The Application of Route Network Analysis to Commercial Forestry Transportation

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ABSTRACT

Transportation costs of commercial forestry farms are generally very high, causing great economic concern. In order to optimise transportation, it is beneficial to eradicate such a high density of road, achieved by adopting the most effective methods and technology. Such methods include that of Route Network Analysis (RNA), which designs a minimalist, yet cost-effective road design of a forestry farm.

The aim of the study was to determine what data is required to optimise economic and timber transportation, based on the commercial forestry farm of Ntonjaneni, located in KwaZulu-Natal, South Africa. The most ideal route from the plantations to the mill was created by manipulating the cadastral shapefile data and digital elevation models, avoiding the environmentally buffered rivers and those slopes which were too steep. As a result, the network was greatly improved. The irrelevant roads were removed and replaced with a less dense route for timber transportation, optimising the economy of the forestry farm.

PAPER BODY

INTRODUCTION

Transportation problems necessitate the search for methods or alternatives that ensure efficient, feasible and faster means of transport (Guruswamy & Thirumalaivasan, undated). Transportation costs are of great concern to commercial forestry farms, which contribute significantly towards South Africa's economy. Morkel (2000) asserts that transport is the largest cost associated with delivering pulpwood, and that people in the forestry industry usually forget that roads are an inseparable part of the road transport. Transportation costs have proved particularly exorbitant, especially if the logistics are numerous, incorporating different contracted companies and a variety of machinery and delivery vehicles. Therefore, in order to minimise or possibly eradicate irrelevant facets, a cost effective logistic line is essential to ensure that planners within the industry incorporate the most modern and applicable models to allow for accurate decision-making relating to timber transportation. Guruswamy & Thirumalaivasan (undated) suggest that recent developments in Geographic Information Systems (GIS) have allowed organisations to perform and provide 'what if' scenarios and sophisticated solutions to pertinent problems within the forestry industry.

The argument exists whether to apply modern methods of analysis to commercial forestry transportation. One such method is RNA, which using a range of data including the existing depots and transportation road network, enables the design of an entirely new route system based on the most cost-effective and economically viable option. One considers information regarding the length, segment, intersections and slope of the road. An enquiry undertaken by ESRI (1996) involves investigating whether the 'best-route' for transportation of the timber from the plantations to mills, is the shortest and quickest route, or the longer route that takes more time, is less costly because steep inclines are avoided. Such decisions are provided by spatial database and Three Dimensional (3D) Modelling.

Route Network Analysis has been extensively used in urban and industrial logistic applications particularly in the Northern Hemisphere, for example, Calicut City in India. Its use in agricultural and forestry logistic applications is in its infancy, especially in South Africa. The findings of Musa & Mohammed (2002), when applying RNA to a forestry farm in Malaysia, suggest that RNA needs to be considered in South Africa. This study seeks to establish whether databases of forestry farms, typically maintained by commercial forestry companies in South Africa, allow for RNA's potential value to be more fully exploited.

The need for analysis of the existing road structure within plantation forestry came to pass when viewing the current 'cob-web' structure of existing roads within the forestry plantations of the Ntonjaneni forestry Farm, Melmoth, KwaZulu-Natal (KZN). The haphazard display of roads provides a link to transport the timber from the road-side to the existing loading zones, (or more commonly known as depots), and furthermore, to the mill at Richard's Bay. The Ntonjaneni area has been selected as the study site as its transportation system is an area of economic concern. *Eucalyptus sp.* and *Pinus sp*. are grown in this region, and as a result contribute a means of commercial benefit towards the paper and pulp industry of South Africa. In addition, the existing data is current, assumed accurate and provides a variety of criteria including varying slope and environmental considerations, which need to be considered. Ntonjaneni is a hazardous area, due to the steep gradient of the roads as well as the varying seasonal climatic changes. In addition, this area requires a new and cost-effective approach to the management of roads and transportation, as a large amount of capital is assigned to such practices.

In order to perform RNA of an area, a modern technique needs to be designed, which will include all the relevant data of the particular area. The final routing model will contain a spatial model, which will determine whether applying RNA, based on existing data, is deemed economically quantifiable.

