The use of Time Study, Method Study and GPS Tracking in improving Operational Harvest Planning in Terms of System Productivity and Costs

by

Benedict O. Odhiambo

Thesis presented in partial fulfilment of the requirements for the degree of

Master of Science in Forestry

at the

University of Stellenbosch

Supervisor: Mr Pierre A. Ackerman

Co-supervisor: Prof RE Pulkki

December 2010

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: 16 November 2010

Signature:

Abstract

This study aims to quantify the benefits of implementing an operational harvesting plan in forest harvesting operations. This is to be achieved by comparing productivity and costs from unplanned and planned harvesting operations. The study was conducted on a *Pinus radiata* plantation owned by Mountain to Ocean Forestry Company (Pty) Ltd (MTO) located near the town of Grabouw in the Western Cape Province of South Africa.

MTO conducts harvesting operations using semi-mechanised tree-length harvesting systems. A wheeled H67 Clark Ranger cable skidder is used to extract tree-lengths from infield to the landing. Data was obtained both manually (work study) and from GPS tracking. Choking and dechoking data was obtained through time and method studies. GPS tracking was used to measure travel loaded and travel empty times, as well as travel distances and travel speeds. The aim of using both manual techniques and GPS tracking was to obtain detailed and spatially accurate information about the operation. The operating costs were estimated using South African Harvesting and Transport Costing Model.

Productivity of the newly introduced tagline system (45.97 m^3/pmh) exceeded that of mainline system (37.85 m^3/pmhh) by 26%. The unit production cost of using tagline system (R20.21/m^3) was 10% lower than the unit production cost of using mainline system (R22.54/m^3). There were no benefits to be gained from improving the level of skid trail construction by removal of logging residue or cutting down stumps to as near the ground level as possible. A combination of manual (time and method studies) data collection and GPS tracking provided more detailed and accurate information on the semi-mechanised harvesting system.

Key words: Operational harvesting planning, time study, method study, GPS tracking, tagline system, directional felling, designated skid trails.

Uittreksel

Hierdie studie beoog om die voordele van die uitvoering van ŉ operasionele inoestingsplan te kwantifiseer. Dit word bereik deur produktiwiteit en kostes van beplande en onbeplande inoestingswerksaamhede te vergelyk. Die studie is gedoen in *Pinus radiata* opstande van Mountain to Ocean Forestry Company (Pty) Ltd (MTO) naby Grabouw in die Wes-Kaap provinsie van Suid Afrika.

MTO gebruik semi-gemeganiseerde boomlengte inoestingstelsels in hul inoestingswerksaamhede. ŉ H67 Clark Ranger wielsleeptrekker met kabel en wenas is gebruik om boomlengtes van die veld na die pad te sleep. Data is versamel deur van beide hand (werkstudie) en GPS-opsporing gebruik te maak. Afhaak en aanhaak data is verkry deur van tyd- en metodestudies gebruik te maak. Gelaaide en ongelaaide tyd, spoed en afstande is met behulp van die GPS gemeet. Deur van beide hand en GPS versamelingsmetodes gebruik te maak, kon omvattende sowel as ruimtelik akkurate inligting oor die werksaamhede verkry word. Die bedryfskostes is verkry van die South African Harvesting and Transport Costing Model.

Produktiwiteit van die nuut ingestelde verbindingslynstelsel (45.97 m^3/pmh) het die hooflynstelsel (37.85 m^3/pmh) met 26% oorskry. Die eenheidsproduksiekoste van die verbindingslynstelsel (R20.21/m^3) was 10% laer as die eenheidsproduksiekoste van die hooflynstelsel (R22.54/m^3). Daar was geen voordeel in die verbetering van die sleeppad konstruksie deur afval te verwyder of stompe nader aan die grondvlak af te sny nie. ŉ Kombinasie van hand (tyd- en metodestudies) dataversameling en GPS-opsporing het meer akkurate en omvattende inligting oor die semi-gemeganiseerde inoestingstelsel verskaf.

Sleutelwoorde: operasionele inoestingsbeplanning, tydstudie, metodestudie, GPS-opsporing, verbindingslynstelsel, hooflynstelsel, rigtingvel, voorgeskrewe sleeproetes.

Dedication

Is to Sylvia Jerusa Achieng Mulure. Mama. In me her spirit lives on.

Acknowledgement

I would like to acknowledge my Supervisor, Mr. Pierre Ackerman for all his support both academically and financially throughout my studies and for his professional guidance as I went through my final project and eventual thesis writing. I also wish to thank him for providing the funds that enabled me carry out the project. Additionally, I wish to thank Dr. Dirk Längin for helping in designing my project and Professor Dr. Reino Pulkki for supervising and providing insight and comments during the writing of the document. I wish to thank MTO (Pty) Ltd for allocating me the study area and allowing me to conduct my project on their harvesting operations. I specifically, want to thank Mr. Jos Badenhorst for his guidance throughout the study period.

Special thanks go to Professor D.G. Nel and Gail Jordan for helping with data analysis and giving statistical advice.

To all the teaching staff, fellow students and technical staff at the Department of Forest and Wood Science, Stellenbosch University who helped in one way or the other, my sincere gratitude. Special thanks to Anton Kunneke for helping with the GPS work.

The support of my Uncle Dr. Paschal Wambiya and my Dad Lucas Odhiambo Wambiya is greatly appreciated. My immediate family, especially my brother Japheth and mom Ann, and to my uncle Ambrose and other members of the extended family I say thank you for the patience, encouragement and support throughout my studies.

Table of Contents

Page

List of Figures

Figure Page

List of Tables

1 Introduction

The study investigated the level of operational efficiency of a typical semi-mechanised tree-length harvesting system used in South Africa. The aim was to improve the level of operational efficiency through selection and implementation of better work methods in an improved plan of operations. Efficiency was measured in terms of productivity using cubic metre (m^3) per unit of resource input and costs per m^3.

Time study, method study and GPS tracking were used to obtain information from the system in order understand the operational work plan and methods in use. Time study provided information on the amount of time consumed by travel, choker-setting and dechoking. Method study techniques were used to critically examine the methods applied in executing the various tasks thus providing information on the specific areas of the operation requiring improvement. GPS tracking was used to compliment time studies and provided spatial detail of machine travel including distances, speeds and travel times. Choking time, dechoking time, travel loaded and travel empty data were combined into a work cycle and used in calculating productivity per unit time.

Information from the system revealed that the operations were being carried out with *ad hoc* plan of activities. In general trees were felled in no specific direction, a system of designated skid trails were not being applied, routes travelled by the skidder were characterised by obstacles in form of rocks, boulders, stumps and tree stems, and the use of a main line and a single set of choker chains. The result of these work methods was prolonged choking and dechoking times, extended travel distances and times at reduced travel speeds, all of which potentially result in reduced productivity and increased cost of operation.

New methods were investigated aimed at improving the operations. These included directional felling, implementation of taglines and mainline systems with a double set of choker chains, and use of designated skid trails.

The new methods were incorporated into a well drawn plan of operation for implementation. Usually planning of forest harvesting operations is a time consuming and expensive process involving collection of the relevant information, preparation of the plans and their implementation in the field (Bengt *et al.*, 1984; Skogsarbeten, 1984). There are also additional costs that come with the plan if it involves acquisition of more equipment or additional preparatory activities not previously carried out: e.g., skid trail and landing construction. The expenses associated with planning is assumed to be the reason why operators do not or are reluctant, as observed in the area of this study, to fully implement a complete plan of operations. In such circumstances it is assumed that the operators are not aware of the full value of planning their operations. It is this belief that prompted an investigation into the real value of operational planning in an attempt to quantify the benefits associated with the plan of activities in terms of productivity improvement (m^3/pmh) and cost savings (R/m^3).

Increased efficiency is an important prerequisite for successful development of forestry business. Better methods can extract ever greater efficiency from existing resources such as people, machines and raw materials. Greater efficiency also helps keep the operational costs at acceptable levels and is important for the continuity of the forest company. With low operational costs, companies are able to deal with eventualities such as increases in fuel prices, high exchange rates, high cost of machinery and technology, and global fluctuations in prices of wood and wood products (Richard, 1984).

1.1 Objectives

1. To quantify the productivity gains (m^3/pmh) and/or cost savings (R/m^3) associated with implementation of an operational harvesting plan.

2. To determine the level of activity planning for highest operational efficiency by:

- Determining the most efficient system of choking between mainline and taglines in terms of cost/m^3 and m^3/pmh.
- Determining a level of skid trial preparation in terms of cost/m^3 and m^3/pmh.
- To evaluate the effectiveness of complementing time study data with GPS derived data in gathering operational forest harvesting data.

1.2 Limitations of the study

1. The efficiency of felling, merchandising and storage at the landing, and secondary transportation did not form part of the study.
2. Delays and scheduled breaks were not considered in the analysis of the results.

2 Literature review

2.1 Operational harvest planning

Forest harvesting operations should always be preceded by a plan of activities clearly described in an operational harvesting plan (Frank, 1985; Stenzel, *et al*., 1985). An operational forest harvesting plan is a short term plan (Brink & Kellogg, 2000), which provides detailed guidelines on how to go about the entire harvesting process successfully (Stenzel *et al.,* 1985). The plans are developed on maps of each individual harvest area, based on the site characteristics and comprise of a choice of the most suitable harvesting system that will optimize the use of both labour, resources and equipment.

Operational harvesting plans are aimed at fulfilling the objective of realization of suitable monetary return, wood volume maximization, profit maximization, cost and risk minimization (Spiers, 1986), or a combination of these (Brink *et al*., 1995; FAO 1998a; Pulkki, 2003).

Operational plans contain details of all activities to be undertaken and careful consideration is given to the location of proposed and existing roads and their standards, details of road spacing, proposed landing locations, recommended skid trail patterns, location of boundaries, bridges, culverts and sensitive zones, timber grades and where possible, cost estimates (Frank, 1985; Stenzel *et al*., 1985; Spiers, 1986; APA, 1988). Operational plans also contain a complete schedule of all phases of operations that ensure completion of the job with maximum efficiency and safety, with minimal damage to the environment, and with consideration to aesthetics and scenic values. The plan also takes into consideration subsequent silvicultural operations (Skogsarbeten, 1984; Staaf & Wiksten, 1984; Spiers, 1986).

2.2 Importance of operational harvest planning in semi-mechanised harvesting operations

A semi-mechanised tree-length system is a common harvesting system in South Africa (Chapman, 2008; Dobson, 2008). The system is made up of motor-manual felling, debranching and topping of the trees using chainsaw. The tree-lengths are then extracted by means of skidders or agricultural tractors to landings where they are merchandised by manual log scaling and crosscut by chainsaws as described by MacDonald (1999). Stacking is usually done using a dedicated loader or similar equipment matching the size of timber handled. In South Africa a three-wheeler loader with telescopic boom is normally used.

The operations comprising semi-mechanised harvesting form an important cost component within the wood product value chain. Correct planning and implementation of these operations offer an opportunity for lowering the costs within the value chain (Frank, 1985; Stenzel *et al*., 1985). A closer look at the operations can help highlight the significance of operational planning.

2.2.1 Felling

It is important to plan for the direction of fall before trees are felled. Usually the orientations of the felled trees need to be kept in line with the proposed skidding direction to facilitate extraction (Bromley, 1969; Spiers, 1986). Disregarding the falling direction leads to significant increases in extraction costs (Conway, 1979; MacDonald, 1999), creates difficulties in removal of wood and also makes debraching, cross cutting and topping more costly and difficult, and leads to increased losses due to breakages (Andersson & Young, 1998).

Plamondon (1998) emphasized the significance of directional felling in his study of a tree-length harvesting operation using a cable skidder. He observed an increase in cycle times of 82% when the trees were not felled with regard to the skidding direction, compared to when the trees were felled in cognisance of the skidding directions. The determination of felling direction is consequently the first step towards ensuring efficiency and effectiveness of logging operations.

2.2.2 Primary transport

Primary transport is defined as the transport of tree or tree sections from infield to roadside. Primary transport, also known as terrain transport, is a specialised field of transport because of the difficult conditions normally encountered on the forest floor (e.g., slopes, soft boggy conditions, boulders and rocky outcrops, stumps and felling debris) which do not normally allow the physical travel of secondary transport trucks to the stump site (Kluender *et al*., 1997). The most common method of primary transportation, as with semi-mechanised forest harvesting operation in South Africa, is skidding. The most commonly used articulated skidders are cable, grapple and clumbunk skidders. The most common skidder in South Africa is the articulated cable skidder fitted with a winch, and agricultural tractors fitted with a winch or draw bar. A plan of operation ensures efficient utilization of these machines by adhering to the site limitations.

Skidders, as with other ground-based equipment, require forest floor conditions that are relatively uniform and free of large, impassable obstacles. Obstacle such as large boulders, stones, rocks, gullies or high stumps may hamper the machine's mobility, and reduce travel speeds and/or load size, thus reducing productivity and increasing skidding costs. They can also become hazards causing the potential roll over of machines (Kluender *et al*., 1997; MacDonald, 1999). Extraction routes should be cleared of obstacles before the timber extraction operation begins. Stumps interfering with the work of the skidder and large vegetation must be cut down and possibly removed. All merchantable wood as well as large tops should be removed from the skid trail, if possible or cut smaller. Slash, however, should not be removed since it does not hamper the skidder but rather may often improve the bearing capacity of the ground (Skogsarbeten, 1967). Skid trails need to be made straight for the longest distance possible and those built on more than 20% slope need to be excavated in order to clear them of all or most forms of obstacles (Dennis, 2005).

Skidding through mud, wet patches, and operating on soils with low load-bearing capacity potentially lowers productivity of the machine (Olsen & Gibbons, 1983). Wet conditions reduce the skidder's travel speed and/or its payload, its cycle times increase and the machine can get stuck in the mud prompting delays (Sever, 1990). Maintenance costs can also be increased because of increased wear and tear on the machine (Skogsarbeten, 1967; George, 1992; MacDonald, 1999). Wet conditions should therefore be avoided as much as possible during the planning process.

Terrain slope must be within the safe operating range for wheeled skidders. The typical maximum adverse and favourable slope limits for a cable skidder are 20 and 35%, respectively (FESA, 1999). Above 35%, machine stability decreases especially if infield turning is required, traction becomes a limiting factor, and cycle times and costs increase. Small obstacles such as windfalls and stumps that can be negotiated safely on lesser slopes may cause the machine to overturn on steep slopes (MacDonald, 1999). Suitable operating conditions for cable skidders according to FESA (1999) are shown in Table 1. The definitions given to the specific index values within the table are given in Appendix B as defined by Erasmus (1994).

Table 1: Work specification requirements for a wheeled cable skidder (FESA, 1999).

Criteria	**Wheeled cable skidder specifications**
Slope (%): up Down	0 -10 0 -35
Ground roughness	1 - 3
Ground strength	1 - 3
Extraction distance (m)	50 - 500

Skidding downhill with cable skidders is more efficient than uphill; skidding on adverse slope reduces travel speed and load size, and thus also decreases productivity. Truck roads should be located at the lower elevations of the felling block whenever possible in order to take advantage of the force of gravity in downhill extraction. In spite of preference to downhill skidding, care should be taken to avoid steep slopes as logs may run ahead into the machine, thus presenting a safety hazard (Stenzel *et al.,* 1985; MacDonald, 1999).

It is rare to find forest conditions that perfectly suit the working conditions of skidders as those mentioned above due to the rough and rugged nature of forest floor conditions. Favourable conditions for machine operation can be created through constructing skid trails and restricting the skidder travel to these trails. This also helps prevent unnecessary travel by the skidder. This is vital for higher productivity and reduced harvesting costs both of which are very sensitive to extraction distances (Andersson, 1994; Gingras, 1994; Egan, 1999; Wagner *et al*., 2000; LeDoux & Huyler, 2001; Kellogg & Spong, 2004; Yaoxiang et al., 2006).

The use of designated skid trails is also viewed as the cornerstone of meeting the objectives of Reduced Impact Logging (RIL) that ensure sustainability of forestry business (FAO, 1999). RIL has been defined as intensively planned and carefully controlled implementation of harvesting operations to minimize the impact on forest stands and soils (Reid & Rice, 1997; Webb, 1997; Sist *et al*., 1998; Ruslim *et al.,* 1999; Van der Hout, 1999; VDF, 1999; Armstrong & Inglis, 2000; Sist, 2000). Most erosion and soil compaction problems in timber harvesting occur on roads, skid trails and landings. The skid trails including the landings should be confined to less than 15% of the area (Dennis, 2005). Studies have demonstrated conclusively that properly planned and supervised harvesting operations not only meet conditions for sustainability but also reduce harvesting costs and increase efficiency of operations as compared to unplanned logging (Marn & Jonkers, 1982; Hendrison, 1989; Holmes *et al*., 2000).

Various studies have investigated the importance of restricting machine movement to defined trails. Blundell (1987) tested two systems: 1) the tract was clearfelled with no pre-planned extraction tracks and the machine was permitted to travel anywhere within the compartment; and 2) extraction tracks were marked and the machine was not permitted to travel off these marked tracks. Blundell (1987) observed that there was a 7% shorter cycle time when the machine used the defined tracks. Surprisingly the cost for extraction in the pre-planned compartment was higher at US$ 9.71/m^3 (R72.85/m^3) using a currency conversion factor of 1$ = R7.51) compared to US$ 9.41/m^3 (R70.61/m3) in the unplanned or random travel compartment. These costs also did not include costs due to planning and preparations that may be incurred with a planned system of tracks. The study was done using a tracked skidder and Blundell (1987) concluded that the skidder was not suited for a strict pre-planned system because the skidder was made to get right to the logs with its track and arch design. He felt that rubber tired skidders would be preferable on planned tracks.

Another study (OSU, 1983) found a 29% increase in harvesting costs associated with planned tracks, while several others (OSU, 1983) found differences of plus/minus 2% in harvesting costs. These findings call for further research to be done that can uncover the real value of the importance of using designated skid trails.

The typical maximum skidding distance for wheeled skidders is approximately 200 - 300 m. The average allowable distance under specific conditions is, however, determined by economics as modelled in Figure 1 and not by physical limitations of the machines. The most economical skidding distance should be determined by comparing the cost of skidding to the cost of moving the landing area and constructing the logging trails. Generally the skidding distances should be kept as short as the terrain and timber stand conditions permit. Longer skidding distances increase the cycle times and skidding costs, while shorter skidding distances increase the road density and road construction costs (Plamondon & Favreau, 1994;

McDonald, 1999). The road cost per unit volume thus becomes less as the spacing of roads increases (Pulkki, 2003).

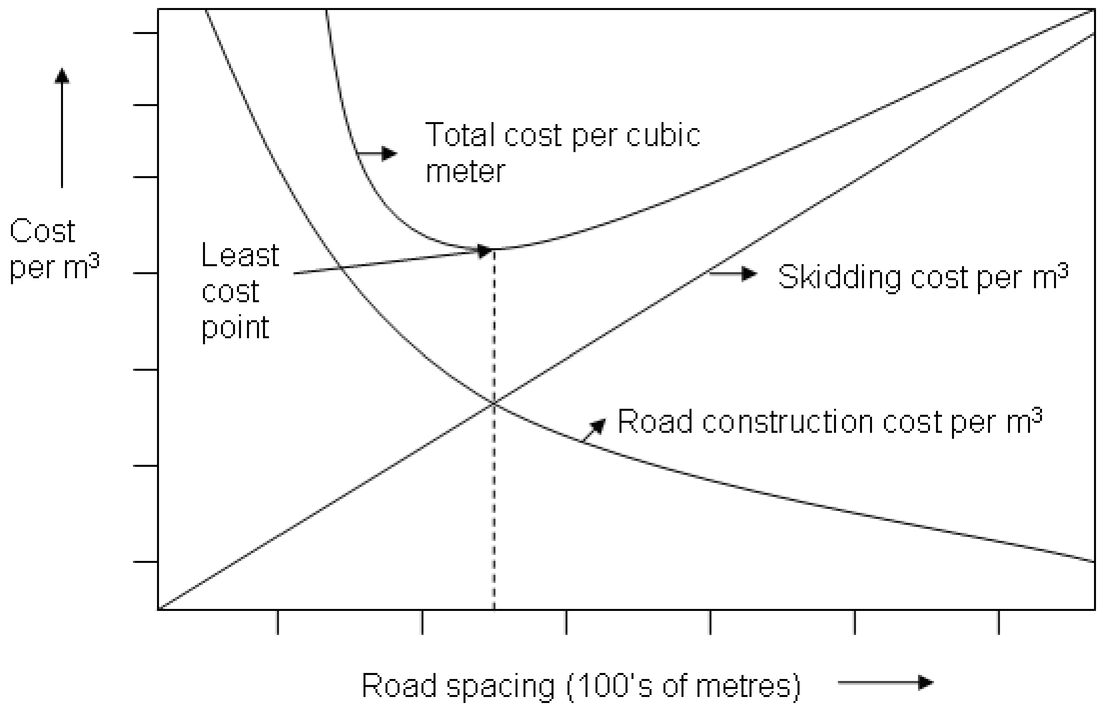


Figure 1: Cost/m^3 of skidding and road construction relative to road spacing (Plamondon & Favreau, 1994).

A sensitivity analysis by Favreau and Gingras (1998) has shown that for extraction machines, a 50 m increase in the extraction distance from 100 m to 150 m would lead to an increase of about 2% in total cost and an increase in skidder driving speed or in payload of 50% would be needed to compensate for this increased distance. This fact has been supported by the findings of another study (Table 2) conducted by Favreau and Lagere (1999) in which the distances varied with the longest extraction distance doubling the shortest extraction distance.

Table 2: Analysis of harvesting costs in a full-tree clear cutting operation of mixed forest (Favreau & Lagere, 1999).

Unit	Method	Average piece size (m^3)	m^3/cycle	Maximum Extraction distance (m)	Productivity (m^3/PMH)
Cable skidder	Full-tree	0.21	3.0	370	9.4
				150	11.6

A study employing a semi-mechanised system similar to the one used in South Africa was done by Hamilton (1999) with the objective of comparing manual and mechanized felling operations. In the manual operations, fallers used chain saws to fell, debranch and top trees before they were extracted by cable skidder to the landing. The results of the semi-mechanised operation are summarized in Table 3.

Table 3: Summary of cable skidder productivity using two-worker crew (Hamilton, 1999).

Average tree volume (m^3)	0.70
Average cycle volume (m^3)	4.0
Average extraction distance (m)	278
Productivity (m^3/PMH)	10.9
Total cycle time (min)	21.99

Further details of some of the elements comprising the work cycle of a cable skidder are shown in Table 4. The results are based on the findings of Dave (1996) who studied a cable skidder working in combination with a swing yarder in a two stage logging operation aimed at improving logging system performance.

Table 4: Cable skidder extraction (Dave, 1996).

Cat 528 cable skidder	Maximum extraction distance (m)	Load volume (m^3)	Time to hook (min)	Time to unhook (min)	Travel loaded (km/h)	Travel empty (km/h)
	369	6.0	4	1	7.8	9.8

2.2.2.1 Methods of extraction using a cable skidder

A cable skidder basically uses either cable or chain type chokers to hold tree stems during extraction. In the mainline method of choking and winching tree-lengths, wire ropes form the main line to which the individual tree-lengths are attached using short wire rope or chain chokers. The wire rope is made of about (depending on particular operations) 50 m of 19 mm diameter (operation dependent) IWRC wire and is fitted with between 4 – 6 sliders each of which will accommodate one stem or log length. The number of sliders fitted to the wire rope is dependent on tree sizes and wire rope configuration. The choker chains bearing the load are hooked onto the sliders with the opposite end of the wire rope attached to the skidder's winch (Figure 2).

Figure 2: Mainline rigging (source: Wallingford's Inc. http://www.wallingfords.com/wallingfords/winchline_hooks.html).

The choker chains are made of 1.8 to 2 m lengths of 12 mm diameter Herc-Alloy chains with rings or hooks at one end which are set around either the top or butt end of a tree-length. During winching, the winch brake is released and mainline wire rope is pulled from the winch drum to groups of tree-lengths identified for the next extraction cycle. The tree-lengths are then attached to the mainline by means of hooks fitted at the end of the wire rope. They are then winched to the fairlead and extracted to the road-side landing. At the landing, a dechoker man releases the tree-lengths from the choker chains and both wire rope along with the choker chains are winched back to the fairlead (APA, 1988).

The use of two sets of choker chains helps reduce terminal cycle times compared to the use of a single set of choker chains. This is made possible by pre-choking of the next load by setting the second set of choker chains or cables. Pre-choking involves choker setting the load using one set of choker chains infield while the skidder is extracting the previous load to the landing. The skidder returns infield with the empty chains which are off-loaded and the set already pre-choked, is attached to the mainline for the next cycle. The result of this is that the skidder spends less time waiting to pick up the load compared to when a single set of choker chains is used (APA, 1988).

