PRODUCTIVITY, COST, WOOD WASTE AND ENVIRONMENTAL IMPACT OF THE CURRENT AND IMPROVED LOGGING OPERATIONS IN UGANDAN FOREST PLANTATIONS

BY

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ABSTRACT

This study was conducted in two logging site in Uganda to collect information on major factors responsible for the current wood waste and ground surface disturbances during logging in order to provide a basis for future selection of the most suitable and appropriate forest harvesting methods and techniques in plantation forests. The two plantation forests selected were Mafuga on steep slopes and Katugo on flat terrain, where Reduced Impact Logging (RIL) and Conventional Logging (CL) methods were compared. Data on logging productivity, cost, wood waste and ground disturbance were collected and analysed. Felling production rates were found to be lower under RIL. In Mafuga for example, felling production was 16.39 m^3/hr as compared to 25.78 m^3/hr when using CL. In Katugo productivity was 20.40 m^3/hr when using RIL as opposed to 34.47 m^3/hr when applying CL. This was because directional felling (RIL) consumed more time than the random and uncontrolled felling during (CL). Productivity however can be improved if workers practice more directional felling and undergo more RIL training courses. During the application of RIL, limbing was carried out as a separate operation in order to improve the quality of logs. Limbing production rates were 19.93 m^3/hr for Mafuga and 17.94 m^3/hr for Katugo plantations. RIL was more productive than CL during the bucking operation in Mafuga, producing 10.09 m^3/hr against 9.29 m^3/hr respectively. In Katugo productivity was almost similar (RIL, 10.08 m^3/hr against 10.61 m^3/hr CL). Productivity when applying RIL can be even better through further practice and training. Log rolling production was higher under RIL, producing 6.99 m^3/hr against 5.79 m^3/hr during CL in Mafuga. In Katugo productivity was 5.22 m^3/hr under RIL against 4.04 m^3/hr under CL. This improvement was achieved through proper application of appropriate logging techniques and close supervision. Production cost per cubic meter delivered at the mill was slightly higher under RIL relative to CL, costing 1738.33 Ushs/m^3 against 1724.11 Ushs/m^3 in Mafuga and 1795.15 Ushs/m^3 against 1755.30 Ushs/m^3 in Katugo. Increase in wood recovery per tree however seemed to have outweighed this slight difference in production cost. RIL managed to reduce wood waste by 30% for Mafuga and 29% for Katugo and ground disturbance by 59% in Mafuga. In Katugo ground surface disturbance was not significant. During the course of the study the following conclusions were drawn; Logging operators and supervisors in most forests have no training in their field, there are no safety precautions and safety gears neither provided nor used. Training of operators can reduce wood losses and ground disturbance besides improving productivity, and Government and funding agencies need to place greater emphasis on the development and delivery of training in the forest industry.

DECLARATION

I, **KIVUMBI HUSSEIN BALIMUNSI**, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis except where otherwise acknowledged is my original work, and it has not been submitted for a degree award in any other university.

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4th April 2007

Date

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4/04/2007

Date

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LIST OF ACRONYMS

AAC	Annual Allowable Cut
AFO	Assistant Forest officer
CIFOR	Centre for International Forestry research
CL	Conventional Logging
cm	Centimetres
DBH	Diameter at Breast Height
DFO	District Forest Officer
FAO	Food and Agriculture Organization
FD	Forest Department
FORRI	Forest Resources Research Institute
GDP	Growth Domestic Product
GIS	Geographic Information System
GPI	Grid Point Intercept
GPS	Global Positioning Systems
LC	Labour Cost
LT	Line Transect
MWLE	Ministry of Water, Lands and Environment
NecDel	Necessary Delay
NFA	National Forestry Authority
PC	Production cost
PPE	Personal Protective Equipment
Prod.PRBT	Production rate per productive bucking Time

Prod.PRFT	Production rate per productive felling Time
Prod.PRRT	Production rate per productive rolling time
PRT.	Productive time
PRBT	Productive bucking time
PRFT	Productive felling time
PRRT	Productive rolling time
PT	Point Transect
RIL	Reduced Impact Logging
SFMS	Sustainable Forest Management Systems
Std	Standard deviation
SUA	Sokoine University of agriculture
TOTBT	Total bucking time
TOTDelT	Total delay time
TOTFT	Total felling time
TOTRT	Total rolling time
UnnecDel.T	Unnecessary delay time
UWA	Uganda Wildlife Authority

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

1.1.1 Forest plantations in Uganda

Uganda has a total land area of 19 965 000 hectares of which, 6 104 000 hectares (31%) are covered by forests, with forest plantations covering only 0.33% (20 000 ha.). These forest plantations, which were established at a large scale in the early 1970's, are made up of two main tree species namely, *Pinus patula* and *Cupressus lusitanica*. While in the past emphasis was on the silvicultural management, of late the main emphasis has been on how to harvest and utilise these forests efficiently and on environmentally friendly manner before they deteriorate further due to age (MWLE, 2001).

The Uganda Forest Department (FD) has been enveloped in a crisis arising out of the delayed harvesting of most of the country's forest plantations that started attaining their rotation age in the late 1980's. The delayed harvesting was due to the initial resistance of the Ugandan market to softwood plantation timber due to the available cheap but superior indigenous hardwoods on which the country had become over dependent. The situation was further worsened by the economic decline from 1972 to 1985, which meant non-undertaking of silvicultural management practices such as weeding, thinning and pruning and the collapse of sawmills after expulsion of Asian owners. This resulted to plantations undergoing diminishing if not negative growth rates in terms of volume, experiencing frequent damages from diseases, droughts and fires that greatly reduced the quality of the saw logs.

1.1.2 Sawmilling industry

Since the onset of the World Bank Forest Rehabilitation project and the European Union Funded Natural Forest Management and Conservation project in 1988, the Government has attached great emphasis on conservation of natural forests for biodiversity and tourism. During the 1970's and early 1980's about 90% of the timber supplied in the market was from the natural forests, which was processed by the medium to large scale stationery sawmills. But the creation of the Uganda Wildlife Authority (UWA) and transfer of substantial areas of natural forest reserves to UWA as well as the FD's creation of forest parks and buffer zones greatly reduced the sources of timber supply from the natural forests. This forced a shift from natural forest timber sources to forest plantations, to private forests and trees on public land. This was followed up with an aggressive promotion of plantation grown timber, which has resulted into the present plantation based mobile sawmilling industry. Most of the large stationary sawmills in the country, which depended on logs from natural forests collapsed in the 1970's. These were owned by the departed Asians (Indians) forced out of the country by Idi Amin (former president), and others closed down in the 1980's (owned by the state) due to the economic decline. To date only Amaply in Budongo forest owned by an Indian is still operational among the large scale stationery sawmills. The rest of the sawmills are small portable mills owned by local Ugandans, which are deployed and operated inside the plantations. Currently timber from softwood plantations constitutes about 50% of the timber in the national market.

1.2 General overview

Although timber harvesting is considered to be one of the main causes of environmental degradation, according to the FAO *Model Code of Forest Harvesting Practice* (Dykstra and Heinrich, 1996) it is possible to conduct forest harvesting operations in ways that are consistent with the concept of sustainability. This requires that such operations do not compromise the forest's potential to regenerate properly and to yield products that are essential for the well-being of both current and future generations. Consequently, timber resources especially in plantation forests must be utilised by means of efficient practices that comply with clear legal regulations and adequate planning and control instruments with all aspects of environmental and social sustainability (FAO, 2001; Poulsen and Applegate, 2001). In order to meet such demand, sustainable forest management is required.

The timber industry in Uganda has been one of the main sources of income to the country's economy contributing about 2 percent of the country's GDP and absorbing about 1.7% of the total labour force (MWLE, 2001). Over the past 20 years, deforestation has been rampant and sustainability of this valuable resource has been questionable. Uncontrolled harvesting, including over harvesting and poor harvesting practices, have been singled out as being amongst the important cause of this deforestation (MWLE, 2001). With the depletion of natural forests, the plantation forests are increasingly playing a significant role in meeting the ever-increasing timber demand in the country.

Timber harvesting is both a management and an economic venture, aimed at producing commercial timber at profit. Unlike in the past, recent concerns for the environment, biological diversity and the aspirations of local communities have brought in other stakeholders in the timber industry. Thus, what used to be thought as a straightforward production process and an independent professional and technical discipline, timber harvesting now requires consultations and considerations of other stakeholders of forests in order to achieve the desired goals and objectives of sustainable forest management.

So far, little research on timber harvesting has been done in Uganda in recent years. There is scarcity of data on the productivity, production cost and the environmental impact of the current logging operations. According to the available information, the logging methods applied have mainly been geared to suit available techniques or equipment, rather than seeking appropriate technologies that meet appropriate criteria. Also timber harvesting has mostly been driven by volume required with little regard to logging efficiency and environmental conservation (Karani, 2001; MWLE, 2002). Efficiency and sustainability of forest management generally depend on the quality of harvesting operations, which in fact constitute a major forests management tool.