GIS-based applications and methodology allow for an immediate access to large amounts of data. Although this is exceedingly advantageous, the validity, reliability and redundancy of data need to be considered (Goodchild & Gopal, 1989). In addition, Foody and Atkinson (2002) suggest that although efforts may be made to eradicate each or all of these factors, one needs to realise that the data is supplied by a variety of sources as well as the fact that particular knowledge is needed in order to manipulate the data.

AIM AND OBJECTIVES

The aim of the study was to demonstrate what data was necessary to perform Route Network Analysis which designs an environmentally sensitive, cost-effective and economically viable route system in a forest plantation. In addition, the explicit objectives of the study were:

- To identify the most appropriate software model and data sets for carrying out RNA in the study area.

- To apply RNA analysis to develop a revised depot network within the plantation, and establish the closest route from the plantation to the forestry mill.
- To perform the RNA to identify the best route from depots to the mill, and from the plantations to the depots.
- To identify parameters and conditions, including additional data sets, that need to be in place for the successful application of the RNA.

METHODOLOGY

In order for RNA to be effectively performed, it was essential to identify a study area meeting the requirements previously mentioned as well as the most current and accurate spatial data relating to the routing system.

Materials

The Study Area

The Ntonjaneni Farm, located near Melmoth on the North Coast of KwaZulu-Natal, provided an ideal location for the application of RNA. A site visit was essential to ensure that the existing data was in fact up to date and represented the area with as few errors as possible.

Map Units

The data's map units were metres, and the map distance were kilometres.

Data Required for Route Network Analysis

In order for a RNA to be effectively performed, it was imperative that the information was current and was an accurate representation of the Ntonjaneni Farm. Data was supplied in the form of two types of GIS data, including shapefiles (with adjoined attribute data) and Digital Elevation Models (DEM) (Table 1).

Table 1. Types of data used for Route Network Analysis

SHAPE FILES	**DEM**
Original Plantation Compartments	*Original Dem 110*
Original Non Plantation Compartments	*Original Dem 210*
Original Fell Plan	
Original KZN Roads	
Original Ntonjaneni Forestry Roads	
Original Ntonjaneni Road Slope	
Original Ntonjaneni Rivers	
Original Ntonjaneni Depots	
Original KZN Contours	

Spatial and Attribute Data

The spatial and attribute data was provided by a commercial forestry company who manage Ntonjaneni Farm.

Original Plantation Compartments

The data was in the form of shapefiles and was made up of polygons delineating each compartment. Each compartment had a unique identifier (code), and the area of each compartment was also included in the attribute data.

Original Non-Plantation Compartments

The data was in the form of shapefiles and was made up of polygons delineating each compartment. Each compartment had a unique identifier (code), and the area of each compartment was also included in the attribute data.

Original Felling Plan

The data was in the form of shapefiles and was made up of polygons delineating each compartment. Each compartment had a unique identifier (code) as well as the particular date which each compartment would be felled. The felling plan was based on a five year rotation harvesting plan, starting on 1st January 2004, and completing on 1st August 2008.

Original KZN Roads

The entire road network of KZN was obtained in shapefile format. The accompanying attribute data had values describing each road segment's length, name, and unique code. Only roads pertaining to the study area were clipped and used for the analysis.

Original Ntonjaneni Forestry Roads

The data was in the form of shapefile line data, with each line segment represented by a unique code, route number as well as a description of the type of road. Table 2 outlines the properties relating to the roads, which should be incorporated within the RNA.

Table 2 Forestry Road Description (Forest Engineering Technical Department, 1999)

Description	**Class C**
Traffic Direction	1 lane
Recommended maximum speed (km/hr)	40
Sight distance (m)	60
Road width (m) road reserve construction width wearing course	 6 6 4 (driving surface)
Desirable maximum gradient (%) Mountainous terrain	 12
Road junctions – hazardous sites	Yield / warning sites
Speed restrictions	As appropriate

Original Ntonjaneni Rivers

The data was in the form of shapefile line data, with the attribute data describing the river's unique identity code of each segment.

Original Ntonjaneni Road Slope

The data was in the form of shapefiles and each line segment represented the variance of slope for the Farm. In addition, the attribute data described the individual length and gradient of each road segment.