Chokers can also be used in the tagline system of assembling tree stems for extraction. The use of taglines involves an extension of the mainline winch line (20 -30 m of 19 mm diameter IWRC wire rope) using an additional length of wire rope for carrying additional choker chains. Three taglines of ~ 15 m in length and of the same construction as the main winch line are used. The number of choker chains matching the desired load to be extracted per cycle is attached to one end of each of the three taglines. This is done using log slides to allow for easy movement over the tagline (Figure 3).

Figure 3: Tagline rigging components (source: Wallingford's Inc. http://www.wallingfords.com/wallingfords/winchline_hooks.html).

The opposite end of the tagline is fixed with a hook or a loggerhead grab easy for attachment to the mainline before the load can be winched to the fairlead (De La Borde, 1992).

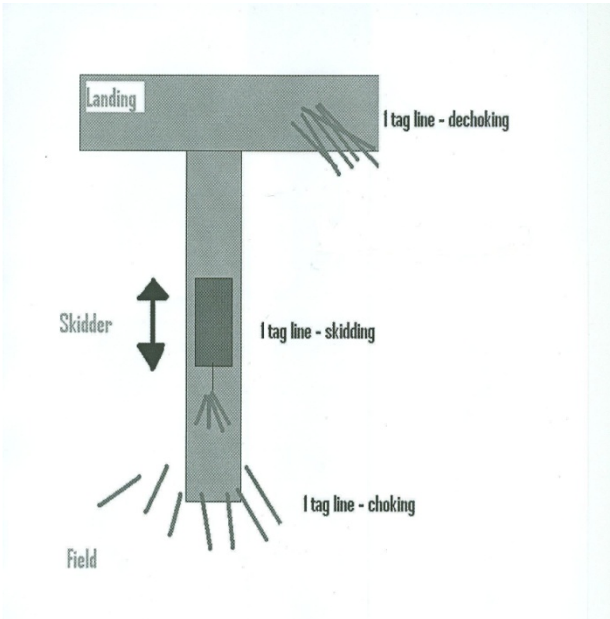


Figure 4: Three tag-line rotating system.

At any time during an operation one tagline is infield being choked to tree-lengths, the second is travelling with the skidder, either with the load or returning infield, and the third is being dechoked at the landing (Figure 4).

Loads are pre-choked so that when the skidder arrives infield, the fresh tagline is taken off the skidder and the tagline which has already been set to the tree-lengths is attached to the main winch line via a shortening clutch. When the load arrives at the landing, the tagline with the load is unhooked and a fresh tagline attached for the skidder to winch it and return with it infield (Bromley, 1969; De La Borde, 1992).

The use of taglines can reduce the cycle time compared to the use of mainline system. Choker setting and dechoking operations using the tagline system can take a quarter to half a minute once the chockers have been set to the logs to be extracted. MacDonald (1999) has however stated that taglines are more suited for small size trees.

The use of chokers requires that the driver continually dismount to hook and unhook the chokers. This exposes the driver to slip-and-fall accidents and accounts for a significant amount of time per skidding cycle. Increasing the number of field crew to include dedicated choker setters and a dechoker man can help to reduce the total time per trip and also reduce the risk of injury (Bromley, 1969; APA, 1988).

2.2.3 Landings

Landings are areas where debranching, cross cutting, loading, storage or a combination of these are performed and from where the wood is transported to a mill. Planning for activities at the landing is important to ensure the efficiency of any of the operations (Richard, 1984). The landing area needs to have sufficient space to allow efficient wood piling and manoeuvring of equipment without any delays. A turn-around for trucks must be constructed nearby if the road is not looped (Pulkki, 2003). A smooth flow of operations at the landing encourages productivity of skidding, merchandising and hauling operations. On the other hand, a crowded landing is a production bottleneck (APA, 1988).

During the planning process a decision should be made whether to use a continuous or central landing and their exact locations must be determined before logging operations begin. The best location for landings is on firm ground which is slightly elevated to allow for water drainage. The landing should be optimally spaced in relation to the skidding distance (Stenzel *et al.*, 1985).

Road side logging operations do not require construction of a landing, thus the costs and environmental impacts associated with the landings are eliminated (MacDonald, 1990). When road side logging systems are operated with matched equipment and work schedules, interference between logging phases is reduced and each machine can work at its own best pace (Skogsarbeten, 1967). However, without proper planning and scheduling, equipment utilization is reduced, and costs are increased.

2.3 Cost of harvesting

Productions costs of harvesting wood are generally categorized into equipment fixed and variable costs, and labour costs. Equipment fixed costs comprise the cost of owning the machines, depreciation, interest, insurance, licenses and monies paid whether the machine is working or not (e.g., administration expenses). They are thus independent of production and should be kept as low as possible by achieving high productivity. Productive operations lower the proportional contribution of fixed cost to a unit of production as demonstrated in Figure 5.

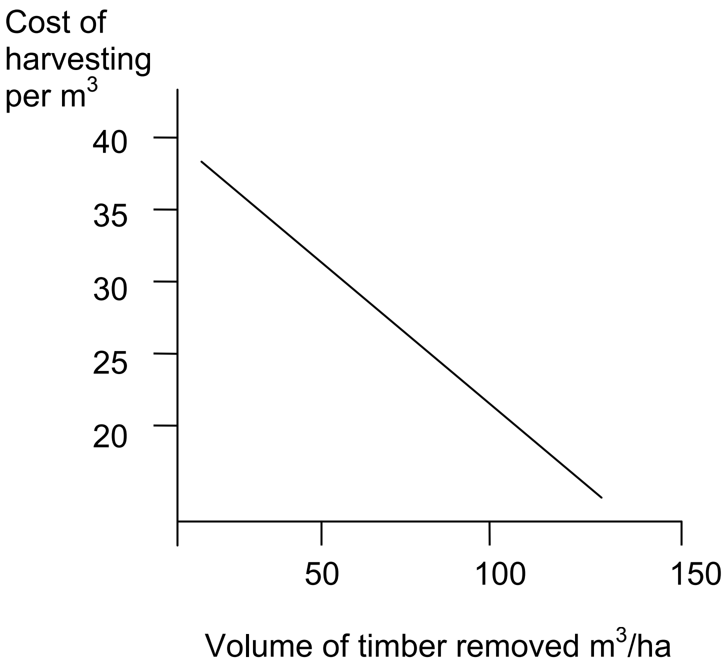


Figure 5: Relationship between cost of harvesting and volume of timber cut per hectare (Staaf & Wiksten, 1984).

.

Equipment variable costs are costs paid only when the machine runs. They comprise cost of fuel, oil and lubricants, repair and maintenance, and tyres. Variable costs increase with increase in engine size and load size. They also increase with depreciating[1] machine condition, more difficult terrain conditions and poor operator skills (Staaf & Wiksten, 1984; Favreau & Gingras, 1998). Labour costs are the wages and employment expenses (e.g., health care, transport levies) paid for the work done by the workers per time period (e.g., day or per hour) or by piece rate. This includes a basic wage, overtime and benefits. This can also include any other additional employment expenses such as insurance, food subsidy, housing, leave pay, annual bonus, free transport, medical care and other indirect expenses (Staaf & Wiksten, 1984; Favreau & Gingras, 1998).

---

[1] Depreciation is the reduction in value of the machine over time. Depreciation occurs due to wear that gradually reduces the capacity of the equipment to perform its function due to more downtime and repair costs or technological advances.

Fixed, variable and operator costs comprise the unit cost of wood which is the cost of harvesting a single cubic metre of wood. Reduction in the unit costs is important to the overall cost saving of a harvesting operation. One way of achieving unit cost reduction is through improving productivity of operations. Productivity has the biggest impact on changes in costs. When production is high the unit production costs is lowered. More important is the proportional contribution of fixed costs per unit of production as well as the impact of wages which are reduced (Bengt, *et al*., 1984; Skogsarbeten, 1984; Warkotsch, 1985).

Over planning (i.e., exceeding the necessary level of planning) of harvesting operations to include operations that are not necessary to the objective of moving wood from infield to the landing can lead to an increase in unit costs (Staaf & Wiksten, 1984; Favreau & Gingras, 1998). It is important that operations that are inevitable to the completion of the work task are included in the plan (Ralph, 1958; Richard, 1984; George, 1992; Kanawaty, 1992; FAO, 1998b; McDonald, 1999; Van Daele, 2000; Anton & Tomislav 2004; Nurminen *et al*., 2006;). In this way unnecessary costs associated with unnecessary planning are avoided (Stenzel *et al.,* 1985; Nurminen *et al.,* 2006).

2.4 Time studies

Van Daele (2000) has stated that successful planning of harvesting operations for higher productivity is dependent on the availability of relevant information and facts about the work system. Suitable data analysed from a work system enable a full understanding of a system, help in investigating factors affecting work productivity with a view of improving the level of productivity, and guide decision making when formulating plans for highest operational efficiency (Richard, 1984; Van Daele, 2000; Anton & Tomislav, 2004; Nurminen *et al*., 2006).

Time studies are used to generate facts about a system of interest upon which good planning decisions can be based. Time studies measure the time consumed to do a job under specific conditions of work and have been used to establish how long it should take to do a job for detailed repetitive jobs. This is done by breaking down the sequence of operational activities into elements. Individual elements are timed separately and the results examined in detail with a view to simplifying and developing more productive methods (George, 1992). Time studies are also important in identifying critical areas within a harvesting system or operation that require improvement, leading to minimization of work time, increased production and reduced costs. Time study results also enable the evaluation of the effect of changing work patterns on productivity (George, 1992) and have been used successfully in forest harvesting operations (FAO, 1998b) to investigate the level of efficiency with which operations were conducted.

2.5 Method study

Method study is the systematic recording and critical examination of existing and proposed methods of doing work, as a means of developing and applying easier and more effective methods and reducing costs (Richard, 1984; Van Daele, 2000; Anton & Tomislav, 2004; Nurminen *et al*., 2006). The method involves systematically following six steps:

2.5.1 Selection of work to be studied

Most operations consist of many discrete jobs or activities. The first stage is to select those jobs to be studied that will give the best returns for the time spent. Activities with the best scope for improvement include: those with extended delay times; areas where lots of waste is being produced or where lots of resources are spent; those with bottlenecks; or those resulting in high costs.

2.5.2 Recording the present method

Method study uses formal techniques to record the sequence of activities, the time relationship between different tasks, the movement of materials and the movement of staff.

2.5.3 Critical examination of the facts

Once all the details of the work have been recorded, critical questions are formulated that help in critically examining the current methods of doing work with the motive of seeking answers to the critical questions. The critical questions are about the purpose of performing the activity, the reasons for performing it at a particular place and the sequence of operations, the person who is best suited to perform the operation and the best means to perform the operations.

2.5.4 Development of the most critical and economic methods

Answers to the critical questions are used to develop new and better method of executing the task. The new method is developed by entirely eliminating some activities, combining some operations, changing the sequence of some activities and by simplifying the contents of others.

2.5.5 Installation of the new method

The newly proposed method is implemented and compared to the old one. Implementation of the new method may involve providing modified equipment components and layouts that were previously not part of the operation.

2.5.6 Maintenance of new methods and periodic check

This involves the periodic monitoring of the effectiveness of the new methods and maintaining the same work standards.

2.7 Global Positioning System (GPS)

A global positioning system is a satellite-based global positioning system for measuring positions in three dimensions that use radio signals from a constellation of satellites orbiting the earth. The user must have a receiver to interpret the radio signals. The interpreted signals are used to determine the location of objects and places throughout the world, at all times and irrespective of weather conditions (Darche & Forgues, 1998).

GPS technology has numerous applications in forestry due to its ability to monitor and track mobile machines (Veal *et al.,* 2000). GPS can be used to perform autonomous time studies and the data can be complemented with manual time studies. It may be used independently to provide information in time units allowing for a timely forecast, prediction and correction of actions when necessary. A GPS can also produce detailed summaries of machine system performance over long periods of time, thus allowing safer and less costly investigations of machine systems.

Reutebuch, *et al.* (1999) described a study in which a GPS receiver was placed on a skidder and used to track the machine throughout the course of a harvest; the data recorded was helpful in calculating cycle distances and times. Robert (2002) also conducted continuous time studies using GPS technology, and discovered that it is a more efficient process for conducting automated time studies and evaluating productivity of harvesting systems. The use of GPS has the potential of reducing the costs and safety hazards of traditional time studies and to increase the accuracy of the data collected.

When considering the application of GPS technology on productivity studies of skidding operations, Ronald *et al.* (2006) stated that the device used should meet five basic requirements: 1) accuracy that can guarantee autonomous precision under 5 m; 2) large data storage capacity to handle data over long work hours; 3) ability to use the machine’s power supply; 4) programmability to suit the desired level of precision; and 5) graphic representation of the data on screen for interpretation and low cost of acquisition and installation of the GPS device.

The device should be installed on to the extraction equipment with an external antenna to assure better satellite coverage. The tracking device is programmed to collect data at 10 second intervals or any other interval duration that suits the desired level of precision. At the end of each interval the device records the desired information (e.g., position, altitude, speed and time) which are stored for later retrieval when needed for analysis (Ronald *et al.*, 2006).

Robert (2002) observed that programming the device to collect data at shorter time intervals such as at one second intervals does not add value in terms of additional information. He compared the effectiveness of data recorded at one and five second intervals and discovered an increased number of recorded points at one second intervals than at five second intervals. The increased number of points had no significant benefit in terms of providing additional information instead there were disadvantages associated with the increased number of points. There was difficulty in noticing the break points within elements with increased number of points and difficulty in pinpointing transitions between the tasks; the increased number of points increased the time to analyse the line file created by the GPS and thus also increasing the time to analyse the data. Statistically the one second time interval was equally as accurate as the five second time interval for travel empty and travel loaded and total cycle time.

To perform time studies, an automated system would require some way of identifying the time and location of specific, individual events and then be able to combine those events into sequences meaningful to the machine's function. McDonald (1999) describes a system that can help understand the functionality of an automated system applied in a forest harvesting operation. The system derives time study information from positional data using two components: 1) a "feature" extraction sub-system to identify basic events in a machine path; and 2) an "event processor" to combine characteristic movements and sub-events into machine specific functions.

The approach uses a small set of features measured from GPS-derived data to describe the function of the machine. The path of the machine is filtered to produce a sequence of fundamental events. These events are then paired to form sequences of events, describing machine functionality. The fundamental events in the case of describing a skidder function might include elements like "leave deck" or "enter deck" or 'travel empty'. Combination of these events would then represent a more complicated structure, in this case a skid cycle (McDonald, 1999).

This process can be implemented as two computer programs: (1) event-map to filter a path and extract interesting events; and (2) event-parse to combine event into machine functions. The two programs, event-map and event-parse, each require an input file with syntax outlining entry and exit of an event within a location, positioning data, linear data, start or stop data and movement data. The analysis is complete when no more event parse rules can be matched (McDonald, 1999).

Despite the importance of GPS in automated time studies, various studies (Spruce *et al*., 1993; McDonald, 1999; Reutebuch *et al*., 1999; Veal *et al*., 2001) have highlighted the decrease in accuracy between the true positions and the GPS positions. This is due to apparent large errors (occasionally over 100 m) in the positional data, that hinders the accurate calculation of the vehicle travel distances. This inaccuracy is attributed to signal disturbance associated with the geometry of the satellite constellation and selective availability, forest vegetation and topography, multipathing, and atmospheric and ionospheric conditions.

The geometry of the satellite constellation affects the signal quality of GPS signals. Geometry of satellite constellation is measured using Position Dilution of Precision (PDOP). Low PDOP values indicate good satellite geometry and gives better accuracy. Low PDOP occurs when satellites have the greatest separation in the sky view. High PDOP values means there is greater variation between the GPS position and the true position.

Forest vegetation and topography may block satellite signals causing a loss in position fixes. There are studies done to determine the accuracy of GPS under open sky and under canopy conditions (Spruce *et al.,*1993; Reutebuch *et al*., 1999; Veal *et al.,* 2000). These studies have shown that the accuracy of GPS is decreased under canopied conditions due to the deflection of the GPS signal by branches, foliage and stems. This increases the incoming signal travel time from satellites to receivers and thus introduces a significant error in position determination. Signal interference under the forest canopy is also attributed to multipathing from vegetation leading to considerable errors in GPS positional data.

The atmospheric and ionosphere conditions at the time of work study influences the quality of the signal transmitted to the receivers while selective availability can cause errors in position accuracy from approximately 25 m to no worse than 100 m from the true position (Liu, 2002). Differential GPS (DGPS) can reduce the errors and yield greater accuracy between the GPS-measured position and true position to a few metres (Liu, 2002).

3 Methodology

3.1 Materials and methods

Time study, method study and satellite tracking were used to obtain information from the system in order to understand the operational work plan and methods in use. Time study provided information on the amount of time consumed by travel, choker-setting and dechoking. Method study techniques were used to critically examine the methods applied in executing the various tasks thus providing information on the specific areas of the operation requiring improvement. Satellite tracking was used to compliment time studies and provided spatial detail of machine travel including distances, speeds and travel times. Choking time, dechoking time, travel loaded and travel empty data were combined into a work cycle and used in calculating productivity per unit time. Efficiency was measured in terms of productivity using cubic meters (m^3) per unit of resource input and costs per cubic metre.

3.2 Study Site

The study was undertaken in three compartments owned by MTO located near the town of Grabouw in the Western Cape Province of South Africa (Figure 6). The individual compartments in which the study was done were M6, M7a and M7b.

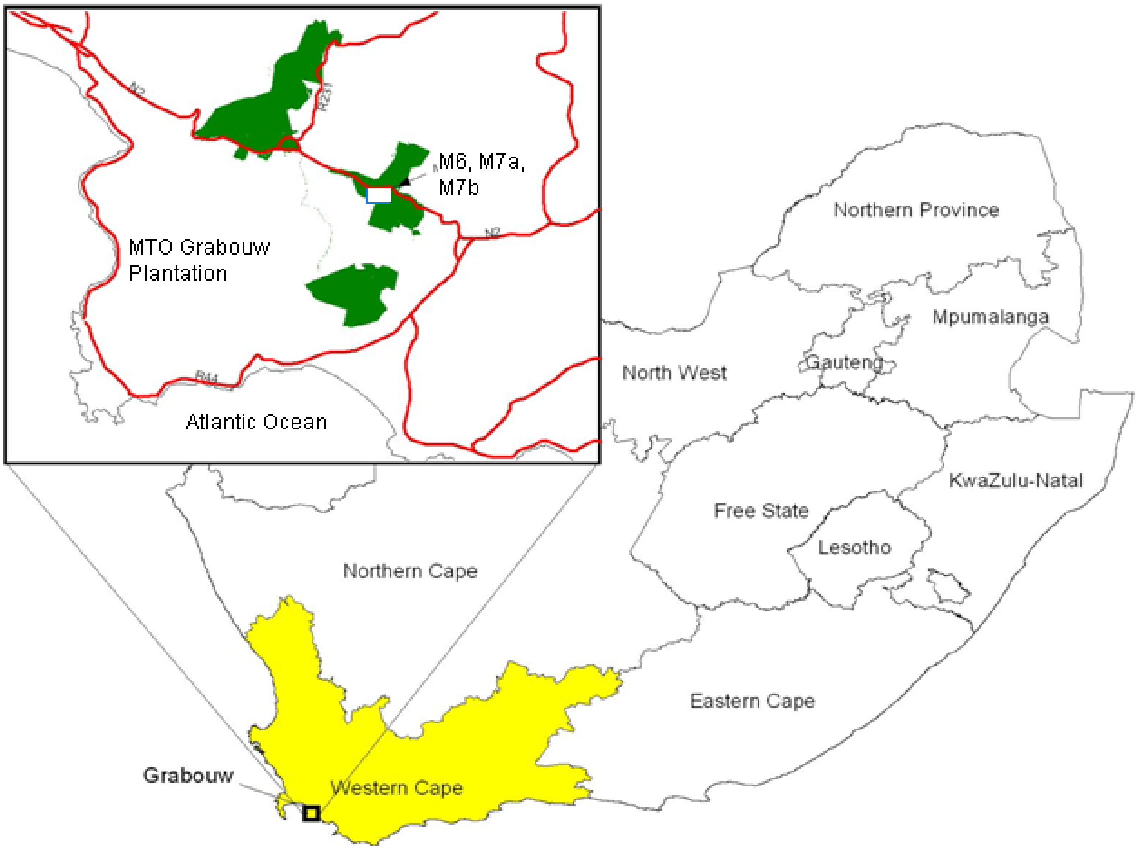


Figure 6: Location of study area.

3.3 Experimental design

Compartments M6, M7a and M7b were divided into a control strip and three planning strips. Each of the planning strips had two predetermined designated skid trails located parallel to each other 30 m apart (Figure 7).

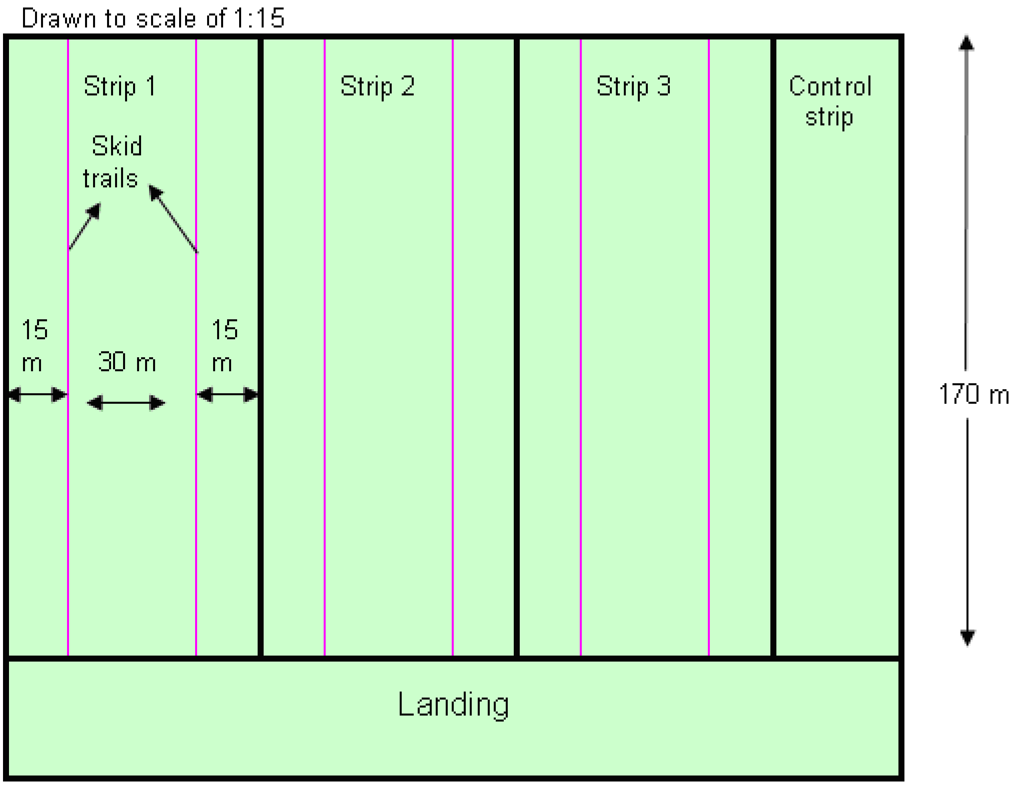


Figure 7: Graphical representation of the planning design within one compartment.

The location of each of the predetermined skid trails in the entire compartment was marked and all the trees standing along them felled and extracted to the roadside to be merchandised into log-lengths. The level of planning entailed:

- In the first planning strip: directional felling of the trees within the strip after the skid trails had been marked and the trees in the skid trails felled and extracted.
- In the second planning strip: directional felling of the trees within the strip and improving the level of skid trail preparation by clearing them of logging debris and slash material using the skidder's blade after all the trees standing in the skid trails had been felled and extracted.
- In the third planning strip: directional felling of the trees within the strip, felling and clearing the trees standing along the skid trails, clearing the skid trails of logging debris, slash material and lowering the stump

heights in the skid trail to as near the ground level, or below, as possible.

There was neither directional felling nor any form of skid trail preparation in the control strip beyond that normal to operations and planning undertaken by the company personnel and management. The improvements to the skid trails applied in the planning strips thus represented additional preparations beyond the normal planning strategies. To complete the design each of these treatments in the planning and control strips were replicated three times in exactly the same way: i.e., once each in compartment M6, M7a and M7b.

Directional felling was done to facilitate the tree-length extraction phase. The direction of fall of trees was dependent on the lean of the trees. In compartments M6 and M7b the trees leaned away from the road-side landing zone and were felled away from the predetermined skid trails for butt-first skidding. In compartment M7a the trees leaned towards the road-side landing zone and were felled towards the predetermined skid trails for top-first skidding. During skidding in the planning strips, the skidder remained confined to the predetermined skid trails and winched the tree-lengths, from up to 15 m on both sides of the skid trail, to the skid trail before returning to the roadside landing.

Each of the two predetermined skid trails in each planning strip were randomly allocated either a mainline winching system or a tagline winching system; i.e., each system being applied in one of the skid trails in each strip. The mainline system comprised of two sets of six choker chains (total 12). The two sets of choker chains facilitated pre-choking of tree-lengths infield while the skidder was hauling the previous load to the landing. The tagline system comprised of three taglines each having four choker chains attached (total 12).

