to 3 650 m ASL. Natural forests characterize the area, which composed of a variety of species and stand density. The dominant hardwood is dipterocarps with occasional emergent trees that have regular canopies at heights of around 40-meter. The region has a tropical climate with a wet and dry season. The area is also characterized by high variability in the distribution of rainfalls and means temperatures per year and high humidity.

Procedure for Forest Road Alignment

The model developed here search for the lowest value and shortest route between origin and destination points over a different value surface within an integrated GIS platform. There are four basic stages required to create the road locations: data base development, computer based approach, value modeling and output. A simplified flow diagram summarizing the various stages is shown in Figure 1. The model allows the restricted road segments to be identified and attributed in a matter of minutes. However, data layers, featured in each coverage and the attribute data needed for each feature must be coded and organize correctly.

In this model, the sources and destination point may affect the outcome of the route analysis. A preliminary routing simulation was run several time as a practice tool to determine the route that minimize the value of bridging the gape between two point of interest and suite the proposal.

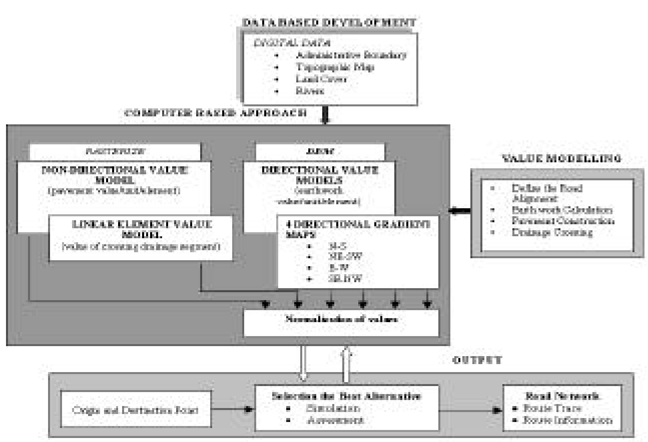

Figure 1: Simplified flow diagram of the model to generate forest road network

Results of The Analysis

The alignment and locating forest road network model presented here are tools to help the forest manager judge the efficiency and determine an optimal location for a forest road network, while considering and determining the technological criteria, gradient and other topographical features of the area. In other word the Forest Manager begins identifying alternatives for road network location and alignment and then evaluates each alternative so that the best can be selected from the identified alternatives.

Figure 2 show the forest road network resulting from the calculation. The red line was generated from the analysis of best path model. The black line shows the result of the calculation for the roads through office design method. Meanwhile the yellow line shows the road using field reconnaissance. Here the three methods are compared and was done from point A to point B. This is because at that time the contractor only finished their work at that level.

Qualitatively, from Figure 2, the three resulting road varied and there was relatively little overlay between the results. Even though, the results have shown the differences, but the exceptions are the deviating result for best path analysis. The key idea is that the road network derived from the analysis produced qualitative spatial reasoning. Thus harnessing the geospatial computing produced better result. Through best path analysis, it incorporated and consider every inches of the difference between the two points of the routes. Meanwhile, the other two methods highlight the deficiencies in the ability of tracing roads in that area. The performance benchmarks indicate that best path approach to solving the road alignment and locating analysis problem is more effective and efficient than using traditional methods. It can see from Figure 2 that both traces having almost similar tracing.