Original Ntonjaneni Depots

The Original Ntonjaneni Depots are areas which have been demarcated within the forestry plantation as loading points, and are used in accordance with short-haul distances as well as volume measurements relating to the timber. In addition, depots act as the middle-medium in order to assist in the switching of loading from short-haul to long-haul transportation. Depots need to be well planned and positioned to allow easy access to the timber stacks and to meet the haulage volume amounts. In addition depots need to be well drained to eliminate flooding and act as a loading ground particularly during wet conditions (Engelbrecht, 2002). The data was in the form of shapefile data, with the accompanying attribute data describing the location of each depot, as well as the amount of timber they can withstand (in tons).

Original KZN Contours

The KZN contours consisted of shapefile data, described by the height of each line segment representing altitude in mamsl.

Digital Elevation Models

Digital Elevation Models (DEM) have been developed to reform the spatial data into a Three Dimensional (3D) view. The DEM was not supplied with attribute data.

Software

ArcView 3.3 (ESRI, 2001) was used in this study to view and manipulate geographic data. The software was used specifically to query, explore and analyse data from a statistical and spatial perspective. ArcView 3.3 extensions were also used in the analysis, including Network Analyst, Spatial and 3D Analyst.

ArcView Network Analyst

The ArcView 3.3 Network Analyst (AVNA) extension allows the user to perform *'Find Best Route'*, which solves a network problem by finding the 'least cost impedance' path on the network from one specified stop to one or more stops. Network modelling in ArcView allows the user to include the rules relating to the objects, arcs and events in association with solving transportation problems (Husdal, 2000).

The Pathfinding Algorithm

Network Analyst software determines the best route by using an algorithm which finds the shortest path, developed by Edgar Dijkstra in 1959. Dijkstra's algorithm is the simplest pathfinding algorithm, even though to this day many other algorithms have been developed. Dijkstra's algorithm reduces the amount of computational time and power needed to find the optimal path. The algorithm strikes a balance by calculating a path which is close to the optimal path, which is computationally manageable. The algorithm breaks the network into nodes (where lines join, start or end) and the paths between such nodes are represented by lines. In addition, each line has an associated cost representing the cost (price) of each line needing to reach a node. There are many possible paths between the origin and destination, but the path calculated depends on which nodes are visited and in which order (Anon. 1, undated).

Three Dimensional Modelling

Three Dimensional Modelling was performed using the 3D Analyst and the Spatial Analyst extensions. These extensions are tools which enable the analysis of spatial relationships within data. The fundamental component of the Spatial Analyst is the grid theme, which is the raster equivalent of a feature theme. The Spatial Analyst performed the *Derive Slope* function, appropriate for the analysis of gradients (ESRI, 2001).

Methods

The methods performed during the RNA are summarised in Figure 1, after the RNA has been explained in detail.

Selection of relevant data

The original data set contained a large quantity of data relating to the entire KwaZulu-Natal region. It was therefore essential to select the data which was related to the Ntonjaneni Farm as well as the KwaZulu-Natal roads which connect the Ntonjaneni Farm with the mill at Richard's Bay. Therefore, only data pertaining to the study area was clipped out using Geoprocessing Wizard extension of ArcView. Such data included KZN Roads, KZN Road Slope, KZN Contours and KZN Rivers.

Digitizing

Clipped KZN Roads

The Clipped KZN Roads and the Ntonjaneni Farm Roads were not properly aligned once viewed, and therefore the KZN roads had to be digitized in order to match the Ntonjaneni Farm Roads.

Manipulation of the attribute data relating to the spatial features

KZN Roads

The attribute data of KZN Roads did not include data relating to the true cost, speed or travel time for the transportation of timber along these roads. Such data were sourced from the commercial forestry farm and consequently added to the attribute file of KZN Roads.

Ntonjaneni Farm Roads

The *Ntonjaneni Farm Roads* did not have to be altered spatially, however their attribute table contained a large number of unnecessary fields (columns) and records (data within the rows). These had to be removed. In addition, the roads contained no data relating to the cost, speed or travel time relating to the transportation of timber. These data was obtained from the commercial forestry company and the attribute data was updated accordingly.