The harvesting system studied is a traditional semi-mechanised tree-length harvesting system used in South Africa. The system (Figure 8) consists of motor-manual felling, debranching and topping of the trees infield. The tree-lengths are extracted by means of a 138 kW wheeled H67 Clark Ranger cable skidder to the landing where they are merchandised by manual log scaling and crosscut by chainsaw. Stacking at the landing is done using a Bell three-wheel loader fitted with a telescopic boom.

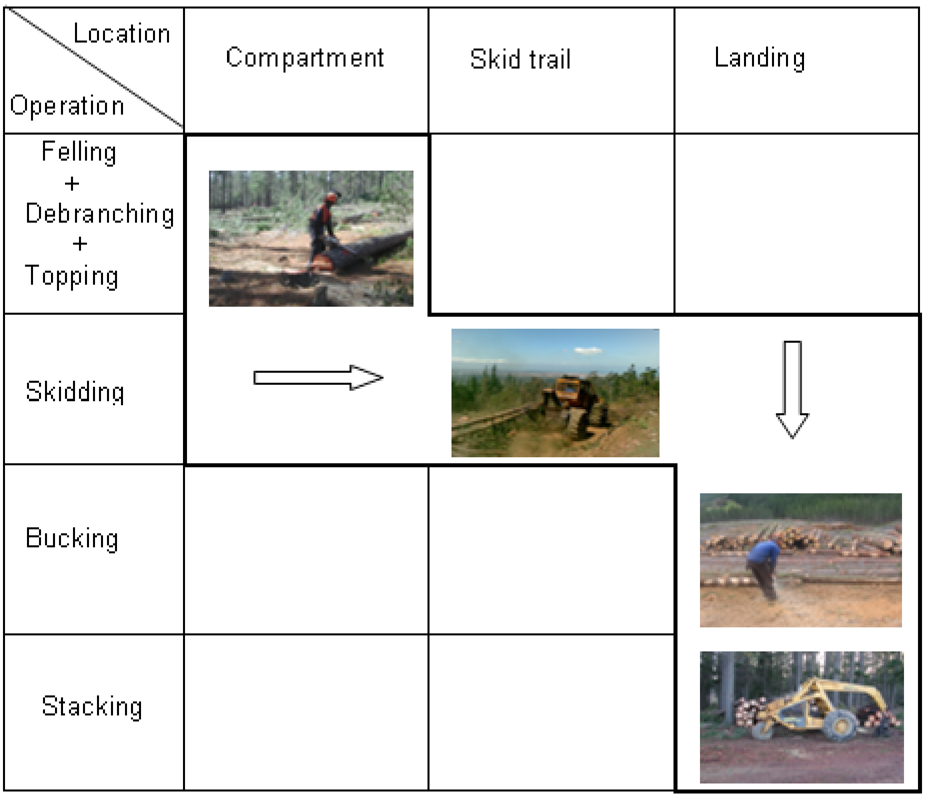


Figure 8: Harvesting system matrix of current semi-mechanised harvesting system.

The harvesting team consists of 14 - 16 personnel ranging from the supervisor to cross-cutter and other manual labour and are detailed in Table 5. These represents the full team to maintain daily production targets set by the company.

Table 5: Semi-mechanised harvesting team personnel.

Personnel	Number
Foreman	1
Skidder operator (Clark Ranger)	1
Loader operator (Three-wheeler)	1
Tree fallers (chainsaw operation)	2 - 4
Choker setters	2
Dechoker man	1
Log scaler	2
Log recorders	2
Cross cutters (chainsaw operation)	2

3.4 Compartment inventory

In order to determine the stand densities and tree sizes (volume, breast height outside bark diameter (DBH) and height) compartment inventory was carried out in all compartments prior to harvesting. The stand density measurements were derived from four randomly selected 20 m by 20 m square plots in each compartment. The number of trees within each plot was obtained and the results averaged to obtain mean number of trees. The average number of trees from the four square plots in each compartment was used to calculate the stocking of the compartments on a per hectare basis.

A 5% sampling intensity was used to obtain tree samples for height and DBH measurements from which the tree volumes were calculated in each compartment. Compartment M7a and M7b were adjacent to each other but separated by a stream channel. Their terrain and stand conditions were thus similar. The compartment records obtained from MTO showed that the compartments had been planted at the same time and had also been subjected to similar silvicultural treatments since establishment.

For the purpose of determining the height and DBH measurement of the trees, compartments M7a and M7b were considered as a single compartment then divided into four rectangular sections of relatively equal dimensions as shown in Figure 9. A total area of 0.99 ha was then sampled from four circular plots. Each of the four circular plots was systematically located in the four rectangular sections. The circular plots were separated by a uniform distance of 155 m along the rectangular plane (Figure 9). Each had a radius of 30 m and all trees in the circle were measured for height and DBH. Tree DBH's were measured using a diameter tape while height measurements were done using a hypsometer.

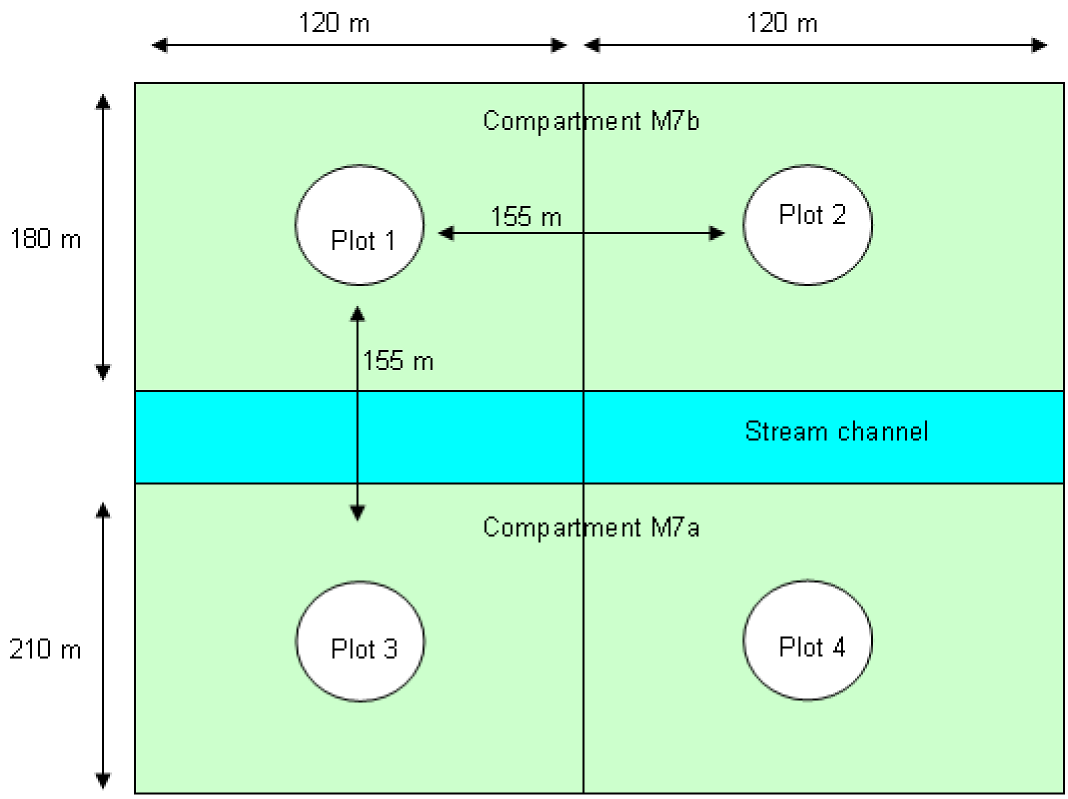


Figure 9: Inventory of sample plots for height and DBH measurements.

In compartment M6 a sample size of 0.375 ha was taken. This was a smaller sampling area compared to 0.99 ha taken in the combined area of compartments M7a and M7b. Due to the smaller size of the sampling area only three circular plots of 20 m radius could be taken for height and DBH measurements. The position of the circular plots relative to each other was determined by a systematic sampling design. They were located at 65 m apart to ensure representation of the entire compartment. All the trees within each circle were measured for DBH and height.

3.5 Sequence of operations

The operations commenced sequentially from compartment M7a to M7b and finally to M6. Within each compartment, the operations were scheduled to start with the control strip using the normal harvesting operations undertaken by the harvesting team as prescribed by the management of the company. The operations in the control strip were characterised by haphazard felling and random travel by the skidder as mentioned previously.

The trees in the control strip were however felled directionally and the skidder followed dedicated paths during extraction, which were not prepared but turned into skid trails after the skidder ran over them a few times. The results from the control strip had been affected by the introduction of the plan of activities resulting into the activities in the control strip mirroring the plan of activities in planning strips. Objective 1, which was aimed at quantifying the benefits of an operational harvesting plan by comparing the productivity and cost results of the planning strips and control strips could therefore not be fully realised. The data from the control strips were thus unfortunately distorted and unsuitable for analysis and interpretation and were discarded. The experimental design was therefore revised to exclude the control strip (Figure 10).

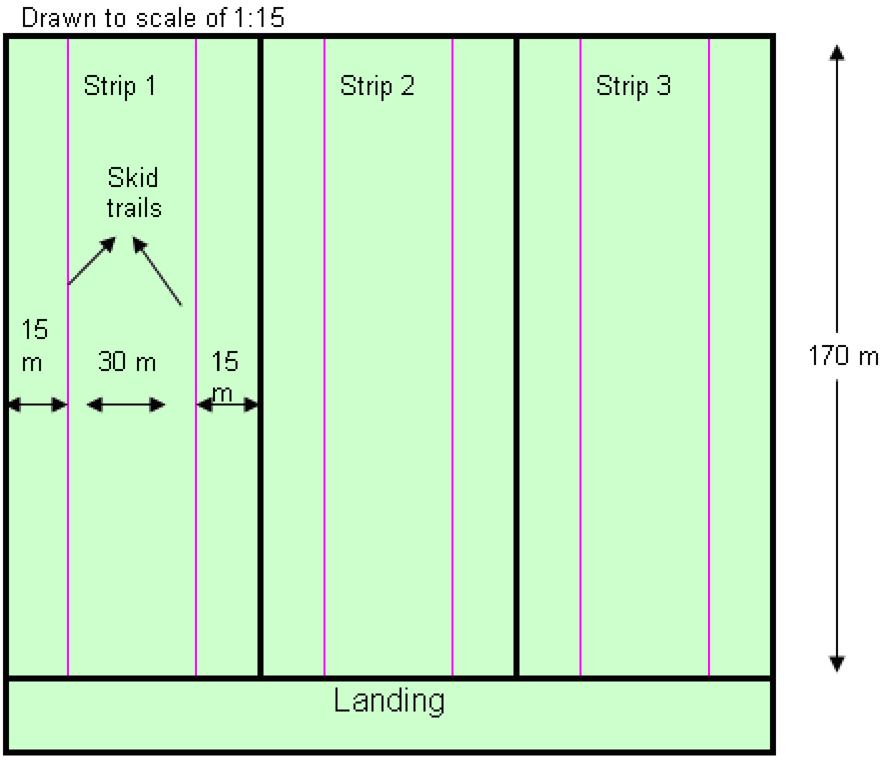


Figure 10: Revised experimental design.

The operations would then proceed to the planning strips. Firstly, the designated skid trails were prepared starting from planning strip 1 followed by planning strips 2 and 3. The trees lying along the 15 m mark (Figure 10) on either side of each designated skid trail were then marked using spray paint to create a boundary to each strip.

The extraction operations began in planning strip 1 after demarcating the strip boundaries. The operations were carried out in an alternating sequence between the strips: i.e., once work was complete along one skid trail within a single strip, the operations moved to the next strip leaving a section of trees marked for the second skid trail in the first strip standing as shown in Figure 11. This was to eliminate the chance of extracting trees along the skid trails which were not earmarked for their extraction.

Figure 11: Alternating felled and standing strips.

The operations in strip 1 begun by felling trees marked for one of the designated skid trails (selection of which of the two skid trail to use per strip was randomised) and only after the entire strip was felled did extraction begin. During extraction of strip 1, the fallers proceeded to strip 2 where they felled a section of the strip earmarked for one of the designated skid trails. The operations then proceeded to strip 3 where they also felled a section of the strip earmarked for one of the designated skid trails. The fallers were followed in that order by the rest of the crew working in sections they had already felled. The operations returned to complete work on the second skid trails, starting in strip 1, after all the trees earmarked for the first skid trails were extracted and processed.

3.6 Data collection

Study data was obtained for travel loaded, travel empty, choking, dechoking, travel distance and travel speeds using time study, method study and GPS tracking. Time study was done using stop watches to record choking, dechoking, travel empty and travel loaded times in deciminutes. It was conducted by two people, one positioned at the landing to record dechoking time and the movements of the skidder on the roadside landing, while the other person was located at the stump site to record the choking time and the movements of the skidder there. The two enumerators communicated via small hand-held radios. The elements had defined break points (Table 6) to allow consistent and accurate timing of each of the elements.

Table 6: Elements comprising a skid cycle and their break points.

Element	Start point	Stop point
Choking and winching	When the skidder operator releases the winch break to drop chokers to ground.	When skidder starts to move towards landing with load.
Travel loaded	When skidder starts to move towards landing with load.	When the skidder drops the load at the landing (releases winch brake).
Dechoking	When the skidder drops the load at the landing	When the skidder starts to move for its travel back to the field.
Travel empty	When the skidder starts to move for its travel back to the field.	When the skidder operator releases winch break to drop chokers to ground.

Method study was used for systematic and critical examination of choking and dechoking and recording of the sequence of all activities involved in conducting the two operations.

GPS tracking system was used for accurate measurement of travel loaded and travel empty times and to log the actual travel paths of the skidder during extraction. This was achieved by tracking the machine path from location data recorded by the GPS device then reducing the machine path into element times. Travel speeds and distances associated with the recorded times were also extracted from GPS recorded data.

Collection of satellite data was made possible through data recorded on a GPS device (FM LOC GPS) supplied by MiX Telematics. The GPS device was installed on the skidder with an external antenna. It was then programmed to record data at 10 second intervals. The device monitored and tracked the skidder throughout the course of the harvest and stored a record of events in its memory.

The GPS data was then uploaded onto a computer for analysis by software for vehicle tracking (FDO Fleet Manager Professional Version 8.3). The Fleet Manager (FM) contains a GPS Log Viewer Extension that was used to analyse the data. The Extension uses a Criteria Wizard allowing the selection of the information needed for analysis (Figure 12).

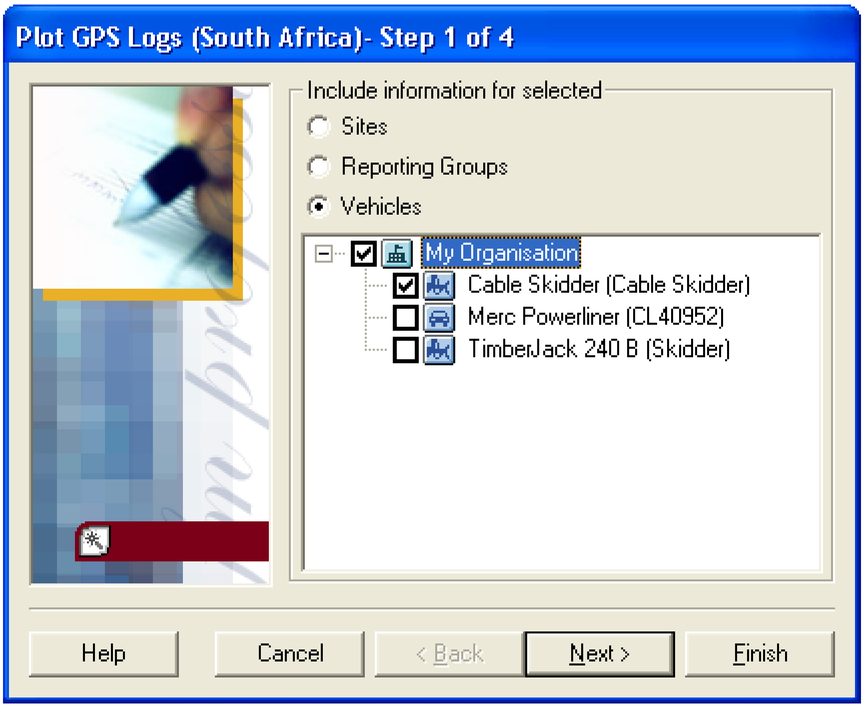


Figure 12: Fleet Manager Criteria Wizard.

Information for each complete cycle was retrieved from the FM database by entering the dates and the start and stop times for each of the cycles (Figure 13).

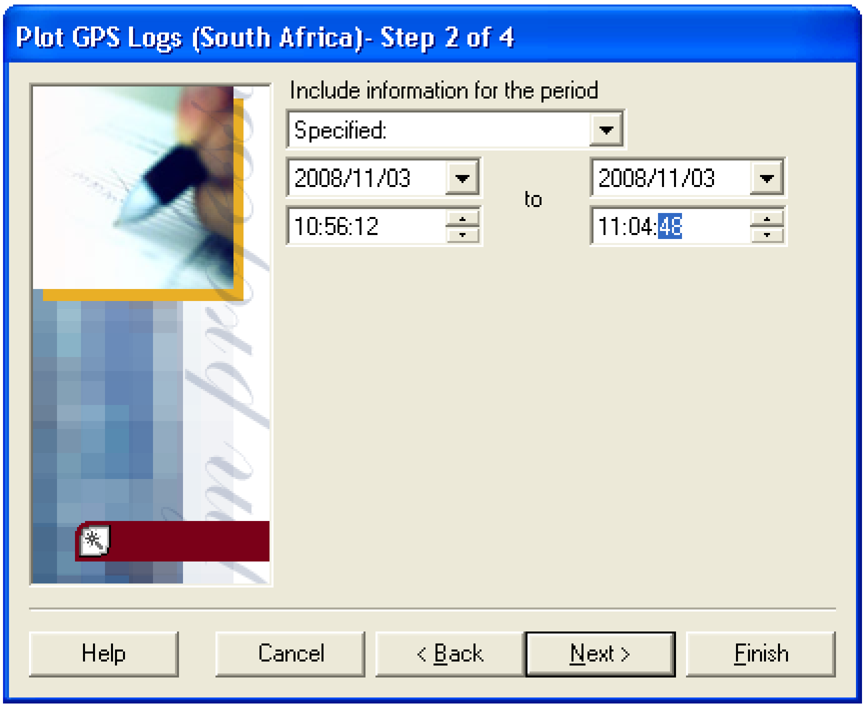


Figure 13: Criteria wizard for specified functions.

The criteria wizard then filters the GPS data in the FM database based on the selections and the required GPS Logs representing the cycles are exported to the viewer. The viewer then automatically loads and displays the data on a map (Figure 14).

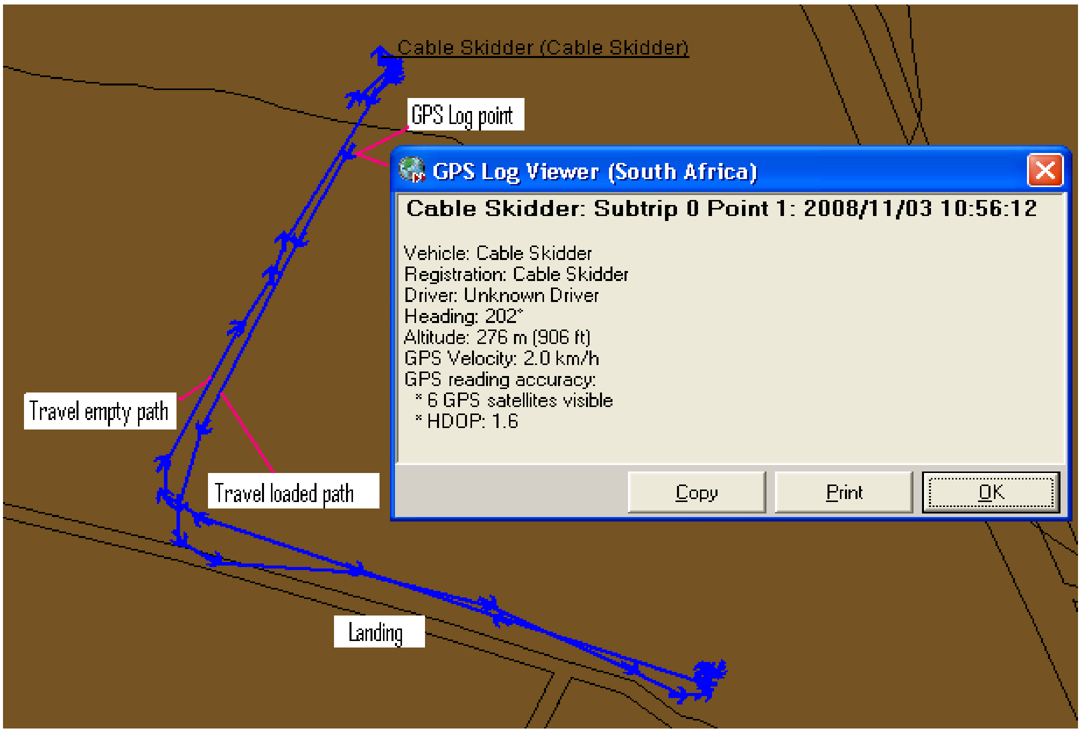


Figure 14: GPS map extract.

Each GPS log point is then examined to obtain speeds of travel of the machine in the field. The speeds along the designated skid trails are averaged to obtain the average speeds during travel loaded and the same is repeated to obtain average travel speed during travel empty.

Distances for both travel loaded and travel empty were measured using the measuring tool available in the map viewer menu. The distances were measured by tracing the path of the skidder through the line joining the GPS Log points from the start point of the cycle at the stump site to the point where the skid trail joined the roadside landing. Distances travelled along the landing were not included in the study to avoid distortion of travel data gathered along the skid trails. The running surface on the roadside was not prepared to match those on the skid trails and therefore differed with that on the skid trails.

The number of cycles taken per skid trail was determined by considering the skidder average work and non-working times per shift. The average work and non-work times were calculated from past records provided by MTO. The formula (George, 1992) used to arrive at the number of cycles per skid trail is given by:

$$\sigma p = \sqrt{\frac{PQ}{N}}$$

Where: σp = 5% Standard error of proportion (the confidence level is 95%)

P = 14.5% = Percentage non-work time

Q = 85.3% = Percentage work time

N = Number of cycles per skid trail

This resulted into a total of 20 cycles per skid trail. The data was recorded on time study sheets and comprised of element times in every cycle and the load size (m^3) extracted per cycle. The load sizes were obtained by multiplying the number of tree-lengths extracted per cycle by predetermined average tree sizes (m^3) established during the compartment inventory.

Information on quantity and costs of material and labour use required for cost calculation and machine costing was obtained from MTO. Machine costing was done using the South African harvesting and costing model (Hogg *et al.*, 2007). Equipment was cost at replacement value. Standard personnel cost also applied. The skid trail costs were calculated in Microsoft Excel.

3.7 Statistical techniques

The non-parametric bootstrap and Kruskal-Wallis tests were used to analyse the data. When data are not normally distributed and transformation of the data is not successful, non-parametric bootstrap multiple comparison tests are often used for statistical inference. H_0: $P(X < Y) = P(X > Y)$ H_a $P(X < Y) \neq P(X > Y)$ at $\alpha = 0.05$. Bootstrappping is best for non-normal data as it contains procedures developed for the analysis of non-parametric data focused on hypothesis test *(*Jen˝o et al., 2005) and is a common choice for the comparison of two independent samples.

The bootstrap methods replace inaccurate approximations to biases, variances and other measures of uncertainty and has proved to work better than traditional methods in solving non-parametric problems (Davison & Hinkley, 1997). Bootstrap methods can also be used for fully parametric, and semi-parametric tests since they apply for any level of modelling (Davison & Hinkley, 1997). The Bootstrap methods perform the analysis without replacing clear critical thought about the problem at hand, or interfering with the design of the investigation and data analysis, and incisive presentation of conclusions (Davison & Hinkley, 1997).

The Kruskal-Wallis test is used to compare three or more samples, and it tests the null hypothesis that the different samples in the comparison were drawn from the same distribution or from distributions with the same median. The interpretation of the Kruskal-Wallis test is basically similar to that of the parametric one-way ANOVA, except that it is based on ranks rather than means (Siegel & Castellan, 1988). The parametric one-way ANOVA procedure assumes that the errors in the model are independently and normally distributed with homogeneous variation over all treatments. The Kruskal-Wallis test is applicable in situations where the assumptions of ANOVA are violated.

