INFORMATION SYSTEMS IN FORESTRY LOGISTICS OPTIMISATION: A GEOGRAPHIC INFORMATION SYSTEMS APPROACH FOR SMALL SCALE TIMBER GROWERS IN RURAL KWAZULU-NATAL

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PREFACE

I................. Kundai Bertha Bhobho.., declare that

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ABSTRACT

This proposal seeks to provide a comprehensive outline of the researcher's intended Master's study. The intended study will include a thorough analysis on timber forestry value chain optimisation and the challenges associated with timber transport route optimisation, from harvest areas to the mills in particular.

The objectives of the research study are as follows:

- To provide a comprehensive literature review on challenges experienced in timber transport vehicle routing in South Africa, with particular emphasis on the origins and applications of the Timber Transport Vehicle Routing Problem (TTVRP).
- To assimilate and streamline the timber supply chain to critically analyse the extent to which the implementation of Geographic Information Systems technology improves traceability and agility along the timber supply chain in South Africa.
- To conduct a descriptive analysis on innovative advancements implemented in timber logistics aimed at improving accessibility, while minimising total travel time and aggregate costs of the organisation.

Little attention has been placed on forestry supply chains in South Africa. Over the past few decades the optimisation of timber transport supply chains has been overlooked. This has resulted in higher operational costs to forestry companies, and typically exceeding amounts of damage to existing forest roads. It has been highlighted that although vehicle routing problems have been widely researched over the past decades, the unique nature of the forestry sector requires the implementation of more innovative methodologies and formulations to provide solutions (Gregory, 2014). The study intends on filling these existing gaps, as well as on making a positive contribution towards the body of knowledge on South African forestry value chain optimisation research.

The relevance of the timber and forestry sector to national economic growth, reflects in itself how vital it is to address, and seek methods to develop permanent solutions in designing more effective and economical routes for the delivery of timber from the forest plantations to the mills. The research findings will be presented in a concise compendium of extensive reviews, with particular focus being placed on three core areas. The first will be on the Timber Transport Vehicle Routing Problem, the second, on advancements in timber logistics which have reduced the negative effects of timber transportation on forest roads and the third will provide an analysis on the application of GIS in timber transport route mapping and design.

LIST OF ABBREVIATIONS OR SYMBOLS

DAFF	Department of Agriculture, Forestry and Fisheries
DTI	Department of Trade and Industry
GDP	Grosse Domestic Product
GIS	Geographic Information Systems
CGIS	Canadian Geographic Information Computer System
ESRI	Environmental Systems Research Institute
VRP	Vehicle Routing Problem
CVRP	Capacitated Vehicle Routing Problem
SDVRP	Single Depot Vehicle Routing Problem
VRPTW	Vehicle Routing Problem with Time Windows
MDVRP	Multi-Depot Vehicle Routing Problem
HVRP	Heterogeneous Vehicle Routing Problem
VRPPD	Vehicle Routing Problem with Pickups and Deliveries
TTVRP	Timber Transport Vehicle Routing Problem
PDP	Pick-up and Delivery
TSP	Traveling Salesman Problem
MILP	Mixed Integer Linear Programme
FTPP	Forestry, Timber, Pulp and Paper
ISO	International Organisation for Standardisation
IDC	Department of Trade and Industry
CTI	Central Tyre Inflation
TPCS	The Tyre Pressure Control System
LAP	Load accreditation programme
FSA	Forestry South Africa
RTMS	Road Transport Management System

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1. INTRODUCTION

Burt, Dobler and Starling (2003) refer to the supply chain as a system, which includes all the internal functions and external suppliers involved in identifying and fulfilling the needs related to materials, equipment and services, in an optimised manner. Supply chain management integrates key business processes from the end-user to the supplier, as well as essential information that can add value for customers and other stakeholders. Logistical activities are a key facilitator in the implementation and control of effective transportation flow mechanisms (Schrijver, 2009; Crafford, 2010). In the forestry sector, the main modes of transportation used to facilitate the delivery of timber include truck, ship, train and shipping According to Mendell *et al*., (2006) and Parsakhoo and Mostafa (2015), delivery by water can be achieved "directly from landings to mills or indirectly to storage locations". This study is based on the delivery of harvested eucalyptus by truck, and the logistics sector of the timber supply chain. Project Grow places emphasis on eucalyptus tree growing.

1.1 Background to the Study

With increased globalisation in the past decade, South Africa's national timber supply chains have become characterised by the increased use of transportation systems, which have had extensive negative effects on existing forest roads as well as the environment. (Syahruddin and Kalchschmidt, 2010). Due to these effects, and a variety of other factors, sustainability has become a growing concern in timber and forestry businesses today. Stakeholders and organisations are being urged to comply with environmental and industry standards such as the ISO14001 of 2004 and the ISO/TC 211, which were initiated by the International Organisation for Standardisation (ISO) to implement the standardisation of metadata and data quality of geographic information (Kainz, 2004; Heizner & Render, 2011). Through increased awareness, organizations can reduce the long-term risks associated with bio-resource depletion and higher costs of energy.

The Department of Trade and Industry of South Africa (DTI) has identified the Forestry, Timber, Pulp and Paper sector (FTPP) as a high growth potential sector, providing opportunities for black economic empowerment, development and poverty alleviation in rural areas of the country (DTI, 2003). There is vast evidence of the job creation opportunities provided by the Agriculture, Forestry and Fisheries sector, which makes up 8.7% of the total employment in South Africa. The forestry industry alone creates direct employment of up to

62 700 jobs, of which 20 000 are in sawmilling. The timber board industry is reported to employ 6 000 workers and a further 2 200 are employed in the mining timer industries across the country (Department of Agriculture Forestry and Fisheries (DAFF), 2014; Industrial Development Corporation (IDC), 2016). The forest sector, which includes both forestry and forest products, contributes an approximated 1% towards the national gross domestic product (GDP). At a regional level, the sector contributes towards 4.4% regional GDP in KwaZulu-Natal, 3.7% in Mpumalanga, and 0.6% in Eastern Cape and Limpopo provinces. Timber products contribute up to R20 billion towards the South African Economy (Department of Environmental Affairs, 2015; IDC, 2016). Over the past decade, the value of forest product exports has grown by 23%, to a value of R13.8 billion from R11.2 billion in 2002 (DAFF, 2014). This sector is vital and deserves much attention.

An efficient information system is vital to any logistics management operation. The primary goal of any logistics information system is to enhance operational performance through smooth information and connection flows (Prates *et al.*, 2003; Mladenović *et al.*, 2014). There is a growing need for the development of improved and cost-effective approaches to the management of road networks. Advances in the technological evolution of information systems and transportation has resulted in greater motivation for continuous improvement of supply chain networks. Modern day information systems have enabled businesses to improve their competitive advantage, allowing for transparency along the supply chain (Parsakhoo and Mostafa, 2015). This study will attempt to use information systems technology to discover the optimal route based on the premise of cost minimisation. As costs contribute directly to the price of the product, *ceteris paribus*, higher operational costs will in turn result in an increase in the price of the final product. On average, transportation costs account for 30-50% of total operational costs. According to Syahruddin and Kalchschmidt (2010), regardless of the increased attention placed on sustainable supply chains and logistics management, little contribution has been made to the forestry sector in South Africa.

2. A REVIEW ON TIMBER TRANSPORT ROUTE DESIGN AND EVALUATION TECHNIQUES

Due to the negative environmental impacts associated with forestry roads, it has become vital to develop network designs, which facilitate sustainable forest resource and environmental management. The level of efficiency in timber transportation and fleet scheduling is highly dependent on the existent route design. Achieving the most desirable path requires implementation of route planning methods, which will used to determine a particular path between two or more points (Harris *et al.*, 2008; Tampekis *et al*., 2015). It has been discovered that the optimal pathway is not always a straight line between two points, but that which provides the greatest safety, reliability and economic benefit (Harris *et al*., 2008; Akay *et al*., 2012). Organisations are more interested in technological software solutions, which are aimed at optimising route planning.

The route planning and development phases of forest harvesting and operations are a vital component of forest management. Road access network planning is a difficult and lengthy task, therefore timely planning is needed to ensure the safe and economical delivery of harvested timber (Abdi *et al*., 2009). Audy *et al*. (2012) highlight that there are four decision-making segments in forestry transportation route planning:

- **Strategic Planning**: approximately five years (Decision-making is made on the modes of transport to be used as well as the construction of transport infrastructure).
- **Tactical Planning**: approximately six months to five years (Decisions are made on upgrading transport infrastructure and adjusting capacity utilisation levels).
- **Operational Planning**: approximately one to one hundred and eighty days (Designating routes and schedules to be used by fleets of trucks to deliver timber to the mill, as well as the allocation of volumes).
- **Real Time Planning**: less than one day (The dispatch of trucks and organising loads).

This research will place emphasis on the operational planning phase, which encompasses determining the designated road routes to be used by fleets of freight vehicles, in order to deliver the timber from the point of origin to each destination. Gregory (2014) defines vehicle routing as the order in which pickups and deliveries of each vehicle occurs, thereby forming a desirable geographical route. Typically, a driver's duties will consist of delivering the timber logs to the mill, then returning to the post. Prior to this, the driver will have departed with an unloaded vehicle when headed for loading at the timber forest site. The truck will be loaded to full capacity at the forest location then unloaded fully at the mill. Vehicle scheduling refers to the determination of the exact timeframe at which the Pick-ups and Deliveries (PDP) will occur (Gregory, 2004; Derigs *et al.*, 2012). A vast amount of research has been dedicated towards the operational segment of transportation planning, which is akin to the Vehicle Routing Problem (VRP). The main reason organisations conduct vehicle route planning is to address the VRP.

2.1 The Vehicle Routing Problem

The VRP was introduced by Dantzig and Ramser in 1959, and has since become one of the most widely studied combinational optimisation models (Cacetta and Hill, 2001; Cordeau *et al.*, 2007). At the time this formulation was first introduced, there were not yet any algorithms in existence to solve integer linear programs (Matai *et al.*, 2010). Gregory (2014) highlights that although vehicle routing problems have been widely researched over the past decades, the unique nature of the forestry sector requires the implementation of more innovative methodologies and formulations in order to provide solutions.

Several organisations which are in the transportation business experience the VRP on a regular basis, in the context of distribution management. The main challenge is due to a wide variety of constraints which are experienced in industry practice (Laporte *et al.*, 2013). In addition, due to the methodological challenges the VRP poses, vast amounts of resources have been invested into conducting operational studies and solving this problem in countries around the globe. The problem is challenging to solve, however, increased research efforts on VRP have led to a deeper understanding on the concept of metaheuristics (Cordeau *et al.*, 2007; Laporte *et al.*, 2013).