Original Felling Plan

In order for RNA to be effectively performed, a start and end point (represented by nodes) as well as a line feature (arc) in order to find the best route, need to be obtained.

It was essential therefore to manipulate the Ntonjaneni Felling Plan compartments so that a start point is represented by a node. Each node was based on a central position within each compartment, which was randomly assigned.

Original Depots

Only depots situated on the Ntonjaneni Farm were selected for the analysis. Additional data describing the depots, as well as the location of the forestry mill at Richard's Bay, on the North Coast of KwaZulu-Natal, were obtained from the commercial forestry company.

Buffering

A buffer zone of 30m surrounding the clipped farm rivers was created (Forestry South Africa, 2002). However, roads could cross the buffered areas.

Spatial and Three Dimensional Modelling

The Clipped Farm Road Slope consisted of small segments of road, often only reflecting half a metre. It was therefore necessary to use Three Dimensional Modelling, to determine the complete variation in gradient of the slope, as opposed to the changes of height of each small segment.

Ntonjaneni Farm Contours

The Ntonjaneni Farm Contours provide a measurement of altitude for the study area, represented by a Z value. The Z value of each line represents all contiguous locations which have the same height, (concentration or magnitude) values, stored in the attribute table. Contours form the basis for creating a *Triangular Integrated Network* (TIN).

Ntonjaneni TIN

The surface of the earth was represented by a TIN, in addition to storing specific structures with regards to the surface area, which was divided into a set of contiguous, non-overlapping triangles (ESRI, 2001). A specific height value (gained from the Z value within the Ntonjaneni Farm Contours*)* was recorded for each individual triangle node. Because of this, the height between each node was determined, creating a continuous surface, thus allowing for the representation of a very complex and irregular surface within the data set.

Derived Slope

The Ntonjaneni TIN was used to create a Derived Slope, which identified the slope or more simply, the rate of change from each grid cell to the next. The output slope grid therefore represented the degree of the slope for each cell location, which ranged from 0 to 89.2 degrees, from the horizontal.

Map Calculator

The Map Calculator function creates mathematical statements from grid themes. An output grid using an expression, based on the requirements of a road slope, was created, which was less than 12 %. (Derived Slope < 12%=1, Derived Slope > 12% =1)

The output called *Acceptable Slope* was then converted into a shapefile, using the *Convert to Shapefile* function which converts the data from raster to vector.

Route Network Analysis

The data required to perform the RNA was corrected and manipulated so that the analysis could be performed, by ‘Find Best Route’.