The intuitive logic behind Kruskal-Wallis test is that the responses within a group due to a particular treatment are ranked in order from the lowest responses, to the next lowest responses and so forth. In the event of any tied values then the average of the ranks they would have received had they not been tied is assigned to them. When the responses in all the groups have been ranked, the differences between the sums of ranks for the responses in the groups will indicate how much the groups differ from each other (Elvar, 1986). The Kruskal-Wallis test statistic is given by:

$$K = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_{i\cdot} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - \bar{r})^2},$$

where:

- n_i is the number of observations in group i
- r_{ij} is the rank (among all observations) of observation j from group i
- N is the total number of observations across all groups
- $\bar{r}_{i\cdot} = \frac{\sum_{j=1}^{n_i} r_{ij}}{n_i}$,
- $\bar{r} = \frac{1}{2}(N+1)$ is the average of all the r_{ij}.

3.8 Data Analysis : Methodology

Both time study and GPS derived data were compiled in Microsoft Excel before being imported into a statistical package for analysis. The analysis was conducted using Statistica Version 8. Hypothesis testing was used for testing the differences with a p-value less than 0.05 being considered significant and thus rejecting the null hypothesis. The Shapiro-Wilk test was performed on the residuals of all data to test for normality. The results were assessed graphically to determine the fit of the data sets to a normal distribution, and confirmed using p-values.

Because the data were not normally distributed, they were subjected to log, square root and exponential transformation in an attempt to normalise the data (Appendix A). These transformation attempts proved ineffective. The original data was used and non parametric analysis continued through the use of non parametric Kruskal-Wallis tests and Bootstrapping the data.

Productivity (m^3/pmh) and volume were the dependant variable used in the models. The times, speeds and distances measured for travel loaded and travel empty, were independent variables used to investigate productivity between the three levels of skid trail preparation and the two choking systems. Other independent variables included tree volume and stand density data.

3.8.1 Kruskal-Wallis test

The non-parametric Kruskal-Wallis test was used for testing the differences between groups. It was specifically used to test:

1. Differences between the compartments (M6, M7a and M7b) in terms of tree sizes and stocking (m^3/ha).
2. Difference between data collected using manual time study and satellite tracking.
3. Differences in travel loaded and travel empty distances between the three compartments.

3.8.2 Bootstrap test

Bootstrapped data was used for the analysis of all variables. This comprised all data generated using both the mainline system and tagline systems. The following were investigated:

1. Difference in productivity due to mainline and tagline systems.
2. Difference in choking time due to mainline and tagline systems.

3. Difference in dechoking time due to mainline and tagline systems.
4. Differences in cycle times resulting from the use of mainline and taglines systems.
5. Differences in productivity of the different levels of skid trail preparation considering the mainline and tagline systems.
6. Differences in travel empty times on the different levels of skid trail preparation considering the mainline and tagline systems.
7. Differences in travel loaded times on the different levels of skid trail preparation considering the mainline and tagline systems.
8. Differences in travel speeds on the different levels of skid trail preparation considering the mainline and tagline systems.

And finally a cost benefit analysis was done to determine what level of skid trail preparation was optimal.

4 Results

4.1 Test for significant differences among the compartments

Table 7 provides a summary for the compartments and their terrain classification based on Erasmus (1994).

Table 7: Summary of the stand and site conditions of the compartments.

Stand parameters	Compartment M6	Compartment M7a and M7b
Area	7.5 ha	19.8 ha
Age	37 years	37 years
Stand density	425 stem. ha^{-1}	400 stem. ha^{-1}
Average tree volume	0.87 m^3	0.99 m^3
Volume/ha	370 m^3/ha	396 m^3/ha
Ground condition	• good in dry state • moderate in moist state • poor in wet state	• good in dry state • moderate in moist state • poor in wet state
Ground roughness	slightly uneven	slightly uneven
Slope condition	gentle slope +10%	gentle slope +10%

As is indicated in Table 7, compartments M6, M7a and M7b had similar stand and site conditions. Regardless of the similarities the data were analysed to ensure that compartments were statistically similar so that the focus of further analyses could then concentrate on the trial objectives without being influenced by differences in the compartments. This analysis led to the compartments being excluded from the productivity models.

There was no significant difference in tree size or stand density in the three compartments. P-value = 0.89 and 0.99 respectively. Neither the load sizes, extraction distances nor travel times affected productivity in the three compartments, p=0.081, p=0.053 and 0.057 respectively.

4.2 Test for significant difference in productivity between mainline and tagline systems

Null Hypothesis: There is no significant difference in productivity of mainline and tagline systems.

Alternative Hypothesis: There is a significant difference in productivity of mainline and tagline systems.

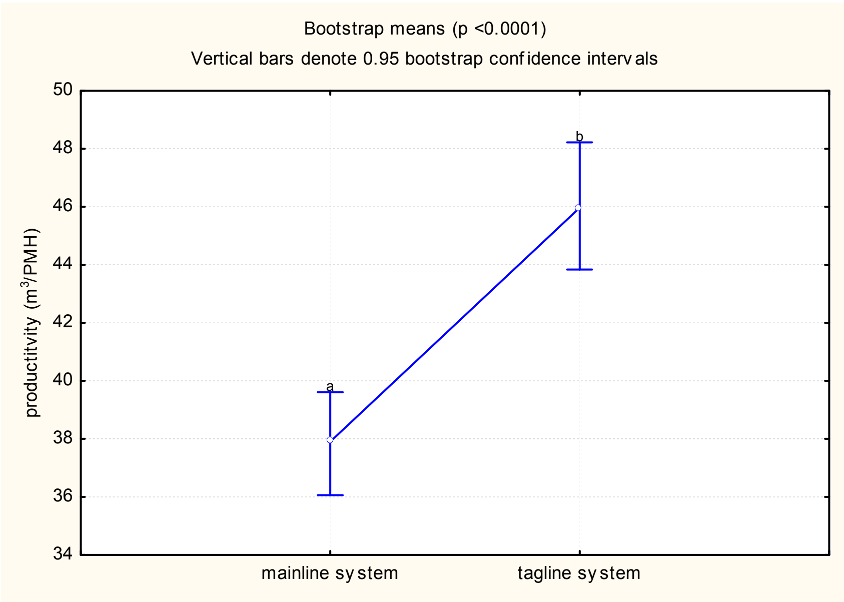


Figure 15: Test for significant difference between productivity of mainline and tagline systems.

There is a significant difference ($p<0.0001$) between mainline and tagline systems (Figure 15). The average productivity of the mainline system (37.8 m^3/pmh) was lower than average productivity of the tagline system (46.0 m^3/pmh).

4.2.1 Test for the effect of mainline and tagline systems on choking time

Null Hypothesis: There is no significant difference in choking time of mainline and tagline systems.

Alternative Hypothesis: There is a significant difference in choking time of mainline and tagline systems.

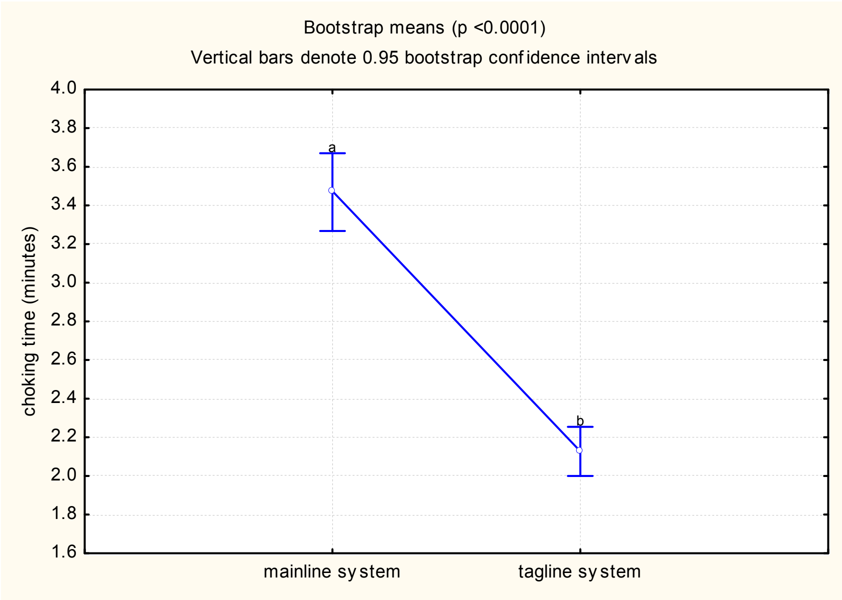


Figure 16: Test of significant difference between choking time in mainline and tagline systems.

The choking time using the mainline system was significantly different ($p<0.0001$) from the choking time using tagline system (Figure 16). The average choking time using mainline system was higher (3.47 minutes) than the average choking time using tagline system (2.13 minutes).

Table 8: Least square means of choking time (minutes) in mainline (1) and tagline systems (2).

	chok sys; LS Means (DATA2 in GIS DATA 20091110.stw) Current effect: F(1, 435)=118.44, p=0.0001					
	chok sys	choking time Mean	choking time Std.Err.	choking time -95.00%	choking time +95.00%	N
1	1	3.47	0.09	3.30	3.64	217
2	2	2.13	0.09	1.96	2.30	220

4.2.2 Effect of mainline and tagline systems on dechoking time

Null Hypothesis: There is no significant difference in dechoking time of mainline and tagline systems.
Alternative Hypothesis: There is a significant difference in dechoking time of mainline and tagline systems.

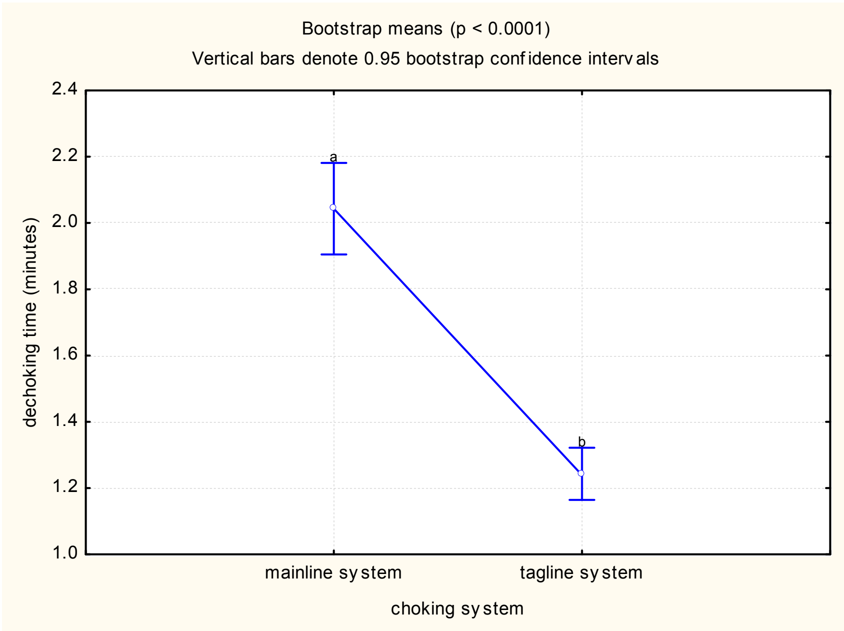


Figure 17: Test of significant difference between the dechoking time using mainline and tagline systems.

The dechoking time using mainline system was significantly different from dechoking time using tagline system ($P<0.0001$). The average dechoking time using the mainline system (2.05 minutes) was higher than the average dechoking time using tagline system (1.24 minutes).

Table 9: Least square means of dechoking time (minutes) in mainline (1) and tagline (2) systems.

Cell No.	chok sys; LS Means (DATA2 in GIS DATA 20091110.stw) Current effect: F(1, 435)=94.860, p=0.0000 Effective hypothesis decomposition chok sys	dechoking time Mean	dechoking time Std.Err.	dechoking time -95.00%	dechoking time +95.00%	N
1	1	2.05	0.06	1.93	1.93	217
2	2	1.24	0.06	1.12	1.35	220

4.2.3 Effect of mainline and tagline systems on cycle time

Null Hypothesis: There is no significant difference in cycle time using mainline and tagline systems.
Alternative Hypothesis: There is a significant difference in cycle time using mainline and tagline systems.

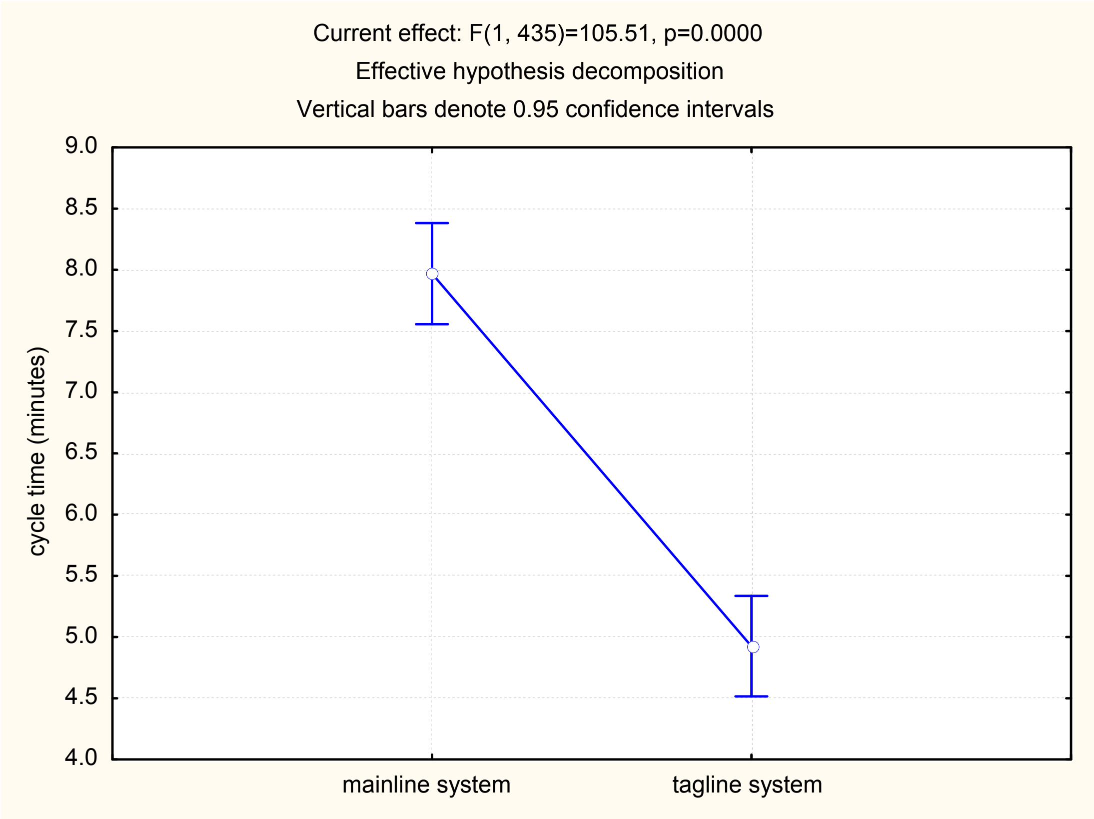


Figure 18: Cycle time of mainline and tagline systems.

There was a significant difference (p=0.001) in cycle times using the mainline and tagline systems (Figure 18). The cycle time using mainline system (7.97 minutes) was higher than the cycle time using tagline system (4.93 minutes).

Table 10: Cost of skidding using mainline and tagline systems.

System	R/m^3	R/PMH
Mainline system	22.54	695.31
Tagline system	20.21	691.14

The unit cost of operating the skidder using the mainline system significantly exceeded the unit cost of operating the skidder using the tagline system by 2.33 R/m^3.

4.3 Effect of different levels of skid trail preparation on productivity

4.3.1 A test for interaction between each of the choking systems and the three levels of skid trail preparation

Table 11: LS Means of the test of interaction between choking systems (1 - mainline system; 2 - tagline system) and the levels of skid trail preparation.

Cell No.	Strip*choking system; LS Means Current effect: F(2, 431)=.25184, p=.77749 Effective hypothesis decomposition						
	Strip	chok sys	productitvity Mean	productitvity Std.Err.	productitvity -95.00%	productitvity +95.00%	N
1	1	1	41.26	1.52	38.27	44.24	98
3	2	1	34.76	1.89	31.04	38.48	63
5	3	1	35.36	2.01	31.42	18.98	56
2	1	2	49.09	2.24	44.68	53.49	45
4	2	2	44.84	44.84	44.84	44.84	92
6	3	2	45.54	1.65	42.30	48.78	83

There was no significant interactions (p=0.777) between the two choking systems and the three levels of skid trail preparation. The effect of skid trail preparation on productivity was therefore investigated by considering each of the choking systems.

4.3.2 Effect of different levels of skid trail preparation on productivity of mainline and tagline systems

Null Hypothesis: All the three levels of skid trail preparation had the same productivity for both mainline and tagline systems.

Alternative Hypothesis: The three levels of skid trail preparation did not have the same productivity for both mainline and tagline systems.

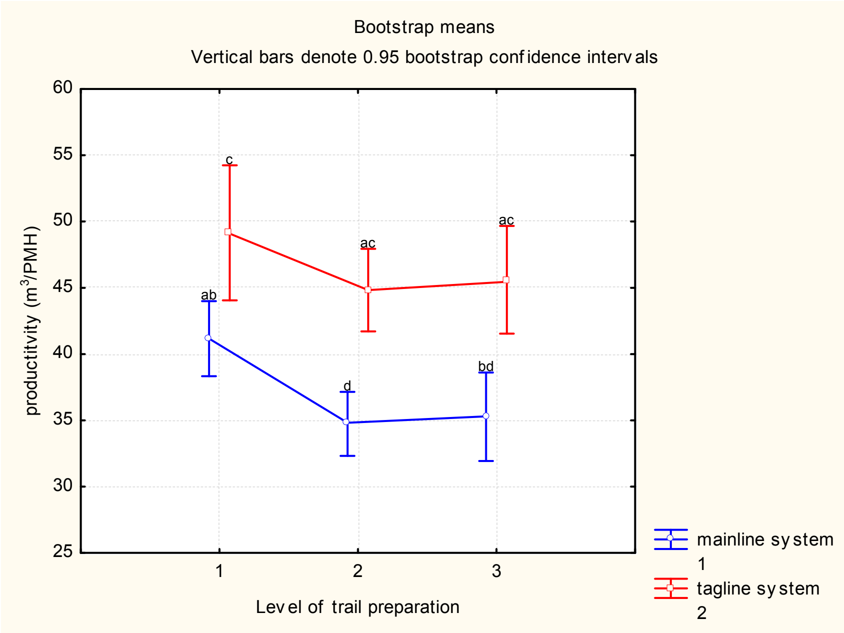


Figure 19: Effect of skid trail preparation on productivity using mainline and Tagline systems.

There was significant difference (p=0.0075) in productivity caused by the levels of skid trail preparation between levels 1 and 2 using the mainline system. There was no significant difference (p=0.1275) in productivity resulting from the levels of skid trail preparations in levels 1 and 3 using the mainline system. There was also no significant difference (p=1) in productivity resulting from the levels of skid trail preparations in levels 2 and 3 using the mainline system. There was no significant difference in productivity resulting from the three levels of skid trail preparation using the tagline system.

Table 12: Summary of productivity of choking systems (m^3/pmh).

Planning strip	Mainline method (m^3/pmh)	Tagline method (m^3/pmh)
1	41.26	49.09
2	34.76	44.84
3	35.36	45.54

4.3.3 Effect of skid trail preparation on travel loaded time

Null Hypothesis: There was no significant difference in travel loaded times among the three levels of skid trail preparation.
Alternative Hypothesis: There was a significant difference in travel loaded times among the three levels of skid trail preparation.

Table 13: Post Hoc Test showing no significant differences in travel loaded time among the strips for each of the choking systems (1 - mainline system; 2 - tagline system).

	BOOTSTRAP test; variable traveloaded time Probabilities for Post Hoc Tests							
Cell No.	Strip	choking system	{1} 1.2604	{2} .83600	{3} 1.2961	{4} .88207	{5} 1.6957	{6} .63181
1	1	1		0.11	1.00	0.05	0.31	0.00
3	2	1				0.00	0.53	0.00
5	3	1						0.00
2	1	2			0.05	1.00	0.00	0.28
4	2	2					0.00	0.00
6	3	2						

Table 13 shows that there was no significant difference in travel loaded times in the three levels of skid trail preparation using the mainline system; there was also no significant difference in travel loaded times using the tagline system. The average travel loaded distance was 63.98 m.

4.3.4 Effect of skid trail preparation on travel empty time

Null Hypothesis: There was no significant difference in travel empty times among the three levels of skid trail preparation.
Alternative Hypothesis: There was a significant difference in travel empty times among the three levels of skid trail preparation.

Table 14: Post Hoc Test showing no significant differences in travel empty times among the strips for each of the choking systems (1 - mainline system; 2 - tagline system).

Cell No.	BOOTSTRAP test; variable travel empty time Probabilities for Post Hoc Tests Strip	chok sys	{1} .68929	{2} .66444	{3} .80984	{4} .66891	{5} .86756	{6} .64699
1	1	1		1	1	1	0.65	1.00
3	2	1				1	1.00	0.89
5	3	1						0.29
2	1	2			1	1	0.49	1.00
4	2	2					0.01	1.00
6	3	2						

Table 14 shows that there was no significant difference in travel empty times in the three levels of skid trail preparation using the mainline system; there was also no significant difference in travel empty times in the three levels of skid trail preparation using the tagline system. The average travel empty distance was 66.72 m.

4.3.5 Effect of skid trail preparation on travel loaded speed

Null Hypothesis: There was no significant difference in travel loaded speed among the three levels of skid trail preparation.

Alternative Hypothesis: There was a significant difference in travel loaded speed among the three levels of skid trail preparation.

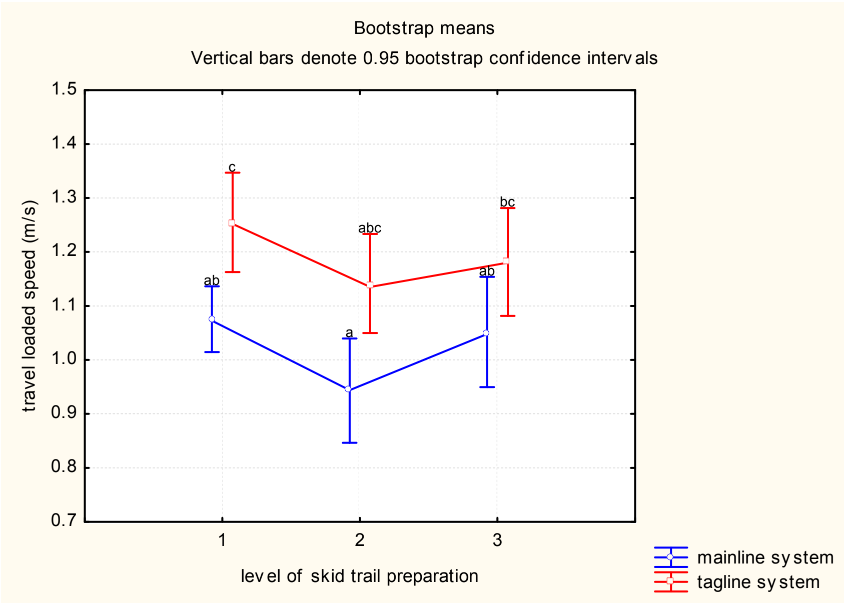


Figure 20: Effect of skid trail preparation on travel loaded speed.

There was no significant difference in travel loaded speeds among the three levels of skid trail preparation using the mainline system. There was also no significant difference in travel loaded speeds among the three levels of skid trail preparation using the tagline system as shown in Figure 20.

4.3.6 Effect of skid trail preparation on travel empty speed

Null Hypothesis: There was no significant difference in travel empty speed among the three levels of skid trail preparation.

Alternative Hypothesis: There was a significant difference in travel empty speed among the three levels of skid trail preparation.

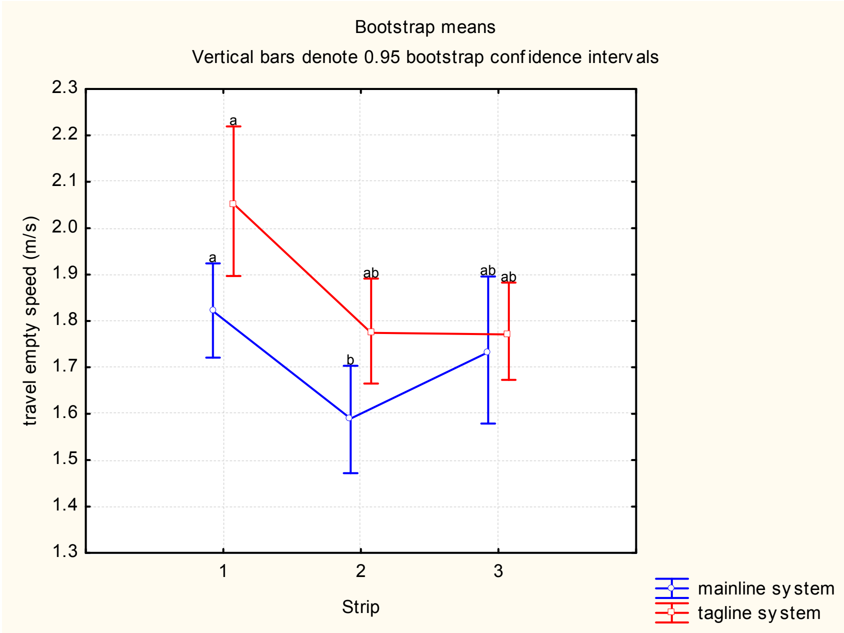


Figure 21: Effect of skid trail preparation on travel empty speed.