1.2.1 Conditions of forest plantations in Uganda

The current situation of the forest plantations in Uganda calls for immediate steps to be taken to safeguard them. Due to the increased emphasis on natural forest conservation and increased harvesting of plantations as well as the government failure to fund a planting programme, the Government of Uganda has introduced a new condition requiring sawmilling concessionaires to replant areas they harvest (McCaughan and Carvalho, 2003). Despite few successful replanting operations by sawmillers, the overall policy of forcing sawmillers to replant harvested areas has clearly been a failure. Most of the new plantations established by these sawmillers have failed due to poor tending and poor quality of trees. Lack of knowledge, proper advice from the Forest Department and uncertainty on the future ownership of the new plantations has resulted in many plantations being planted with poor quality seedlings and wrong species for certain sites. In any case, since sawmiller's business is harvesting and processing of timber, it is unfair and unprofessional to demand them to plant and tend plantations (Jacovelli and Carvalho, 1999). The harvesting rate of 226.7ha/year far exceeds replanting rate of 17.9 ha/year, indicating that timber production from industrial forest plantations is unlikely to be sustained (Gombya – Ssembajjwe, 2004).

Data relating to supply and demand of various forest products in Uganda has for a long time been lacking. On average, it is estimated that the annual demand for sawn timber generally is about 186 000m^3. Since recovery rate is about 25-30%, this means therefore that about 620 000-744 000m^3 of saw logs are required annually (McCaughan and Carvalho, 2003). The 2001 Harvesting Plan for plantations (Tugumisirize 2001) has been ignored and sawmilling permits have been issued regardless of the recommended Annual Allowable Cut (AAC). The result has been severe and unsustainable felling as records show that consumption of softwood timber has been at an increase. The installed production capacity of existing sawmills in plantations amounting to 300 000m^3 exceeds the available AAC of 99 000m^3 of round wood per year by 200% (McCaughan and Carvalho, 2003). The following figures, which are estimates from state owned softwood plantations, give a clear indication of the situation in the country's plantations.

Table 1. Merchantable volume of wood in Ugandan softwood plantations.

Volume	m^3
Volume at time of plan(2002)	1 120 000
In the year 2003	831 000
Annual Allowable Cut (AAC)	99 000
Annual actual cut	289 000
Annual over-cut	190 000

(Source -Uganda Forest department (2003)).

The current levels of consumption greatly exceed sustainable supplies from plantations and natural forests. The current rate of depletion is excessive and demand is only being met by over cutting plantations, private natural forests and by timber imports from neighbouring countries especially from Democratic Republic of Congo (Jacovelli and Carvalho, 1999: McCaughan and Carvalho, 2003).

Although according to Aluma (1976), reliability of any written information on logging methods, productivity and cost of timber harvesting in Uganda is doubtful due to little research done in this field, experience shows that the current harvesting practices produce a lot of wood wastes and damage to the environment.

In order to address the challenges facing the logging industry in plantation forests in Uganda, the existing logging methods have to be analysed and where necessary alternative ways and means of improving the current methods suggested. In addition some negative impacts of logging on environmental and social-economic aspects due to poor planning of logging operations have to be investigated and ways to improve the situation recommended.

1.2.2 Wages

What a worker earns for his/her efforts is the most effective incentive for good work. The efforts must be rewarded by an equivalent value in the form of wages. It is common knowledge that manual workers are often paid the lowest wages without realising that what they do may be the largest contribution to the overall work process. Despite machines doing the job, the operator's pay may influence the worker's attitude and contribution to the effective use of the machine. Forest workers in Uganda, like in most other developing countries, are amongst the least paid in the country. This is because forestry employs the least trained and skilled labour force and a majority of them take the job as the last resort after failing to secure better paying jobs elsewhere (Abeli, 2000)

1.2.3 Training and organisation

Nearly all the forest workers in Uganda practicing logging have not been through a formal training for this type of work. This is evidenced by their poor working and tool maintenance techniques. Although majority of them have acquired skills while on the job, to say the least, it was from a bad practice. Their employers and supervisors have not been trained either on the best logging practices. The few, who might have received some training, find their way into managerial posts and have nothing to do with the actual logging on the ground. In other words, they don't contribute much towards the improvements of the logging methods and worker's safety in the logging industry. Overall there is no good work organisation in the field due to poor supervision resulting in unnecessary delays and low production.

1.3 Objectives

The overall objective of the study was to evaluate the current logging systems in Ugandan forest plantations and suggest improvements.

The specific objectives were:

- To determine logging productivity and costs of the current logging methods.
- To assess the amount and cause of wood waste in the current logging methods.
- To assess the environmental impact of the current logging methods.
- To propose appropriate logging practices, which will improve productivity and log quality, reduce logging cost, wood waste, soil disturbance and general forest degradation.

- To compare the current logging methods with the proposed and improved logging methods in terms of productivity, reduced cost and wood waste and, environmental improvement

1.4 Research hypotheses.

This study considers several hypotheses concerned with the variables believed to influence production rates and costs, and causes of soil disturbances and wood waste of various phases of on-going logging operations as follows:

Hypothesis 1

The current harvesting methods in forest plantations of Uganda result to low productivity, high costs and cause high soil disturbances and wood waste.

Hypothesis 2

The major variable in felling operation is diameter at breast height (Dbh).

FT= f (Dbh)

Where;

F T = felling time per tree,

Hypothesis 3

Log rolling time is a function of rolling distance, log size and slope.

RT= f (DIST×S×V)

Where;

RT = rolling time,

DIST = one way rolling distance,

V = the load size in cubic meters and,

S = the slope.

Hypothesis 4

Bucking time is a function of stem mid-diameter and number of bucking cuts per tree.

$BT = f(D_m \times N)$

Where;

BT = bucking time per tree,

D_m = merchantable stem mid- diameter and,

N = the number of bucking cuts.

CHARPTER TWO

2.0 LITERATURE REVIEW

2.1 Plantations development in the tropics

Plantations establishment is on a rapid increase throughout the tropics, and is one of the major reasons for current natural forest conversion (Poulsen and Applegate, 2001). Forest plantations with higher biomass productivity were identified as having the potential of reducing the high demand for timber from the natural forests (Tugumisirize, 1999). It is also an important factor affecting the state of biodiversity within these managed tropical forest landscapes and the people dependant on the resources within those areas. This in itself would imply and suggest that considerable emphasis should be put on ensuring that ecological, environmental and social adverse impacts and externalities should be minimised (Poulsen and Applegate, 2001).

In order to meet such demand, sustainable plantation management is required. The introduction of coniferous tree species (Pine and cypress) for timber production was a positive step by Uganda Government as it supplemented sawn timber and other wood products from the natural high forests (FORRI, 2001). The growth and development of these plantations was generally good in the past. Until mid 1970's prescribed thinning and pruning regimes were strictly followed on schedule and thinnings used to be sawn into timber at Lendu, Mafuga and Kapkwata plantation forests.

For sustainable forest management, plantation management should not be driven by an extractive philosophy, which views plantation management and plantations as a separate entity from the surrounding environment and social economics of the local community (Nambiar and Brown, 1997). Rather in order to ensure plantation sustainability there should be maximum alignment between key interdependent variables including: ecological capacity of the site, intensity of management, soil, water and other environmental values, and economic benefits and social goals (Nambiar and Brown, 1997). Plantation forestry can continue to make a significant and expanding contribution to the needs of the world for wood (FAO, 1993).

Many externalities associated with plantations are related to improper and inappropriate management practices. Hence new and more appropriate standards and practices are required to be developed on a site-specific level (Applegate and Poulsen, 2001).

2.2 Timber logging

Logging is an integrated part of forest management, and the way it is planned and executed affects both short and long-term revenue from forestry (Johnson and Lingren, 1990). The terms and concepts of forest practices have changed over time. While in the past the term logging was widely used for operations related to felling of trees, extraction and transportation of their stems from the forest to subsequent processing into industrial products. Nowadays the preferred term is wood harvesting in the strict sense or forest harvesting (Heinrich, 2001). Forest harvesting no longer refers only to the process of extracting trees from the forest to the roadside but also takes into account the importance of forests as a source of non-wood forest products and environmental services, as well as for the conservation of biodiversity. This increased complexity makes the planning and execution of harvesting operations more difficult, since they must be designed and implemented in such a way as to accommodate and, if possible enhance the multifunctional character of forests (Heinrich, 2001).

Harvesting of wood is usually divided into four main phases: planning, cutting, extraction and long distance transport. The main objective of timber harvesting is to deliver the wood in the desired form to the consumer at the lowest possible cost (FAO, 1994). According to Abeli (1993), factors affecting logging production and logging costs are: climatic factors, forest factors, social-economic factors and machine factors.

If the logging operations are to be carried out effectively and economically, planning of timber harvesting operations is important (Shemwetta, 1997). Planning involves making decisions about the location and design of roads and landings, the physical design of felling units, the logging system to be used and the scheduling of activities, equipment and personnel required during logging operations. The primary objective of a logging plan is to achieve the most economic logging operation consistent with silvicultural and any other forest objectives (Shemwetta, 1997). Aluma (1976) stated that improper cutting techniques, the use of poorly maintained tools and lack of protective gear usually result in trees falling in any direction, accidents, loss of wood and work stress.

2.2.1 Manual logging (Extraction)

Forest operations and techniques were the first forestry problem created by man because he needed to use wood for a variety of purposes (Samset, 1971). In developing countries, of which Uganda falls, most harvesting methods are labour intensive. Under labour intensive methods, work is done using manual tools while long distances between worker's homes and work places are covered on foot (Aluma, 1976). Intermediate-technology logging methods should constitute a competitive option for developing countries in which there is a poorly developed infrastructure, an abundant supply of labour and where labour costs are fairly very low (Skogsarbeten, 1983).