In 1984, an innovative VRP approach was established by Laporte, Desrochers and Nobert (Laporte *et al*., 2013). The original concepts of linear programme relaxation of an integer linear model have been incorporated into more recently developed algorithms through strengthening techniques (Caccetta and Hill, 2001; Laporte *et al*., 2013). The first evidence of records showing the development of modern heuristics can be dated back to the 1990s with the introduction of metaheuristics. Laporte *et al*., (2013) highlight that early research surrounding the topic consisted of several gaps. The publication of two papers in 1981, namely; Mingozzi and Toth in Networks (Christofides *et al*., 1981), and Mathematical Programming (Christofides *et al*., 1981) brought to surface the development of specific VRP algorithms. Gregory (2014) argues that although much attention has been placed on the VRP from an operations perspective, a gap still exists in research surrounding the synchronisation constraints, which exist between the vehicles, and connecting equipment, such as a crane.

2.2 VRP Components

In most cases, the VRP is defined under the constraints of route length and capacity. There are two problems, which make up the VRP.

The first variant is the Routing Problem, which considers the customers to be served, and which routes or vehicles are to be used. In summary, the given routes have to satisfy the three following constraints in order to constitute as a VRP (Danesh, 2006; Applegate *et al.*, 2007):

1) Each customer is to be visited exactly once.
2) All the routes will begin and end at the depot.
3) The sum of all the demands on a route should not exceed the capacity of a vehicle.

The main objective of the VRP is to attend to a given set of client locations, through the use of a fleet of vehicles which will deliver a commodity at the minimal aggregate travel cost. Each client location should be served precisely once, with each particular route commencing and ending at a depot location. The depot refers to the start and end nodes of the route. In this Single Depot Vehicle Routing Problem (SDVRP) multiple delivery vehicles depart from a single depot and return to the same depot (Gregory, 2014; Chakroborty, 2016). This description is illustrated in Figure 2.1.

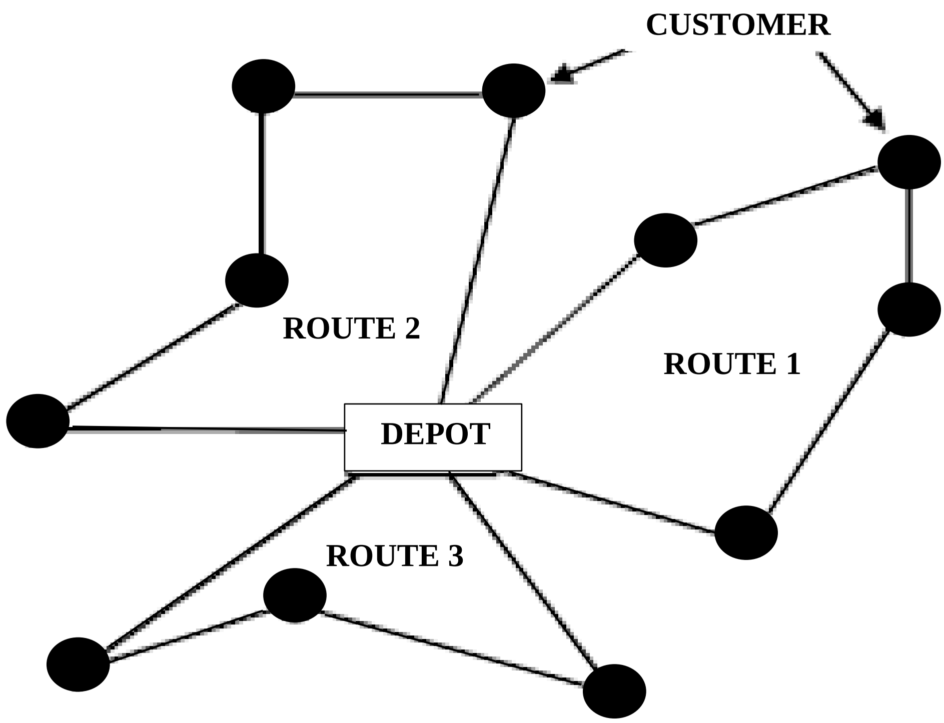


Figure 2.1 The Vehicle Routing Problem showing combinations of route plans to discover the optimal set of routes for a fleet of trucks to deliver timber from the depot, to mill areas at the lowest aggregate cost (after Ghoseiri and Ghannadpour, 2009)

The second variant is the Scheduling Problem, which considers the order in which clients are served on each route. An efficient schedule would be one which minimises the amount of waiting time between each client, given a set of constraints Chakroborty (2016). The VRPs usually provide the assumption that each client's demand is less than, or equal to a single vehicle's capacity (Danesh, 2006; Cordeau *et al.*, 2007). However, Gregory (2014) argues against this notion and highlights that the requirement for a single visit cannot be met when it is necessary to conduct more than one visit to the customer. The savings resulting from this Split Delivery Vehicle Routing Problem have been reported to accrue significantly as the client's demand increases, relative to the vehicle capacity.

2.3 Common Variants of the VRP

The VRP consists of a wide range of variants which are suited for different delivery scenarios, depot and mill locations, in relation to the plantation area. The following section provides a concise analysis of some core variants of the VRP.

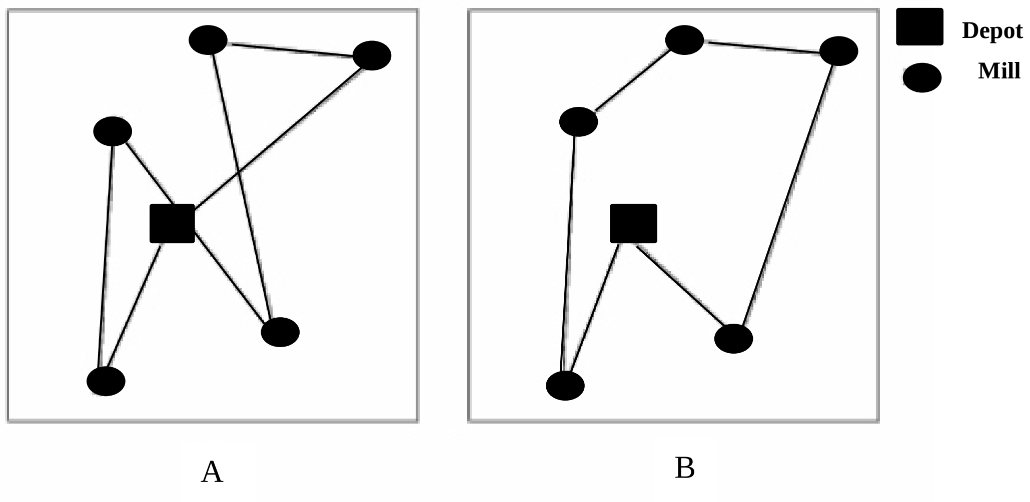
2.3.1 The capacitated vehicle routing problem (CVRP)

Adntzig and Ramser (1959) are recorded to have introduced the Capacitated VRP (CVRP), which is the VRP where a homogenous fleet is limited only to the capacity constraints of the commodity being delivered. The CVRP is similar to the VRP with an additional constraint limiting each vehicle to a uniform capacity for a single commodity (Danesh, 2006). Laporte *et al*. (2013) and Gregory (2014) illustrated the solution through what was referred to as a "match-based heuristic" through the means of a toy-sized example. This example was represented through a Mixed Integer Linear Programme (MILP).

In the following years, with increased research, several heuristics emerged which were based on a number of principles such as geographical proximity, intra-route and inter-route improvement steps (Laporte *et al*., 2013). One-phase heuristics are also known as constructive heuristics, which iteratively expand on a fractional solution in order to build a complete solution (Gregory, 2014). The information from the rankings is analysed and modified to provide a solution by combining the merged routes in order to maximise on the occurrence of the particular client pairs, which have proven to yield the greatest savings. Two-phase heuristics then dissect the problem into two distinctive sub-problems, in which the most common are the cluster, for the first, and the route for the latter (Gregory, 2014). The use of one and two-phase heuristics may fail to reach a global optimum solution because they tend to come together to reach only a local optimum. It is for this reason that focus has shifted to metaheuristics. Metaheuristics are defined as algorithms which seek to find optimal solutions in a random manner (Luke, 2015). According to Olafsson (2006) and Gregory (2014), metaheuristics, when effectively implemented, can provide timely and optimum solutions, where alternative optimisation methods have proven to be inefficient. The Clarke and Wright saving heuristic of 1964 can be considered the most famous of these heuristics due to its "speed, simplicity and reasonably good accuracy" (Pichpibul and Kawtummachai, 2012). The Clarke and Wright saving heuristic is a classic one-phase CVRP heuristic, in which pairs of clients are ranked according to savings realised. These savings are achieved through the consecutive visits of customers, in comparison to using separate routes (Pichpibul and Kawtummachai, 2012).

2.3.2 The travelling salesman problem (TSP)

The Traveling Salesman Problem (TSP) is a special case of the VRP, where the VRP generalises the TSP, and is in its most simple form (Applegate *et al*., 2007). The idea behind the TSP is that a given salesman needs to visit each individual location, starting from the depot, and returning to that starting position. The problem lies in that the salesman needs to minimise the total distance travelled by calculating the optimal path which passes through all the vertices only once, at the lowest cost (Cordeau *et al.*, 2007; Gregory, 2014). The optimal route is therefore considered as the shortest route length of the salesman leaving home, moving through neighbouring towns exactly once then returning home (Cacetta and Hill, 2001). Typically, the TSP is considered to be difficult to solve due to the fact that an increase in the number of locations concurrently results in an increase in the number of possible feasible routes. A graphical representation is illustrated below:



(A) A feasible path through five nodes

(B) A better and feasible path through the same five nodes

Figure 2.2 Travelling Salesman Problem. Figure (A) shows the path a salesman can take to make deliveries from the point of origin, to different towns then back home. Figure (B) shows a more optimum route sequence the salesman can take to make deliveries to the same towns (after Chakroborty, 2016)

Applegate *et al*. (2007) and Matai *et al*. (2010) highlight that past research has not provided a clear indication in terms of who created the TSP. Early records however, indicate the first reference pertaining to the TSP being cited by Julia Robinson in a 1949 report titled “On the Hamiltonian game (a traveling salesman problem)” Applegate *et al*., (2007). In 1983, a German author, Heiner Muller-Merbach, brought attention to TSP research through his book, “The Commis-Voyageur”. Danesh (2006) and Matai *et al.,* (2010) however argue that evidence exists of the TSP studies in the 18th century, from the works of mathematicians, Sir Rowam Hamilton of Ireland through the Icosian Game, and Thomas Penyngton Kirkman of Britain. Both the VRP and the TSP are similar in that, given a set of constraints, they attempt to discover the minimal cost and optimal route, with a pre-defined set of points (Gregory, 2014). A challenge associated with TSP is that the problem implies that the aggregate demand at the location is less than the available vehicle capacity.

