PLANNING OF FOREST ROAD ALIGNMENT USING MODIFIED LEAST COST-PATH MODEL AND REMOTE SENSING TECHNOLOGY

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ABSTRACT: Forest road planning plays a crucial role in sustainable forest management. Thus, effective forest management depends on the construction and maintenance of appropriate forest road network. Forest roads construction for harvesting operations are always been subjected to certain constrictions and limitations. Engineering practices on forest road alignment are hindered by costly environmental and operational assessment. The advancement of remote sensing which can provide more accurate and latest information on environmental parameters, and GIS analysis can be an alternative method to align and locate forest road networks. The main objective of this study is to determine the suitability of forest road network by using Least Cost-Path Analysis (LCPA) with additional parameters. From this study, the main parameters influence the road construction was identified, i.e. slope, aspect and elevation. The results showed that the road alignment planning by least cost-path modelling has an accuracy of 85%. It can use to assist forest managers to evaluate alternatives and select the most optimal path for construction of forest road networks.

1. INTRODUCTION

Integrated planning of the forest areas is important to ensure continuous timber supply while ensuring forest and environmental protection. Hence, all forest management activities i.e., forest harvesting, forest conservation, site identification and forest road construction should be carefully planned and taking into account the underlying attributes of each and every side of the activities.

The conventional practice of preparing road plan and drawing requires various stages of map preparation, drafting, design and planning which are very complicated, time consuming and costly (Kamaruzaman and Shamsul, 1999, Hasmadi and Taylor, 2008, Muhammad Farid and Abdul Rahman, 1995). The growing complexity of planning and design of forest roads has rendered the need of effective and efficient mapping, planning and design of forest roads.

In Peninsular Malaysia, the Forest Road Guidelines (GPJH 2010) is used as a guide for the construction of forest roads to reduce the impact on environmental quality. These guidelines cover all types of forest roads; namely main roads, secondary roads and skid trails. GPJH 2010 is a combination of views and techniques that can be applied to minimize any impact on the environment as a result of forest harvesting. GPJH 2010 embraces good construction specifications and methods.

The advancement of remote sensing in providing more accurate and latest information on environmental parameters coupled with the capability of GIS in integrating spatial and non-spatial information for multi-criteria decision analysis approach is useful in forest road planning. The Least Cost-Path Analysis (LCPA) method in GIS environment has been widely used in various type of application such as study on routeing of power lines through least-cost path analysis and multi criteria evaluation to minimise environmental impacts by (Stefano, et al., 2011). However, due to complexity of tropical forest environment, the LCPA may require additional parameters in order to produce more accurate forest road alignment.

The aim of this study is to analyse the best "cheapest" route for forest road network by using LCPA with additional parameters such as slope, aspect and elevation.

2. STUDY AREA

Description of study area

The study area is located in Ulu Jengai Forest Reserve, Terengganu state of Peninsular Malaysia (Figure 1) with a total coverage of approximately 370ha. The area is hilly, with a minimum and maximum elevation of 52m to 390m above sea level, respectively. The area has been categorized as a natural forest comprised a variety of flora species and stand density. The slope gradient of the study area is undulating with steep rugged terrain ranging from 0°-46°. Being in the tropical climate with a wet and dry season, the area has high variability in rainfall distribution and high humidity.