There was no significant difference in travel empty speeds in the three levels of skid trail preparation using the mainline system. There was also no significant difference in travel empty speeds in the three levels of skid trail preparation using the tagline system. The p-values for the tests are shown in Table 15.

Table 15: Test showing no significant differences in travel empty speeds among the strips for each of the choking systems (1 - mainline system; 2 - tagline system).

	BOOTSTRAP test; variable travel empty speed Probabilities for Post Hoc Tests							
Cell No.	Strip	chok sys	{1} 1.8220	{2} 2.0531	{3} 1.5886	{4} 1.7749	{5} 1.7314	{6} 1.7701
1	1	1		0.10	0.45	1.00	1.00	1.00
3	2	1				0.25	1.00	0.32
5	3	1						1.00
2	1	2			0.00	0.07	0.05	0.05
4	2	2					1.00	1.00
6	3	2						

4.4 Comparison of average travel loaded and travel empty speeds

Table 16: Travel speeds along the three levels of skid trail preparation.

Level of trail preparation	Travel loaded speed (m/s)	Travel empty speed (m/s)
1	1.17	1.94
2	1.04	1.68
3	1.12	1.75

Null Hypothesis: There is no significant difference in travel loaded and travel empty speeds.
Alternative Hypothesis: There is a significant difference in travel loaded and travel empty speeds.

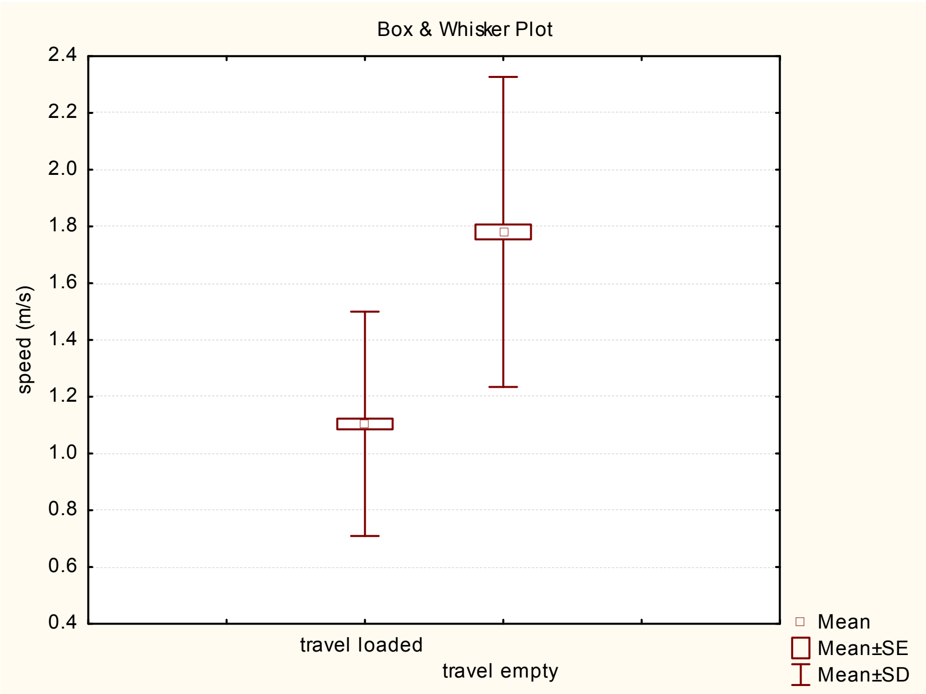


Figure 22: Comparison of travel loaded and travel empty speeds.

There is a significant difference (p=0.023) between the average travel loaded speed and the average travel empty speed (Figure 22). Average travel empty speed was 1.78m/s, this was higher than travel loaded speed which was 1.10 m/s.

4.5 Costs of trail preparation

Table 17: Cost of skid trail preparation.

Cost of felling on skid trail	-Average number of trees per skid trail = 8 -Average required time to fell & debranch a tree = 4 mins -Relaxation allowance using chainsaw = 14%= (0.14x4) = 0.56 mins -Time to fell a single tree = (4 + 0.56) = 4.56 mins -Total time to fell 8 trees = (8x4.56) = 36.48 mins -Labour rate for chainsaw operator = R 22.44/hour -Therefore 36.48 mins = (36.48 x R 22.44)/60 mins = R 13.64 - cost of operating the chainsaw (R 64.42/hour) -Therefore 36.48 mins = (36.48 x R 64.42)/60 mins = R 39.17 - Total cost = (13.64 + 39.17) = R 52.81
Cost of extraction on skid trail	-Extracting tree-lengths from a single trail = 6.44 mins - Skidder cost using mainline system = R690.41/pmh - Cost of extracting on a single skid trail = (R 690.41 X 6.44)/ 60 mins = R74.10
Cost of clearing skid trails	-Skidder blading single trail = 10 mins - Skidder cost without winching accessories = R685.52 - Cost of blading single skid trail = (R 685.52 X 10)/ 60 mins = R114.25
Cost of cutting stumps	-Time to cut each stump = 1.13 mins - Relaxation allowance 18% - Time plus relaxation allowance = 1.33 mins -Time to cut 8 stumps = 10.64 mins - Chainsaw operator cost = (R22.44/h X 10.64 mins/ 60) =R3.98 -Cost of operating chainsaw =(10.64mins x R 64.42/pmh)/60 = R 11.42 -Total cost = (3.98 +11.42) = R15.40
Cost of strip 1	-Cost of felling + cost of extraction = (52.81 + 114.25) X2 trails = R334.12
Cost of strip 2	-Cost of felling + cost of extraction = (52.81 + 114.25) X2trails = R334.12 -Cost of clearing skid trail = R74.10 X2 trails = R148.21 -Total cost of strip = R482.33
Cost of strip 3	-Total cost of strip 2 = R482.33 -Cost of cutting stumps = R15.40 X2 = R30.80 -Total cost of strip 3 = R513.13

Table 18: Summary of total cost of the various levels of skid trail preparation.

Level	Activity	Cost (R)	Total (R)
1	Felling	105.62	334.12
	Extraction (no additional preparation)	228.5	
2	Felling	105.62	482.33
	Extraction	228.5	
	Clearing trails	148.21	
3	Felling	105.62	513.13
	Extraction	228.5	
	Clearing trails	148.21	
	Stump cutting	30.80	

Table 19: Skidding cost (R/m^3) for the three levels of skid trail preparation calculated using the South African costing model.

Level	Mainline method (R/m^3)	Tagline method (R/m^3)
1	8.10	6.81
2	13.88	10.76
3	14.51	11.27

4.6 Comparing manually collected and satellite tracked time data

An analysis to determine the differences between the times recorded by manual time study and GPS tracking showed significant differences (p=0.0001) between the travel loaded times collected by manual time study and those recorded by GPS tracking. There was also a significant difference (p=0.0001) between the travel empty times recorded using manual time study and the times recorded using the GPS unit. Choking and dechoking times were not obtained by GPS tracking and were therefore not considered in this analysis.

Table 20: Method study results of the activities comprising choking in mainline system.

No	Operation	Quantity	Distance units	Time units	Comments
1	Choker chains removed from skidder	4	-	4	Four choker chains taken out of the skidder at point where it makes final stop in stump site. No distance covered, four time units each to handle a single choker chain
2	Transport chains to the position of tree-lengths	4	4	4	Transport 4 choker chains after taking out of skidder to first tree-length and then to the rest of the 3 tree-lengths. Each distance unit consuming 1 time unit.
3	Pull mainline to the choked tree-lengths	1	4	4	The single mainline is pulled from the skidder to the first tree-length, then pulled to the rest of the 3 tree-lengths. Each distance unit consuming 1 time unit.
4	Attach mainline to the pre-choked tree-lengths	4	-	4	Attach the mainline to the 4 pre-choked tree-lengths, a single time unit spent on each tree-length, distance is already covered in step 3.
5	Winch	1	1	1	Winch a single load, within single motion and time unit.

Table 21: Method study results of the activities comprising choking in tagline system.

No	Operation	Quantity	Distance (units)	Time (units)	Comments
1	Remove tagline from skidder	1	-	1	One empty tagline containing the 4 choker chains is removed from the skidder, at the point where it makes final stop at the stump site and put on the ground. A single time unit is spent.
2	Pull mainline to the tagline already Pre-choked with next load.	1	1	1	Pull the mainline within 1 time and distance units from the skidder to point of the already pre-choked tagline
3	Attach mainline to the tagline pre-choked with tree-lengths	1	-	1	Attach the mainline, to the tagline pre-choked with tree-lengths.
4	Winch	1	1	1	Winch a single load, within single distance and time units.

Table 22: Method study results of the activities comprising dechoking in mainline system.

No	Operation	Quantity	Distance (units)	Time (units)	Comments
1	Dechoke the tree-lengths	4	-	4	Four choker chains are dechoked after load is dropped by skidder at the landing. No distance is covered and four time units are spent, each on a single choker chain.
2	Re-attach loose chains to the mainline	4	-	4	Four empty choker chains are re-attached to the mainline. Four time units are spent, each on a single choker chain.
3	Winch	1	1	1	The mainline with the four empty choker chains attached is winched to the skidder. A single distance and time unit is spent.

Table 23: Method study results of the activities comprising dechoking in tagline system.

No	Operation	Quantity	Distance (units)	Time (units)	Comments
1	Detach the tagline from the winchline	1	-	1	The tagline is detached from the winchline after load is dropped by skidder at the landing. No distance is covered and a single time unit is spent for the operation.
2	Re-attach empty tagline	1	-	1	An empty tagline is then re-attached to the winch line. A single time unit is spent for the operation.
3	Winch	1	1	1	The winch line to which the empty tagline is attached is winched to the skidder in 1 motion using a 1 time unit.

Table 24: The summary of the choking and dechoking activities.

Description	Mainline system		Tagline system	
	choking	dechoking	Choking	dechoking
operation	14	9	4	3
distances	9	1	2	1
time	17	9	4	3
Total	**40**	**19**	**10**	**7**
Grand total	**59**		**17**	

5 DISCUSSION

The three compartments were adjacent and their stand and site conditions were homogeneous. The stand densities were not significantly different; the compartment records showed that the compartments had been subjected to the same silvicultural treatments from the time of establishment. This explains why there was no significant difference in tree sizes in the three compartments. Details of espacement at the time of establishment were not available in the compartment records but the records showed that the compartments had undergone two thinning regimes at age 11 and 16 respectively. As a result of the similar ages and composition, the compartments produced the same total volume of wood. Similarities in stand and site conditions provided the statistical validity for comparing the various efficiency indicators including productivity (m^3/pmh), element times, extraction distances and extraction speeds obtained from the three compartments.

The roadside landings were located on the lower side of the three compartments for downhill skidding. This was planned to in order to increase efficiency of the operations by taking advantage of down hill skidding which is more efficient compared to uphill skidding as observed by Stenzel *et al.,* (1985) and MacDonald (1999). The skidder travelled down the gentle slope while loaded and up the slope while unloaded. The results showed no significant difference between an average travel loaded and travel empty speeds of 1.10 m/s and 1.78 m/s, respectively. Had the skidder travelled up the slope while loaded, there is a chance that at +10% grade, up hill travel could have impacted negatively on productivity and costs of operations by reducing travel loaded speeds as observed by Stenzel *et al.,* (1985) and MacDonald (1999). It was therefore more efficient to plan for down hill travel while loaded and uphill travel while empty so as to take advantage of the effect of gravity to enhance travel loaded speeds.

The effect of butt-first or top-first skidding did not have an impact on productivity because there was not a single strip within the compartments in which the tree-lengths were all extracted from the same end. There was often a mixture of butt and top-first extraction per cycle that was as a result of some trees falling opposite to the felling direction. The trees fell opposite to the felling direction either because they leaned in that direction or because of inadequate skills by the fallers. Because of the mix of top-first and butt-first skidding in the cycles, it was not possibly to determine with accuracy the effect of butt or top-first skidding on productivity.

5.1 Planning in the planning strip

The operations in the control strip were to be carried out using the normal harvesting operations undertaken by the harvesting team which did not follow a harvesting plan. The operations in the control strip were characterised by haphazard felling and random travel by the skidder. There was neither directional felling nor any form of skid trail preparation. The routes taken by the skidder were characterised by obstacles in the form of rocks, boulders, stumps and previously felled tree stems. The method used to hold the load during extraction (i.e. use of a single set of choker chains) was inefficient.

Studies within the literature (Bromley, 1969; Conway, 1979; Spiers, 1986; Brink *et al*., 1995; FAO, 1998a; MacDonald, 1999; Pulkki, 2003), have pointed at haphazard felling, use of a single set of choker chains and lack of designated skid trails as main causes of inefficiency within a harvesting system. During the implementation of the study in compartments M6, M7a and M7b, improved and planned operations were implemented in the planning strips. The results of the control strips and the planning strips were to be compared in order to quantify the benefits of introducing a well laid out plan of operations.

Unfortunately the results of the control strip were distorted by the introduction of the plan of activities in the planning strips. This resulted into the operations in the control strip imitating exactly the plan of activities in the planning strips. Objective 1, which was aimed at quantifying the benefits of an operational harvesting plan by comparing the productivity and cost results of the planning strips and control strips was therefore not realised. Nevertheless, an operational harvesting plan as put forward by Spiers (1986), Brink *et al*. (1995), FAO (1998a) and Pulkki (2003), is an important first step for ensuring smooth flow of operations, improved productivity, and cost and risk minimization.

The improved and planned operations in the planning strips were aimed at enhancing efficiency of felling, choking and dechoking and extraction from the stump site to the landing. Felling was improved by the introduction of directional felling in the planning strips. The trees in the planning strips were felled directionally to minimize the losses in productivity suspected to be associated with by haphazard felling according to Bromley (1969), Conway (1979), MacDonald, (1999), and Spiers (1986). It is expected that when trees are haphazardly felled, the choking times can be prolonged due to the difficulty in assembling the randomly lying tree-lengths. It was observed in the planning strips that directional felling enhanced efficiency of choking by:

1) Minimizing the time spent in locating the end of tree-lengths to be choked. Haphazardly felled trees lie randomly infield often covered by logging debris, making it difficult to locate the position of the tree-length top or butt ends. With directional felling the tree-lengths fall closer together and are more or less orientated parallel to each other making it easier and faster to locate the ends of the tree-lengths. The movements between tree-lengths and time spent in pulling the winch line to randomly lying tree-lengths are thus reduced.

2) Directional felling eliminates the time spent by the skidder manoeuvring infield before picking up the entire load. Often when trees are felled randomly some lie far apart prompting the skidder to manoeuvre its way closer to each of them. The time spent manoeuvring can be reduced or

eliminated by orienting the trees in a single direction through directional felling.

3) Directional felling reduces the winching time that is extended when the trees are felled haphazardly. Extended winching time is due to additional time of accumulating the tree-lengths by aligning them to the winching direction before winching takes place. The tree-lengths have to be accumulated using the winch line because they are hooked onto the winch line while facing different direction as a result of haphazard felling. When trees are aligned in one direction through directional felling the ends of tree-lengths are not far separated and do not have to be accumulated using the winch line. Instead the load aligned in the winching direction through directional felling is winched directly to the skidder after choking. The time spent in accumulating the tree-lengths with the winch line is thus eliminated.

Losses in wood volume due to occasional breakages that occur during winching as a result of haphazard felling, observed by Andersson and Young (1998) can be greatly reduced through directional felling. Breakages to the tree-lengths occur when the tree-lengths that are being accumulated using the winch line, encounter or get lodged between obstacles such as stumps, rocks and other tree-lengths. In the event of breakages, the process of choking may need to be repeated to capture the broken pieces, directional felling reduces the time loss associated with the breakages.

Random travel observed in the pilot study was improved by construction of designated skid trails in the planning strips. Confining the skidder to the designated skid trails is assumed to have increased efficiency of extraction due to the reasonably straight and short routes (Figure 23) connecting the stump site and the landing.

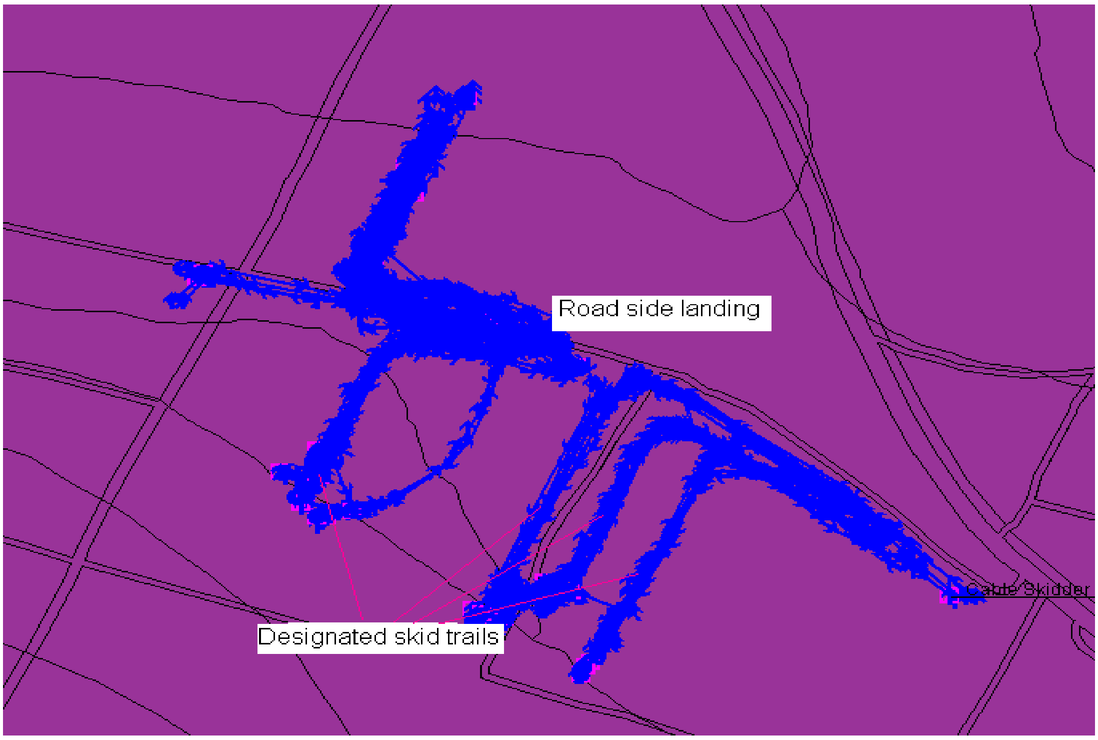


Figure 23: An extract from GPS tracking data showing travel pattern of the skidder in the planning blocks.

The designated skid trails controlled the skidding distances limiting them to an average extraction distance of 66 m. The travel loaded and travel empty distances were not significantly different. By using designated skid trails the skidder travelled the same distance while loaded and while unloaded. The chances of lost productivity and increased skidding costs associated with unnecessary travel were thus minimized. The designated skid trails were cleared of obstacles including felled trees, stones and logs minimizing hindrance to the movement of the skidder.

The use of designated skid trails helped minimise damage to the soils during skidding. The skidder was confined to the designated trails, concentrating compaction and erosion within a smaller area occupied by the designated skid trails (Figure 23). This is unlike in random travel in which damage to the soil could be extended to a larger compartment area. Extensive damage to the compartment area can potentially affect establishment of the next crop of trees. The use of designated skid trails as also observed by FAO (1999) is therefore important in ensuring sustainability of future forest growth.

5.2 Evaluating productivity of tagline and mainline systems

Choking and dechoking was done in the planning strips using mainline system with a two sets of choker chains and a tagline system. This was an improvement from the use of mainline system with a single set of choker chains in the control strip. The use of mainline system with two sets of choker chains can significantly increase productivity of operations by reducing the choking time. Two sets of choker chains allow pre-choking to be done while the skidder is travelling to the landing. Pre-choking cannot be done using a single set of choker chains. With a single set of choker chains the choker setters have to wait for the skidder to return infield before they can start with the choking process. The absence of pre-choking can prolong the choking time considerably. The length of choking times can be minimised by pre-choking made possible by the use of two sets of choker chains.

Productivity of tagline system was compared with the productivity of mainline system with two sets of choker chains on a productivity per hour basis within the planning strips. The average productivity of the tagline system (46.0 m^3/pmh) exceeded that of the mainline system (37.8 m^3/h) by 26%. The difference in productivity of mainline and tagline systems were investigated at the terminal points of choking and dechoking at which the handling procedures differed. The differences were deemed to have occurred at the terminal points because the conditions for travel along the designated skid trails were the same for both systems. There was no significant difference in travel loaded and travel empty times of both systems and there was also no significant difference in the extraction distances in the three compartments. When the extraction distances in the three compartments showed no significant differences, it followed that there were no difference in extraction distances between skid trails as well. Statistically if the group effects (in this case the average extraction distance per compartment) do not show significant differences, then the main effects (extraction distances per skid trail) cannot be considered to be different. The extraction distances did not therefore contribute to a significant variation in productivity in the three compartments.

Productivity is sensitive to extraction distance. A significant variation in extraction distances within or between the compartments would have either reduced productivity at longer extraction distances or increased it at shorter extraction distances according to the literature. This would have however, relied upon the skidder driving at the same speed and carrying the same payload in all the skid trails.

A method study examination of the choking operation revealed that the tagline system reduced the number of activities comprising choking by 71% as compared to the activities in mainline system. A total of 14 activities were observed using the mainline system while with the tagline system only a total of 4 activities were observed. Method study results showed that the ease of hooking the tagline already pre-choked with the load, to the winch line at the stump site, quickened the choking process. This was unlike in the mainline system where it required each of the pre-choked tree-lengths to be hooked to the mainline.

Consequently the choking time in using tagline system was reduced by 39% from an average of 3.47 minutes using the mainline system to an average of 2.13 minutes. When choking using the mainline system, the choker setters have to move from one pre-choked tree-length to another in order to hook the entire load to the mainline. Hooking the tagline already pre-choked with the load to the mainline eliminates these movements. It was observed that as a result of eliminating the movements (Table 24), the distances units covered during choking using tagline systems is reduced to 2 from 9 distance units using the mainline systems. The times associated with the movements were thus also reduced resulting in a reduction in cycle times.

As compared to the mainline system, the tagline system reduced the number of activities comprising dechoking from a total of 19 to a total of 7 (Table 24). Dechoking with the tagline system involved a single activity to detach the tagline bearing the load from the winchline and another single activity to reattach an empty tagline to the winchline before winching back to the skidder. The unhooking of the individual tree-lengths from the tagline is done when the skidder is travelling back infield. On other hand dechoking using the mainline system involved unhooking each of the four tree-lengths comprising the load from the mainline. It also involved reattaching each of the four empty choker chains to the mainline before being winched back to the skidder. Consequently using a tagline system reduced dechoking time by 40% from an average dechoking time of 2.05 minutes using mainline system to an average dechoking time of 1.24 minutes. Reducing the number of activities required in dechoking and the times to perform them contributed to shorter cycle times in the tagline system.

Taglines were effective in reducing the terminal times and consequently shortening the cycle times. The average cycle time using mainline system (7.97 minutes) exceeded average cycle time using tagline system (4.93 minutes) by 62%. Reduced cycle times was the main contributor to the higher productivity observed in tagline system compared to the mainline system. The tagline system thus provides an easier and efficient method of choking compared to the mainline system.

Tagline systems are more expensive to install compared to mainline systems. The difference in implementation costs between the two systems is restricted to the costs of equipping the skidder with the accessories required in holding the tree-lengths. The high cost of using tagline systems is due to the extra costs incurred in acquiring the taglines (a single pair containing three taglines) and additional choker chains required for each tagline. It cost approximately R22 400 to equip the skidder with the tagline system. This comprised the cost of the winch line cable, an additional winch line cable from which the taglines were cut off, and a set of between 12 and 14 choker chains. It cost R19 172 to equip the skidder with the mainline system with two sets of choker chains. The cost comprised those of acquiring the winch line and the two sets of choker chains.

The return of tagline system in terms of productivity (46.0 m^3/pmh) is much higher compared to the mainline system (37.8 m^3/pmh). The higher costs of using the tagline system compared to mainline system is thus offset by the higher productivity realised using the tagline system. This makes tagline system more cost effective compared to mainline systems. The unit production cost of operating the skidder using the tagline system (R20.21/m^3) was 10% less than the unit production cost of operating the skidder using the mainline system (R22.54/m^3).

5.3 Determining an optimal level of skid trail preparation

In an attempt to determine an optimal skid trail surface conditions for highest skidding efficiency, the skid trails were prepared to three surface conditions. The results (productivity and speeds) of operating in the three conditions were compared. The details of the three surface conditions are as mentioned in the methodology of this thesis.