2.3.3 The vehicle routing problem with time windows (VRPTW)

In the event that time frames are a factor to consider, the problem will be referred to as a Vehicle Routing Problem with Time Windows (VRPTW). The time window is associated with each location. The travel time of the truck may be determined by factors such as road speed limits, the slope of the road as well as the road surface attributes (Dahal and Mehmood, 2012). The problem is also known as vehicle scheduling where general time restrictions are placed. The time constraint stipulates that a client can only be served during the specified time interval (Audy *et al*., 2012; Gregory, 2014). Therefore, the route is not considered optimal if the delivery location is served prior to its agreed time, or if the pick-up node is not visited within the stipulated time (Chakroborty, 2016).

2.3.4 The multi-depot vehicle routing problem (MDVRP)

The VRP consists of multiple extensions, another being the Multi-Depot Vehicle Routing Problem (MDVRP). This is a generalised version of the SDVRP, where instead of vehicles being routed from an individual location, the fleet is routed from a set of facilities. In MDVRP, due to the additional depots, the grouping problem is an additional factor. A decision is made on the set of customers to be served, as well as the associated depots (Danesh, 2006; Gregory, 2014). The vehicle and commodity capacities are stipulated to each facility, indicating the maximum commodity amount which each facility can serve.

2.3.5 The heterogeneous vehicle routing problem (HVRP)

This VRP variant occurs when a fleet of vehicles is available to conduct deliveries. The fleet however will be characterised by a different set of costs and capacities. Heterogeneous vehicles bring constraints associated with a variety of capacities, variables as well as fixed costs. The Heterogeneous Vehicle Routing Problem (HVRP) was first introduced by Golden *et al*., (1984) (Baldacci *et al*., 2007; Gregory, 2014).

2.3.6 Pick-up and delivery problem (PDP)

The PDP methods are similar to the TSP, however each location is either a pick-up location or a delivery location. The PDPs can be classified into three structures in which the set number of commodity origins and destinations can be differentiated (Berbeglia *et al*., 2007).

1) Many-to-many problem:

   The commodities are transported either from the client to the depot, or from the depot to the client, as the client request will require both a pick-up and delivery location. A random selection occurs, as any site is able to serve as the origin or destination for any commodity (Danesh, 2006; Gregory, 2014).

2) One-to-many problem:

   The depot is referred to as the site at which the fleet of trucks will be based. Initially, the commodities are available at the depot and will be designated to the customers. Conversely, the commodities which are available to customers will be designated at the depot. Audy *et al*., (2012) highlight that in this structure, the PDP includes both commodity allocations as well as and truck routing decisions. Each commodity has a fixed origin and destination. According to Danesh (2006), this is considered the most difficult, as the pickup and delivery locations are required to be on the same line. In addition, the pickup point should pave the way to a delivery location on each occasion. The one-to-many problem may also be referred to as the Vehicle Problem with Pickups and Deliveries (VRPPDs). Other related services include door-to-door transportation (Gregory, 2014).

3) One-to-one:

   A given commodity will have a designated origin and destination (Gregory, 2014).

2.4 The Timber Transport Vehicle Routing Problem (TTVRP)

The Timber Transport Vehicle Routing Problem (TTVRP) refers to the complications involved in the transportation of round logs from the forest location to the mills and industrial sites. In transporting timber from the plantation to the mills, the transport tasks are predetermined. A main objective would be to keep the number of empty truck movements to a minimum by discovering the lowest cost route (Derigs *et al*., 2012; Wang, 2013).

In timber transportation, the VRP can be referred to as a modified version of the (PDP). Audy *et al*. (2012) indicate that in timber transport, there is no single definition of a PDP. An objective is set, relative to a known set of constraints. Similar to the TSP, each location may have a different set of service requirements. Vehicle routes are then created for a designated fleet of trucks, to transport products between a point of origin and destination (Gregory, 2014; Chakroborty, 2016). Berbeglia *et al*. (2007) discusses the relevance of information availability in the planning segment, which is an aspect found in PDP. When conducting dynamic PDP planning, current results are adjusted in a time-based manner; as new information is received (Audy *et al*., 2012). It is vital to anticipate changes throughout the day so that future plans can be more easily adjustable. PDP is also distinct in the sense that the available information at the time of planning is uncertain. The information which is received is limited, in that it is information regarding the next trip, and the route may change at any time during the day. Each route is revised after an event occurs. The event may set off a re-optimisation–e.g. after supply and demand levels have been reviewed. Audy *et al*. (2012) explain this component by indicating that the system should be able to "re-optimise given a current partial solution."

A vast number of papers which address the VRP in timber transportation, analyse deterministic problems. The key feature of a deterministic problem is that it is assumed that all the received information is identified as definite. In comparison, the stochastic problems consist of data sets which are random variables such as demand and supply levels. According to Berbeglia *et al*. (2007), these distributions are usually known. A few planning methods, such as McDonald *et al*. (2001), which are simulation-based, do include data on stochastic information. In timber transport PDP, subject to a given set of constraints, a collection of routes are generated in order to meet either a set of requests, or a set of demand points. The requests represent the one-to-one structure, while the demands represent the many-to-many structure. The VRPDP is an extension of the VRP where the critical factor is that goods are also transported from the customers and back to the depot (Wassan and Nagy, 2014; Audy *et al.*, 2015)

A request allows time constraints to be included and it indicates specifications of the volume, the origin and destination as well as an assortment. The demand point is the node at which a specific volume in an assortment group is required. A supply point is the location which provides specific volumes in an assortment, and is available to satisfy the set of demand points (Audy *et al*., 2012). Typically, available volumes usually exceed a single truckload, therefore the origin and destination sites may be visited multiple times. The fleet of trucks may consist of relevant characteristics, with vehicles being either homogenous or heterogeneous. In addition, as the trucks are usually dispersed over either a single depot or a set of sites, the planned route usually commences and ends at the home base. In the event that the planning period extends to the next day, the vehicle can return to the home depot without a full load, and the delivery can be performed the next day. Transhipments are usually prohibited. This occurs when the truck drops off a volume in order to pick it up at a later time (Gregory, 2014; Wassan and Nagy, 2014).

The chosen route should adhere to specific time constrains, which include the truck's available working hours and time windows at different demand and supply points, as multiple driver work shift could be assigned to a single vehicle. The time windows at the demand or supply point consist mainly of either opening hours or on-site loader operation hours (Audy *et al*., 2012). The opening hours indicate the specific timeframe at the depot, in which the truck is able to pick up a load or make a delivery. The latter shows the time specification in which the loader is able to conduct loading operations. Waiting time can be computed and will be permitted when the truck arrives before an obligatory time window. The PDPs in timber transportation differ considerably from a general PDP.

2.5 Drivers of Route Optimisation Problems

Forest road configuration practices can be greatly hindered by high costs of assessment (Ismail and Jusoff, 2009). Typically, there are two key drivers for the problems of timber transport route optimisation, namely high timber transport cost and increased timber road deterioration levels. The following section will provide a detailed dissection of these two elements.

2.5.1 Timber transport cost

Forest Plantations make up to 1.4% of total land in South Africa, which amounts to over 40 million hectares of the South Africa's total land surface area with over 80% of the plantations being located in Mpumalanga, Eastern Cape and KwaZulu-Natal (Department of Environmental Affairs, 2016). The transportation of timber from the plantation to the saw mills represents an important segment of the overall supply cost in forestry industries and is a high energy demand phase, amounting 70-78% of overall energy requirements and 68-75% of greenhouse gas emissions (Sosa *et al*., 2015). As the transportation is mainly facilitated through road, the associated logistics costs concurrently depend heavily on the scale of the operation, triggering a ripple effect where costs will continue to multiply along the rest of the value chain.

The relevance of secondary timber transportation has been widely studied. Forestry road and maintenance can be one of the most costly activities in forest operations. *Ceterus paribus*, high operations costs in turn will result in an overall increase of the final product cost. Logistics expenses of a company can account for up to 50-60%, while typically during the harvesting operation, transportation from the forest to the mills can account for up to 30 – 50% of the total operations cost (Dahal and Mehmood, 2012). Total transportation cost is a function of a variety of factors which include distance travelled, the characteristics of the terrain, whether the logging is wet or dry, the driving technique as well as the specifications of the truck used.

Due to the large volumes and unique transportation requirements of saw timber, this expense affects mostly forestry companies in particular (Nicholls *et al.*, 2004; Gregory, 2014). The forestry industry today is faced with the challenge of becoming more of a proactive, rather than a reactive industry (Bruchner, 2002). Over the past decades, corporations have discovered that the slightest reduction in costs can result in significant savings. It is for this reason that companies have increased their efforts to conduct significant amounts of research towards improving the efficiency of these operations to reduce costs (Nicholls *et al*., 2004; Audy *et al*., 2012).

2.5.2 Poor road infrastructure

Forest roads are an essential part of many aspects of forest management as they are essentially the means of accessing the forest. Most plantation roads in South Africa were historically not intended for haulage operations but were constructed mainly for silvicultural and fire rescue crews. Forest roads can cause issues such as residue accumulation and water pollution in off-site areas, ecological disintegration, loss of habitats and in addition, cause imbalances in forest landscapes (Delgado *et al*., 2007; Fu *et al.*, 2010; cited in Tampekis, 2015). Therefore, in some cases, due to a variety of constraints, forestry roads may not be suitable for the truck type used, as the roads are unfavourable for extraction. In order for a truck to be able to access the road, it should be able to go through all the road curves while all the wheels remain in contact with the surface of the road (Oberholzer, 2001; Ballindalloch *et al.*, 2010).

It has been proven that the quality of the road can optimise timber transportation. Therefore a distinct interface exists between the truck and the road (Derigs *et al*., 2012; Nicholls *et al*., 2004). Factors such as the grade and width of the roads, as well as the radius of the curve centreline, play a significant role in determining if the given truck configuration can enable road access. When creating a route plan, the paths design objectives can be linked to specific vehicle configurations. If a road curve radius is too small for the vehicle configurations, off-tracking can occur. Off-tracking occurs on any road segment, where the back wheels of the truck fail to follow along the same path as the front wheels. This lateral movement usually occurs in a lane change exercise lying outside the range of the steer axle. A longer truck creates more off-tracking, with maximum off-tracking occurring at sharp curves (Pa *et al.*, 2008; Oberholzer, 2014;). It is recorded that Erkert (1989) developed the Off-track Computer simulation specifically to address forest road networks. The computer simulation programme is deemed the most appropriate method of analysing the off-tracking of vehicle and trailer combinations when going through compound curves. Results gathered from the off-track programme can be used to conclude on the curves which lie on existing road networks which limit the use of certain vehicle configurations (Oberholzer, 2014). The effect of vehicle offtracking is illustrated in Figure 2.3.