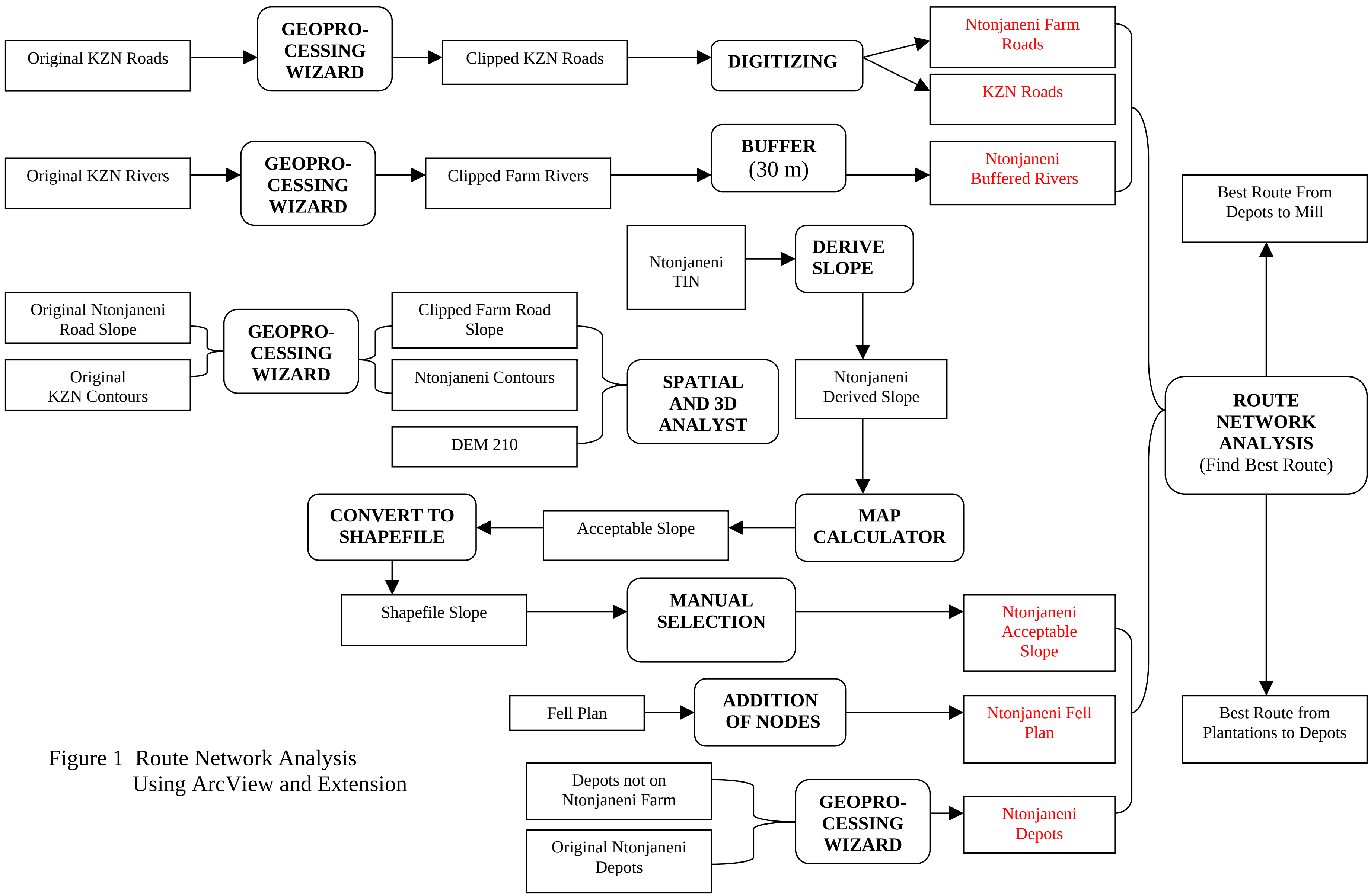

Figure 1 Route Network Analysis Using ArcView and Extension

RESULTS

The results of the study are based on the data collected and the analysis undertaken. The results show a successful completion of spatial and attribute data manipulation, Three Dimensional Modelling and RNA. The final result of the GIS manipulation revealed a best route from the depots to the mill (Figure 2), and from the plantations to the depots (Figure 3), however the data was found to be inadequate relating to the rivers and varying speed of roads, which alters the results of the RNA.

The RNA performed on the Ntonjaneni Farm has created a less dense transportation system, which has reduced the large amount of road which previously existed on the Ntonjaneni Farm, before the analysis was performed. The roads which now no longer form part of the network should be abandoned and replaced with compartments which once re-planted and harvested, will reap more economic returns.

Although the RNA has produced the most optimal route, it has not included the environmental considerations of the rivers and varying speed of the roads influenced by a chance of road slope. The data is therefore incomplete and additional data must be sourced for future RNA to be successful and accurate.

CONCLUSION

In order to determine whether the study has been successful, it is imperative to review the aim of the study, which was to determine the type of data required to perform RNA, in order to optimise economic timber transportation. This has been achieved by firstly, identifying the need for applying RNA to commercial forestry transportation in South Africa. Studies performed in India and Malaysia motivated the application, as RNA improved planning as well as greatly improved the economic efficiency of each area. An applicable forestry farm, which was identified as having a transportation problem was Ntonjaneni Farm, near Melmoth on the North Coast of KwaZulu-Natal in Zululand. An appropriate software model for transportation routing was selected which would as a second requirement, analyse the existing data to determine the type of data required in order for RNA to be effectively achieved over a five year felling plan, from an environmental and economic perspective.