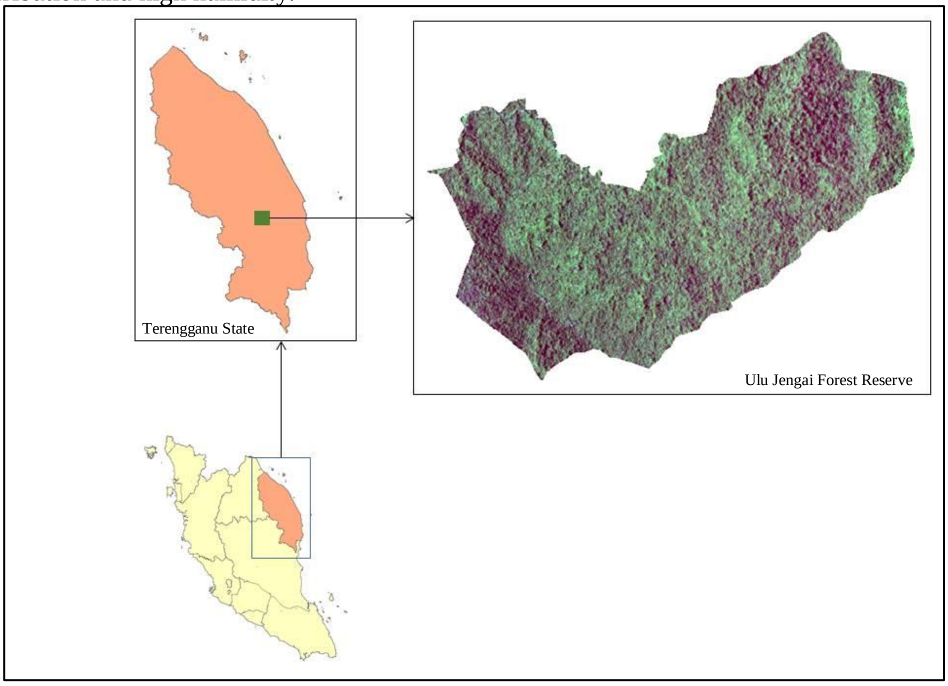

Figure 1: Location map of the study area

3. DATA AND METHODOLOGY

Overall workflow of this study is illustrated in Figure 2 comprises of data preparation and modelling.

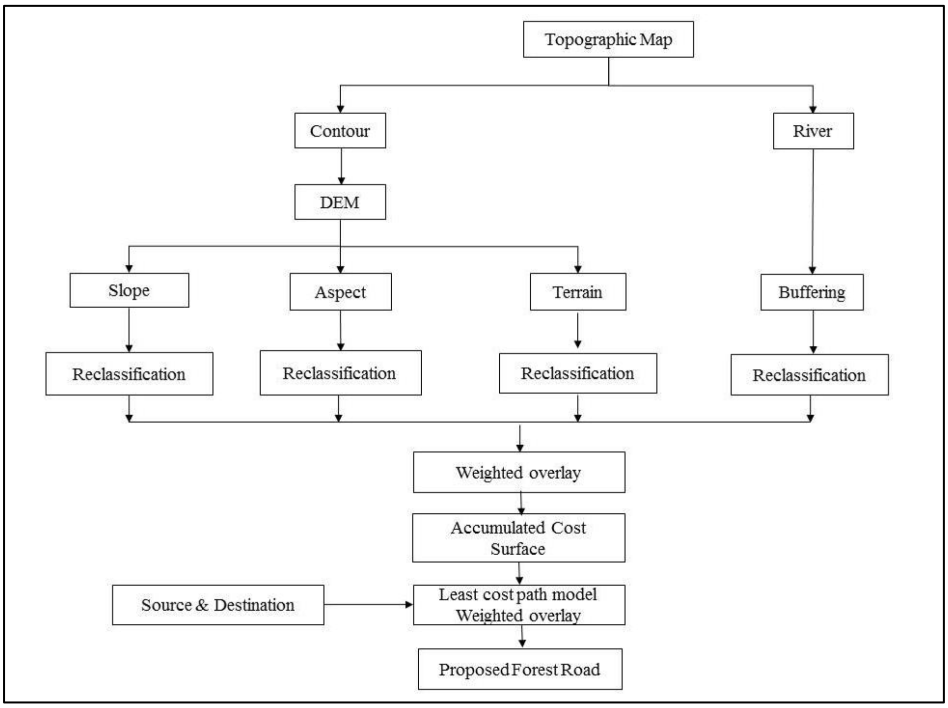

Figure 2: Workflow of the study

3.1. Data Preparation

A digital elevation model (DEM) is digital representation 3-dimensional information (X, Y, Z) of the continuous topography of the bare earth surface in a particular reference coordinate system (Rectified Skewed Orthomorphic). In this study, DEM was generated from 20m contour line from 1:50,000 topographic map (Figure 3) to produce slope and aspect. River network extracted from topographic map is used to generate the river buffer zone within forest compartment.