The oldest and simplest but not necessarily the cheapest method of log transport is by rolling it along the ground directly from the stump to the conversion centre, or a central landing (Aluma, 1976). According to Migunga (1997), manual extraction of trees or logs is possible for logs or trees of diameter less than 30cm and when extraction distances are less than 100m. The extraction can involve carrying the logs on the shoulders or hand rolling on the ground. On steep terrain, logs can be extracted by rolling or sliding them down the slope, utilising gravity force to a great extent. Manual operated sledges, skidding or forwarding sulkies can also be used for transporting logs for short distances.

2.3 Environmental impact assessment

Harvesting trees is a tool for accomplishing many management objectives, and operations can be conducted to protect environmental quality and reduce visual impacts. Key requirements for environmentally sound forest harvesting (will) include good planning, reputable contractors, skilled workers, and professional foresters who understand the concepts and application of sound forest practices (Long, 2001).

According to FAO (1997), an environmentally sound forest harvesting system is based on a general forest inventory for the entire forest area and a comprehensive pre-harvest survey of each cutting unit prior to harvesting, which enables one to thoroughly plan all harvesting operations associated with skid trail alignment and directional tree felling in order to reduce environmental impacts. Although it is evident that any harvesting system and technique, even the most advanced will have an impact on the environment, it is important when undertaking harvesting operations to bear this in mind in order to minimize the environmental impacts of harvesting operations on the forest sites (Heinrich, 2001). For example helicopter extraction system is used by many timber operators because of its high production performance and its ability to extract logs from otherwise inaccessible areas with minimal damage to the forest (Chankee, 2002).

Poor planning, weak forest regulations and inappropriate logging techniques have resulted in the unsustainable harvesting of the forest products and the degradation of the resource base (Aluma, 1976; Migunga and Dykstra, 1983; Migunga, 1996; Sist, 2000). The forest harvesting and related activities on steep terrain often cause slope instability and mass movement of soils (Mingteh, 2002). Conventional logging practices release large volume of green house gasses through the rapid decay of trees and other vegetation and soils damaged or disturbed during logging operations (FAO, 1998a). With Reduced

Impact Logging (RIL), felling and bucking damage is minimum and soil disturbance is significantly reduced (FAO, 2004). RIL result in less damage to the environment than Conventional Logging(CL) (Healey *et al.*, 2000). Pinard *et al.* (2000) reports that in general the implementation of RIL reduced the soil disturbance substantially when compared to conventional harvesting techniques, both in terms of area damage (from 13%-9%) and degree of disturbance. RIL research results in south eastern Asia indicate clear benefits from a productivity point of view as well as environmental benefits (Klassen, 2002). Observations by Killman *et al.* (2002) indicate that the area covered by skid trails in Reduced Impact Logging operations is almost 50% less than in CL and utilization rates are better with RIL, however, many more studies are needed.

Bowyer (1997) reported findings, which showed that forest damages associated with conventional logging could be reduced by 30% through planning of harvesting operations and better training of logging crew. In some Reduced Impact Logging experiments in lowland tropical forests, the damage to the soil and advanced regeneration was reduced by 50% relative to Conventional Logging. Implementation of Reduced Impact Logging techniques can reduce impacts to the soil from heavy logging machinery by 25%, and lead to a gain of as much as 50% in the "carbon storehouse" benefits from the remaining vegetation (CIFOR, 1998). As Dykstra (2001) reports RIL has become associated with logging technologies that have been introduced into tropical forests explicitly for the purpose of reducing the environmental and social impacts associated with industrial timber harvesting. The pattern of vegetation development created by careful logging has important implications for silvicultural decisions and stand modeling (Harvey and Brais, 2002). As reports Vergara (2002) reduced impact logging often concentrates on felling/bucking and yarding/skidding operations simply because their negative impacts on the residual stand and forest ecosystem as a whole are highly visible, and readily measurable in physical and monetary terms. In Van der Hout (2000), skidding appeared to have a lower impact on the environment in the RIL operations than in the CL operation.

Crome *et al.* (1992) report of 1600m of major logging tracks, averaging 5m in width (0.8ha) from which all vegetation was cleared and with mineral soil exposed along their entire length (4.2% of area). He further reports that, field operators have the power to eliminate or significantly reduce the environmental damage caused by logging operations. Their management determines the success of management plans through enhancement of the skills and cooperation of field staff. To achieve more efficient and environmentally sound logging practices, training is urgently needed. If logging training is not given higher priority, very little progress will be achieved in improving forest management and environmental protection (FAO, 2004). The results in Suparma *et al.* (2002) suggest that there is the potential of increasing productivity and reducing environmental impacts through the adoption of improved operational planning and control. There is a need to expand harvesting studies to look at impacts and trade-offs across larger forest landscapes, to expand RIL beyond silvicultural concepts and to include the maintenance of other forest goods and services (Sist *et al.*, 2003).

2.3.1 Methods for assessing soil disturbance

Measurement and prediction of soil disturbance must integrate several complex relationships. An ability to predict how much and under what conditions a forest soil will get disturbed (compact) most would greatly improve soil management. Soil compaction can for example be predicted by determining changes in the soil parameters like; bulk density, cone penetration resistance, water infiltration capacity, and soil surface disturbance such as root formation and exposure of mineral soil. Laboratory and in situ measurements of the above parameters can be used in assessing forest soil disturbances and compaction that result from logging operations (Greacen and Sands, 1980; Wingate-Hill and Jakobsen, 1982; Braunack, 1986a, b; Ole-Meiludie and Njau, 1989, Malmer and Grip, 1990; Warkotch *et al.*, 1994; Wasterlund, 1992; 1994; Migunga, 1996; Abeli and Sawe, 1999). At present, there is no systematic approach to assessing site disturbance in forestry. However, the literature reviewed suggest a number of methods that can be used in assessing the impact of forest harvesting operations on forest sites and soils.

The results of studies on soil disturbance suggest: visual inspection, micro-relief measurement, the measurement of dry soil bulky density changes, and measurement of soil resistance to cone penetration as ideal for the study of soil disturbances in the field. These methods can provide an insight in soil changes that may be caused by log skidding operation (Migunga, 1996; FAO, 1998b).

Furthermore, assessment of soil disturbance can provide forest managers with information to make appropriate decisions on site rehabilitation and monitoring, and efforts in minimizing soil changes during harvesting operations. In addition, site disturbance may also be required by regulatory bodies to assess compliance with certain rules and regulations imposed from time to time (Migunga, 1996).

2.3.2 Visual assessment of soil disturbance

Visual assessment of forest soils after operation of forest machines has been used to assess the impact of the machines on the soil and environment (Froehlich and McNabb, 1984; Ole-Meiludie and Njau, 1989; Malmer and Grip, 1990; Wasterlund, 1991, 1992, 1994; MacDonald *et al.*, 1995). Abeli and Sawe (1999) reported that in one study area logging did cause soil surface disturbances in form of rut development and removed the topsoil and organic matter materials. Migunga (1995) found that where transportation of logs on forest stands occurs on the ground (which is used as a growth substrate), the forces acting on the contact area beneath a foot, wheel or truck causes a reaction in the forest floor, which in turn increases soil bulky density.

Visual assessment of site damage along line transects on established sample plots can be performed. The percentage of each disturbance class can be determined by measuring the area covered by the damage in the field. The classes could be: undisturbed soil, disturbed soil, depressed soils, organic scarification, mineral scarification and mineral mounds (Martin, 1988; Migunga, 1996). Though this method is easy to use, it is very subjective to quantify the soil compaction that has occurred (Wasterlund, 1991).

Ground survey methods are often used in assessing soil disturbance in forestry

(McMahon, 1995). Four ground survey methods have commonly been used by researchers to assess site and soil disturbances after logging operations. These are; the Point Transect (PT) method, Line Transect (LT) method, Grid Point Intercept (GPI) method and Global positioning System (GPS) / Geographic information system (GIS) method (Ryder *et al.*, 1994; MacMahon, 1995).

Point Transect (PT) method characterizes soil disturbance at predetermined points along the surveyed transect. Transects may be orientated parallel to the contours, where the predominant extraction direction is down slope (Evanson *et al.*, 1994), or perpendicular to the contours irrespective of the extraction directions (Lousier, 1990).The distances between classification points located along the transects may range from 1 to 3m, allowing for measurements of all skid trails. In this technique, the coverage of each disturbance class is determined from the number of points in each class and the total number of points sampled.

For the line transect (LT) method, as with PT, disturbance along surveyed transects is classified. The disturbance corresponding to changes in disturbance classes of interest are recorded. The lengths of each of the disturbance classes are summed to determine the relative coverage (%) of the net-forested area. Transects are evenly located over a site parallel to the site contours or a combination of two orientation perpendicular to each other (McMahon, 1995).