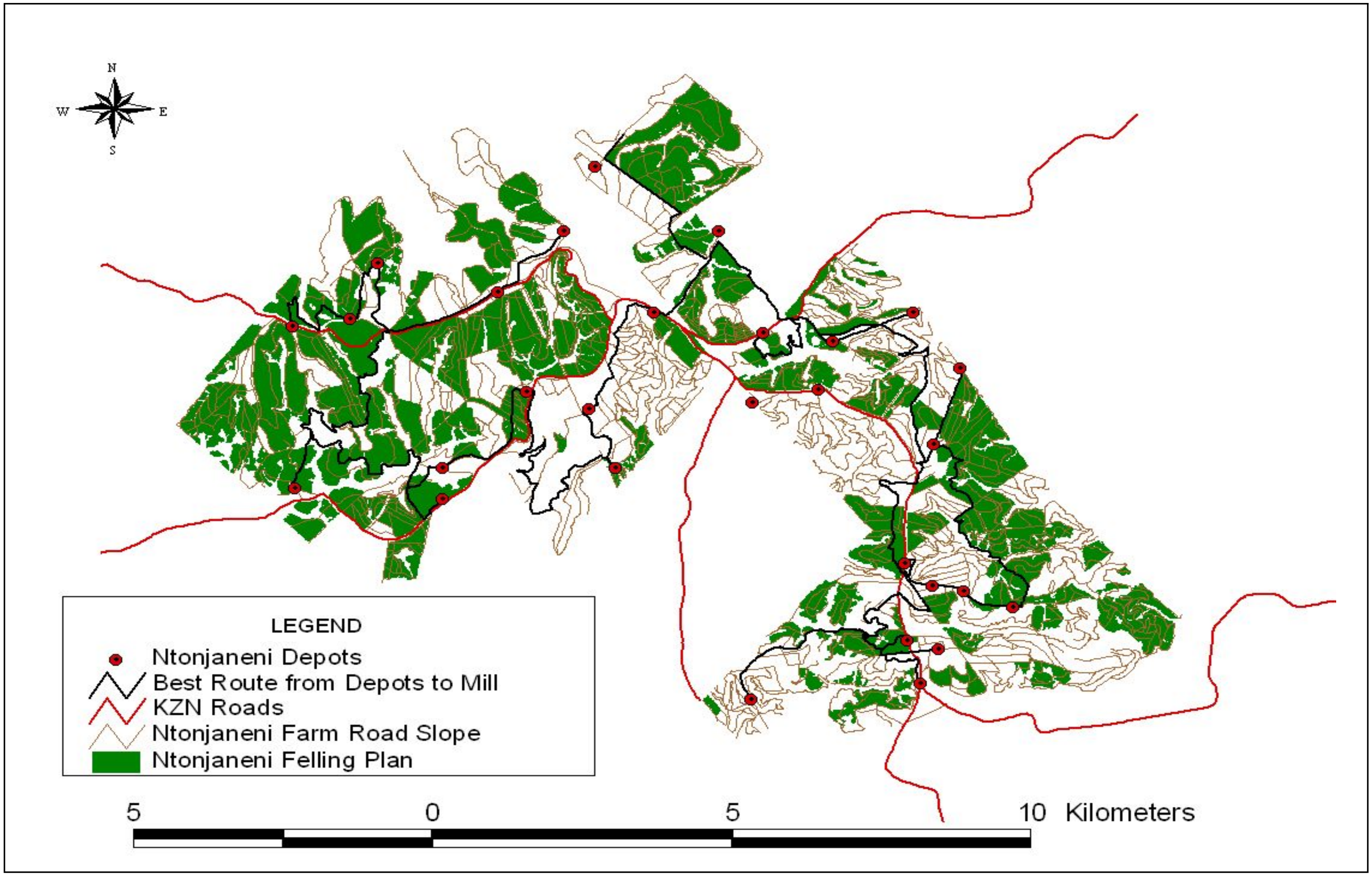

Figure 2. Route Network Analysis (Best Route from Depots to Mill)