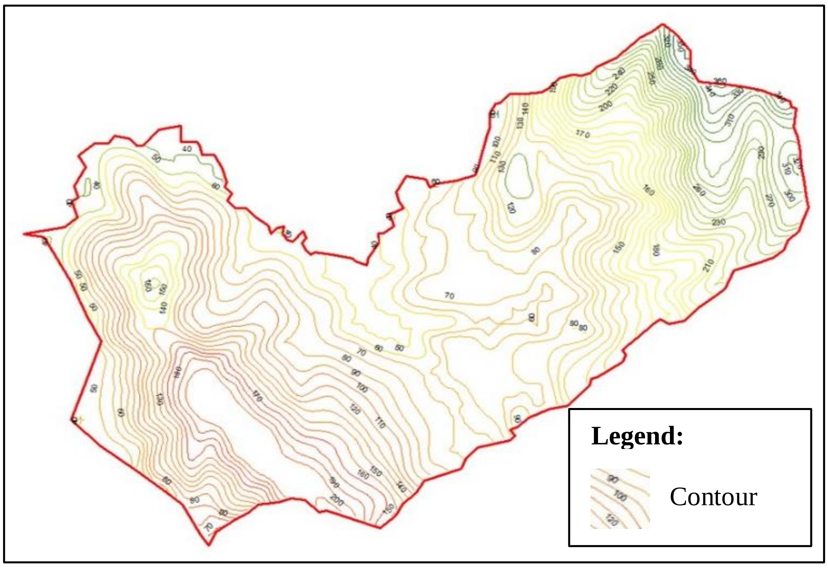

Figure 3: Contour map of the Study Area

3.1.1. Slope

The slope is the main factor to consider in allocating the suitable forest road network. The slope values were ranked into three levels of suitability class where slope value <10 degree for main road, <14 degree for secondary road and <20 degree for skid road. This means that slopes with a lower value are much more suitable than higher slope values for forest road network alignment. The slope values were ranked into three level of suitability class according to the types of road as specified by GPJH 2010 refer to Table 2. The reclassified slope then used to identify potential areas for a log yard which is storage for forest product before transported to a main log yard accessible from the main road. Therefore, log yard is an important factor in the route setup as the location of the log yard will determine the direction of the road network. According the GPJH 2010, slope gradients below 5 degrees with an area of at least 20m x 20m are suitable for a log yard.

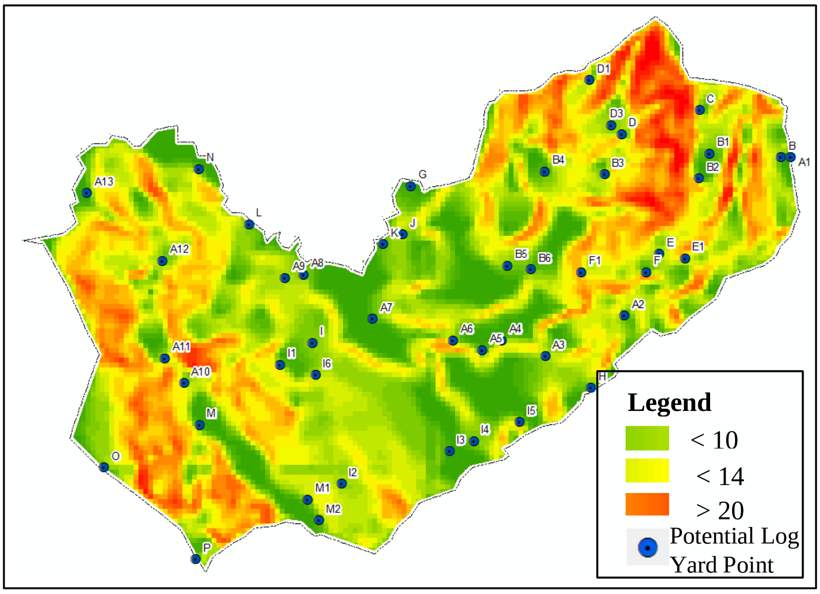

Figure 4: Slope classes and potential log yard points

3.1.2. River Buffer

Rivers are one of the crucial parameter to be considered in the forest road network alignment planning. This parameter was selected based on the GPJH 2010 in order to protect terrestrial habitat and water quality. Each river was buffered by at least 20 meters on both sides (Figure 5).