The removal of logging residue comprising of a layer of interwoven small diameter branch wood and stem material < 7 cm, tree tops and pine needles, from the surface of the skid trail did not significantly increase travel speeds of the skidder as expected. Along the skid trails on which the logging residue was removed the skidder travelled at 1.04 m/s while loaded and 1.68 m/s while unloaded. Along the skid trials on which the residue were not removed the skidder travelled at 1.17 m/s while loaded, and 1.94 m/s while unloaded. The results of travel speeds correspond with those of travel times. There were no significant differences in average travel times along the skid trails on which the logging residue were removed and along the skid trails on which they were not removed. The figures of travel speeds suggest that the removal of logging residue could have reduced the travel speeds instead of increasing them due to reduced traction needed to enhance fast movement. However, this could not be statistically proven as there was no significant difference in travel speeds between the trails in which the logging residue was removed and those in which the logging residue was not removed.

Olsen and Gibbons (1983) noted that the effect of loss of traction is more pronounced in wet weather. This study was conducted in dry weather conditions where the ground was dry and suitable for skidding. This can explain why the difference in travel speeds between the trails in which the logging residue was removed and those in which the logging residue was not removed were not significantly different. Continuous skidding on wet sections where slash material has been removed can however, slow down extraction, reduce payload, and increase cycle time. Operating in wet conditions can also make the trails impassable thus causing delays and lowering productivity of operations. The presence of slash material on skid trails under wet weather conditions is therefore important in ensuring productivity of operations.

There was no productivity gain associated with the costs of clearing the trails of logging residue. It would be important to leave logging residue on the surface of skid trails to enhance traction on gently sloping forest tracts. Removal of logging residue and/or stones and boulders from the skid trails is beneficial on more than 20% slope as stated by Dennis (2005).

The stumps had been cut in order to test if they were obstacles in the way of the skidder. The findings revealed that the presence of stumps along the skid trails did not lower travel speeds. The skidder travelled at 1.12 m/s while loaded and 1.75 m/s while empty. These speeds did not have a significant difference with 1.04 m/s loaded and 1.68 m/s empty where the stumps were present but residue removed and 1.17 m/s loaded and 1.94 m/s empty where both residue and stumps were present. There were also no significant differences between the travel times recorded on the skid trails where the stumps were cut and those recorded where the stumps had not been cut.

Fresh stumps can cause impediments to the movement of the skidder when they occur frequently or when the skidder does not follow a defined extraction path. Frequently occurring stumps can cause breaks in motion, reduce travel speeds, increase cycle times, reduce productivity and increase skidding cost.

According to the South African terrain classification system (Erasmus, 1994), stumps are not counted as obstacles in descriptive terrain classification because they do not permanently remain on the terrain but get degraded over time. The presence of stumps was however, an important consideration in this study because the study was done immediately after felling, when the stumps were fresh and could have formed a formidable obstacle to the movement of the skidder.

The stumps which averaged at a height of 25 – 30 cm, were sparsely distributed and isolated along the skid trails. Each skid trail had an average of eight stumps spaced at an average distance of 16 m along the approximately 170 m skid trail length. The compartments had undergone two thinnings prior to harvesting which was responsible for the wider gaps between the stumps. The isolation of the stumps along the skid trails minimised the interference effect of the stumps on the movement of the skidder because the skidder operator could see the stumps from a distance and avoid them. The operator manoeuvred past the stumps by driving past them without the wheels of the skidder coming into contact with them. The wheeled skidder (as with all custom built skidders) in use had sufficient ground clearance that enabled it to straddle the stumps on its path without any hindrance. Confining the skidder to the designated skid trails helped to ensure the impact of the stumps was not felt as there were only a few stumps on the skid trails. In an area with frequently occurring stumps, it would be difficult to manoeuvre around all of them and it would be preferable to cut them down to minimize hindrance to skidder mobility.

Improvements to the surface of skid trails were accompanied by increased skid trail construction costs. Planning strip 1 in which the logging residue was not removed from the trails nor were the stumps cut down had the lowest skid trial construction costs. The costs involved those of felling the trees standing along the demarcated location of the skid trails and then extracting the trees to the roadside. It cost a total of R334.12 to construct the two skid trails in planning strip 1. There was additional cost of clearing the logging residue from the skid trails of in planning strip 2. It cost R148.21 to clear both the skid trails of logging residue. This in addition to felling and extraction cost of trees along the skid trails added to a total cost of R482.33 to construct the two skid trails in planning strip 2. The cost of constructing the two skid trials in planning strip 3 was R513.13. Planning strip 3 was an improvement of planning strip 2 and the increased costs compared to planning strip 2 were due to the additional cost of cutting down the stumps. It cost R30.80 to cut the stumps in the two skid trails.

The costs were compared to the productivity emanating from the planning strips. Planning strip 1 had the lowest production costs of R8.10/m^3 using the mainline system and R6.81/m^3 using the tagline system. Since there was no significant difference in productivity in the three planning strips, the lower cost in planning strip 1 are attributed to lower skid trail construction costs compared to planning strips 2 and 3. The production costs in planning strips 2 was R13.88/m^3 using the mainline system and R10.76/m^3 using the tagline system, while those in strip 3 were R14.51/m^3 using the mainline system and R11.27/m^3 using the tagline system.

The level of skid trail preparation in planning strip 1 with the lowest skid trail construction costs was best for adoption under the prevailing stand conditions. The additional preparation to the skid trails in strips 2 and 3 did not result in increased extraction speeds that could have led to shorter travel times, shorter cycle times and increased level of productivity. The high costs per unit wood volume associated with the trail preparatory practices in planning strips 2 and 3 rendered them unnecessary as they did not bring back expected dividends in terms of reduced costs/m^3. Instead planning strip 1 recorded the lowest production cost per unit wood volume. It was therefore not necessary to proceed with preparation of the skid trails by removal of slash material and cutting of stumps to near the ground level.

A plan of primary extraction routes for use with a wheeled cable skidder should therefore not be extended to include cutting down of stumps or clearing skid trails of logging residues like leaves, small branches and tops. Unless there is need for further improvement, this study has found that the skid trails to be used by a wheeled cable skidder should be prepared by demarcation of the skid trails, felling and clearing of trees and other vegetation standing along them and removal of heavy debris. Heavy debris in the form of thick diameter branches, large diameter non-saleable logs and tree tops that can impede movement of the skidder should be removed from the skid trail if possible to create a uniform running surface free of large, impassable obstacles. In effect the skidder itself could accomplish this with his decking blade on the first entry to the skidding area.

5.4 Combining of manual time study and GPS tracking

Skidding cycle times used for productivity and cost calculations comprised of choking and dechoking times obtained manually and travel loaded and travel empty times obtained via GPS tracking. The reason for combining GPS and manual techniques of data collection was to obtain all the relevant information and facts from both manually performed and tasks and those done by the skidder. The availability of relevant information from the system as stated by Richard (1984), Van Daele (2000), Anton and Tomislav, (2004) and Nurminen *et al*. (2006) would then guide decision making aimed at improving the level of efficiency of the operations.

Time study was used to measure choking and dechoking times while method study was used to systematically and critically examine the steps and procedures in carrying out choking and dechoking. The manual methods were advantageous in gathering information aimed at improving the choking and dechoking operations compared to GPS tracking. GPS tracked data provides information on the time spent to do choking or dechoking, but does not give detail breakdown of all the activities involved in conducting the terminal operations. This is because choking and dechoking operations are performed externally by manual labour and not by the skidder onto which the GPS device is installed.

During the choking and dechoking operations, when the skidder is parked, the GPS points are recorded in the same location within the event map. An analysis of the recorded points using fundamental events such as stop travel and start travel is used to provide information on time spent performing the terminal activities. Other than time data, no further details on choking and dechoking is provided by GPS tracked data as already mentioned in the previous paragraph. Method study and time study were used to provide details of all the activities comprising choking and dechoking and their associated times (Table 20; 21; 22 & 23). This enabled identification of activities that needed to be eliminated, shortened or done with a different method in order to improve efficiency of chocking and dechoking operations. The result after the necessary improvements was a decrease in choking and dechoking times recorded through GPS tracking by 39% and 40% respectively as discussed in section 5.2.

On the other hand GPS-derived data was useful in providing detailed information on travel loaded and travel empty elements. The path of the machine was filtered from the event-map and a series of fundamental events used to describe the machines movement along the skid trail. The specific events included start travel, stop travel, travel loaded, travel empty, and idling at the stump site or landing. The GPS points linking these events were replayed repeatedly and analysed to obtain travel times, travel speeds and travel distances.

GPS tracking was advantageous over manual data collection in obtaining travel information. Only travel times could be obtained using time study by recording the start and stop times of every travel phase. Obtaining travel distance manually meant an additional person and equipment to follow the skidder and measure the distance covered during skidding. Obtaining travel speeds would have involved additional time in calculating the speeds in every cycle. GPS tracking thus provided an easy way of simultaneously recording information on travel times, speeds and extraction distances compared to manual time and method study.

Travel loaded and travel empty times had also been recorded manually and when these were compared with those obtained by GPS tracking, the correspondence in all the cycles was close. The difference averaged less than 12 % (about 0.12 s) for travel loaded and 20% (about 0.67 s) for travel empty. These differences were however, significant at $\alpha = 0.05$ with the manually recorded time data exceeding time data obtained via GPS tracking.

Time study recorded the travel times between the break points of start travel and stop travel for both loaded and empty trips. Recording the times relied on the use of a radio link between the two time study persons, at the landing and the stump site. There is likelihood of error in recording the exact time of start travel or stop travel when from one end one cannot see the skidder and rely fully on the radio communication. In the event that both time study persons miss events such as the deviation from normal path, abrupt stops or other miscellaneous time spent along the skid trial, an error of an additional extra time is included in the recorded event time. However with GPS tracking, any deviations from the normal path, abrupt stops or trail work that would have been missed by people on the ground are identified by repeatedly analysing the GPS line file. The miscellaneous times are then subtracted from the total travel time to obtain the exact event times. GPS recorded data therefore provided a much more detailed view of the skidders activities along the skid trails. This can explain the reason why the manually collected time data exceeded the GPS tracked time data.

The GPS device was programmed to record data at 10 s intervals. A study done by Robert (2002) to compare the effectiveness of data recorded at 1 and 5 s intervals showed a difference in the number of recorded points with the number of points increasing drastically at shorter timing intervals. However, the increased number of recorded points had no significant benefit in terms of providing additional information when compared to the points obtained at 5 s intervals. The study noted a difficulty in identifying the break points within certain elements at shorter timing intervals due to increased number of points. The increased number of points also increased the time to analyse the line file created by the GPS thus also increasing the time to analyse the data and the difficulty in pinpointing transitions between the tasks. Statistically the I sec time interval was equally as accurate as the 5 sec time interval for travel empty and travel loaded and total cycle time. The 10 s time interval selected for this study was therefore sufficient to precisely provide required information with less number of recorded points. The fewer number of points as compared to for instance if a 5 s or 1s timing interval was used, allowed easier and faster analysis of the recorded GPS points. The use of GPS tracking also provided some other advantages, including:

- Reducing the number of people required to conduct the data collection. After the installation of the GPS device onto the skidder, it took one person to program the GPS receiver to collect line data. The same person downloaded the data recorded by the device at the end of every shift.
- The amount of time needed to collect the data was reduced, as the GPS device recorded all the needed information simultaneously.
- The safety of the operation was enhanced by eliminating the danger of a person having to collect data next to the machine while it is in operation.
- The data obtained was accurate enough and not subject to human error
- The costs associated with conducting productivity studies were also reduced since the number of people required to conduct the time study is reduced to one and equipment requirement is reduced to the obtaining the GPS device.

There were a total of 437 skid cycles timed using manual time study. All of these cycles were also identified from GPS tracked data. This shows that GPS tracking bears 100% chance of correctly identifying skid cycles recorded using manual time study in a clear-cut forest harvesting operation. A combination of manually collected data and GPS tracked data provided a more detailed and accurate information about the work system. The more facts available from a work system the better the chance of formulating plans for highest operational efficiency. Combining manual and GPS data collection methods is more effective in semi-mechanised harvesting systems. The effectiveness of combining GPS derived data and manual data can however not be guaranteed in all circumstances. This is because of GPS signal disturbance that can result in positional errors when using GPS to collect scientific data. The disturbance of GPS signals can occur due to various reasons including atmospheric and ionospheric delays, deflection of the signal from forest canopies and the geometry of the satellite constellation that can also affect the signal quality. It is important to take precaution by using Differential GPS (DGPS) to improve the position accuracy of GPS receivers.

6 Conclusions and recommendations

6.1 Conclusion

It was not possible to quantify the productivity gains (m^3/pmh) and/or cost savings (R/m^3) associated with the implementation of an operational harvesting plan. This is because the results of the control strip, in which the unplanned operations characterised by haphazard felling, random travel by the skidder and use of mainline system with a single set of choker chains, were distorted. The trees in the control strip were felled directionally and the skidder followed dedicated paths during extraction, the paths were not prepared but turned into skid trails after the skidder ran over them a few times. Data for unplanned operations similar to those carried out by the harvesting team as prescribed by the management of the company could not therefore be obtained; the similarities between the control and planning strips made it impossible to quantify the benefits of implementing an operational harvesting plan in the planning strips.

The average productivity of the tagline system exceeded that of the mainline system by 26%. The tagline system was more productive than the mainline system due to its shorter terminal times compared to the mainline system. The shorter terminal times resulted in shorter cycle times which directly contributed to the high productivity of the tagline system compared to the mainline system.

Tagline systems are more expensive to install compared to mainline systems due to the extra costs incurred in acquiring the taglines and additional choker chains required for each tagline. However, the high productivity of tagline system compared to the mainline system offsets the higher costs of using the tagline system. The unit production cost of operating the skidder using the tagline system (20.21 R/m^3) was 10% less than the unit production cost of operating the skidder using the mainline system (22.54 R/m^3). The tagline system is therefore a faster, more efficient and cost effective method of choking compared to the mainline system.

There was no productivity gain associated with the costs of clearing the trails of logging residue nor cutting down the stumps to as near the ground level as possible. The removal of logging residue from the surface of the skid trail and cutting down of stumps along the skid trails did not reduce travel times of the skidder as expected. It was therefore not necessary to neither remove the logging residue from the surface of the skid trails nor cut down the stumps. Instead, the logging residues should have been left on the surface of the skid trails to enhance traction.

A plan of primary extraction routes for use with a wheeled cable skidder should not be extended to include clearing of logging residue nor cutting down of stumps. Unless there is need for further improvement, the skid trails to be used by a wheeled cable skidder should be prepared by demarcation of the skid trails, felling and clearing of trees and other vegetation standing along them and removal of heavy debris. The costs of clearing the skid trails of logging debris and cutting of stumps should be avoided on even ground surfaces with minimum obstacles.

The aim of using both time study and GPS tracking was to obtain detailed and accurate information from the harvesting system. The findings showed that GPS tracking had 100% chance of correctly identifying skid cycles recorded using manual time study in a clear-cut forest harvesting operation. Manual data collection entailing time and method study was consequently used effectively in measuring and recording information at the terminal points (choking and dechoking) while GPS tracking was used to record all the details of travel along the skid trail (travel loaded and travel empty). Data from manual and GPS tracking comprised the skid cycle used in analyzing system efficiency.

A combination of manual data collection and GPS tracking provides more accurate and detailed information useful in system analysis. This is particularly so for semi-mechanised harvesting operations so that manual data collection is used for manually performed operations and GPS tracking is used to gather spatial data on operations conducted with the harvesting machine.

6.2 Recommendations

There is need to quantify the value of implementing an operational harvesting plan in terms of productivity gains (m^3/pmh) and cost savings (R/m^3). This will provide the forest harvesting companies and contractors in South Africa with vital information on the importance of implementing operational harvesting plans. Implementation of the plans could potentially result in high returns on investment that will encourage sustainability of the businesses. The methodology adopted in this study is suitable for the pursuit of such an objective however; the control operations should be carried out before introduction of the improved plan of operations. This will prevent chances of distortion of data experienced in this study.

Semi-mechanised forest harvesting operations in South Africa using a cable skidder should adopt the use the tagline system rather than the commonly used mainline system. This study has proven tagline systems to be a faster, efficient and cost effective method of choking compared to the mainline system.

Continuous improvement is an important prerequisite for maintaining sustainability of forest harvesting business. To continually improve a system there is a need to continuously obtain detailed information about the system. This information is important in determining where improvements are most vital like areas in which the operations slows down, or where time and resources are being wasted. Appropriate improvements action is taken once the need for improvement has been identified. Both time study, method study and GPS tracking are proven methods of gathering information from a forest harvesting system. A combination of the manual data collection and GPS tracking is more effective in gathering information from a semi-mechanised harvesting system as already mentioned in the conclusion. Future researchers should therefore consider the use of both systems in collecting information from semi-mechanised systems aimed at improvement of operations.

7 References

1. Andersson, B. 1994. Cut-to-length and tree-length harvesting systems in central Alberta: A comparison. Tech. Rept. No. TR-108. FERIC. Saint-Jean, Pointe-Claire, QC, Canada. 32 pp.
2. Andersson, B. & Young, G. 1998. *Harvesting coastal second-growth forests: summary of harvesting systems performance*. FERIC Technical report – 120.
3. Anton, S. & Tomislav, P. 2004. Skidding of Fir Roundwood by Timberjack 240C from Selective Forests of Gorski Kotar. *Croatian Journal of Forest Engineering* 26.
4. APA. 1998. *Timber Harvesting.* Fourth edition. American Pulp wood Association. Danville, Illinois: The Interstate Printers & Publishers.
5. Armstrong, S. & Inglis, C.J. 2000. RIL for real: introducing reduced impact logging techniques into a commercial forestry operation in Guyana. *International Forestry Review,* 2(1): 17-23.
6. Bengt, B., Gardh, R. & Lindgren, P. 1984. *Work planning and Cutting Methods*. Spanga, Sweden: Skogsarbeten.
7. Blundell, M.W. 1987. *Environmental constraints on forest harvesting*. Proceedings of a seminar on environmentally sound forest roads and transport. Sianaia, Romania, 17 – 22June 1987. IAHS Publication No. 159, pp.31 – 39.
8. Brink, M. & Kellog, L.D. 2000. *Planning the Forest Engineering Value Chain – a system approach*.. p. 275-284 In: South African Forestry Handbook. Southern African Institute of Forestry. V&R Printers. Pretoria, South Africa.
9. Bromley, W.S. (*ed.*). 1969. *Pulpwood Production* 2nd edition. Illinois: Interstate Printers & Publishers.
10. Chapman, C. 2008. Adapt or die – the forestry industry is changing. *South African Forestry Magazine,* January/February 2008: 2.
11. Conway, S. 1979. *Timber Cutting practices*. San Francisco, CA: Miller Freeman Inc.

12. Darche, M.H. & Forgues, I. 1998. *Modes of GPS Positioning: Introduction and Application in Forestry*. FERIC Technical note -277.
13. Dave, B. 1996. *Two- stage logging to improve logging system performance*. LIRO Report N0.22; vol.21.
14. Davison, A.C. & Hinkley, D.V. 1997. *Bootstrap Methods and their Application*. Cambridge University Press: New York.
15. De La Borde, R.M. 1992. *Timber harvesting Manual*. Institute for Commercial Forestry Research, Pietermaritzburg, South Africa.
16. Dennis, L. 2005. *Foresters Field Handbook*. Colorado State University Bulletin no. XCM-185, 2005.
17. Dobson, D. 2008. Challenges of translating Charter ideals into practice. *South African Forestry Magazine,* March/April 2008: 43 - 44.
18. Egan, A.F. 1999. Residual stand damage after shovel logging and conventional ground skidding in an Appalachian hardwood stand. Forest Prod. J. 49(6):88-92.
19. Elvar, T.N. 1986. *Kruskal-Wallis test: BASIC computer program to perform nonparametric one-way analysis of variance and multiple comparisons on ranks of several independent samples.* Department of Clinical Chemistry, Karolinska Hospital, S-104 01 Stockholm, Sweden
20. Erasmus, D. 1994. *National Terrain Classification Systems for Forestry*. Institute for Commercial Forestry Research, Pietermaritzburg, South Africa, Bulletin Series 684/3/3.
21. FAO. 1998a. Forest Harvesting Planning. *Seventeenth session of the Asia-Pacific Forestry Commission (APFC).* Indonesia, Yogyakarta *February 1998*. Available at: http://www.fao.org/DOCREP/004/AC142E/ac142e09.htm#TopOfPage. [2009, May 19].
22. FAO. 1998b. *Commercial timber harvesting in the natural forests of Mozambique.* Available at: http://www.fao.org/docrep/004/Y3061E/y3061e01.htm#TopOfPage. [2008, September 30].
23. FAO. 1999. *Code of Practice for Forest Harvesting in Asia-Pacific.* RAP Publication: 1999/12. Food and Agriculture Organization of the

United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand.

24. Favreau, J. & Gingras, J.F. 1998. *An analysis of harvesting costs in eastern Canada*. FERIC Special Report -129.
25. Favreau, J. & Legere, G. 1999. *An analysis of harvesting costs in mixed wood forest.* FERIC Technical Note -284.
26. FESA, 1999. *Guidelines for Forest Engineering Practices in South Africa*. Forest Engineering South Africa, Pretoria, South Africa.
27. Frank, G. 1985. *A Primer for Timber Harvesting EB1316.* Pullman, Washington: Washington State University.
28. George, T. 1992. *Harvesting Forest Products*. Thessaloniki, Greece: Stobart Davies ltd.
29. Gingras, J.F. 1994. A comparison of full-tree versus cut-to-length systems in the Manitoba model forest. SR-92. Forest Eng. Inst. of Canada, Pointe-Claire, Quebec, Canada. 16 pp.
30. Hamilton, P.S. 1999. *Clearcuts, Shelterwood cuts, and Selection cuts in the Turkery lakes watershed*. FERIC Technical Note -295.
31. Hendrison, J. 1989. *Damage-controlled logging in managed tropical rain forests in Suriname.* Series on the Ecology and Management of Tropical Rain Forests in Suriname, Wageningen Agricultural University, Netherlands.
32. Hogg, G.A., Krieg, B., Ackerman, P.A. & Längin, D.W. In-print. Harvesting System and Equipment Costing. In Längin, D.W. & Ackerman P.A. (eds.). Ground Based Harvesting Handbook. FESA Publication. Pp88.
33. Holmes, T.P., Blate, G.M., Zweede, J.C., Pereira, R., Jr., Barreto, P, Boltz, F. & Bauch, R. 2000. *Financial costs and benefits of reduced impact logging in the Eastern Amazon.* Tropical Forest Foundation, Alexandria, Virginia.http://www.tropicalforestfoundation.org/costbenefits.html
34. Jen˝o, R., Ildikó, Z. & Lajos, R. 2005. A Bootstrap Test of Stochastic Equality of Two Populations. *The American Statistician*, Vol. 59, 2005
35. Kanawaty, G. 1992. *Introduction to Work Study (fourth edition).* Geneva; International Labour office.

36. Kellogg, L.D. and Spong. B. 2004. Production and costs of cut-to-length thinning: Experience from the Willamette young stand project. Forest Res. Lab., Oregon State Univ., Corvallis, Oregon. 23 pp.
37. Kluender, R., Lortz, D., McCoy, W., Stokes, B. & Klepac, J. 1997. Productivity of Rubber - Tired Skidders in Southern Pine Forests. USDA Forest *Products Journal*. 47(11/12):53-58.
38. LeDoux, C.B. and N.K. Huyler. 2001. Comparison of two cut-to-length harvesting systems operating in eastern hardwoods. Inter. J. of Forest Eng. 12(1):53-59.
39. Liu, C.J. 2002. Effects of Selective Availability on GPS Positioning Accuracy. *Southern Journal of Applied Forestry* AUG 2002; 26, 3:140.
40. MacDonald A.J. 1990. *A case study of Roadside Logging in the Northern interior of British Columbia*. FERIC Technical Report No. TR – 97.
41. MacDonald, A.J. 1999. Harvesting Systems and Equipment in British Columbia*. FERIC Hand book No. HB – 12.* British Columbia.
42. Marn, H.M. & Jonkers, W. 1982. Logging damage in tropical high forest. In: Srivastava, P. B. L. *et al*., Editors, *Tropical forests - source of energy through optimisation & diversification.* Proceedings of an international conference held 11-15 November 1980 at Penerbit Universiti Pertanian, Serdang, Selangor, Malaysia. pp. 27-38.
43. McDonald, T.P. 1999. Time study of harvesting equipment using GPS-derived positional data. *Preedings of the International Conference on Forestry Engineering.* Edinburgh, Scotland: Edinburgh University.
44. Nurminen, T., Korpunen, H. & Uusitalo, J. 2006. *Time Consumption Analysis of the Mechanized Cut-to-Length Harvesting System*. Silva Fennica 40(2): 335-363.
45. Olsen, E.D. & Gibbons, D.J. 1983. *Predicting Skidder Productivity: A mobility model.* Oregon State University, Forest research laboratory Research Bulletin 43. 19 p.
46. OSU 1983. Designated skid trails minimize soil compaction. *The woodland workbook*. Oregon State University Extension Circular 1110.