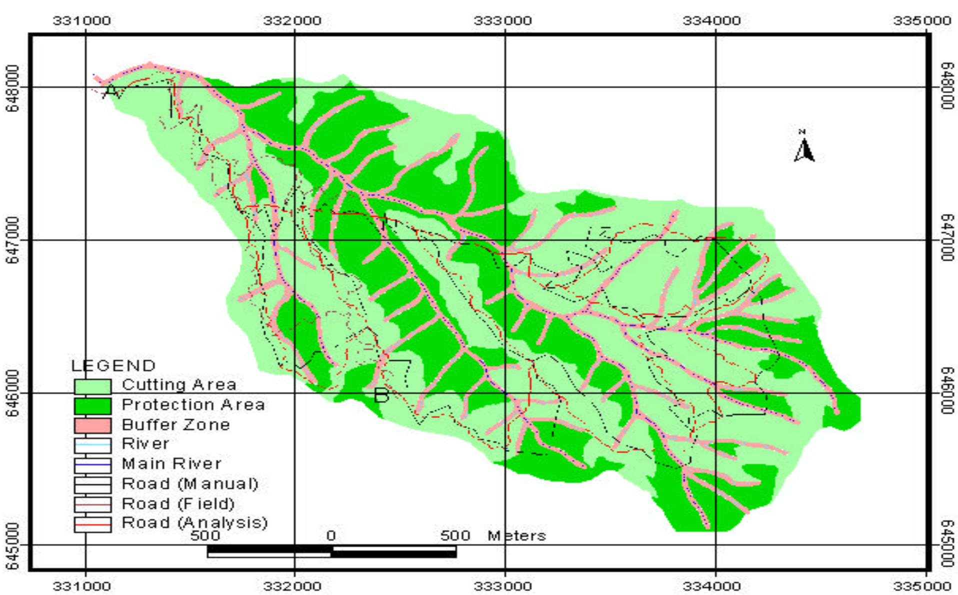

Figure 2: Traces of the Roads superimpose on non-directional value surface

In the series of presentations given in Figures 1A, 2A and 3A (Appendix A) the results has been performed in term of elevation and slope of the terrain. In general, within the best path analysis, it is clear that the emphasis of the analysis is to avoid the most costly anomalies. As noted, the higher slope indicates possible higher construction costs. Figure 1A shows the results of the terrain, profiles of elevation (in meter) and percentage slope in degree for Route from A to B (best path analysis method). It is estimated that most of the slopes are greater than 53^0 but do not exceed $70^{0.}$ It also showed that the highest elevation used in this route is 2750 meter, and from the elevation profile we can also conclude that the route took the ridge as main alternative, so it will reduced the cost and environmental impact when building the road. The location of the river is noted on both figures. The distance of the route (A-B, best path analysis method) is approximately 3,857 meter.

For the route which was constructed in the field by the contractor (Figure 2A), the elevation profile show that the pick elevation is less compared to the first one, but the route use less ridge compare to the first route (Best path Analysis). Figures 2A also indicate that the location of the river crossing is more compared to the first one. It is estimated that most of the slopes are greater than 60^0 with 4 locations exceed 81^0. The distance of the route (A-B, GIS analysis method) is approximately 4,640 meter.

The manual route is produce by calculation, which is done for every contour step. This was done based on contour interval and a guideline, which was produced by Forestry Department. The criteria is, the initial slope of 20% and the length of slope less than 200 meter was chosen as the lowest acceptable slope for a route. In figure 3A, its alignment was significantly altered in an effort to create a moderate graded route tread. The majority of the route alignment was excessively steep, more than half of the route located on the hillside whose slope is greater than 61^0. The distance of the route (A-B, GIS manual method) is approximately 3,887 meter.

Further opportunities for research lie in statistically examining the correlation between various land use attributes and the occurrence of route. The study has shown that the roads differ in their exact location but follow the same general direction. The exception seems to be the building value of optimized alternative. The above presentation has also shown that the alternatives road length will differ substantially.

Table 1 contains a summary of the properties of the alternatives, which minimize the three main indicators. The five rows can be said to represent goal indicators with independent values in the decision process. For example, if little buffer zone area is used for the road it means that the river will be less disturbed. Table 1 also provides the possibility of assessing the impact of the route against the route location. For instance, in best path modeling method, the building of forest route network will have relative little risk of damage to aquifers. In the same row,

Table 1: Trade offs between three road locating and alignment methods

Alternative and ensuring Land Categories (Pixels and Area)	**Route Alignment and Locating Methods**					
	Traditional Method (Office Method)		**Contractor Experience (Actual on the Field)**		**GIS Technology (Best-Path Modeling)**	
	Pixels	**Area (m^2)**	**Pixels**	**Area (m^2)**	**Pixels**	**Area (m^2)**
Cutting Area	982	24032.3	858	20997.7	894	21878.7
Protection Area	60	1468.4	35	856.5	17	416.0
Buffer Zone	113	2765.4	46	1125.7	38	930.0
River	6	146.8	5	122.4	3	73.4
Main River	1	24.5	1	24.5	-	-
Total Use of Land /Area	1162	28437.4	945	23126.8	952	23298.1

other methods indicating relatively higher risk of impact, because location of river crossing is more in office method and on actual field survey method.

CONCLUDING REMARKS

The case study above demonstrates that the analyzed result can be map and used as a base map for considering optimum alignment and location of a forest road network. In addition, Forest Manager can use the results as an aid to help identify the area which investigations in the forest road network planning process should be done, so that they are able to gain the location correctly. Thus the method describe here are good for initial planning purposes. However the results of the model lie in data envelopment analysis and the objectives. This case study can be enhanced in several ways. Further testing must be conducted with more comprehensive data and different authorities and experts should be brought in to provide judgments on which indicators are relatively more and less important.

It does appear that the model is effective in solving the roads alignment and locating analysis problem. It enables forest manager to analysis the problem in a matter of minutes which usually took multiple man-months. Although the results of this case study are associated with the forest transportation, but at the same time this model can be a useful tools for identifying risk of negative environmental impact. For example, Forest Managers could use this modeling structure to minimize sediment production and stream water impacts given alternative forest road locating practices. This is because drainage from roads and their associated features can cause erosion and locations of forest roads influence the amount of sediments contributed to streams.