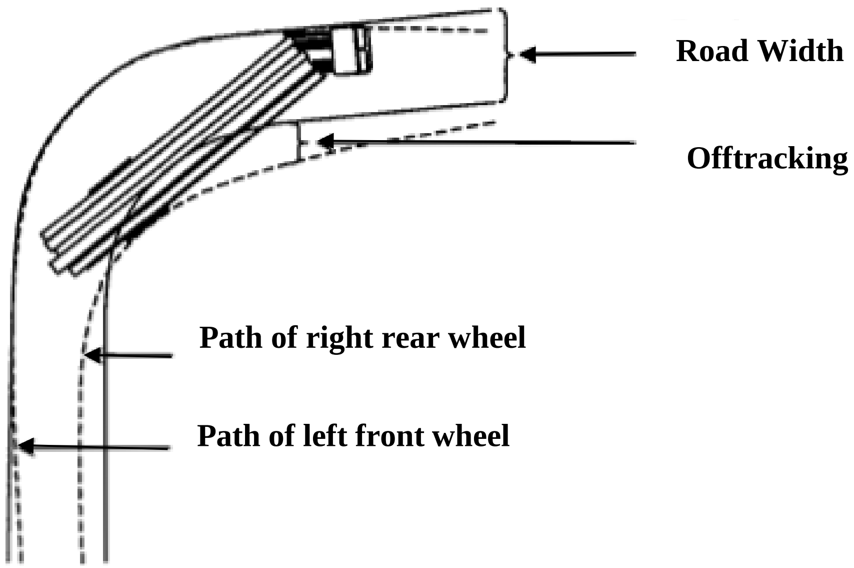


Figure 2.3 Vehicle Offtracking in which the effect of the back wheels following the path of the front wheels results in the truck veering off the designed road path (after Oberholzer, 2001:12)

One of the main contributors to forest road deterioration in the past can be attributed to overloading. As a result, the South African government has made attempts to address this issue. The Load accreditation programme (LAP) was initiated in 2003 with the aim of promoting good corporate governance. The focus was on reducing overloads in the timber industry, which resulted in a reduction in overload of up to 40% within the first two years. This led towards the initiative being established in other industries, in efforts to minimise overloading which contributes to the deterioration of road infrastructure (Nordengen and Naidoo, 2014). A national pilot project came about as a direct result. The project initially was funded by the Department of Trade and Industry (DTI) and Forestry South Africa (FSA), under the DTIs Sector Partnership Fund. The project was aimed at incorporating other industries with the forestry industry through a buy-in. Active members were represented on the Steering Committee. In 2005, the initiative was renamed as the Road Transport Management System (RTMS). This scheme allows companies with a stake in the road logistics value chain, to voluntarily implement management systems which encourage road infrastructure preservation and value chain optimisation (Pa *et al.*, 2008; Nordengen and Naidoo, 2014).

2.6 Advancements in Road Logistics Infrastructural Preservation

The past decade has seen a significant move towards technological logistic advancements, in attempts to address the challenges associated with forest road infrastructural damage. The use of more 'road-friendly' vehicles has significantly reduced previously dominant environmental effects on national forest roads.

2.6.1 The super single wheel

The super single wheel was produced by Michelin and was first installed by James Jones on a super single trailer Mackenzie (2007). It has taken the place of the traditional twin wheel in timber industries, previously used on articulated truck trailers. Mackenzie (2007) and Brito (2011) highlight that 95% of major timber hauliers have made this shift, in the move towards a more streamlined truck design.

The super single wheel is designed in such a way that it increases the space in-between the main supporting beams of the trailer. The load will be spread wider if the distance between the tyres is bigger, and this improves stability thereby minimising the risk of overturning accidents. A road friendly timber truck will usually have several widely dispersed wheels running with soft tyres. This brings about the advantage of improved traction (Pletts, 2006). A forest road theoretically has a predetermined serviceable life-span and the life of the road can vary depending on whether the vehicles which travel on it are road-friendly (Morkel, 1994; Pletts, 2006). A larger number of wheels will adversely result in a reduced load per wheel. Researchers have highlighted the idea that the impact of the super single on the minor roads with trafficked pavements can be up to seven times more damaging than the effect of the twin wheels carrying the same load. It has been argued that the smaller area of contact of super single wheels, can affect road pavement life adverse. Research shows that this instinctive thinking is highly debatable and this study will reveal the results of a broad investigation on the subject, based on existing literature (Mackenzie, 2007; Brito, 2011)

2.6.2 Central tyre inflation (CTI) or tyre pressure control systems (TPCS)

The impact of a truck onto the road occurs when the load is transferred from the vehicle to the road. This can also be referred to as the road- tyre interface. A variety of factors influence the impact level on the roads. A bigger footprint reduces the surface pressure on the road. The footprint is described as the surface area of the tyre which is in contact with the road. Less tyre pressure results in a longer footprint and reduces the tyre slip (Pletts, 2006; Mackenzie, 2007;). The Tyre Pressure Control System (TPCS) was designed to reduce the air pressure in tyres, thereby improving the load distribution on the road surface. It is described as an on-board mechanical system that allows the tyre pressure to be controlled electronically from the cab of the vehicle, while it is in motion. The alterations will be made in accordance with the changes in road and land conditions, as well as the vehicle speed. The TPCS is the modern terminology of the Central Tyre Inflation technology (CTI) which is known to have been first used during the Second World War by the US military. It was later developed further by several countries up to the 1990s. Today this technology is widely used in the forestry industry (Pletts, 2006; Mackenzie, 2007; Ballindalloch *et al.*, 2013). Compressed air from the trucks on-board compressor is moved through the hoses in a controlled manner, in order to inflate the vehicle's tyres. In order to deflate the tyres, valves which are on the wheels, are opened and air is released to reach the optimum level. The control panel is located on the dashboard, enabling the driver to operate the changes. The technology requires the tyre pressure to constantly be monitored. Brito (2011) highlights that the effective management of tyre inflation is an optimal means to control the deterioration of road pavements in forest road networks. With the tyre operating at its optimum inflation pressure, there will be less blowouts, which are caused by overheating, as well as more tread wear. (Pletts, 2006; Brito, 2011). This description is highlighted in the Figure 2.4 below.

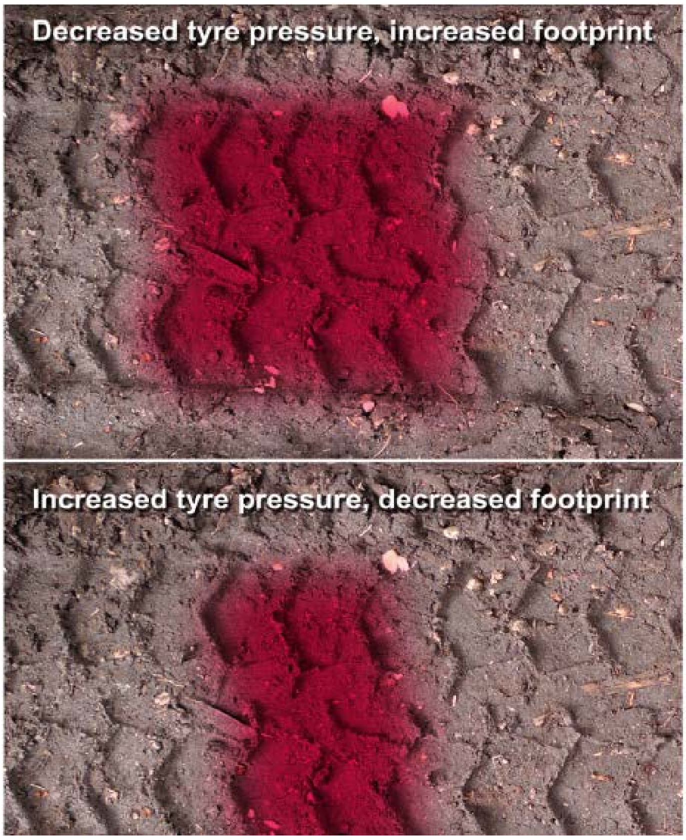


Figure 2.4 Effects of Tyre Pressure Control on road footprint. A lower air pressure can result in a contact area 60% higher than when operating under normal air pressure (Ballindalloch *et al.*, 2013)

2.6.3 Low ground pressure trailers (LGP)

Low Ground Pressure Vehicles commonly refer to balloon tyre vehicles, which are lightweight and capable of travelling across soft areas. This definition can also be extended to include a vehicle which is designed to extend it's load over the largest area possible. John Scott of Ayr has made significant progress in this area of research. It is reported that he has extracted up to 500 000 tonnes of timber using specifically LGP equipment (Mackenzie, 2007; Brito, 2011). The tractor unit is able to spread the load across the pavement thereby minimising the breakage of the back of the road. This technology has increased flexibility and durability of haulage on poor quality and wet condition forest roads, which considerably reduces the cost of road operations and irreversible damages. The trailer consists of a unique axle and wheel configurations designed to spread out the weight across the entire carriageway, and to reduce overall ground pressure (Brito, 2011). Refer to Figure 2.5 below:

LGP Trailer Axle Layout

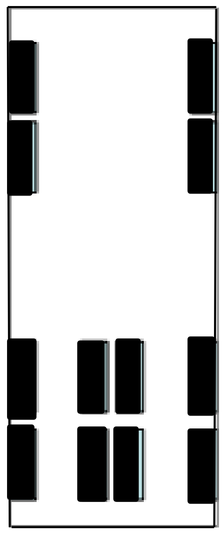


Figure 2.5 Low ground pressure vehicle and its axle configuration. (after Brito, 2011)

2.7 FREDD Vehicle Scheduling System

The FREDD Vehicle Scheduling System is an innovative solution designed in an attempt to tackle the VRP and improve South African value chain efficiency. The initiative was originally designed in Australia and has been customised to suite the South African mill and road setting. The system uses GPS monitors to track both the trucks and the harvesters. Through synchronising the rate vehicles arrive to the mill, with the rate the mill completes a batch operation, the system can reduce cycle times. In addition, the use of on time communication, facilitated by LAN and WAN facilities, will allow for improved vehicle utilisation as the number of trucks used per day is set to match the exact load quantities.

2.8 Geographic Information Systems (GIS)

Geographic information sciences have the ability to manage large volumes of data sets. The discipline can be synonymously referred to as geo-informatics. This system is used for integrating limitless combinations of data set disciplines with geography, and over past decades, they have been used in response to human and physical geographic questions. Modern technological advancements have led to the incorporation of information technology and computers in all the aspects of handling spatial data, in a manner, which was not possible in the pre-modern computer era. The dynamic nature of GIS is rapidly changing at the same rate as changes in information technology (Baral, 2004). Now, raster and vector files can manipulate large data files by forming a combination with advanced digital images. GIS enables the spatial data sets to be analysed and electronically combined in order to create maps (Aguirre, 2014; Rogers, 2015). In essence, these map the spatial representations of weighted data sets, with their datum being the earth's surface. Through GIS technology, the maps created can be stored in a digital database and can be accessed worldwide. A variety of researchers have recorded evidence on the economical nature and ease of use associated with GIS technology in comparison with the simplified traditional approaches to analysing data, such as cartography. Both approaches are similar in that data can be added onto a base map. However, GIS is a modern extension in that the data which can be included onto the map is multitudinous. In addition, GIS allows supporting data to be presented in the form of statistics and analyses tools (Bilgili, 2006, Dempsey; 2012).