47. Plamondon, J.A. 1998. *Trials of mechanized tree-length harvesting in Eastern Canada.* FERIC Technical note – 273.

48. Plamondon, J.A. & Favreau, J. 1994. *Establishing the optimal skidding or forwarding distance as a function of road cost.* FERIC Technical Note - 219.

49. Pulkki, R. 2003. Minimizing negative environmental impacts of forest harvesting operations. Chapter 15. In *Towards Sustainable Management of the Boreal Forest. Edited by* P.J. Burton, C. Messier, D.W. Smith, and W.L. Adamowicz. NRC Research Press, Ottawa, Ontario, Canada. pp. 581-628.

50. Ralph, M. B. 1958. *Motion and Time study*. 4th edition. New York: John Wiley & Sons.

51. Reid, J.W. & Rice, R.E. 1997. Assessing natural forest management as a tool for tropical forest conservation. *Ambio,* 26(6): 382-386.

52. Reutebuch, S.E., Fridley, J.L. & Robinson, L.R. 1999. *Intergrating Real-time Forestry Machine activity with GPS positional data.* ASAE Technical Paper No. 99-5037.

53. Richard, F.B. 1984. *Operations Management in the Forest Products Industry*. Miller Freeman Publications: San Francisco.

54. Robert, H.D. 2002. *The Feasibility of using GPS Technology for Continuous Time Studies of Rubber-tired Grapple Skidders.* MSc Thesis. Louisiana State University.

55. Ronald, C., Mauricio, M. & Oscar, M. 2006. Evaluation of Forestry Machinery Performance in Harvesting Operations using GPS Technology. *Proceedings of the International Precision Forestry symposium.* South Africa, Stellenbosch University 5 – 10 March 2006.

56. Ruslim, Y., Heinrichs, A. & Ulbricht, R. 1999. *Technical guideline for reduced impact tractor logging*. SFMP Document No. 10a. Indonesian-German Technical Cooperation. Ministry of Forestry and Estate Crops in Cooperation with Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

57. Sever, S. 1990. Skidder Traction Factors. *International Journal of Forest Engineering*. 1 (2) 15 - 23.

58. Siegel, S. & Castellan, N.J. 1988. *Nonparametric statistics for the behavioral sciences*. McGraw-Hill International, Singapore.
59. Sist, P. 2000. Reduced impact logging in the tropics: objectives, principles and impacts. *International Forestry Review*, 2(1): 3-10.
60. Sist, P., Dykstra, D. & Fimbel, R. 1998. *Reduced impact logging guidelines for lowland and hill dipterocarp forests in Indonesia*. Occasional Paper No. 15. Bogor, Center for International Forestry Research.
61. Skogsarbeten, 1967. *Strip road felling for tractor forwarding*. Stockholm: Skogsarbeten.
62. Skogsarbeten, 1984. *Work Planning and Cutting Methods*. Spånga, Sweden : Skogsarbeten.
63. Spiers, J.J.K. 1986. *Logging Operations Guidelines*. Wellington: LIRO.
64. Spruce, M.D., Taylor, S.E., Wilhoit, J.H. & Stokes, B.J. 1993. Using GPS to track forest machines. Paper presented at the *"1993 International Winter Meeting sponsored by the American Society of Agricultural Engineers,"* December 14 -17. Chicago, Illinois: ASAE.
65. Staff, K.A.G. & Wiksten, N.A. 1984. Tree harvesting techniques. Martinus Nijhoff/DR W. Junk Publishers, Dodrechts/Boston/Lancaster.
66. Stenzel, G., Kenneth, J.P. & Thomas, A.W. 1985. *Logging and Pulpwood Production*. New York: John Wiley & Sons.
67. Van Daele, P. 2000. Work Study in Forestry. *South African Forestry Handbook* Vol.1. Pretoria: SAIF. pp 407.
68. Van der Hout, P. 1999. *Reduced impact logging in the tropical rain forest of Guyana*. Dissertation. University Utrecht. 1999.
69. VDF. 1999. *Vanuatu reduced impact logging guidelines*. Vanuatu, Department of Forests.
70. Veal, M. W., Taylor, S. E., McDonald, T. P., McLemore, D. K., Dunn. M. R. 2000. *Accuracy of Tracking Forest Machines with GPS*. American Society of Agricultural Engineers, Annual Meeting 2000. paper No. 00- 50 10.
71. Veal, M.W., Taylor, S.E., McDonald, T.P., Tackett, D.K. & Dunn, M.R. 2001. Accuracy of tracking forest machines with GPS. Transaction of ASAE. In Press.

72. Wagner, F.G., C.E. Fiedler, and C.E. Keegan. 2000. Processing values of small-diameter sawtimber at conventional stud sawmills and modern high-speed, small-log in the western United States-A comparison. Western J. of Applied Forestry 15(4):208-212.
73. Warkotsch, W. 1985. The Relevance of Harvesting in Forestry. *South African Forestry Handbook*, 1994. Pretoria: SAIF.
74. Webb, E.L. 1997. Canopy removal and residual stand damage during controlled selective logging in lowland swamp forest of northeast Costa Rica. *Forest Ecology and Management* 95: 117-129.
75. Yaoxiang, L., J. Wang, G. Miller, and J. McNeel. 2006. Production economics of harvesting small-diameter hardwood stands in central Appalachia. Forest Prod. J. 56(3):81-86.

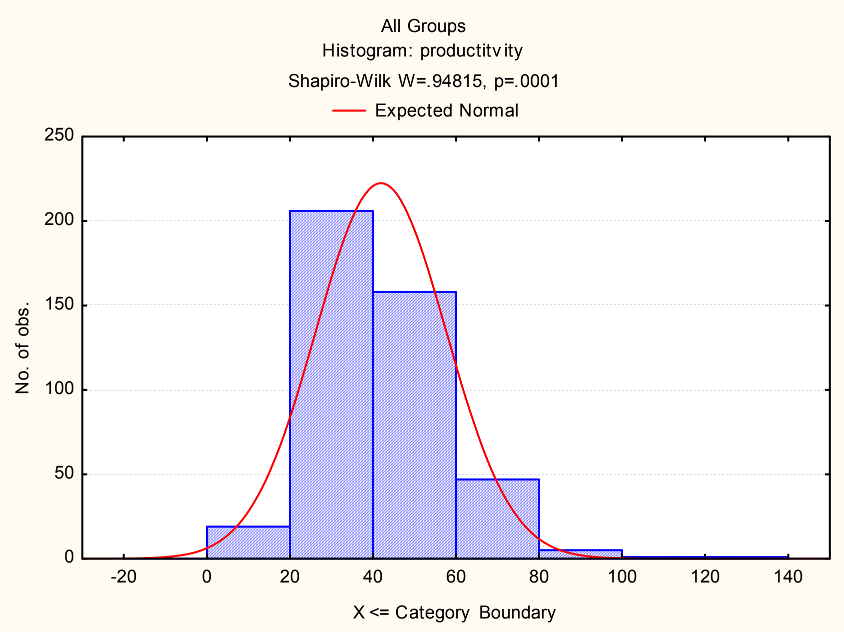
8 Appendices

Appendix A:

Tests for normality

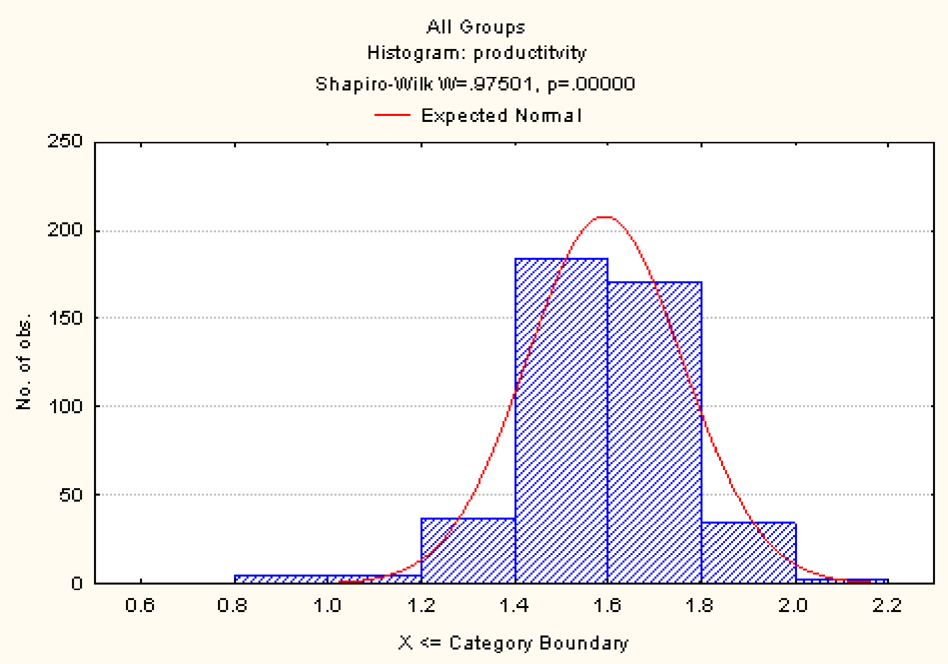
Test for normality of all groups

Test for normality of combined productivity data of mainline and tagline systems.



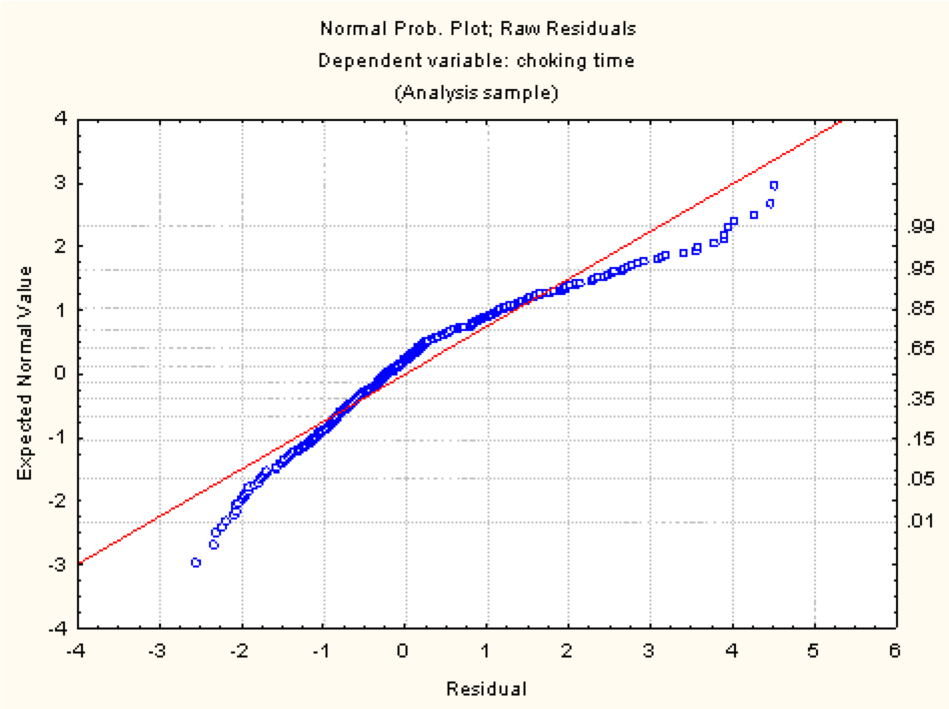
The combined productivity data was not normally distributed (p=0.0001).

Test for normality of log transformed productivity data of mainline and tagline systems



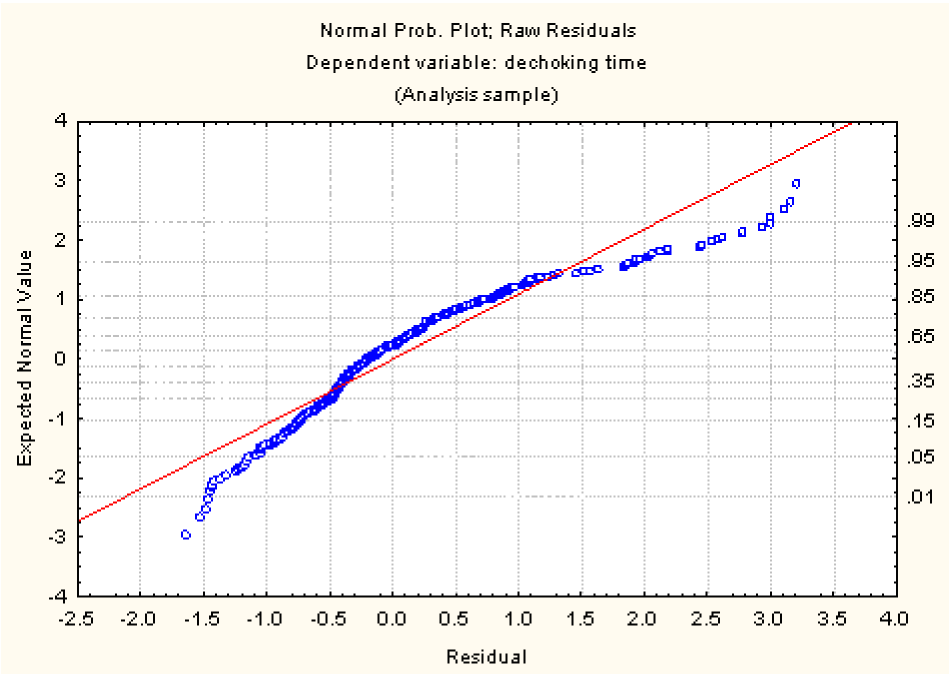
The log transformed data of combined productivity data was not normally distributed (p=0.0001).

Test for normality of the residuals of choking time of mainline and tagline systems



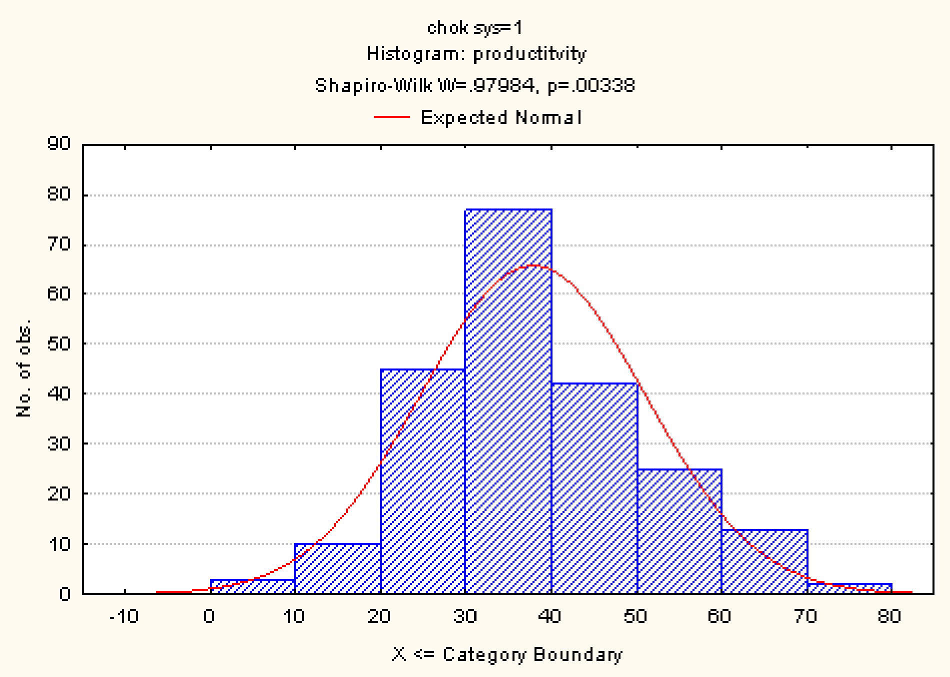
The residuals of choking time were not normally distributed.

Test for normality of the residuals of dechoking time of mainline and tagline systems



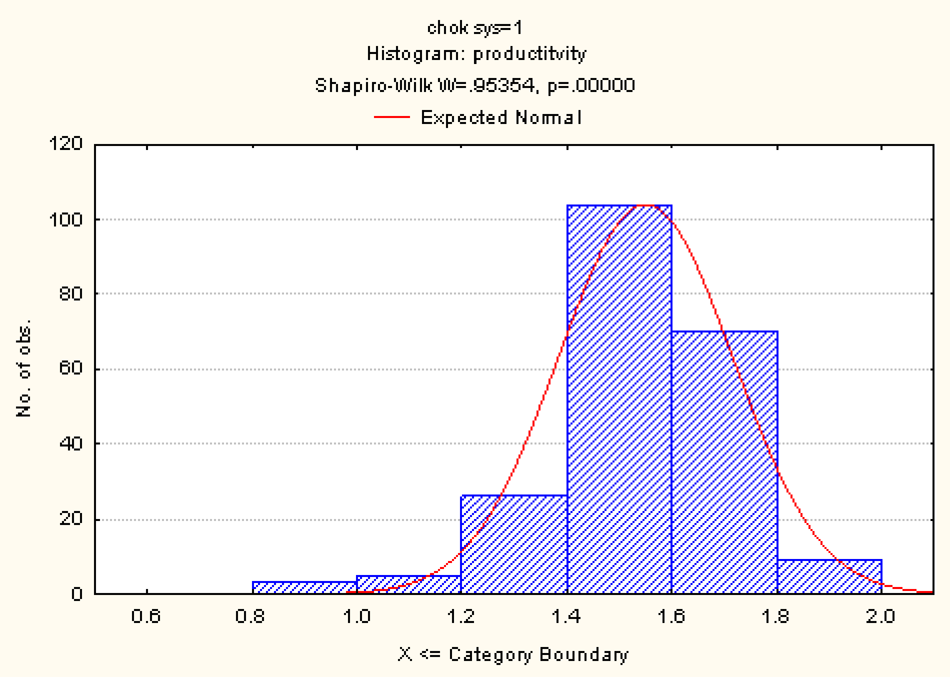
Residuals of choking time were not normally distributed.

Test for normality of productivity of mainline system



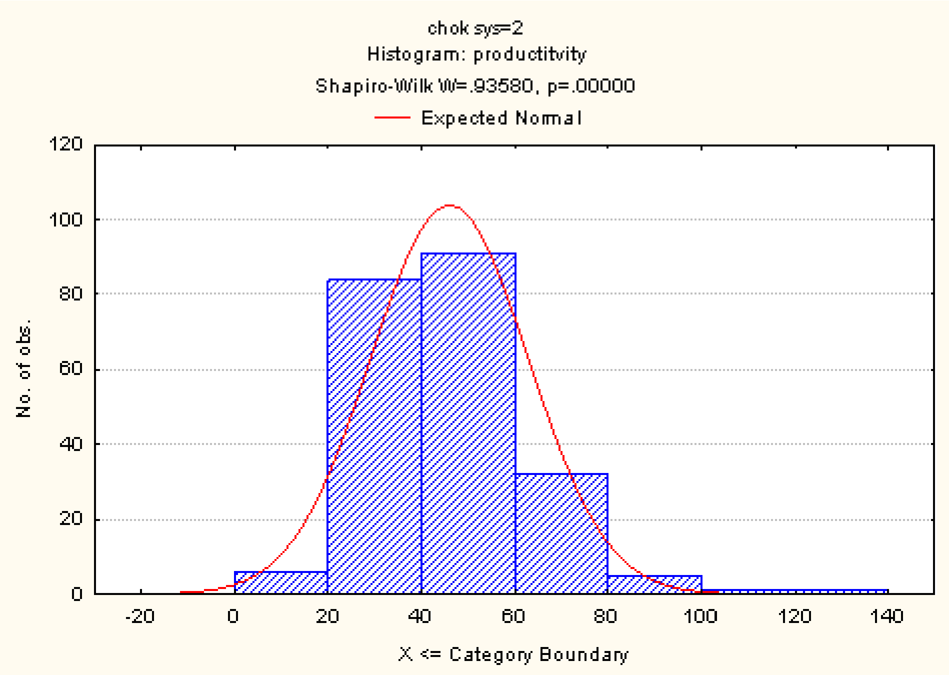
Productivity data obtained using mainline system was not normally distributed (P=0.00338).

Test for normality of log transformed productivity data of mainline system



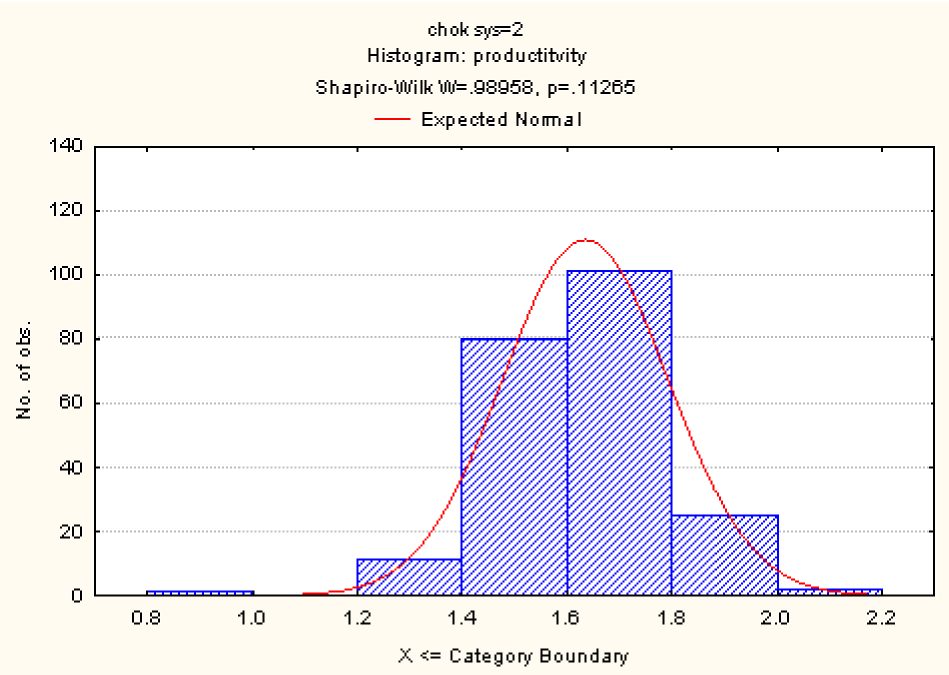
log transformed productivity data obtained using mainline system was not normally distributed.

Test for normality of productivity of tagline system



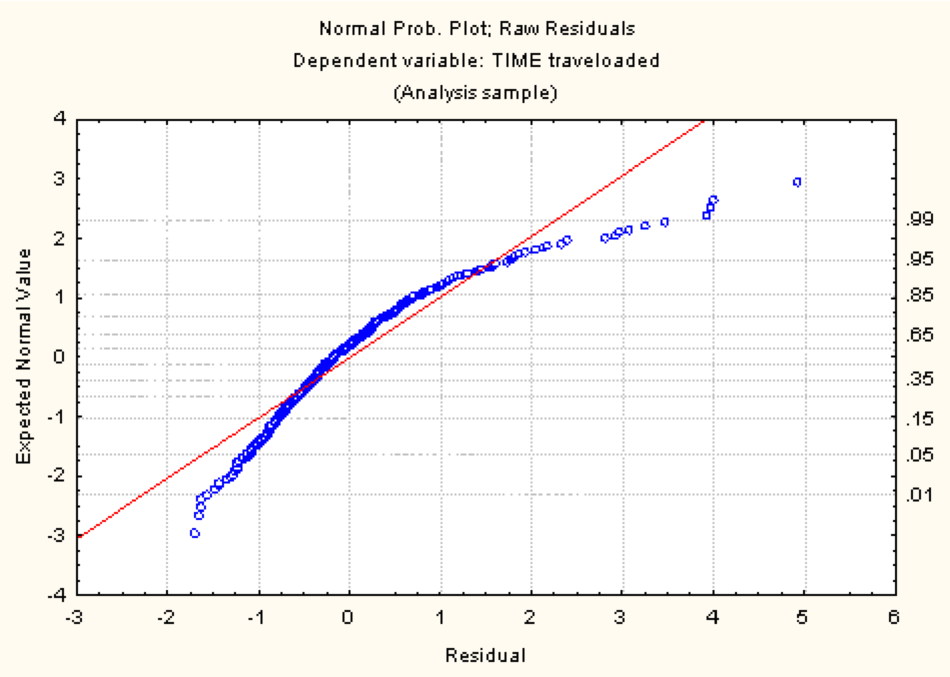
Productivity of data obtained using tagline system was not normally distributed (p=0.0001).