The Grid Point Intercept (GPI) method uses a grid system randomly orientated over a study site at a pre-defined spacing, and a grid point located at the intercepts at each grid point, two or four transects, 30m in length, are established. When the study area is less than 6 ha, four transects are used at each grid point. For areas greater than 6ha, only two transects are used at each grid point (Curran and Thomson, 1991). The first transect is located randomly, and subsequent transects oriented at 90 degrees, 180 degrees, and 270 degrees from the original (McMahon, 1995). Research done in New Zealand recommends the PT method with 30m spaced transects, as it is less likely to miss disturbance features relative to GPI method (McMahon, 1995). It provides the most accurate estimate of disturbance, and is more consistent than GPI method.

Global Positioning System (GPS) and Geographic Information System (GIS) have been combined and used to create a map and database for the study of soil disturbance in the United States of America (Ryder *et al.*, 1994). GPS created database for mapping of the disturbed area while GIS facilitated stratification of skid trails by disturbance levels. This system of sampling has been reported to ensure adequate representation across the entire range of trails and disturbance levels. This sampling procedure has been used to quantify the relationship between degree of soil disturbance and selected skid trail variables such as side slope, trail curvature and depth of ruts (Ryder *et al.*, 1994; Migunga, 1996).

2.3.4 Timber harvesting systems

Harvesting methods mainly depend on forest ownership and vary from motor-manual felling to partly and fully mechanized systems (Otto, 1996). The harvesting system being used in logging a particular area can influence the amount of disturbance and compaction a particular area can experience. Thinning and clear cutting prescriptions using tractors are among the management practices most likely to produce soil disturbance and compaction (Greacen and Sands, 1980; Migunga, 1996). Scheduling of logging operations has great influence on site disturbance too. Other factors related to logging operations are; site layout, work organization, skid trail patterns, harvesting method and logging crew (Krag *et al.*, 1986; Migunga, 1996). The working technique employed in skidding operations affects the type and seriousness of the potential damage to the soils and stands. The extent of damage is influenced by the assortment type and size, the layout of individual loads on the terrain, loading system, and the characteristics of the specific forest implement mounted on the tractor (Spinelli, 1994). Rice *et al.* (1999) states that, it is feasible to prevent surface erosion from roads and logged areas but quite difficult (nearly impossible) to prevent mass erosion on steep terrain. The cost of erosion control tends to increase geometrically with the erosion potential. Mobile skyline yarding is one of the most preferred methods on steep terrain, but its share of about 15% of the total harvested volume is still rather low because of the relatively high cost (Otto, 1996).

The main limiting factors of forestry are mountainous terrain, high labour costs, patterns of ownership and environmental restrictions on harvesting. Planned timber harvesting can reduce costs significantly by comparison with conventional logging in contrast to the strongly held belief that RIL must necessarily cost more than CL (Winker and Nobauer, 2001).The skidding methods show a great variety mainly depending on the type of the forest property. Ground skidding by means of a farm tractor with rear winch on moderate terrain and manual gravity skidding on steep terrain (slopes) still are the most preferred methods in small private forests (Otto, 1996). The position of the log after felling is directly correlated with the degree of damage caused by extraction and with operational productivity (FAO, 1997). FAO (2004) further report that logging waste develop due to poor working methods and techniques, which result in the splitting and breaking of felled trees. High stumps, felling above the buttress and topping at large diameter also result in excessive waste.

2.4 Sustainable forest harvesting systems

Since forest based development depends on industrial use of forest resources, timber harvesting is an unavoidable component of sustainable forest management (Leslie, 2001). A sustainable Forest Management System (SFMS) incorporates optimum production and utilisation of forest products as one of the key Sustainable Forest Management (SFM) objectives. This includes the promotion of timber harvesting systems that are environmentally sound, economically feasible, and socially acceptable. Such harvesting systems are referred to as Reduced Impact Logging (RIL) systems (FAO, 2001). As stated earlier it is possible to conduct forest harvesting operations in ways that are consistent with the concept of sustainability (Dykstra and Heinrich, 1996). Well planned and carefully controlled harvesting systems are superior economically, environmentally and silviculturally, and such harvesting systems should be fully integrated with the management system (FAO, 1989). In the utilization of tropical moist forests, emphasis should always be put on low disturbance levels similar to the natural rate of tree falls that form an integral component of the mature forest (Kasenene and Murphy, 1991).

Before felling, the falling direction should be determined. Notch and back-cut should be done appropriately while retaining hinge wood. Felling levers and wedges are used where necessary to control the falling direction. Operators should always be working on a safe distance (two full tree length) (Applegate and Raymond, 2001). Before bucking, the stems should be measured and the number of logs to be bucked should be determined in advance. Bucking the stem should be at an angle not more than 10^0 from vertical (Applegate and Raymond, 2001). FAO (2004) state that logger training is a key factor in reducing logging waste and value loss. A study by Janckers (2002) proved that by reducing wood waste through proper planning of harvesting operations, logging costs per cubic meter extracted can be reduced by 23%.

Skid trail locations should be clearly flagged on the ground and the skidding equipment should as far as possible remain on the skid trails at all times and only the winch line should be pulled to the logs (FAO, 1997; Sist *et al.,* 1998; Applegate and Raymond, 2001). Steep terrain is a common logging problem in many developing countries. Manual skidding is often a feasible method, especially on steep and short slopes (Skogsarbeten, 1983). Recently Codes of Practice and Criteria and Indicators for sustainable development of industrial plantations in the tropics have been developed and adopted in many countries (Poulsen and Applegate, 2001; Applegate and Raymond, 2001).

Efforts towards sustainable forest management (SFM) have promoted the implementation of RIL techniques. RIL's main objectives are to reduce soil disturbance and impacts on residual trees (Sist, 2000). The key elements of RIL are: planning, implementation and control, harvest assessment and training of a well-motivated work force (Heinrich, 2001).

The effectiveness of RIL techniques in reducing damage and optimising resource utilisation has been demonstrated by several studies (Sist et al., 1998; FAO, 2000; FAO, 2001). According to Heinrich (2001) there is need for a continuous refinement of forest harvesting and engineering methods or systems in order to make them fully compatible with the objectives of sustainable forest management. Increased operational efficiency is an important benefit of RIL, one that largely determines its cost effectiveness relative to conventional practices (Boltz et al., 2003). While the benefits of reduced impact logging (RIL) are widely acknowledged, the incremental costs of adopting RIL practices are commonly viewed as a principal impediment to their adoption by loggers. RIL requires increased investments in training and planning. This in turn result in a more efficient logging operation and optimal use of logging equipment (reduced skidding distance and improved log recovery) (FAO, 2004). About 20% of the harvesting damage could have been avoided using the full range of RIL elements (Jankers and Leersum, 2000). The profitability of uncontrolled logging can be a significant obstacle to sustainable forest management, especially in the tropics (Pearce et al., 2003).

2.4.1 Factors influencing terrain transport operations

Consideration of alternative terrain transport method/ technique for a particular logging area requires a clear understanding of the factors influencing the performance and costs of the system. Therefore, the first step in understanding the factors influencing the logging production rates and costs of a particular logging system is to determine the factors that affect production rates and costs. Conway (1976) points out that, each system responds differently to same variables. The sensitivity of response is system specific. Differences in topographical, soil and hydrological conditions will alter the savings made by RIL when the costs of these environmental impacts are counted (Hammond *et al.*, 2000).

Several studies have been conducted worldwide to find out factors influencing production rates and costs of logging operations. Based on these studies, the influencing variables can be grouped into two main types: objective measurable factors and subjective estimated factors (Samset, 1990). Included in the two classes are: terrain, climatic, and forestry conditions, labour factors and machine characteristics. The planning and control of transportation of timber must always take into consideration these variables. Terrain and forestry conditions are the main limiting factors for the use of ground based machines, such as log skidding tractors.

2.4.1.1 Terrain factors

Environmental and forestry factors play an important role in the determination of productivity and cost of logging systems. The major variables affecting terrain transport systems are: terrain slope, soil surface conditions, ground roughness, soil strength, number and height of obstacles, average skidding distance, tree size, total volume to be harvested, residual stand densities, distribution of logs on stand, season of year, climate, soil moisture and topography or elevation (Bradley and Biltonen, 1974; Conway, 1976; FAO, 1977; Hartsog and Cass, 1979; Migunga, 1996).

Of the above variables research has identified the following factors to be the most important terrain variables affecting log skidding: terrain slope, ground roughness, number of obstacles on ground surface, soil types and strength. Terrain slope determines the amount of skidding resistance to the movement of a skidding machine (Fiske and Fridley, 1975; Fue, 1987). Slope determines the forces needed to pull the log. In logging, ground roughness is a term used to describe the prevalence of obstacles that hinder forest operations such as stump height, boulders, stones and land evenness (Haarla, 1973; Heinrich and Ole-Meiludie, 1990).

In skidding operation, obstacles are those that hinder the movement of the machines and the log being skidded. Such obstacles include stumps, rocks, boulders, windfalls, depressions and logging debris. The distribution of such obstacles on the terrain will affect the performance and cost of skidding operation (Wackerman *et al.*, 1966; Fue, 1987). Skidding and yarding distances will influence the amount of soil disturbance (Legault and Powell, 1975; Olsen and Gibbsons, 1983; Ole-Meiludie, 1984).Terrainn soil properties such as type, depth and texture of mineral soils have effects on surface firmness and traficability of soil under varying climatic conditions (FAO, 1976).