2.8.1 Origins of spatial analysis

Spatial analysis is a form of geographical analysis, which creates and extracts information from spatial data in order to compute optimal routes and models. Spatial analysis is considered to belong to the class of GIS technology because it provides the basis for GIS through incorporating different fields, handling spatial reasoning. The spatial reasoning provides a framework for time and space, which identifies relationships between objects (Kainz, 2004; Mayhew, 2005).

The first spatial data application was documented in 1832. Charles Picquet, who was a Geographer from France, created a map to visually represent data gathered on a cholera epidemiology in the form of halftone colour gradients (Dempsey, 2012). In September 1854 John Snow further developed on this through the Snow map. The map highlighted the locations in central London where deaths caused by cholera had occurred. This early evidence of geographical analysis was used to track the source of the cholera outbreak.

Historical maps played a significant role in the use of historical GIS as it enabled a deeper understanding on the concept of cartography. Historical GIS encompasses past research which makes use of geographic information systems. The maps were based on the cartographer's interpretation of information gathered from surveys and maps, therefore, the reliability of cartography was limited to the readers' acuteness and skills of interpretation. According to Kainz (2004), cartography is the science of functions related to map making. Applications date back to the period during the American Revolution, when a French Cartographer named Louis-Alexandre, drew a map to direct the movement of troops in the Battle of Yorktown. Another example is that of the Wheeler Survey. Goerge M. Wheeler combined survey points with other spatial data to construct a three-dimensional landscape map of the Yosemite Valley (Knowles, 2005; Rumsey and Williams, 2009). By the early 20th century, photo-zincography was created, allowing attributes such as water and vegetation to be printed out as separate themes. Maps were originally considered as the main information source for GIS databases and as computer systems were introduced, analogue cartography was replaced by the modern digital cartography, allowing the map content to be transferred to a computer database. Maps have been proven to be successful models of reality among various applications. They are effective in communicating and storing geographic information (Kainz, 2004; Baral, 2004).

Since the introduction of the personal computer in the late 1980s, efforts have been placed towards a continuous improvement process, with the first textbook on GIS being published in 1986. This was followed by the launch of the International Journal of Geographic Information Systems in 1987 (Kainz, 2004). This period was characterised by expansion as agencies in the commercial market place began to develop and provide GIS software. Among the agencies were Intergraph and the Environmental Systems Research Institute (ESRI). Today, ESRI has become a market leader and the world's largest GIS firm estimated to be worth over $1 billion ESRI. Awareness Advancements led to the release of ArcView in the 1990s, which allows mapping systems to be produced through a Windows based interface. ArcView has become an industry standard. Corporations in the industry have been debating on optimal solutions to solve the problems associated with data ownership on public platforms (Aguirre, 2014; Carlsson, 2013).

2.8.2 Functions of GIS

GIS consists of four functional modules, which indicate the basic processes that GIS performs. Figure 2.6 highlights the flow of spatial data travel through the modules of GIS.

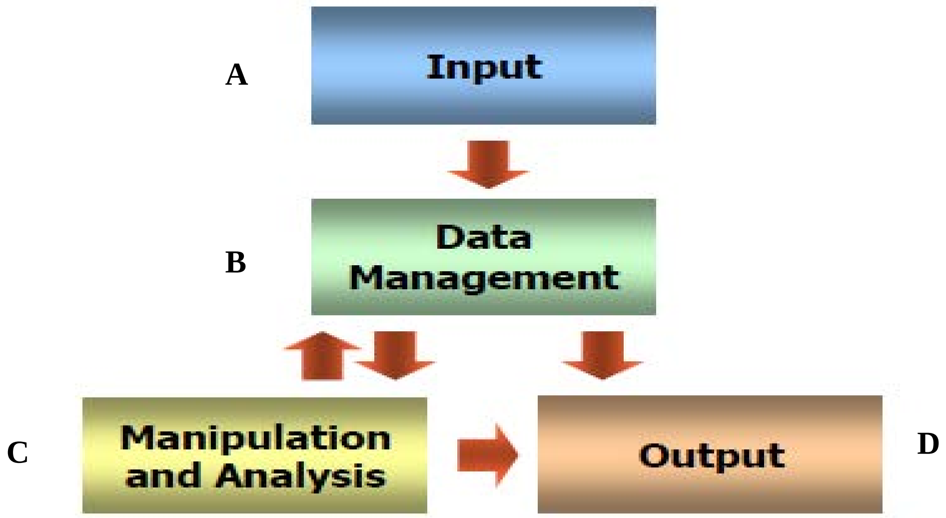


Figure 2.6 Functional Modules of a GIS show the functional movement of spatial data flow in GIS process implementation (after Kainz, 2004)

A) Data Input

Data input is the process of encrypting information into a computer readable format. The data is then transferred to the GIS database (Aronoff, 1989, cited by Baral, 2004). The data needs to be gathered and reformatted before being compiled and documented. This process of creating an accurate database is the most important task in preparing to demonstrate realistic GIS applications.

B) Data Management

The methods used to store and manage data have a direct effect on the effectiveness of the system in operating data. The data types used for GIS in particular, can be manipulated to enable their compatibility with the system. This includes altering all the data to the same format and scale. The two core models for data storage in geographic data storage are vector and raster files. Raster and vector files differ in that, while raster files are capable of managing complex natural features which are of a curved nature, vector files work better with man-made features and linear data. Vector data files can handle complex linear attributes, and manmade features, through combining the data files with sophisticated digital imagery (Baral, 2004; Rogers, 2015).

C) Data Manipulation and Analysis

When analysing data, the researcher may need to follow a series of steps from a sequence of geographic datasets in order to reach a final result. According to Baral (2004), the most common types of geographic analysis are:

i. Proximity Analysis – the method can also be referred to as neighbourhood analysis and it explores the relationship between the features in terms of distance factors.

ii. Overlay Analysis – data layers information such as soil type, slopes and vegetation cover can be integrated through the process of overlay. Each layer will contain features with the same attributes. This is a simple yet versatile concept which has made GIS invaluable in its ability to solve real world problems in forest management.

iii. Network Analysis – involves an analysis on the connectivity of data layers and the flow of resources through linear features.

D) Data Output

The final result can be visually represented in the form of graphs and maps. The map can be integrated with a variety of output methods such as 3D views, photographic images and reports.

2.9 GIS in Timber Forest Route Mapping

Overtime, a variety of definitions on GIS have been established over different industries. In many cases, GIS is used as a problem solving tool. This tool can be used to develop solutions to complex logistics problems over a wide variety of geographic scales. Such solutions can contribute significantly to cost reductions in operations (Dahal and Mehmood, 2012; Dempsey, 2012). According to Alzab *et al.* (2011), this computer based application tool is used in route mapping to effectively collect and store both spatial and non-spatial information which may not be perfectly structured. Aguirre (2014) and Rogers (2015) argue that GIS is used mostly to influence spatial data. The descriptive data is analysed and presented on maps through both visual and computational means (Akay *et al*., 2012).

GIS technology has become common in all fields related to engineering as well as the natural and social sciences. Increased availability of personal computers and access to GIS has resulted in the increased use of software in relevant fields (Baral, 2004). Through receiving real-time information, on traffic flows, this technology can be utilised in forestry settings to discover the optimum route, while keeping in consideration, the travel limitations. The power of GIS lies in its unique ability to thoroughly analyse relationships between the data associated with specific features. The forestry sector takes part in the management of a wide array of natural resources enclosed within a forested area. Forest engineers now have access to an explicitly reasoned land evaluation process which poses a variety of advantages over the conventional traditional methods which deemed to be time-consuming. Traditional methods include the use of paper-based maps alone, interpreting aerial content as well as field work which could take weeks to complete (Rogers and Schiess, 2001; Abdi *et al.*, 2009). The development of effective road infrastructure is a vital element of forest management. Upadhyay (2009) and Sonti (2015) suggest GIS as a potential means of dealing with the complexity associated with forest management applications and has become increasingly popular amongst foresters for research management. In forestry, the most commonly used are the plantation maps, in order to locate relevant features such as roads and ecological topographies for further planning. Harvest plans include a variety of activities aimed at maximising the efficient use of harvesting equipment and resources, such as identifying felling directions and danger zones as well as locating depots. Typically, a detailed harvest plan is a prerequisite for the tactical extraction route identification. The associated challenges in the allocation of the optimal path for forest road access can be better solved through computer based approaches. The spatial modelling can be used to compute the factors which suite different road allocations (Ismail and Jusoff, 2009)

3. CONCLUSION

A large percentage of companies involved in timber logistics will experience challenges associated with the TTVRP in their operations. The timber forestry sector in South Africa is a large value adding entity to the economy. The majority of timber harvested from the forests is transported by road along the supply chain. Therefore, logistics and supply chain value adding activities are a fundamental part of economic development and in order for South Africa to remain competitive in the forestry sector, continuous improvement processes are required to ensure lean operations in timber logistics. The complexities associated with route optimisation require meticulous investigations, to discover innovative ways to optimise the supply chain, allowing organisations to begin the move towards more economical operations.

Optimising timber supply chains in South Africa is vital, however the concept is complex and covers a wide range of dimensions. As the predominant mode in timber haulage is through road transportation, an increase in timber harvests will in turn have a substantial impact on existing forest road networks. Therefore, in order to allow for the effective implementation of value chain optimisation tools, industry participants need to have a concise understanding of the subject at hand. Optimising timber supply chains will require the re-engineering of pre-planning phases in order to reschedule the PDPs on existing road networks. The move towards pre-planned route optimisation techniques will result in a reduction in the cost per kilometre and an associated increase in the aggregate route revenue per day.

GIS technology can be used to facilitate route optimisation by utilising developed geo-referenced databases. This database will highlight the spread of the mill and depot locations in relation to the harvest site. A thorough application of GIS will be used to analyse current systems, and ultimately design new and more effective shortcut routes for timber transportation. The incorporation of network analysis through ArcView's Network Analyst, will reflect the associated benefits of computer- based planning in enabling feasible solution identification. Through efficient pre-planning and route mapping, timber haulage processes can be optimised, thereby improving the earning potential per truck and reducing overall operations cost of the organisation. There is a significant gap in forestry value chain optimisation research and implementation methods in South Africa, and through this study, the researcher aims to make a positive contribution to the body of knowledge and devise sound solutions to timber companies facing the challenges associated with the timber transport vehicle routing problem.