Test for normality of log transformed productivity data of tagline system



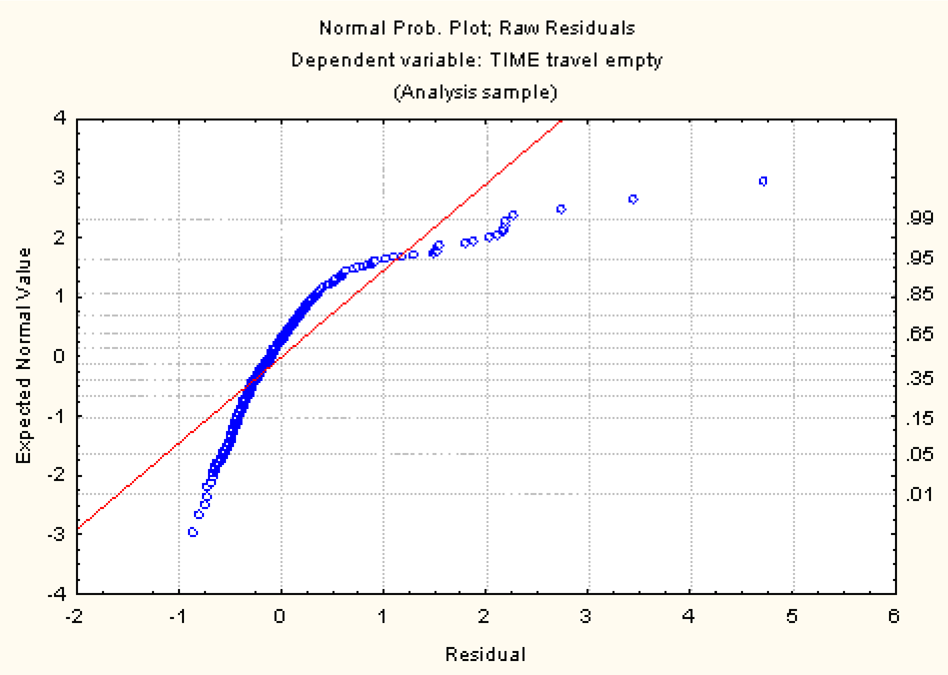
The log transformed productivity data of tagline system was normally distributed (P= 0.11265). However, the non-parametric productivity data of tagline system was used for analysis using the Bootstrap test.

Test for normality of the residual of travel loaded time of mainline and tagline systems



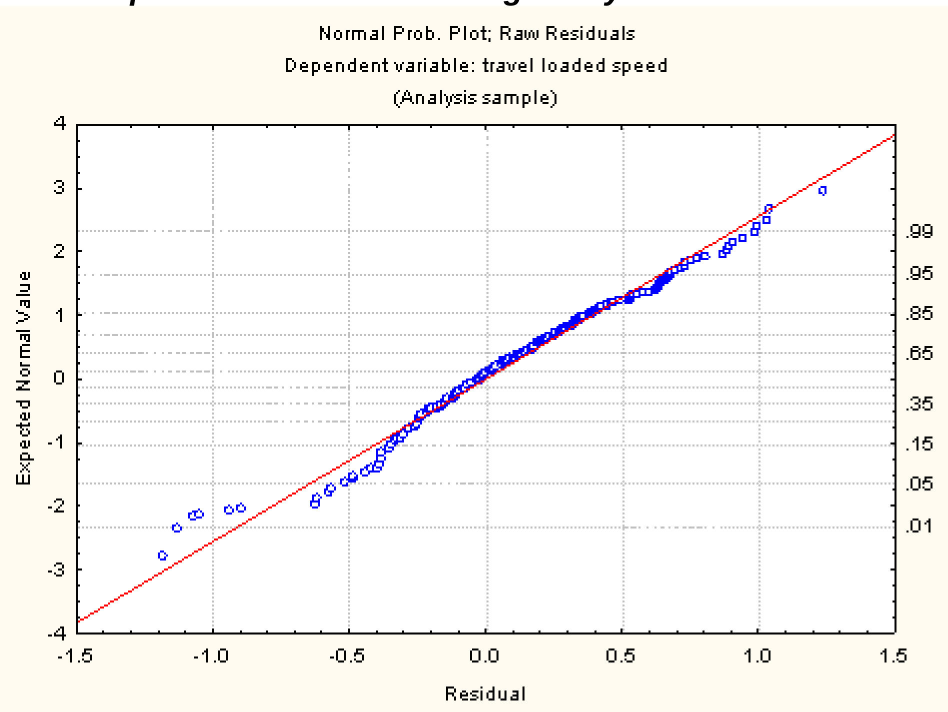
The residuals of travel loaded times were not normally distributed.

Test for normality of the residual of travel empty time of mainline and tagline systems



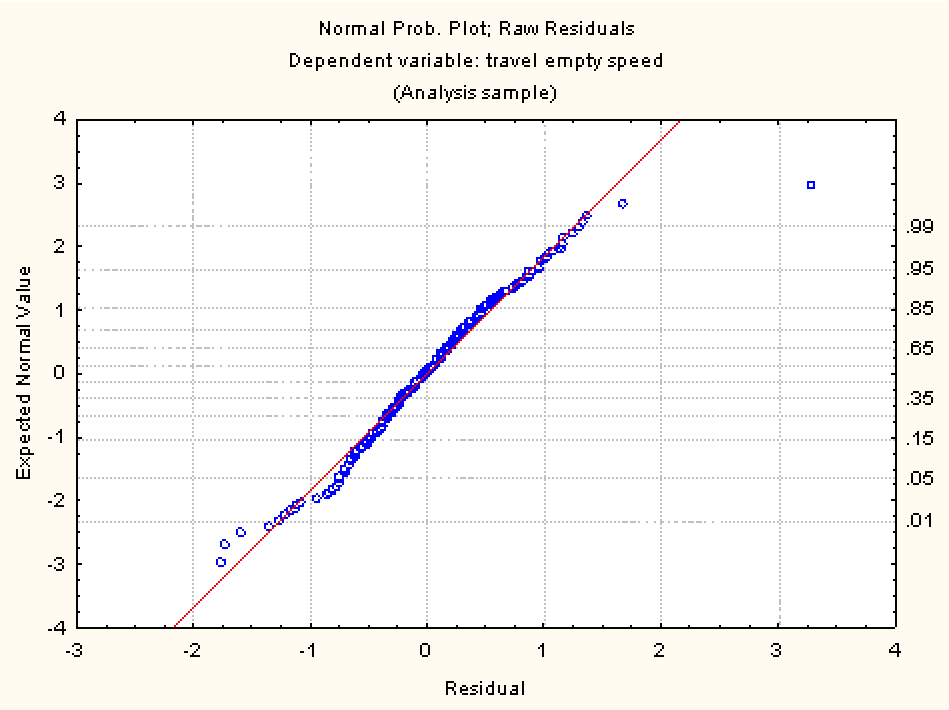
The residuals of travel empty time were not normally distributed.

Test for normality of the residual of combined travel empty and travel loaded speeds of mainline and tagline systems



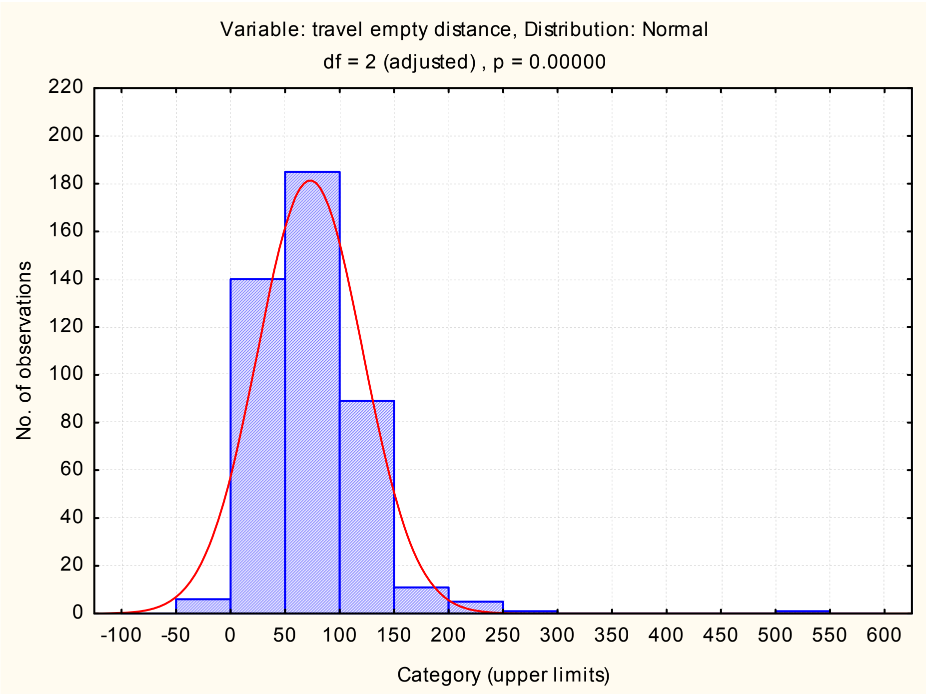
The residuals of combined travel empty speeds using both mainline and tagline systems were not normally distributed**.**

Test for normality of the residuals of travel empty speeds



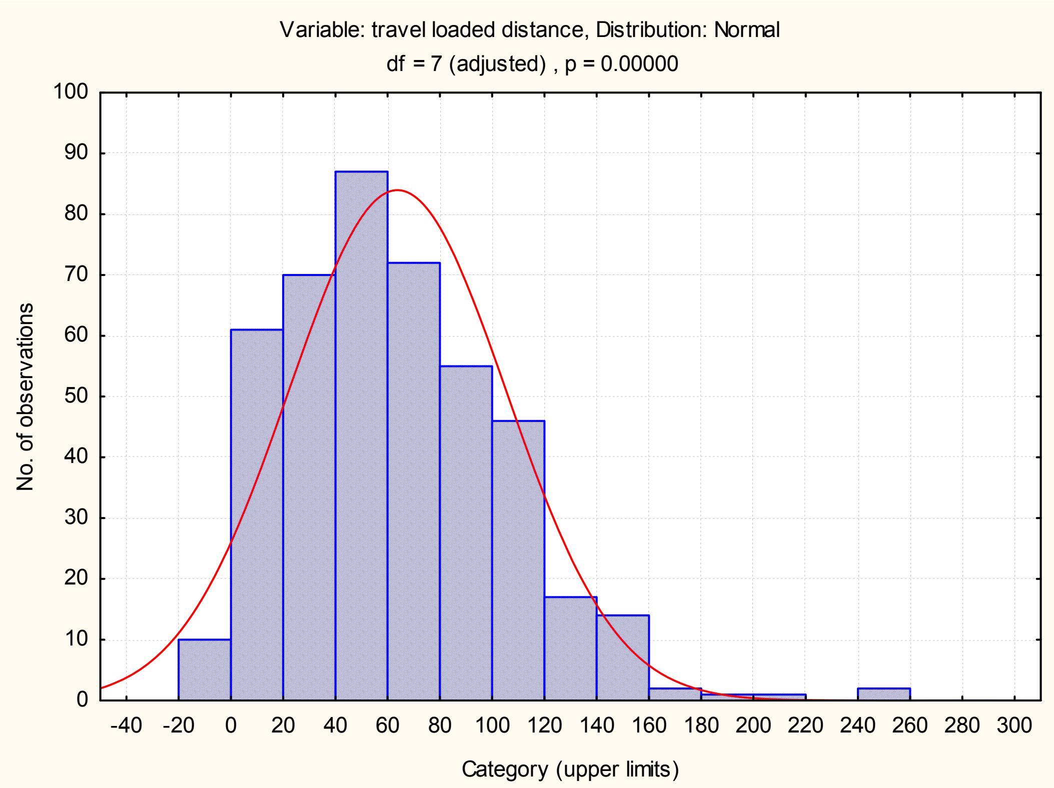
The residuals of travel empty speed were not normally distributed.

Test for normality of travel empty distances



The travel empty distances were not normally distributed.

Test for normality of travel loaded distances



The travel loaded distances were not normally distributed.

Test for normality of exponentially transformed productivity data

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.02357	**Pr < W**	<0.0001
Kolmogorov-Smirnov	**D**	0.516126	**Pr > D**	<0.0100
Cramer-von Mises	**W-Sq**	36.30679	**Pr > W-Sq**	<0.0050
Anderson-Darling	**A-Sq**	168.4874	**Pr > A-Sq**	<0.0050

The log transformed productivity data was not normally distributed; Shapiro-Wilk p <0.0001.

Appendix B:

Index Values for Different Terrain Conditions **(Erasmus, 1994).**

Ground conditions (trafficability within the stand)	
1	Very good
2	Good
3	Moderate
4	poor
5	Very poor

Ground roughness	
1	Smooth
2	Slightly uneven
3	Uneven
4	Rough
5	Very rough

Ground strength (trafficability within the stand)	
1	Very good
2	Good
3	Moderate
4	poor
5	Very poor

Slope Class	Gradient	
	Percent	Designation
1	0 - 11	Level
2	12 - 20	Gentle
3	21 - 30	Moderate
4	31 - 35	Steep 1
5	36 - 40	Steep 2
6	41 - 50	Steep 3
7	> 50	Very steep

Appendix C:

Machine costing using mainline with a single set of choker chains

Skidder (wheeled)		
Mainline with a single set of choker chains		
General Inputs		
Number of working days per year	240	days
Number of shifts per day	1	shifts
Work week	5	days
Scheduled hours per shift	9	SMH
Machine utilisation	90	%
Estimated productivity	13.78	m^3/PMH
Expected economic life	12000	PMH
Fixed Cost Inputs		
Purchase price	2000000	R
Salvage value ratio	10	%
Interest rate	14	%
Machine license and road user taxes	0	R/Annum
Insurance	0	R/Annum
Annual relocation cost	0	R/Annum
Variable Cost Inputs		
Fuel price	10	R/Litre
Fuel consumption	22	Litres/PMH
Oil and lubricant cost	20	%
Maintenance and repair cost	100	%
Number of tyres on working machine	4	tyres
Single tyre cost	22000	R
Estimated tyre life	3000	PMH
Consumables		
Cable life	720	PMH
Cable cost	3000	R
Choking chains life	12000	PMH
Choking chains cost	8736	R
Tyre chains life	0	PMH
Tyre chains cost	0	R
Annual tyre chain utilisation	0	%
Other non-depreciable item/s cost	0	R
Additional Calculations		
Scheduled Hours/week	45	SMH/week
Scheduled Hours/annum	2160	SMH/annum
Productive Hours/annum	1944	PMH/annum

Expected Economic Life (EEL)	6.17	Years
Salvage Value (SV)	191200	R
Estimated Productivity/SMH	12.4	m³/SMH
Estimated Productivity/PMH	13.78	m³/PMH
Estimated Productivity/Shift	111.62	m³/Shift
Estimated Annual Productivity	26788.32	m³/annum
New Tyre Set Cost	88000	R
Total non-depreciable value	58736	R
Output Calculations		
	R/m³	***R/PMH***
Depreciation	R 10.41	R 143.40
Cost of Capital	R 6.49	R 89.45
Insurance	R 0.00	R 0.00
License Fees	R 0.00	R 0.00
Relocation costs	R 0.00	R 0.00
TOTAL FIXED COSTS	R 16.90	R 232.85
Fuel	R 15.97	R 220.00
Oil and Lubricants	R 3.19	R 44.00
Maintenance and repairs	R 12.09	R 166.67
Tyres	R 1.60	R 22.00
Cable	R 0.30	R 4.17
Choking Chains	R 0.05	R 0.73
Tyres Chains	R 0.00	R 0.00
Other non-depreciable item/s	R 0.00	R 0.00
TOTAL VARIABLE COSTS	R 33.20	R 457.56
TOTAL COSTS	R 50.10	R 690.41

Appendix D:

Machine costing using mainline with a double set of choker chains

Skidder (wheeled)		
mainline with double chain set		
General Inputs		
Number of working days per year	240	days
Number of shifts per day	1	shifts
Work week	5	days
Scheduled hours per shift	9	SMH
Machine utilisation	90	%
Estimated productivity	30.66	m^3/PMH
Expected economic life	12000	PMH
Fixed Cost Inputs		
Purchase price	2000000	R
Salvage value ratio	10	%
Interest rate	14	%
Machine license and road user taxes	0	R/Annum
Insurance	0	R/Annum
Annual relocation cost	0	R/Annum
Variable Cost Inputs		
Fuel price	10	R/Litre
Fuel consumption	22	Litres/PMH
Oil and lubricant cost	20	%
Maintenance and repair cost	100	%
Number of tyres on working machine	4	tyres
Single tyre cost	22000	R
Estimated tyre life	3000	PMH
Consumables		
Cable life	720	PMH
Cable cost	3000	R
Choking chains life	12000	PMH
Choking chains cost	17472	R
Tyre chains life	0	PMH
Tyre chains cost	0	R
Annual tyre chain utilisation	0	%
Other non-depreciable item/s cost	0	R
Additional Calculations		
Scheduled Hours/week	45	SMH/week
Scheduled Hours/annum	2160	SMH/annum
Productive Hours/annum	1944	PMH/annum
Expected Economic Life (EEL)	6.17	Years

Salvage Value (SV)	191200	R
Estimated Productivity/SMH	27.59	m³/SMH
Estimated Productivity/PMH	30.66	m³/PMH
Estimated Productivity/Shift	248.35	m³/Shift
Estimated Annual Productivity	59603.04	m³/annum
New Tyre Set Cost	88000	R
Total non-depreciable value	67472	R
Output Calculations		
	R/m³	***R/PMH***
Depreciation	R 4.68	R 143.40
Cost of Capital	R 2.92	R 89.45
Insurance	R 0.00	R 0.00
License Fees	R 0.00	R 0.00
Relocation costs	R 0.00	R 0.00
TOTAL FIXED COSTS	R 7.59	R 232.85
Fuel	R 7.18	R 220.00
Oil and Lubricants	R 1.44	R 44.00
Maintenance and repairs	R 5.44	R 166.67
Tyres	R 0.72	R 22.00
Cable	R 0.14	R 4.17
Choking Chains	R 0.05	R 1.46
Tyres Chains	R 0.00	R 0.00
Other non-depreciable item/s	R 0.00	R 0.00
TOTAL VARIABLE COSTS	R 14.95	R 458.29
TOTAL COSTS	R 22.54	R 691.14

Appendix E:

Machine costing using tagline systems

Skidder (wheeled)		
Tagline method		
General Inputs		
Number of working days per year	240	days
Number of shifts per day	1	shifts
Work week	5	days
Scheduled hours per shift	9	SMH
Machine utilisation	90	%
Estimated productivity	34.41	m^3/PMH
Expected economic life	12000	PMH
Fixed Cost Inputs		
Purchase price	2000000	R
Salvage value ratio	10	%
Interest rate	14	%
Machine license and road user taxes	0	R/Annum
Insurance	0	R/Annum
Annual relocation cost	0	R/Annum
Variable Cost Inputs		
Fuel price	10	R/Litre
Fuel consumption	22	Litres/PMH
Oil and lubricant cost	20	%
Maintenance and repair cost	100	%
Number of tyres on working machine	4	tyres
Single tyre cost	22000	R
Estimated tyre life	3000	PMH
Consumables		
Cable life	720	PMH
Cable cost	6000	R
Choking chains life	12000	PMH
Choking chains cost	17472	R
Tyre chains life	0	PMH
Tyre chains cost	0	R
Annual tyre chain utilisation	0	%
Other non-depreciable item/s cost	0	R
Additional Calculations		
Scheduled Hours/week	45	SMH/week
Scheduled Hours/annum	2160	SMH/annum
Productive Hours/annum	1944	PMH/annum
Expected Economic Life (EEL)	6.17	Years

Salvage Value (SV)	191200	R
Estimated Productivity/SMH	30.97	m³/SMH
Estimated Productivity/PMH	34.41	m³/PMH
Estimated Productivity/Shift	278.72	m³/Shift
Estimated Annual Productivity	66893.04	m³/annum
New Tyre Set Cost	88000	R
Total non-depreciable value	117472	R
Output Calculations		
	R/m³	*R/PMH*
Depreciation	R 4.17	R 143.40
Cost of Capital	R 2.60	R 89.45
Insurance	R 0.00	R 0.00
License Fees	R 0.00	R 0.00
Relocation costs	R 0.00	R 0.00
TOTAL FIXED COSTS	R 6.77	R 232.85
Fuel	R 6.39	R 220.00
Oil and Lubricants	R 1.28	R 44.00
Maintenance and repairs	R 4.84	R 166.67
Tyres	R 0.64	R 22.00
Cable	R 0.24	R 8.33
Choking Chains	R 0.04	R 1.46
Tyres Chains	R 0.00	R 0.00
Other non-depreciable item/s	R 0.00	R 0.00
TOTAL VARIABLE COSTS	R 13.44	R 462.46
TOTAL COSTS	R 20.21	R 695.31

Appendix F:

Machine costing without any choking attachments

Skidder (wheeled)		
General Inputs		
Number of working days per year	240	days
Number of shifts per day	1	shifts
Work week	5	days
Scheduled hours per shift	9	SMH
Machine utilisation	90	%
Estimated productivity	41.81	m^3/PMH
Expected economic life	12000	PMH
Fixed Cost Inputs		
Purchase price	2000000	R
Salvage value ratio	10	%
Interest rate	14	%
Machine license and road user taxes	0	R/Annum
Insurance	0	R/Annum
Annual relocation cost	0	R/Annum
Variable Cost Inputs		
Fuel price	10	R/Litre
Fuel consumption	22	Litres/PMH
Oil and lubricant cost	20	%
Maintenance and repair cost	100	%
Number of tyres on working machine	4	tyres
Single tyre cost	22000	R
Estimated tyre life	3000	PMH
Consumables		
Cable life	0	PMH
Cable cost	0	R
Choking chains life	0	PMH
Choking chains cost	0	R
Tyre chains life	0	PMH
Tyre chains cost	0	R
Annual tyre chain utilisation	0	%
Other non-depreciable item/s cost	0	R
Additional Calculations		
Scheduled Hours/week	45	SMH/week
Scheduled Hours/annum	2160	SMH/annum
Productive Hours/annum	1944	PMH/annum
Expected Economic Life (EEL)	6.17	Years

Salvage Value (SV)	191200	R
Estimated Productivity/SMH	37.63	m³/SMH
Estimated Productivity/PMH	41.81	m³/PMH
Estimated Productivity/Shift	338.66	m³/Shift
Estimated Annual Productivity	81278.64	m³/annum
New Tyre Set Cost	88000	R
Total non-depreciable value	0	R
Output Calculations		
	R/m³	***R/PMH***
Depreciation	R 3.43	R 143.40
Cost of Capital	R 2.14	R 89.45
Insurance	R 0.00	R 0.00
License Fees	R 0.00	R 0.00
Relocation costs	R 0.00	R 0.00
TOTAL FIXED COSTS	R 5.57	R 232.85
Fuel	R 5.26	R 220.00
Oil and Lubricants	R 1.05	R 44.00
Maintenance and repairs	R 3.99	R 166.67
Tyres	R 0.53	R 22.00
Cable	R 0.00	R 0.00
Choking Chains	R 0.00	R 0.00
Tyres Chains	R 0.00	R 0.00
Other non-depreciable item/s	R 0.00	R 0.00
TOTAL VARIABLE COSTS	R 10.83	R 452.67
TOTAL COSTS	R 16.40	R 685.52

Appendix G:

Costing of Chain saw

Chainsaw:		
General Inputs		
Number of working days per year	240	days
Number of shifts per day	1	shifts
Work week	5	days
Scheduled hours per shift	9	SMH
Machine utilisation	60	%
Estimated productivity	0.01	m³/PMH
Expected economic life	1000	PMH
Fixed Cost Inputs		
Purchase price	5000	R
Salvage value ratio	5	%
Interest rate	14	%
Insurance	0	R/Annum
Variable Cost Inputs		
Fuel price	20	R/Litre
Fuel consumption	1.2	Litres/PMH
Oil and lubricant cost	104.1667	%
Maintenance and repair cost	100	%
Non-depreciable Items		
Cutting bar life	200	PMH
Cutting bar cost	350	R
Cutting chain life	100	PMH
Cutting chain cost	250	R
Sprocket life	100	PMH
Sprocket cost	50	R
Flat File life	200	PMH
Flat File cost	35	R
Round File life	200	PMH
Round File cost	25	R
Other non-depreciable item/s	0	R

cost		

Output Calculations:

	R/m³	R/PMH	R/shift	R/month	R/annum	% of Total
Depreciation	475	4.75	25.65	513	6156	7.37
Cost of Capital	61.61	0.62	3.33	66.54	798.42	0.96
Insurance	0	0	0	0	0	0
TOTAL FIXED COSTS	536.61	5.37	28.98	579.54	6954.42	8.33
Fuel	2400	24	129.6	2592	31104	37.26
Oil and Lubricants	2500	25	135	2700	32400	38.81
Maintenance and repairs	500	5	27	540	6480	7.76
Cutting bar	175	1.75	9.45	189	2268	2.72
Cutting chain	250	2.5	13.5	270	3240	3.88
Sprocket	50	0.5	2.7	54	648	0.78
Flat File	17.5	0.18	0.95	18.9	226.8	0.27
Round File	12.5	0.13	0.68	13.5	162	0.19
Other non-depreciable item(s)	0	0	0	0	0	0
TOTAL VARIABLE COSTS	5905	59.05	318.87	6377.4	76528.8	91.67
TOTAL COSTS	6441.61	64.42	347.85	6956.94	83483.22	100