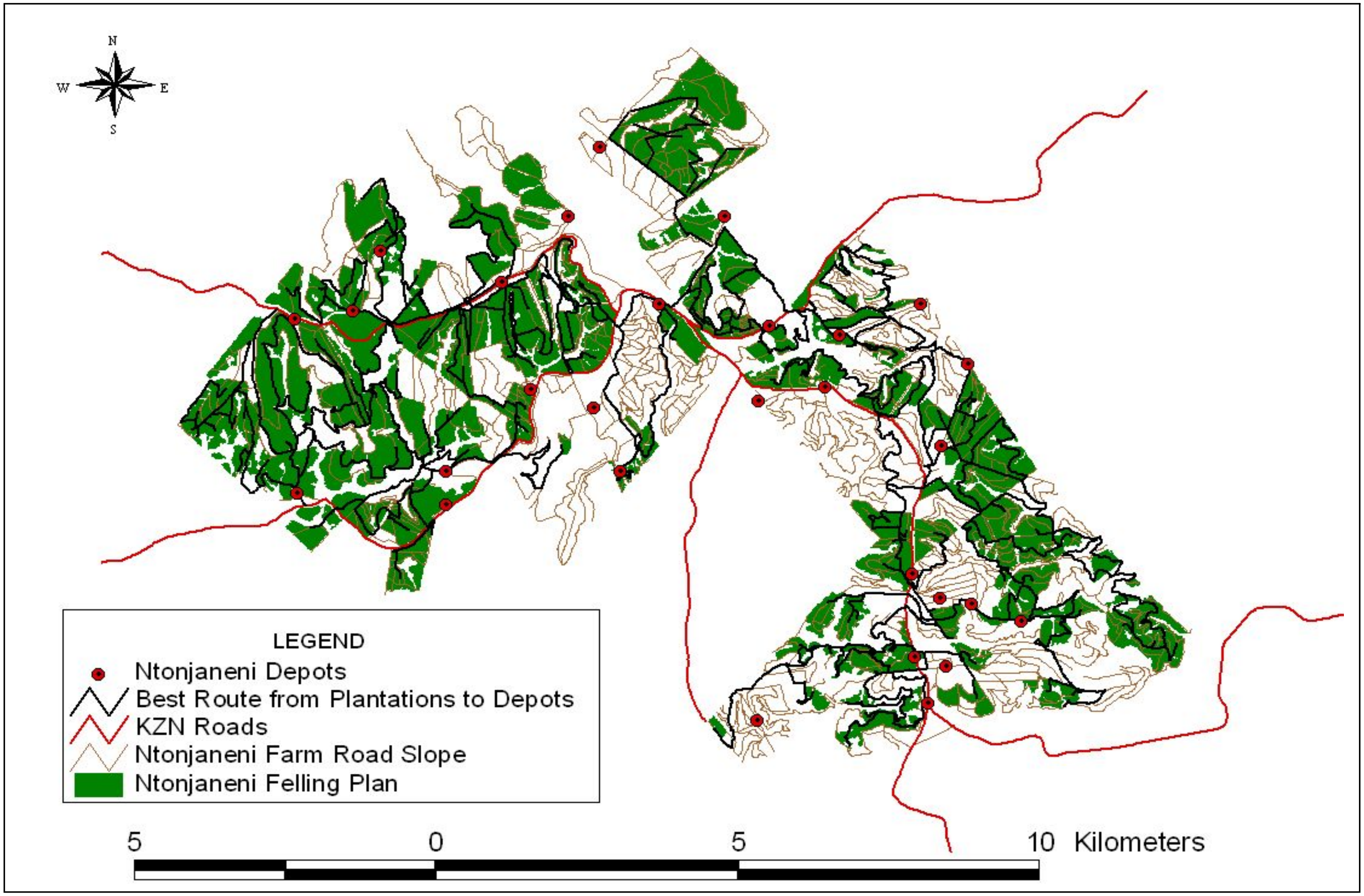

Figure 3. Route Network Analysis (Best Route from Plantations to Depots)

It has been proven that RNA is a very powerful tool for solving transportation problems, as well as optimising a forestry company's economic. However, the study had limited success in incorporating various factors relating to a network, such as the environmental aspect of the buffering of rivers as well as the variation of gradient which in turn influences the speed and time travelled on the roads. This has huge implications on the cost of transportation.

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