The project proposal which follows will highlight the methods the researcher aims to achieve these desired results.

4. PROJECT PROPOSAL

The main aim of the intended research will be to provide a comprehensive literature review on the challenges associated with timber transport vehicle routing, and subsequently the innovative tools and methods used to discover the optimal route which minimises total costs of the organisation and resource depletion. In addition, a descriptive analysis will be conducted to provide insight on technological logistic advancements being implemented in the forestry industry to tackle this challenge.

Through the use of modern technological advancements, road network planning and road network analysis can provide solutions for more economically and environmentally effective transportation resolutions. In addition, technological advancements can be used to predict alternative routes for timber delivery management (Mackenzie, 2007). Due to the vast array of operational costs associated with logistical network accounts, effective supply chain and logistics management skills have become vital. Through streamlining the supply chain, the researcher aims to allow insight into the extent to which the implementation of these lean systems will limit bioresouce depletion. The study will also provide a descriptive display of innovative models which will improve traceability and agility along the timber supply chain. For the purpose of this study, the researcher will use a case study approach. The literature provided will not only answer the research questions, but will attempt to provide a comprehensive theoretical background of the study to put forward a full theoretical framework. In order to fulfil the purpose of the study, the focus of the literature review will be limited to logistical systems in the South African timber industry.

This study will analyse the role of technological advancements and road network planning in determining shortcut routes in a typical rural- based timber supply chain. The study will apply to a case study of the Khulisa Umnotho Project Grow. Khulisa Umnotho is a South African Government forestry initiative which is aimed at empowering subsistence timber growers in the rural areas of South Africa. Research will be conducted based on research data gathered from the KwaZulu-Natal area. Research findings will be tailored and applied to associated provinces across South Africa, in which the project has currently expanded to. The aggregate of the area through which the programme is being run is currently recorded at up to 22 717 hectares of forest area (Sappi, 2017).

4.1 Research Methodology

The researcher will use Geographic Information Systems technology to capture a land use map of the selected study area (Mangusi, Ixopo and Nongoma). This system uses a data range which will include the existing travel routes and delivery points. Digitising converters will then be used to convert the map into digital raster files to convert the output into a vector format for a more detailed view of the relevant forest roads to be reviewed.

The information will be extracted from the visible road coverage in order to determine possible vehicle accessibility to the proposed road networks. The road coverage includes information on road attributes such as with length and width, which is the source of the road data (Oberholzer, 2001). Information stored in a GIS database will serve as the basis for information to be retrieved and analysed for this study. (Ramsey and Williams, 2009 and Rogers, 2015).

The incorporation of GIS in logistical planning can bring about a significant reduction in aggregate costs, vehicle usage as well as the overall productivity of the driver during moments of heavy road transport congestion (Alzbab *et al.*, 2011). GIS is described as a computer based application tool which provides effective methods to collect, store, view and analyse spatial data. The descriptive information gathered is presented on maps (Akay *et al.*, 2012; Sonti, 2015). The study will evaluate the feasibility of using GIS technology in forestry settings to discover the optimum route, while keeping in consideration, the travel limitations. A variety of researchers have recorded evidence on the economical nature and ease of use associated with GIS technology in comparison to the traditional approaches to analysing data. Better designs may emerge through the evaluation of alternative routes, as traditional route development techniques are being incorporated into GIS (Bilgili, 2006; Abdi *et al.*, 2009)

Implementation will be achieved through the use of the node labelling method in ArcView's Network Analyst in order to determine the critical path. Network analysis can be utilised in forestry to determine the optimum route. The critical path will be as the most economic option which provides the shortest and more efficient route from the harvest area to the saw mill (Anderson and Nelson, 2004; Parsakhoo and Mostafa, 2015). Alazab *et al.*, (2011) enhance this definition by highlighting that the critical path can also be the most scenic route. The route composed of fewer links, the shortest length and which gives the maximum vehicle speed at the lowest total cost, will be the finest.

The network will be composed of a set of links which will connect the nodes. The links give access routes from the harvest area to the mills, while the nodes may lie at the intersection points of the roads. Three parameters will be used to record information of the trucks on each link in order to establish the network data-base. These include:

a) The length of the road

The Measure tool in ArcMap will be used to measure the route distance and travel time within the parameters, on the map of the area under study. The road types will be divided into three main classes, namely, Highway, Main roads, and Secondary roads. As the extracted timber is usually transported over a variety of distances and conditions, the state of the roads will also be analysed and put into consideration.

b) The average speed of the vehicle

The calculations of each road class will be based mainly on the type of road as well as the road conditions (gravel, tarred, top surface age and roughness), in relation to the vehicle configuration. The road conditions to be considered include surface characteristics and alternative attributes like speed limits. These factors all directly impact the performance level of the vehicle (Dahal and Mehmood, 2012).

c) The time travelled

Travel time for the timber trucks for each link will be calculated using Equation 4.1:

$$T_{ij} = L_{ij}/V_{ij} \times 60$$

Where: T_{ij} = travel time on the road between two nodes (*i* and *j*) measured in minutes.

L_{ij} = the length of the road between two nodes (*i* and *j*) measured in kilometres.

V_{ij} = the vehicle speed between tow nodes (*i* and *j*) measured in $km \cdot h^{-1}$.

60= the coefficient which converts the time from hours to minutes.

This study will consist of fundamental research conducted from a single case study. The research is done with the intention of improving understanding on challenges related to value addition occurring in forestry supply chains, while providing possible solutions to fill existing gaps (Rajasekar *et al.*, 2013). This study aims to impact the performance, action and policy decisions of the proposed organisation.

4.1.1 Approach to research

Due to the nature of the information required, network analysis will be included to permit the use of real-time information gathered from GIS, as well as historic databases, to be incorporated thereby creating the optimal routing solution (Parsakhoo and Mostafa, 2015). This method will determine the meaning and description of the problem (Rajasekar *et al*., 2013). The approach is relevant to the study because it will allow easier recognition of important themes, patterns and relationships, while collecting the data.

4.1.2 Data collection methods

Information will be gathered from practical research conducted by the researcher. Additional data sources will be in the form of primary and secondary data from internal company reports such as historical records, workshop presentations, monthly and board reports, books, academic texts and journal articles. The GIS used will be ESRI's ArcGIS. ESRI is a market leader and the world's largest GIS firm estimated to be worth over $1 billion. The Measure tool will be used measure the route distance and travel time within the parameters of the area under study. A structural database for the GIS will be created by modelling the flow of the haulage trucks. The recorded routes will be compared to those simulated in the GIS model.

4.2 Research Questions

In light of the description of the research purpose, the primary research question is as follows:

Which scientific and professional tools can be used to design and evaluate shortcut routes to streamline Timber Supply Chains in South Africa?

To further define the focus of the research study, the following secondary research questions will be addressed:

- What are the key challenges faced in timber transport vehicle routing in South Africa?
- Through critically streamlining the timber supply chain, to what extent does the implementation of Geographic Information Systems technology improve traceability and agility along the timber supply chain in South Africa, by means of a case study implementation?
- What are the results brought about by the successful implementation of innovative advancements in timber logistics, aimed at improving accessibility, while minimising total travel time and aggregate costs of the organisation?

4.3 Research Objectives

Through conducting this study, the researcher aims to achieve the following objectives:

- To provide a comprehensive literature review on challenges experienced in timber transport vehicle routing in South Africa, with particular emphasis being placed on the origins and applications of the TTVRP.
- To assimilate and streamline the timber supply chain in order to critically analyse the extent to which the implementation of Geographic Information Systems technology improves traceability and agility along the timber supply chain in South Africa, by means of a case study implementation.
- To conduct a descriptive analysis on innovative advancements being implemented in timber logistics aimed at improving accessibility, while minimising total travel time and aggregate costs of the organisation.

4.4 Limitations of the Study

The research is based on a single case study in the forestry sector, therefore the findings will need to be tailored to suite the relevant organisations and industries in South Africa.

4.5 Expected Outcomes

- To provide a sound understanding of the logistics costs and road network planning required to service small scale timber growers in the KwaZulu-Natal area (Mangusi, Ixopo and Nongoma).
- The development of a methodology which will successfully apply the project concept in other regions throughout South Africa.
- To provide a tool to evaluate timber logistics from source to mill for small scale timber growers.
- To evaluate the feasibility of using GIS technology in a rural forestry settings, with the objective of discovering the optimum route, while keeping in consideration the limitations.
- To provide a sustainable and agile timber transport vehicle routing solution which will positively contribute towards the success of Khulisa Umnotho.

4.6 Resources Required

The researcher will require the support of the following resources in order to successfully and effectively complete the research study:

4.6.1 Resources

- Research Data- in order to successfully and effectively complete the research study:
    - I. Access to GIS maps, road information and compartment (tactical plans) for the predetermined area and time horizon
    - II. Market information (location and orders)
    - III. Transport fleet information

- Computer – A computer will be used for literature research, communication, operating the GIS software, data capturing and processing.

- Bursary- Research Expenses
- Travel Resources – The researcher will need to visit the forest sites of the particular area of investigation, in order to get first-hand information on the forest networking processes, road terrains and current accessibility of the harvest areas from the existing routes.

4.6.2 Time and work schedule

The Gantt chart highlights the time periods allocated to the various stages of the research project from July 2017 to July 2019. Time periods may alter slightly depending on the outcome of each task.

A. <u>Supporting partners</u>

The project aims to gather support from Sappi, NCT, UKZN and ICFR

	2018												2019												2020					
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
List of Activities																														
Project Proposal	■	■																												
Proposal Defence at UKZN			■																											
GIS Training at UKZN			■																											
Visit Forest Location and Data Collection				■																										
Data Compilation				■	■	■	■	■	■	■	■	■																		
GIS methodology													■	■	■	■	■	■	■											
Analysis and validating results																				■	■	■	■	■	■	■				
Write Up First Draft																											■	■		
First draft submission																													■	
Corrections and Final Thesis submission																														■

Figure 4.1 Gantt chart showing the intended schedule for the study

4.7 Project Costing

DESCRIPTION	AMOUNT	TOTAL
Jan 2018 – Dec 2018		
Registration Fees	R 5 000.00	
Flights		
Harare International – Pietermaritzburg Airport	R 4 500.00	
Pietermaritzburg Airport –Kruger Mpumalanga International	R 3 500.00	
Kruger Mpumalanga International - Harare International	R 4 500.00	
Shuttle Services		
Kruger Mpumalanga International - Sabie	R 500.00	
Sabie - Kruger Mpumalanga International	R 500.00	
Accomodation		
Pietermaritzburg (550 per Night)	R 3 300.00	
Wish List		
GIS Compatabile Laptop	R 19 000.00	Specs!A1
Year 1 Total		**R 40 800.00**
Jan 2019 – Dec 2019		
Registration Fees	R 11 000.00	
Student Fees	R 27 500.00	
Flights		
Harare International – Pietermaritzburg Airport	R 4 950.00	
Pietermaritzburg Airport - Harare International	R 4 950.00	
Pietermaritzburg accomodation (550 per Night)	R 3 330.00	
Site Visit travel arrangements		To be confirmed
Year 2 Total		**R 51 730.00**
Jan 2020 - June 2020		
Registration Fees	R 12 100.00	
Student Fees	R 30 250.00	
Flights		
Harare International – Pietermaritzburg Airport	R 5 445.00	
Pietermaritzburg Airport - Harare International	R 5 445.00	
Pietermaritzburg accomodation (550 per Night)	R 3 330.00	
Site Visit travel arrangements		To be confirmed
Year 3Total		**R 56 570.00**
TOTAL		**R 149 100.00**
Predicted Inflation	10%	
Total Project Funding	R	149 100.00
Total Requested from FSA	R	
Total Co-funding Secured from UKZN Agricultural Engineering	R	50 000.00

5. REFERENCES

Aaker, D. A., Kumar, V. and Day, G. S. 2004. Essentials of marketing research. 2nd Ed. Hoboken, John Wiley and Sons INC.