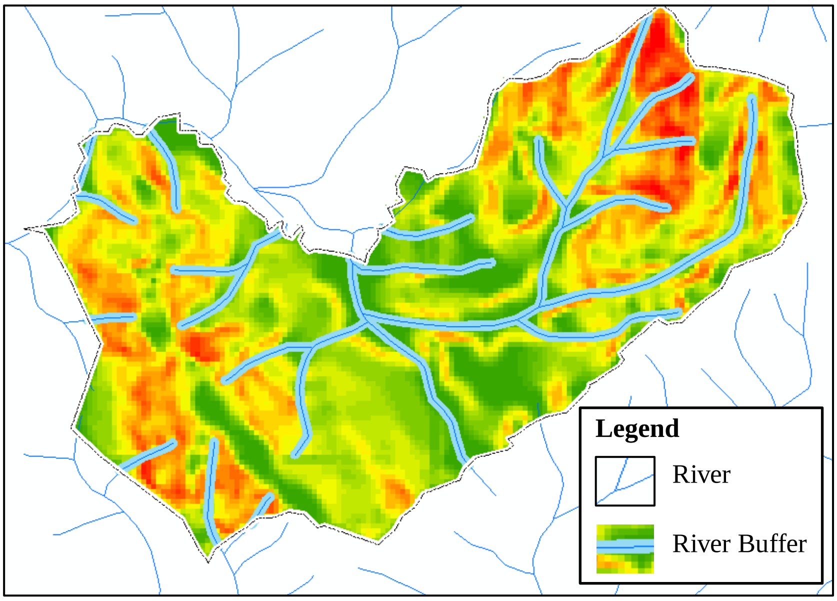

Figure 5: River Buffer

3.1.3. Aspect

The aspect associated parameters such as exposure to sun light; drying winds and rainfall are important factor in forest road. Slope direction map of study area was divided into eight directions of North, Northeast, Northwest, East, South, Southeast, Southwest and West (Figure 6).

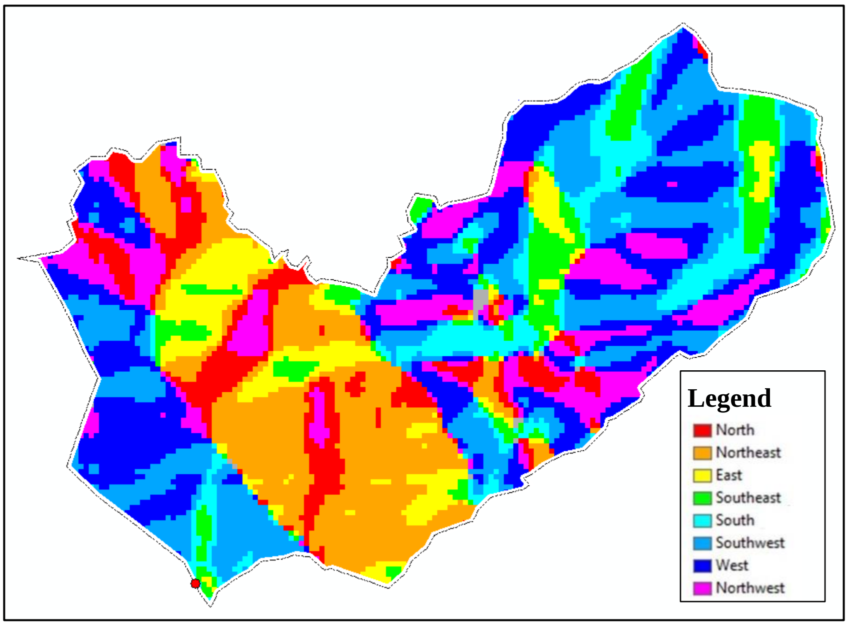

Figure 6: Aspect map of study area

3.3 Forest Road Modelling

Forest road modeling was developed by applying combination of various existing tool in the ARCGIS 10.4 software. One of the main model used in this study is Cost-Path Model.

The least-cost path analysis travels from the destination to the source and is guaranteed to be the cheapest route relative to the cost units defined by the original cost raster that was input into the weighted-distance tool. Parameters used in this model are based on Forest Road Guidelines 2010 provided by Forestry Department of Peninsular Malaysia. It is important to consider how to weight the raster that make up the cost raster. How to weight the raster depends on application and the results to achieve.

If there are multiple cells or zones as input destinations, the least-cost path can be calculated from each cell (resulting in multiple paths, one path for each cell), each zone (one path from each zone), or by best single path (only one path, the cheapest from any zone). A parameter in the tool specifies which process should be utilized.

Use the Cost Path tool to find the best route for a new road in terms of construction costs or to identify the path to take from several potential log yard (sources) to the closest temporary log yard point (destination) that lead to the main road where forest products transported to the main log yard. When applying the tool to a road construction the resulting path is the cheapest route for constructing a road from the source to the destination.

Each parameter used has been identified and compiled by priority ranking (Table 1). Data integration was then performed to generate a value map. The source and destination path is based on the location point of the potential log yard point. Each parameter is based on a weightage and the summation of the weightages must be 100%.

Table 1: Percentage influence of parameter

NO.	PARAMETER	CLASS RANGE	INFLUENCE (%)
1.	**Slope (°)**	>20 (Not suitable) <20 (Skid Road) <14 (Secondary Road) <10 (Main Road)	60
2.	**Log Yard**	>5 (Not suitable) <5 (Suitable)	25
3.	**Aspect**	N – S NE – SW SE - NW E -W	10
4.	**River Buffer (m)**	20 meter (Suitable)	5

In this study, the DEM and river data were processed through several methods of GIS suitability analysis operation such as classification, data extraction, buffering and data integration to produce a value map. All slope, aspect, elevation and river data will be combined and given a weighted analysis result to produce a raster value map. Each forest selection criteria is in accordance with Forest Road Guidelines 2010 as shown in Table 1. The road selection criteria (Table 2) were divided into three types of roads namely main road, secondary road and skidding road. The weighted overlay function was used from the spatial analysis tool. An evaluation to the final road generated by the model must be performed to ensure all the crucial guidelines complied.