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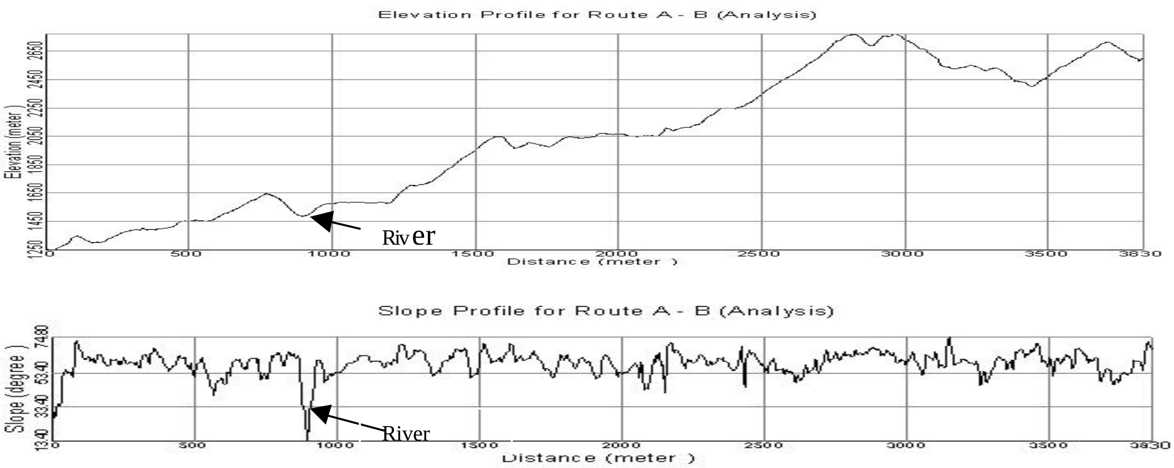

Figure 1A. Elevation and slope profile for Route from A to B (GIS analysis method)

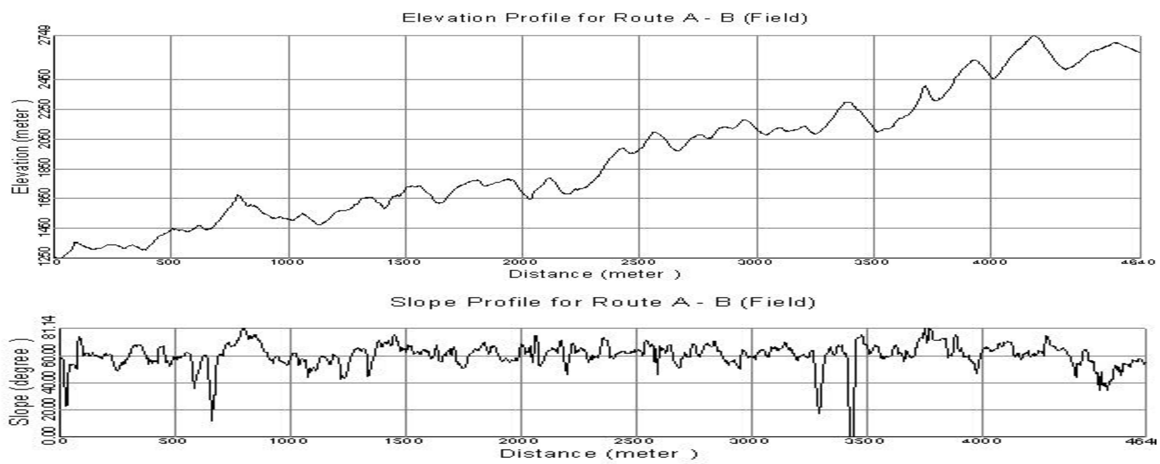

Figure 2A. Elevation and slope profile for Route from A to B (actual on field)

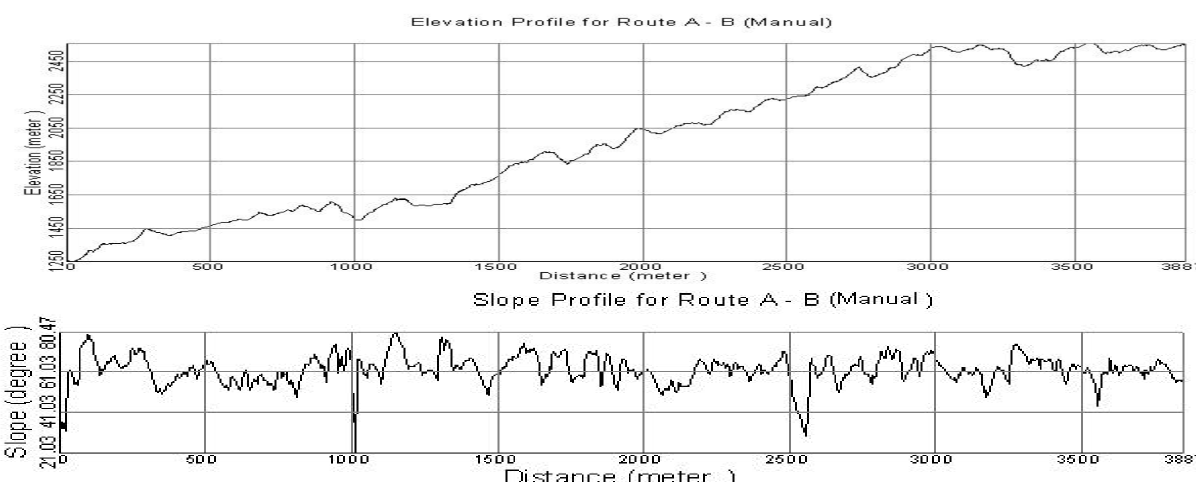

Figure 3A. Elevation and slope profile for Route from A to B (Office method)