The evaluation of terrain factors can be accomplished by terrain classification. Terrain data is needed for forest resource assessment, silvicultural and for the management of harvesting operations in forests. The type of terrain has important influence on silvicultural activities, harvesting and transport of timber from stump site to road side landings. Terrain data is a pre-requisite for planning and control of forest harvesting operations. Furthermore, terrain classification has been used for long-term management planning and short and medium-term operational planning, working site assessment and on follow up activities (LÖffler, 1984).

Several terrain classification systems for forestry have been used in Europe and North America to make possible the prediction about the way terrain affects different forest operations (Haarlaa, 1973; Rowan, 1977; Mellgren, 1980; LÖffler, 1984; Davis and Reisinger, 1990). Terrain classification for forestry is the characterisation and grouping of forest land according to the accessibility or, according to the degree of difficulty and to the possibilities and limitations of forest operations. Two main types of terrain classification systems have been used in forestry. These include: descriptive terrain classification system and functional terrain classification system (Haarlaa, 1973; Migunga, 1996).

In descriptive classification, the site is classified solely in terms of the terrain factors that directly affect harvesting system productivity: terrain slope, ground strength and bearing capacity and surface roughness. The advantage of this system is that the site is classified in terms of physical and permanent terrain factors. But the major disadvantage is that it requires excessive time to be accomplished.

In functional classification system, the site is classified solely in terms of the operability of a particular type of equipment. Terrain is classified on basis of the performance of a particular machine. The terrain is classified every time a new machine is introduced in an area.

An additional terrain classification system recently introduced is that which uses Geographic Information System (GIS) to evaluate terrain conditions. GIS systems combine a data base with computer graphics to efficiently maintain and display spatial information on site terrain factors. This system has been used to develop a terrain evaluation model that can be used for planning large scale industrial timber harvesting operations (Davis and Reisinger, 1990). The model provides an efficient means of classifying forest terrain in terms of individual component terrain factors. The model utilised GIS to store, display and manipulate the large amount of resource and terrain data required for terrain classifications. Terrain is rated and classified in terms of slope, surface roughness, and ground strength. This terrain classification is then combined with harvesting machine operating criteria to produce maps that delineate areas where each harvesting system may operate economically and with minimum environmental damage (Davis and Reisinger, 1990).

The development of terrain classification system for use in planning harvesting operations requires three steps:

(i) identification of terrain factors important or influencing harvesting operations;

(ii) quantification of terrain factors and assigning a value to each factor;

(iii) the range of the measured terrain factor values must be subdivided into classes to form the terrain classification.

2.4.1.2 Forest stand factors

A review of literature has revealed skidding production rates to be significantly influenced by the following stand factors: stand density; density of residual stand after thinning, harvestable volume per hectare, volume per unit area, amount of brush on the ground, number of trees per hectare, distribution of trees on the stand, quality of the trees to be removed and the distribution and size of undergrowth (Conway, 1976; FAO, 1976; Perumprol *et al.*, 1977; McDonald *et al.*, 1978; Migunga, 1996).

2.4.1.3 Timber characteristics

Timber characteristics that are reported to be critical in influencing cutting and skidding times and their costs are: species, size of trees, and dispersion of logs on the ground, number of logs per trip, average piece size and weight (Schneider, 1978; Kellogg and Olsen, 1988; Ole-Meiludie, 1984; Migunga, 1996). Log lengths cause more damage to the soils than tree lengths (Jackobsen and Moore, 1981). Silvicultural methods and requirements (silvicultural variables) can influence the decision to commercially thin or clear-cut, and harvesting system to use for a particular logging site (Migunga, 1996).

2.4.1.4 Climatic factors

The most important climatic factors that affect forest harvesting operations are rainfall, humidity, atmospheric pressure, soil moisture, heat and dust (FAO, 1974). These factors influence the working capabilities of the workers and the machine itself. The temperature of a working place and environment has been reported to influence the capabilities of operators and other workers in logging productivity (Apud and Valdes, 1986). The higher the temperature the lower the performance of the workers. Temperature has direct influence on productivity, costs, and impacts of logging operations on forest soils. The total amount of rain or snow falling on an area would directly affect the productivity of the cutting crew (time wise) and traficability of soils and mobility of skidding machines thus affecting their performance (Arvesen, 1970; Friske and Fridley, 1975). In areas with warm climates, soil compaction after clearfelling operations could persist during next generation if no amelioration is achieved during site preparation (Froehlich and McNabb, 1984).

2.4.1.5 Labour factors

Physical work capacity, motivation, nutrition, health, level of skill or training and general attitudes about work affect logging productivity and costs. However these factors are difficult to measure comprehensively (FAO, 1977; Garland, 1990). Studies of labour productivity have revealed that the most important factors that influence logging crew performance include; crew size, labour availability, labour incentives and motivation, skill and capability, experience, attitude towards work, working capacity, health, nutrition, physical workload, living and working conditions, and training (FAO, 1974; Apud and Valdes, 1986). Inadequate diets which do not meet the energy requirements to allow workers to keep energy balance and little motivation derived from poor living conditions in most forestry camps result to low output during manual works (Apud and Valdes, 1986). Therefore according to Abeli (2000) ergonomics and safety must be considered in logging operations.

Financial incentives to labour, properly designed and implemented can significantly improve logging productivity (Dykstra, 1981). Poor working conditions, lack of proper logging equipment and hand tools, lack of training and lack of safety clothing have further been identified to be contributing to low productivity and high costs of logging operations in plantations in Eastern Africa (Aluma, 1976; Abeli, 1979).

2.5 Logging work studies

The planning, forecasting and control of logging operations depends on the availability of reliable qualitative and quantitative data on logging operations. Time and motion studies give a basis for measuring work production rates and costs over a given period of time, and comparison of harvesting systems operating under the same factors (Wittering, 1973; Anderson, 1976; Samset, 1990). These studies have been used in logging for; planning and scheduling logging operations i.e. cutting, primary transportation (skidding/yarding) and long distance transportation, road planning, construction and maintenance, cost appraisal and budgeting in logging, making decisions about which logging method and system to use for example; comparing alternative logging systems, comparing the productivity of logging machines, methods and logging labour. Also to investigate the productivity of logging machines and how this productivity varies with the influencing factors; determination of time standards as a basis for wages and wage incentives related to logging productivity. Various harvesting systems have been evaluated and compared using time studies (Dykstra, 1977; LeDoux, 1985; Samset, 1990; Abeli, 1985; Migunga, 1996).

Investigations on the production and productivity of forest operations consists partly of time and performance studies and partly of exact measurements of all forestry, terrain and climatic conditions, which influence time consumption (Samset, 1990). Comparisons of production rates and costs of logging systems have been accomplished by time studies (Gibson and Rodernberg, 1975; Dykstra, 1975, 1977). Comparisons of different time study methods for use in forestry have been performed (Olsen and Kellogg, 1983). Time studies of aerial logging systems and log skidding machines have been performed and models developed based on time study data (Dykstra, 1977; Hartsog and Cass, 1979; Ole-Meiludie, 1984, Ndemere, 1991). Efficiencies of logging systems have further depended on time studies for their improvements. They form a basis for measuring work production rates and costs over a given period of time (Aluma, 1976; Abeli, 1985; Samset, 1990).

Time studies have been used to develop timber harvesting models that can be used in simulation of timber harvesting and in prediction of production rates and costs of logging operations under different terrain characteristics (Froehlich and McNabb, 1984; Olsen and Seifert, 1984; Curro and Verani, 1990; Samset, 1990). Typical applications of time studies include: studies evaluating timber harvesting operations when using manual and mechanised harvesting methods (McDermid and Perkins, 1972; Legault and Powell, 1975; Aluma, 1976; Ohmstede, 1977; McDonald *et al.*, 1978).

Time study techniques commonly used in logging performance studies include a number of continuous timing techniques. In these techniques, timing is done continuously from the start until the end of a working shift. Usually stop watches graduated in centiminutes or tenth of minutes are used to record the times (Abeli, 1985). Special digital data recording devices with built in electronic timer have also been used in measuring harvesting work (Dykstra and Howard, 1980). Logging and log transportation in tropical high forests and advanced logging systems in mountainous forests have been analysed by detailed time studies utilising repetitive timing methodology to establish production rates and costs (Aluma, 1976; Ndemere, 1991). Dykstra (1975, 1976) and Hartsog and Cass (1979) used continuous time studies as a basis for comparing cable, balloon and helicopter logging systems.

Continuous timing method can further be subdivided into cumulative, repetitive and work sampling timing method. Cumulative timing method involves an observer using a stopwatch to determine time spent on productive and non-productive activities. The stopwatch is started synchronously when work begins in the morning and runs continuously until work is halted at the end of the day (Dykstra, 1975, 1977; Abeli, 1985). Comparative analysis of this time study methodology by Gardner and Schillings (1969) and Olsen and Kellogg (1983) concluded that a major advantage of the method is that it reveals dependable values. It provides the only unbiased measurement where productive and non-productive times are to be studied. It further keeps a record of sequence of operations observed during the study. The major disadvantage of cumulative timing is high cost involved due to the fact that it requires the constant presence of a skilled observer. It is further observed that the method has a disadvantage that it may cause psychological effect on workers who might deliberately invalidate the data by altering their normal work patterns while being timed. An added disadvantage is that it requires subtraction in order to obtain individual element times. On the spot checking of time study data is usually impossible.