Table 2: Parameters of Forest Road Guidelines 2010 (Forestry Department of Peninsular Malaysia)

NO.	PARAMETERS		ROAD TYPE		
			MAIN	SECONDARY	SKID
1.	**Slope (°)**		<10	<14	<20
2.	**Log Yard**	Area (m^2)	50 x 50	20 x 50	20 x 20
		Slope (°)	<5		
3.	**Aspect**		N – S E – W NE – SW SE - NW		
4.	**River Buffer (m)**		>20		
5.	**Elevation (m)**		0 - 400		

4. RESULT AND DISCUSSION

Location of forest road starting point (Source) in forest road construction determined by Forestry Department of Peninsular Malaysia. The starting point of the proposed new forest road used to be the end point of the previous existing road from the neighbouring licenced forest compartment. This was made to ensure the continuity of the forest road alignment and planning for the next compartment that will be licenced for logging. Total road length of each licenced logging compartment must comply the forest road guidelines 2010 which is below ≤200m/ha for skid road followed by ≤300m/ha for secondary road and ≤1000m/ha for main road.

Forest road alignment construction based on the nearest potential log yard, shortest path and meet the maximum slope criteria that allowed in the guidelines. This parallel with the concept of this road design which is to transport the forest product in shortest path with the minimum slope at the lowest cost.

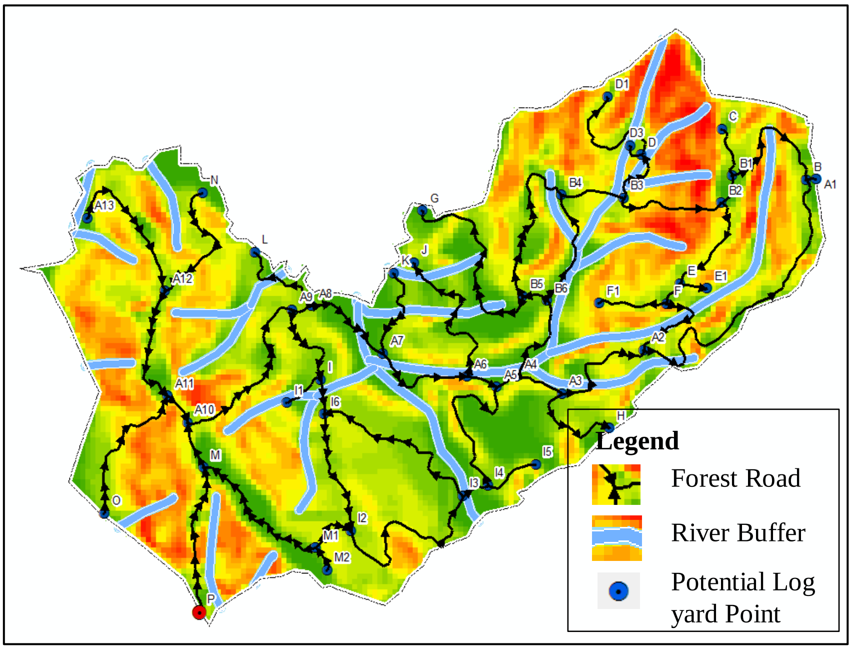

Figure 7: Proposed forest road alignment

Figure 7 shows the proposed forest road alignment within the study area. The result shows that the forest road well distributed at the lowest slope region as required in the forest road guidelines. Most of the proposed forest road generated using modified cost-path model avoid the buffer zone area and minimize the river crossing. This can minimize the construction cost of the bridge and reduce environmental impact. The result shows an acceptable estimation of maximum slope and length. The longest distance of the proposed forest road is up to 4.58km with the maximum slope of 19.73 degree. All proposed road complied the forest road guidelines by the Forestry Department of Peninsular Malaysia.

5. CONCLUSION AND RECOMENDATIONS

The above case study demonstrates that the analyzed result can be mapped and used as a base map for considering optimum alignment and location of a forest road network. In addition, forest managers could use the results as an input to assist in identifying areas which require further optimal route for forest road network planning. Some suggestions that can be recommended for future research by using higher accuracy DEM. Finally, we would like to thank everyone who helped us in this project especially Forestry Department of Peninsular Malaysia, Department of Survey and Mapping Malaysia and Department of Irrigation and Drainage.

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