Abdi, E, Majnounian, B, Darvishsefat, A, Mashayekhi, Z, Sessions, J., 2009. A GIS-MCE Based model for forest road planning. [Online]. University of Tehran, Faculty of Natural Resources, Karaj, Iran. Oregon State University, Department of Forest Engineering, Oregon, USA. Journal of Forest Science. 55(4): 171-176. Available from: http://agriculturejournals.cz/publicFiles/05121.pdf [Accessed 10 October 2016].

Aguirre, J C., 2014. The Unlikely History of the Origins of modern maps. [Online]. Smithsonian. Available from: http://www.smithsonianmag.com/history/unlikely-history-origins-modern-maps-180951617/?no-ist [Accessed 28 September 2016].

Akay, A, E, Wing, M, G, Sivrikay, F, Sakar, D. 2012. A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean region of turkey. Environ Monit Assess, 184 (3), 1391–1407.

Alzab, A, Venkatraman, S, Abawajy, J, Alzab, M., 2011. An Optimal Transportation Routing Approach using GIS-based Dynamic Traffic Flows. [Online]. Deakin University, school of Information Technology, Australia. Ballarat University, Graduate School of Information technology and Mathematical Sciences, Australia. 2011 3rd International Conference on Information and Financial Engineering, Singapore. 12. Available from: http://www.ipedr.com/vol12/31-C036.pdf. [Accessed 13 September 2016].

Anderson, A, Nelson, J. 2004. Projecting vector based road networks with shortest path algorithm. Canadian Journal of Forest Research, 34: 1444–1457.

Applegate, D, Bixby, R, E, Chvatal, V, Cook, W, J. 2007. The Travelling Salesman Problem. [Online]. Princeton University Press. Available from: http://press.princeton.edu/chapters/s8451.pdf [Accessed 14 September 2016].

Audy, J.F., D'Amours, S, and Rönnqvist, M. 2012.Planning methods and decision support systems in vehicle routing problems for timber transportation. [Online]. A review. Technical Report. Available from: https://www.cirrelt.ca/DocumentsTravail/ CIRRELT-2012-38.pdf. [Accessed 14 September 2016].

Baldacci, R, Battarra, M, Vigo, D. 2007. Routing a Heterogeneous Fleet of Vehicles. [Online]. University of Bologna, Cesena, Italy. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.4120&rep=rep1&type=pdf [Accessed 11 October 2016].

Ballindalloch, A&Y, The Scottish Government. 2010. Innovation in Scottish Timber Haulage. [Online]. Freight Best Practice Scotland. Available from: http://www.transport.gov.scot/system/files/uploaded_content/documents/tsc_basic_pages/Road/Innovation_in_Scottish_timber_haulage.pdf [Accessed 20 September 2016].

Baral, H. 2004, August. Application of GIS in community-based forest management in Australia (and Nepal). [Online]. University of Melbourne, School of Forest and ecosystem Science, Institute of Land and Food Resources, Australia. Master of Forest Science. Available from: http://www.iapad.org/wp-content/uploads/2015/07/gis_applications_in_cbfm.pdf [Accessed 11 October 2016].

Berbeglia, G, Cordeau, J.-F, Gribkovskaia, I, Laporte, G. 2007.Static pickup and delivery Problems: a classification scheme and survey. *TOP*, 15(1):1–31, 2007.

Brito, LAT. 2011, March. Design Methods for low volume roads. [Online]. University of Nottingham. Dr of Philosophy. Available from: https://core.ac.uk/download/pdf/387172.pdf?repositoryId=81 [Accessed 12 October 2016].

Burt, D.N., Dobler, D.W. & Starling, S.L. 2003. World Class Supply Management. 7th edition. New York: McGraw-Hill.

Carlsson, M.K. 2008. Stratified, Destratified, and Hybrid GIS: Organising a Cross-

Disciplinary Territory for Design. [Online]. Massachusetts Institute of Technology, Department of Architecture, Master of Science in Architecture studies. Available from: https://dspace.**mit**.edu/handle/1721.1/81657 [Accessed 11 October 2016].

Chakroborty, P. 2016. Optimal Routing and Scheduling in Transportation: Using Genetic Algorithm to Solve Difficult Optimization Problems. [Online]. Available from: http://docplayer.net/9916186-Optimal-routing-and-scheduling-in-transportation-using-genetic-algorithm-to-solve-difficult-optimization-problems.html [Accessed 2 October 2016].

Cordeau, J, Laporte, G, Savelsbergh, M, WP, Vigo, D. 2007. Vehicle routing. [Online]. Canada Research Chair in Logistics and Transportation, Montréal, Canada. Georgia Institute of Technology, School of Industrial and Systems Engineering, Atlanta, USA. University of Bologna, Dipartimento di Elettronica, Informatica e Sistemistica, Italy. Available from: http://dis.unal.edu.co/~gjhernandezp/TOS/ROUTING/VRP1.pdf [Accessed 10 October, 2016].

Crafford, J. 2010. The Strategic sourcing value proposition: A Sasol case study. [Online].Stellenbosch University Library, South Africa, Master of Business Administration. Available from: https://scholar.sun.ac.za/handle/10019.1/8257 [Accessed: 3 September 2016].

Dahal, P, Mehmood, S. 2012. A GIS approach to determining efficient timber transportation routes. [Online]. University of Arkansas at Monticello, Monticello,School of Forest Resources. Available from: http://sofew.cfr.msstate.edu/papers/0604dahal.pdf. [Accessed 15 September 2016].

Danesh, Z, A. 2006. Modelos y metodos de la distribucion de mercancias. [Online]. Universidad de Sevilla. Available from: http://bibing.us.es/proyectos/abreproy/70067/fichero/Thesis+del+master-Zoha+Danesh.pdf [Accessed 12 October, 2016].

Delgado, J, D, Arevalo, J, R, Fernandez-Palacios, J, M. 2007. Road edge effect on the abundance of the lizard Gallotiagalloti (Sauria: Lacertidae) in two Canary islands forests. Biodivers Conserv, 16, 2949–2963.

Dempsey, C. 2012. History of GIS. [Online] GIS Lounge. Available from: https://www.gislounge.com/history-of-gis/ [Accessed 12 September 2016].

Department of Agriculture Forestry and Fisheries (DAFF). 2014. Agriculture. [Online]. South Africa Yearbook 2013/14. Available from: http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/yearbook/2013-4Agriculture.pdf [Accessed 21 September 2016].

Derigs, U, Pullmann, M, Vogel, U, Oberscheider, M, Gronalt, M, Hirsch, P. 2012. Multilevel neighbourhood search for solving full truckload routing problems arising in timber transportation. [Online]. University of Cologne, Department of Information Systems and Operations research, Cologne, Germany. University of Natural Resources and Life Sciences, Institute of Production and Logistics, Vienna, Austria. Available from: http://www.sciencedirect.com/science/article/pii/S1571065312000388 [Accessed 28 September 2016].

Erkert, T, W, 1989. Computer simulation of offtracking of truck and trailer combinations using forest roads. Master of Science, Oregon State University Department of Civil Engineering, Corvallis, Oregon 97331. 89 pp.

Ghoseiri, K and Ghannadpour, S, F, (2009) Hybrid Genetic Algorithm for Vehicle Routing and Scheduling Problem. [Online]. Journal of Applied Sciences 9 (1): 79-87. Available from: http://scialert.net/qredirect.php?doi=jas.2009.79.87&linkid=pdf [Accessed 2 November 2016].

Golden, B., Assad, A., Levy, L., and Gheysens, F. The fleet size and mix vehicle routing problem. *Computers & Operations Research*, 11(1):49–66, 1984. doi:10.1016/0305-0548(84)90007-8.

Grabara, J, Kolcun, M, Kot, S. 2014. The role of Information Systems in Transport Logistics. [Online].Faculty of Management, Czestochowa, University of Technology, Poland. Faculty of Electrical Engineering and Informatics, Technical University of Kosice. Available from: http://www.ijern.com/journal/February-2014/25.pdf [Accessed 10 June 2017}.

Gregory, J, R. 2014. Transportation optimisation in tactical and operational wood Procurement planning. [Online]. Doctor of Philosophy, Ecole Polytechnique de Montreal, Department de mathematiques et de genie industrial. Available from: https://publications.polymtl.ca/1622/1/2014_JamesGregoryRix.pdf [Accessed 28 September, 2016].

Harris, A, J, Bezuidenhout, C, H, Lagrange, L, F, Lyne, P, W, L. 2008. Development of a sugarcane transport route planning model in a geographical information system. [Online]. University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology. South African Sugarcane Research Institute. Available from: http://www.sasta.co.za/wp-content/uploads/Proceedings/2000s/2008_%20Harris_development%20of%20a%20sugarcane.pdf [Accessed 29 September, 2016].

Heizer, J, and Render, B. 2011. Principles of Operations Management. 8th Ed. London: Pearson.

Ismail, M, H, Jusoff, H, K. 2009. Planning of Access Road using Satellite Technology and Nest Path Modelling. [Online]. University Putra Malaysia, Faculty of Forestry, Selangor, Malaysia. Yale University, Yale's Centre for Earth Observation-Environment Science Centre, New Haven, USA. Modern Applied Science.3. Available from: file:///C:/Users/Kundi/Downloads/390-1123-1-PB.pdf [Accessed 10 October 2016].

Industrial Development Corporation (IDC). 2016. Key Trends in the South African Economy. [Online]. Available from: http://www.idc.co.za/images/download-files/economic-overviews/RI-publication-Keytrends-in-SA-economy_March2016.pdf [Accessed 21 September 2016].