Repetitive or "snap-back" or "zero-reset" timing method involves the direct recording of the observed times on the study form as the study continues to be carried out. The method requires one timer for each operation. The observer starts a stopwatch at the beginning of each activity. At the conclusion of the activity, the elapsed time is recorded and the stopwatch is reset to zero. Elapsed time for each event is recorded on the observation sheet and the time study analyst can judge relative variations in event time as the study proceeds (Barnes, 1968; Wittering, 1973; Abeli, 1985). An advantage of this timing method is that it requires no subtraction to get individual element times. It provides immediate insight into the operation being studied. The method has widely been used in Uganda and Tanzania to establish production rates and costs of logging systems in woodlands and plantations (Aluma, 1976; Abeli, 1979; Ole-Meiludie, 1980; Abeli and Dykstra, 1981; Ole-Meiludie and Dykstra, 1983; Mwambu-Mungomu, 1990; Ndemere, 1991).

Work sampling involves observing the operation at intervals rather than continuously. It can be done by observing work at predetermined fixed intervals or at random intervals established from a table of random numbers. Comparative studies by Gardner and Schillings (1969), Olsen and Kellogg (1983) have indicated that work sampling offers economy at no theoretical sacrifice of accuracy and is simple to apply. Its use is recommended when a single analyst intends to observe several operators simultaneously. Empirical data on timber harvesting can be collected by work sampling.

Shift-level or "gross" time study technique measures and records production levels achieved by a work system, machine or crew working per day, shift or a given period of time during an entire season. This method is commonly used by many logging operators though very few reports on it have been published (Dykstra, 1977; Migunga, 1996). Gross time studies are most helpful in showing where detailed time studies are needed. Insight into the operation studied is not revealed because individual elements are not timed independently. A lengthy period is required to accumulate sufficient data. This method is recommended for use when long term and lengthy operating system data is required (Abeli, 1985).

Combination studies involve the use of empirical data collected by time studies, combined with theoretical formulations to facilitate the analysis of harvesting operations. The selection of harvesting system to use for a particular terrain and operating conditions can utilise such methods. Olsen and Gibsons (1983) combined mobility analysis and time study to develop a mobility model that could be used to evaluate the performance of skidders in various terrain and soil conditions. Studies combining skidding force analysis, mobility analysis and time studies have been used in timber harvesting analysis (Calvert and Garlicki, 1970; Perumpral *et al.*, 1977; Lysne and Burditt, 1983; Olsen and Gobsons, 1983).

2.6 Synthesis

Barnes (1968), Gibson and Rodemberg (1975), Olsen and Kellogg (1983) based on their research recommended the use of continuous timing method for logging systems analysis. The repetitive timing method of continuous timing has been evidenced to show superiority over other methods as it provides in-depth of data and can be used for development of statistical models that can be used to compare logging systems. They further suggested the factors that can be included in performance studies in order to accumulate data for analysis with the aim of determining the production rates and costs and factors influencing the performance of certain harvesting systems and their impact on forest soils.

2.7 Analysis of work study data

Analytical results of work study data can be used as a criteria for choice of the appropriate logging system for a given set of environmental and forest conditions. The analysis of work study data has made possible the estimation of the effect of changes in several factors on the production rates and costs of logging systems and labour. A review of some of the analytical procedures that could be applied to analyse logging data is presented in the following sections.

2.7.1 Qualitative analysis

This analysis describes broadly the system under study summarising the dependent and independent variables encountered in the field during the study. It has been used to analyse logging time study data enabling the establishment of statistical distributions which describe the populations studied, estimation of production rates and costs which has facilitated the comparison of production costs and production rates of the logging systems (Dykstra, 1976; 1977; Ole-Meiludie, 1984; Abeli, 1985; Hochrein and Kellogg, 1988). Such analyses have facilitated the understanding of factors influencing productivity and delays, giving descriptive summaries and distributions.

Results of qualitative analysis have been given in form of tables giving summaries of productive and non-productive times and independent variables collected during the study (Gabriel and Nissen, 1971; Gabriel *et al.*, 1974; Aluma, 1976; Dykstra, 1977; Ndemere, 1991). Such a system permits forest managers to design and control logging operations more effectively as they know their parameters, which govern their operating conditions during logging.

2.7.2 Regression analysis.

In characterizing the association between characters, there is a need for statistical procedures that can simultaneously handle several variables. Regression analysis allows a researcher to examine any one or a combination of associations provided that the variables concerned are expressed quantitatively. Regression analysis describes the effect of one or more variables (designated as independent variable) on a single variable (designated as the dependent variable) by expressing the latter as a function of the former (Kwanchai and Arturo, 1984).

Regression analysis has been used by researchers to quantify relationships between dependent and independent empirical parameters (Neter *et al.*, 1983). Logging systems analysis has utilised regression analysis to determine the influence of different biophysical factors on different logging operations. The evolution of computer science has greatly facilitated the use of multiple regression analysis in logging systems analysis (Gibson and Redernberg, 1975: Hartsog and Cass, 1979; Hochrein and Kellogg, 1988). The derivation of models relating logging production to stand factors pertaining in a particular situation has been made possible by regression. Predictions and analysis of performance of logging machines has utilised regression (Legault and Powell, 1975; Aluma, 1976; Dykstra, 1976; Abeli and Dykstra, 1981; Ole-Meiludie, 1984; Hochrein and Kellogg, 1988; Ndemere, 1991)

Furthermore, regression has been utilised in analysing and comparing ground-based logging systems (Ohmstede, 1977; McDonald *et al.*, 1978; Dykstra and Howard, 1980; Ole-Meiludie, 1984) and comparing the performance of advanced logging systems in different terrain conditions (Dykstra 1976; 1977; Hartsog and Cass, 1979; Lysne and Burditt, 1983; Olsen and Gibbons, 1983; Olsen and Seifert, 1984; LeDoux, 1985; Garland, 1990; Randhawa and Olsen, 1990).

Regressions have been applied in studying the effects of logging machines on forest soils. The compaction of forest soils either as a relative or percentage change in bulk density, has been predicted by multiple linear regression with considerable success (Greacen and Sands, 1980; Froehlich *et al.*, 1984). Froehlich *et al.* (1984) incorporated regressions in the study of effects of soil compaction caused by mechanised timber harvesting. The study of the effects of machines on tree growth has used regressions to relate the increase in soil bulk density to decrease in the tree height growth (Youngberg, 1959; Foil and Ralston, 1967).

In logging studies, observations have revealed that multiple correlations between the best fit regression equation and observed values of the response variable are low, often less than 0.25. This explains the great variance in logging production rates, which partially depends on factors that are generally unmeasurable. Furthermore, logging situations vary greatly due to existing variations in terrain and environmental conditions. Therefore logging planners and researchers must be prepared to use regression equations that leave a considerable portion of variance in the response variable unexplained.

2.7.3 Cost analysis in logging

Cost of logging operations has been reported to represent about fifty percent of the total cost of wood delivered to the mill landing or log pile (Grant *et al.*, 1990). Cost analysis is the critical examination of relevant costs among themselves and in relation to external factors that may have influenced them. It involves the actual costs incurred in production activities being considered, an attempt to isolate and explain costs that are exceptionally high or low, and making comparisons of operational costs in the exercise of logging planning with the aim of minimising costs. Cost analysis has become essential for the control of present operations; for the detection of areas in which cost reduction are most feasible; and for the comparison of planned or new alternatives to present alternatives; and in the selection of competing machines for a particular set of terrain conditions

(Miyata and Steinhlib, 1981)

Planning of logging operations in forests depends on cost data availability. In most cases the costs are rarely kept especially in developing countries. Cost analyses facilitate comparisons of logging systems, machines and methods to be used for timber harvesting. In such analyses, determination of costs, productivity and investment in logging machines, tools and labour contributes significantly to logging cost control (Miyata and Steinhilb, 1981; Bushman and Olsen, 1988). A good knowledge and understanding of logging costs and their calculation methods helps keep operations on a sound business basis and enables the logging manager to make sounder decisions (Miyata and Steinhilb, 1981). Economic evaluations of alternative logging systems can be used on logging production cost analysis under conditions in which the machines are likely to be operated (FAO, 1974; Dykstra, 1976; Hartsog and Cass, 1979).

Literature reviewed by Mitaya and Steinhilb (1981) reported about thirty different ways of calculating machine rates and logging costs. They further noted that there was no uniformity in defining the components used in the calculating methods. However, in costing logging equipment, machine rates and cash flow approach are used even though the machine rate method seems to dominate. Each method has its own limitations
(Bushman and Olsen, 1988)

Information on various machine time elements such as scheduled hours and total time a machine is utilised form a basis for determination and improvements of operating costs and machine operations (FAO, 1974). The logging manager must have an accurate knowledge of the real cost of owning and operating current machines and also have a reliable prediction of the prevailing alternatives. Estimation of total logging costs has been based on available cost data, experience, planning documents, manufacturer's documents and guides (Grant *et al.*, 1990).

CHARPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study areas.

3.1.1 Mafuga Forest plantation.

3.1.1.1 Site area

Mafuga plantation is a forest rcserve situated in Kabale District, south-western part of Uganda (see figure 1). It is about 30km north of Kabale town on Kabale-Kanungu road. The total gazetted area of Mafuga Forest Reserve is 3 699.0 ha. while the plantations cover a total area of 2 670.3 ha. The main tree species grown in Mafuga forest plantations are *P. patula, P. taeda* and *C. lusitanica. Eucalyptus grandis* is mainly confined to fire lines and along borderlines.

3.1.1.2 Topography and drainage

The plantation lies between 1 850 and 2 800 meters above sea level. The hills are steep and severely dissected. The main valley bottoms are poorly drained and slightly swampy. The major streams are tributaries of Ishasha River, which drains to Lake Bunyonyi situated in the south-western part of the plantation.

3.1.1.3 Geology and soils

The forest reserve is underlain by Karagwe/Ankolean strata containing shales, slates, phyllites, sandstones and quartzite's folded and distorted by underlying granite intrusions. The soils are acidic, clay and red earths. On the ridges, soil depths are fairly deep but low in nutrients. On steep slopes, the soils are thin, stony and skeletal while on gentle slopes, the soils are deeper and moderately fertile. Flatter, poorly drained valley bottoms contain black swampy soils.

3.1.1.4 Climate

Rainfall pattern is bimodal, with maximum around April and November but generally well distributed. The mean annual rainfall is about 1 264 mm and April rains are generally heavier than those of November although the latter usually has longer duration. The months of July and August tend to be dry thus posing the risk of frequent forest fires.

The average daily temperature for Kabale town for the period 1960-2000 ranges from 10.7 $^{\circ}$C to 23.9 $^{\circ}$C. Analysis of the trend shows that there is a slight increase in temperature with time. The temperatures at Mafuga, which is at higher altitude, are expected to be slightly lower than those of Kabale.

3.1.1.5 Tree Harvesting

Logging operations in Mafuga plantations started in the 1970's and have since continued to date. Saw logs are converted to sawn timber through pitsawing or sawmilling.

Although pitsawing is known to be very wasteful, it still continues to be one of the most appropriate in some areas especially in steep and inaccessible compartments. During the study period there were seven mobile sawmills operated by five concessionaires in Mafuga forest plantation and pit sawing was put on halt by the state.

3.1.2 Katugo forest plantation

3.1.2.1 Site area

This plantation is in a forest reserve in Nakasongola District, about 100 km north of Kampala on Kampala-Gulu road (see Figure 1). The total gazetted area of Katugo Forest Reserve is 3,318 ha. while the total plantation area is 2813.8ha.

3.1.2.2 Topography and drainage

The plantation lies between 1 000 and 1 080 meters above sea level. The area is flat and characterised by broad seasonal swamps. Water flow from the swamps is either very slow or non-existent resulting in stagnation of floodwater, which eventually evaporates.

3.1.2.3 Geology and Soils

The forest reserve is located on strongly weathered basement complex formation of Precambrian age, which consists of metamorphic and igneous rocks, largely composed of gneisses and granites.

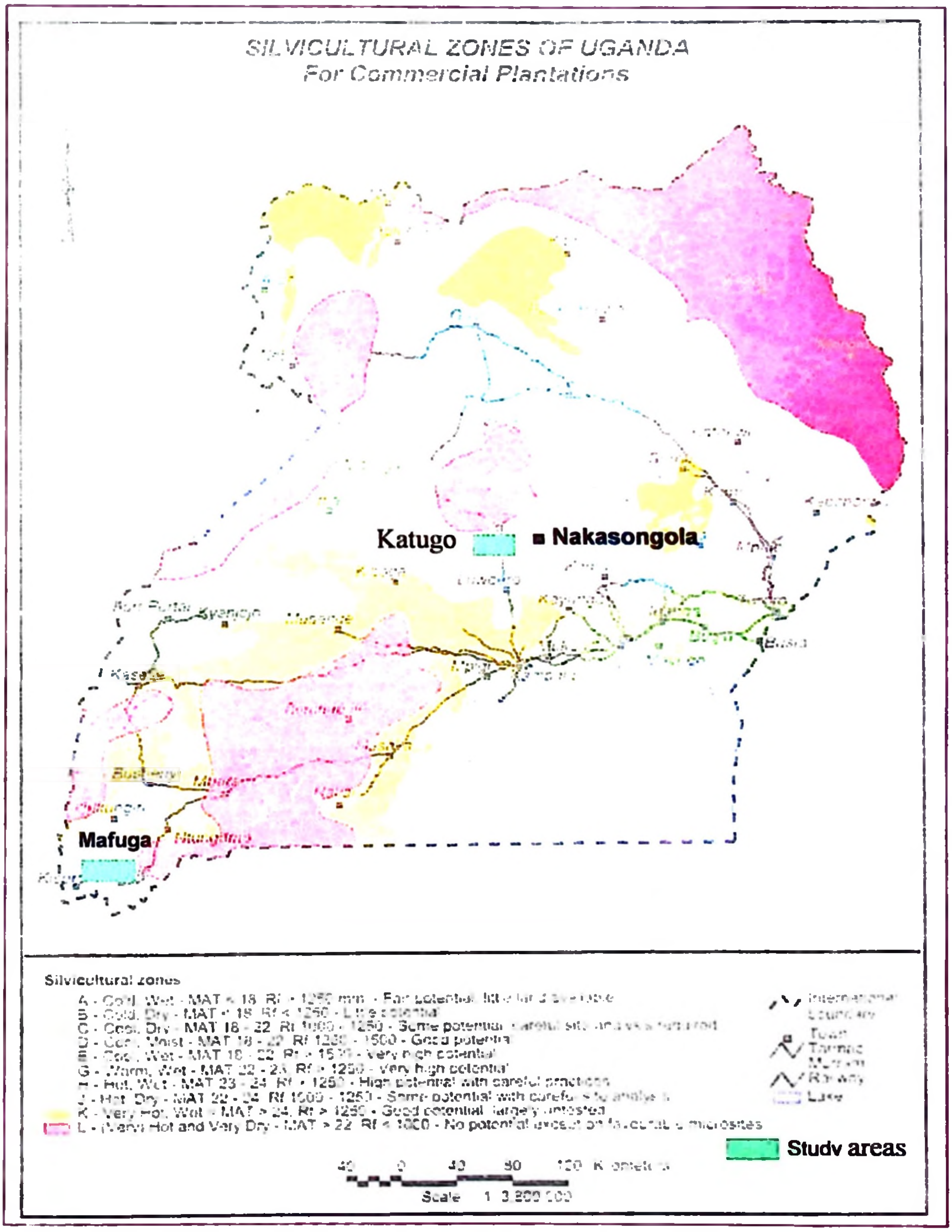

Figure 1. A map of Uganda showing the location of forest plantations where the study took place.

Three types of soils cover the reserve; red *buruli* soils (63%), *lwampanga* soils (19%), and undifferentiated alluviums (18%). The red buruli soils are developed from laterized gneiss and granite-rich basement complex. They are deep to moderately deep, dark-red to reddish brown, strongly acidic and low in organic matter content. The lwampanga soils developed from old alluvial material are brown and dark reddish. They have low organic matter content, are deep and strongly acidic. The undifferentiated alluviums have been developed from recent alluvial deposits.

3.1.2.4 Climate

The mean annual rainfall around the plantation is about 1 230 mm. The total annual evaporation is 1 836 mm which is quite high resulting in very dry conditions. There are two marked dry seasons: December to Mid March and June to July, the former being the most severe. There are also two rainy seasons: Mid March to May and September to October, the former being the longest. From meteorological data, average daily temperature ranges between 22.6° C in July and 24.6° C in March (MWLE, 2002).

3.1.2.5 Legal status

The reserve was first gazetted in 1963 and by 1968, the Forest Reserve area was 2 546.0 ha. (Statutory Instrument No 176, Forest Reserve- Declaration Order, 1968). The swampy area (7 722.0 ha) around river Rugogo was later included in the reserved area in the early 1970's. The present composition of the reserve contained in the Statutory Instrument 1998 No 63 supplement No 23 (Forest Reserves – Declaration Order) shows that the total area of the forest reserve is 3 318.0 ha.

No other rights, other than for the enclaves, exist within the Forest Reserve save for the privileges (Forests Act, Part III Licenses for taking forest produce, section 15) common to all Forest Reserves. This section permits Africans, Local Authorities and travellers to cut free of charge reasonable quantities of firewood of unplanted and reserved trees for own building or domestic use.

3.1.2.6 Silviculture

The first trial conifer planting began in 1964. Broad – leaved trial planting of *Measopisis eminii* and *Terminalia ivorensis* were carried out around the same time. Extensive planting started in 1966 with mainly *P.caribaea, P. oorcapa, P. insulaaris* and *P. patula*. The extension of the plantation continued up to 1976. Although the entire crop was neither thinned nor pruned, the best performers have been *P. caribaea* and *P. patula*

3.1.2.7 Tree Harvesting

Currently the on-going logging operations are carried out actively by two Sawmilling companies: Bulangiti and Kikutte- Obudde sawmill Ltd. The harvesting method applied is clear felling using two-man crosscut saws, power saws and axes (for limbing) and terrain transport (using hand-rolling method). Logging operations started in 1992.

3.1.2.8 Plantation Area

Although the fire lines arc not planted, thcir area together with that covcred by roads has been included in the plantation area. Table 2. shows the area (in hectarcs) distribution of the plantation.

Table 2. Area distribution of katugo Forest reserve.