Kainz, W. 2004. Geographic Information Science. [Online]. University of Vienna, Department of Geography and Regional Research, Cartography and Geoformation, Vienna. Available from: http://www.geografie.webzdarma.cz/GIS-skriptum.pdf [Accessed 25 October 2016].

Laporte, G, Toth, P, Vigo, D. 2013. Vehicle routing: historical perpective and recent contributions. [Online]. The Association of European Operational Research Societies 2013. Available from: http://link.springer.com/article/10.1007/s13676-013-0020-6 [Accessed 16 September 2016].

Luke, S., 2015. Essentials of Metaherristics. [Online]. George Mason University, Department of Computer Science George Mason. Available from: https://cs.gmu.edu/~sean/book/metaheuristics/Essentials.pdf [Accessed 11 October 2016].

Mackenzie, C. 2007. Developments in Timber Transport. [Online]. FEG Symposium. Available from: http://www.iagre.org/sites/iagre.org/files/feg/past_symposia/2007/05%20COLIN%20MACENZIE%20Developments%20in%20Timber%20Transport%20Script.pdf [Accessed: 15 September 2016].

Matai, R, Prakash, S, Mittal, M, L. 2010. Travelling Salesman Problem: An overview of Applications, Formulations and Solution Approaches. [Online]. Management Group, BITS-Pilani, Indian Institute of Technology, Delhi, India. Malviya National Institute of Technology, Jaipur, India. Available from: http://cdn.intechopen.com/pdfs/12736/intechtraveling_salesman_problem_an_overview_of_applications_formulations_and_solution_approaches.pdf [Accessed 14 September 2016].

Mayhew, S. 2005. Geographic Information Systems/ Science: A Research Guide: Spatial Analysis & Modelling. [Online]. Dartmouth College Library Guides. Available from: http://researchguides.dartmouth.edu/gis/spatialanalysis [Accessed 28 September 2016].

Mendell B.C, Haber J, Sydor T. 2006. Evaluating the potential for shared log truck resources in middle Georgia. Southern Journal of Applied Forestry, 30: 86–91.

Morkel R. 1994. The management of South African forest roads in perspective. Unpublished Honours paper. Department of Forest Engineering, Stellenbosch University.

Mladenovic, M, Mladenovic- Ranisavljevic, P, Ranisavljevic, I. 2014. Information Systems in Business Logistics. [Online]. Inpharm Co d.o.o Zemun, Serbia. High Business School of Leskovac, Serbia. Faculty of Technology, Leskovac, University of Nis, Serbia. Available from: http://emit.kcbor.net/Emit%20clanci%20za%20sajt/EMIT%20Vol2%20No4/Information%20systems%20in%20business%20logistics.pdf [Accessed 11 June 2017].

Nicholls, S, J, Ackerman, P, A, Pulkki, R, E. 2004. Provincial road condition and round wood timber transport in South Africa. [Online]. The Southern African Forestry Journal. 207 -1. Available from: http://www.tandfonline.com/doi/abs/10.2989/10295920609505253 [Accessed 29 September 2016].

Nordengen, P, A, Naidoo, O, J. 2014. Evaluation of the Road Transport Management System, a self-regulation initiative in heavy vehicle transport in South Africa. [Online]. Transport Research Arena. Available from: http://repository.up.ac.za/bitstream/handle/2263/6003/081.pdf;jsessionid=D8801D4738E822965BA9636A83F5EA57?sequence=1 [Accessed 10 October, 2016].

Oberholzer, S, F. 2007. Timber Transportation Optimization and Vehicle Routing: A GIS application in South Africa. [Online]. Oregon State University, Department of Forestry. Available from: https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/11474/Oberholzer,%20S.%20Francois%20MF.pdf?sequence=1 [Accessed 29 September, 2016].

Olafsson, S. 2006. Metaheuristics. [Online]. Iowa State University, Department of Industrial and Manufacturing Systems Engineering. Handbook on Simulation, Handbooks in Operations Research and Management Science VII, Elsevier, 633-654. Available from: http://www.public.iastate.edu/~olafsson/metaheuristics.pdf [Accessed 12 September 2016].

Pa, K, Prem, H, Lyne, PWL. 2008. Performance- Based standards (PBS) vehicles for transport in the Agricultural Sector. [Online]. CSIR Built Environment, Mechanical System Dynamics, South African Sugarcane Research Institute. South Africa. Available from: http://www.sasta.co.za/wpcontent/uploads/Proceedings/2000s/2008_Nordengen_performance-based%20standards.pdf [Accessed 11 October 2016].

Parsakhoo, A, Mostafa, M. 2015. Road network analysis for timber transportation from a harvesting site to mills (Case study: Gorgan county – Iran). [Online]. Gorgan University of Agricultural Sciences and Natural Resources Journal of Forest Science. Available from: https://www.researchgate.net/profile/Aidin_Parsakhoo. [Accessed 15 September 2016].

Pichpibul, T, Kawtummachai, R. 2012, June, 20. An improved Clarke and Write savings algorithm for the capacitated vehicle routing problem. [Online]. Thammasat University, Sirindhorn International Institute of Technology, school of Manufacturing Systems and Mechanical Engineering, Thailand. Panyapiwat Institute of Management, Faculty of Business administration, Thailand. Science Asia. 38: 307-318. Available at: http://www.scienceasia.org/2012.38.n3/scias38_307.pdf [Accessed 11 October 2016].

Pletts, T. 2006. A Literature Overview of Central Tyre Inflation Systems. [Online]. MSc Engineering, University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg, South Africa. UKZN Libraries. Available from: http://efwe.ukzn.ac.za/libraries/researchseminars/pletts_t.sflb.ashx [Accessed 20 September 2016].

Prates, A, A, Pimentel, R, C, Patino, M, T, O, Maresea, D, C, C. 2013. Information and Competitiveness: Case of a Logistic Information System. [Online]. University of Ribeirao Preto, Sao Paulo, Brazil. Available from: https://www.pomsmeetings.org/ConfProceedings/001/Papers/GOP-02.2.pdf [Accessed 10 June 2017].

Rajasekar, S, Philominathan, P, Chinnathambi, V. 2013. Research Methodology. [Online]. Bharathidasan University, School of Physics, Tamilnadu, India. Pushpam College, Department of Physics, Tamilandu, India. AKGS Arts College, Tamilnadu, India. Available from: http://arxiv.org/pdf/physics/0601009.pdf [Accessed 4 September 2016].

Ramsey, D, Williams, M. 2009. Historical Map in GIS. [Online]. Available from: http://www.davidrumsey.com/gis/ch01.pdf [Accessed 30 September 2016].

Resnik, D, B. 2011. What is Ethics in Research? [Online]. National Institute of Environmental Health Sciences. Available from: http://www.niehs.nih.gov/research/resources/bioethics/whatis/ [Accessed 3 September 2016].

Rogers, D, J. 2015. Brief history of Geographic Information Systems. [Online]. Missouri University of Science and Technology. Available from: http://web.mst.edu/~rogersda/gis/History%20of%20GIS.pdf [Accessed 28 September 2016].

Rogers, L, Schiess. 2001. Pegger and Roadview- A new GIS tool to assist Engineers in operations planning. [Online]. University of Washington, College of Forest Resources, Seattle, WA. Available from: http://depts.washington.edu/sky2001/proceedings/papers/Rogers.pdf [Accessed 10 October 2016].

Sappi Southern Africa. 2017. Sustainability FAQS. [Online]. Khulisa Umnotho. Available from: https://cdn-s3.sappi.com/s3fs-public/Sappi-FAQs-Khulisa-Umnotho.pdf [Accessed 7 February 2018].

Schrijver, R. 2009. Green Public Procurement; developing a strategy for green procurement in the Civil Engineering Construction Industry. [Online] Delft University of Technology, Faculty of Civil Engineering and Geosciences, Netherlands. Available from: http://www.citg.tudelft.nl/fileadmin/Faculteit/CiTG/Over_de_faculteit/Afdelingen/Afdeling_Bouw/-_Secties/Sectie_Bouwprocessen/-_Onderwijs/-_MSc_Afstudeerprojecten/doc/2009_de_Schrijver.pdf [Accessed 4 September 2016].

Sonti, SH. 2015. Application of Geographic Information System (GIS) in forest management. [Online]. Department of Environmental and Occupational Studies, South Industrial, Cape Town, South Africa, Geography and Natural Disasters. Available from: http://www.omicsgroup.org/journals/application-of-geographic-information-system-gis-in-forest-management-2167-0587-1000145.pdf [Accessed 3 October 2016].

Sosa, A, Klvac, R, Coates, E, Kent, T, Devlin, G. 2015, March, 2. Improving Log Loading Efficiency for Improved Sustainable Transport within the Irish Forest and Biomass Sectors. [Online]. University College Dublin, School of Biosystems Engineering, Dublin, Ireland. Mendel University, Faculty of Forestry and Wood Technology, Zemědělská. Waterford Institute of Technology, Department of Chemical and Life Sciences, Waterford, Ireland. Available from: www.mdpi.com/2071-1050/7/3/3017/pdf [Accessed 28 September, 2016].

Syahruddin, N, Kalchschmidt,M. 2010. Towards Sustainable Supply Chain Management in Agricultural Sector. [Online]. Doctor of Philosophy, Universitia degli Studi di Bergamo, Italy. Available from: http://www.pomlearning.org/reno/fullpapers/020-0072%20Towards%20Sustainable%20Supply%20Chain%20Management.pdf. [Accessed 4 September 2016].

Takes, F, W, Kosters, W, A. 2010 Applying Monte Carlo Techniques to the Capacitated Vehicle Routing Problem. [Online]. Msc Computer Science, Leiden University, Leiden Institute of Advanced Computer Science, the Netherlands. Available from: http://liacs.leidenuniv.nl/assets/Masterscripties/2010-01FrankTakes.pdf. [Accessed 5 September 2016].

Tampekis, S, Sakellariou, S, Samara, F, Sfougaris, A, Jaeger, D, Christopoulou, O. 2015, March, 25. Mapping the optimal forest road network based on the multicriteria evaluation technique: the case study of Mediterranean Island of Thassos in Greece. [Online]. Environmental Monitoring and Assessment. Available from: http://link.springer.com/article/10.1007%2Fs10661-015-4876-9 [Accessed 29 September 2016].

Wang, J. 2013. Management Innovations for Intelligent Supply Chains. 1st ed. Montclair State University, USA: Business Science Reference (an imprint of IGI Global).

Wassan, N, A, Nagy, G. 2014. Vehicle Routing Problem with Deliveries and Pickups: Modelling in Issues and Meta-Heuristics Solution Approaches. [Online]. University of Kent, Canterbury, UK. Kent Business School, Centre for Logistics & Heuristic Optimisation (CHLO), International Journal of Transportation. Available from: http://www.sersc.org/journals/IJT/vol2_no1/6.pdf [Accessed 11 October 2016].