Plantation area distribution	Area, (ha)
Total plantation area (including roads and fire lines	2 682.9
. Fire lines	83.6
. Roads	39.0
Swampy areas	100.0
Field station, Nursery, Settlements, Picnic sites, Schools etc	30.9
Total Plantation area (including Roads and Firc lincs)	2 813.8
Swampy areas outside the plantation area eg. R. Rugogo	504.2
Total Forest Reserve area	3 318.0

Source- Uganda Forest Department (2003).

3.2 Research methodology

3.2.1 Study procedures

The study was conducted in two phases: phase one was a reconnaissance survey followed by the main study, where both the current and improved logging methods were studied. During the reconnaissance survey, logging components were identified and each stage of the harvesting process was studied for an avcrage of three days. The purpose of the pilot study was to test the data forms and study procedures. In order to ensure that time study data were representative of typical logging operation, during the study of the current logging methods, the Researcher avoided interfering in any way with the production process. Observations and measurements were made in unobstractive manner. During the application of the improved logging methods, the Researcher himself supervised the harvesting process after training the workers on reduced impact logging techniques.

Due to time and financial constraints, the study was limited to studying in detail the cutting and skidding/log rolling operations only. In each plantation forest, at least three logging companies were selected and studied independently.

3.2.2 Measurement of output

Work output was measured by determining the solid volume of timber with bark in cubic meter (m^3) produced per unit time. Standard forest mensuration equipment (tapes and calipers) and volume tables were used for determining the tree volume harvested.

3.2.3 Measurement of input.

(a) Time concepts.

Time studies were curried out to assess the time consumption of the various phases of logging operations for the two systems (current and improved). All the time recorded during the operation per day was referred to as work-place time. These consisted of the total time spent in performing a task at a work place, and included effective time and delay time, as illustrated in Figure (2)

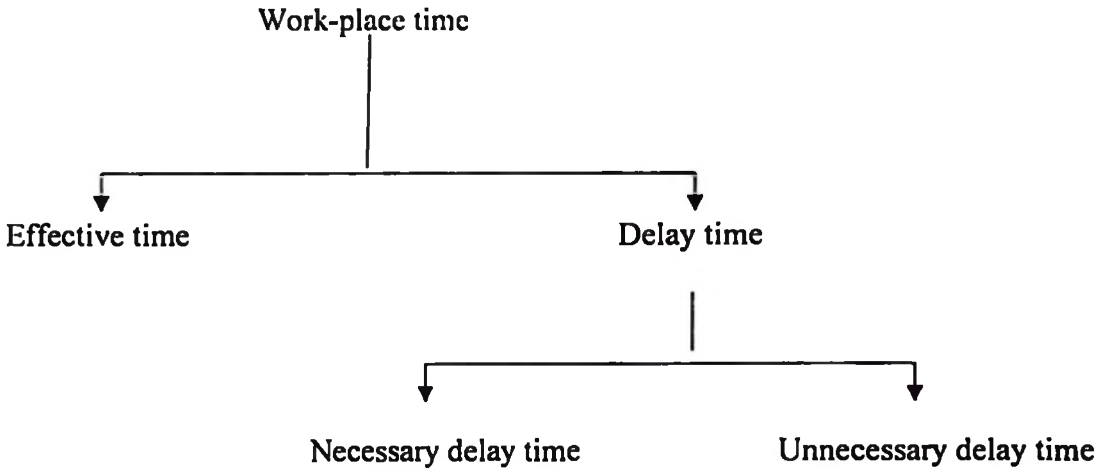

Figure 2. Work-place time classification

In order to be able to undertake detailed time study, the whole logging operation was broken down into the following work elements;

(i) Walking. Time spent walking between trees to be felled, logs to be bucked and logs to be rolled.

(ii) Felling. Time taken to cut a tree until the stem touches the ground.

(iii) Bucking. Time taken to cross-cut a tree into logs.

(iv) Log rolling (skidding): Time taken to manually roll a log from the stump site to the log-pilling yard.

(v) Piling time. Time taken for pilling the log at the landing site (log yard).

(b) Measurement of time

Manually operated electronic stopwatches were used in recording time. The snap back timing method was used and the work elements were timed to the nearest second and recorded in data forms specifically designed for the purpose (Appendix I). During the study of the current logging methods, operations were studied as they were going on. To ensure that time study data were representative of typical logging operations in the area, the researcher avoided interfering in any way with the production process. Observations and measurements were made in an unobstractive manner as far as possible.

During the application of the improved harvesting methods and techniques the following steps were followed:

(i) A five day's training workshop in Reduced Impact Logging was conducted for workers of both Mafuga and Katugo. Workers were trained in order to practice and appreciate the importance of Reduced Impact Logging methods and techniques (Elias *et al.*, 2001).

(ii) Before felling begun, trees were marked and measured (Dbh and height) in the normal procedure.

(iii) A properly trained chain saw operator felled the trees by applying directional felling technique (Notching and back cutting). Stumps were cut as low as possible, (15cm high on average).

(iv) Trees were properly limbed using axes (limbing was done as a separate operation).

(v) Trees were scaled into log lengths by applying a running meter system (from 1.5m) instead of the normal standard log length of 4.2m.

(vi) Trees were bucked into logs by already trained crosscutters. Buckings were made at not more than 10^0 from vertical to avoid under sizing of logs (Elias *et al.*, 2001).

(vii) Log lengths and diameters were recorded.

(viii) Logs were manually rolled to the landings and piled at the sawmill sites. Before rolling, the small logs and branches were spread along the log rolling trail (spring board method) for smooth rolling of the logs and avoiding logs to have direct contacts with the ground.

This time the researcher himself supervised the operations, to ensure proper application of RIL techniques.

(c) Production costs.

Data for computation of hourly costs of labour and machines were compiled from the sawmilling companies' accounts records and recorded in Appendix (3). Where these cost data were not available, standard engineering formulas (FAO, 1976) were used to determine their cost values.

(I) Equipment/tool costs.

Equipment/tool costs included purchasing prices, depreciation, interest, fuel, oil, lubricants and insurance. Most of this information was not available from the companies' records as they are either not known or not recorded. To supplement and update machine/tool cost data, Husqvarna (U) Ltd and STIHL (U) Ltd were consulted so as to get the actual values of machines/tools, which were not available in the field.

(ii) Labour costs

Direct labour costs were obtained from the Accounts section of the companies. Wages were on monthly basis for managers/supervisors while for the logging crews, the terms of payment were either on a daily basis (in Mafuga) or on tasks (in Katugo). There was no information obtained on other forms of costs like fringe benefits (indirect costs), which include free medical services for the operational staff and to the logging crews if they get injured during work. Labour cost per unit of time was expressed by the following equation (1):

$$LC = \frac{Direct\ labour\cos ts\ per\ hour(1 + f)}{Unit\ of\ production\ per\ hour} = Shs / m^3 \qquad (1)$$

Where,

LC = Labour Cost, Shs/m^3.

f = cost of fringe benefits expressed as percentage of Direct Labour costs.

(d) Assessment of work environment.

The general forest climatic and topographic conditions in which the timber harvesting operations were carried out were obtained from official records of the relevant government departments. Direct field measurements were carried out, e.g., rolling trail distances and slopes using standard forest mensuration equipment (Appendix 2).

(c) Assessment of working tools/equipment

Information on the tools/equipment used in logging was recorded. Specifically their type, purchase price, depreciation, taxes, insurance, fuel consumption, repair and maintenance cost plus their mechanical condition (Appendix 3).

3.2.4 Assessment of wood waste

In order to determine the total volume of wood wasted, stumps were measured (height and diameter) and the volume of split and left over logs in the logged sites were all determined (Appendix 4).

3.2.5 Assessment of soil surface disturbance.

Soil surface disturbance was determined by measuring the rut depth using a meter ruler and a reference rod put on the sides of the rut (Wasterlund, 1991, 1992, 1994; Warkotch, 1994; Migunga, 1996; Abeli and Sawe, 1999). Measurement points were sampled systematically along each log rolling trail that was randomly selected in the compartments. The degree of disturbance was classified as;

a) Undisturbed, when the litter was still intact.

b) Slightly disturbed, when the litter was removed and soil was exposed to depth of less than 2.5cm.

c) Deeply disturbed, when the litter was removed and soil was exposed to depth greater than 2.5cm.

The total area disturbed by the rolling logs in the logged sites was determined and measured (Appendix 5).

3.2.6 Data analysis

3.2.6.1 Method

This study had to establish logging production rates, costs, wood waste and environmental damages of the current logging methods and techniques and compare them with those of the improved harvesting techniques. Since the main purpose is to provide analytical summary useful for estimating production rates and costs for future operations (Abeli, 1985), summary statistics and tables were compiled from the data.

Descriptive statistics and regression analysis were carried out using MiniTab 12 software. Linear regression function was applied with pre-determined variables provided to the model. The analysis was started by plotting the checked observations graphically. Statistical testing with the coefficient of determination (R^2) and F-statistic were then used for testing possible differences between the two systems. A total correlation was used to find out linear or curve linear correlations between variables. The purpose of data analysis was to give production rate forecasts for the various phases of logging. Production was related to biophysical factors, which were known from experience to have a strong influence on the operations. Derivation of the cost of delivered wood was arrived at, based on the method used by FAO in similar analyses (Bendz and Jorvholm, 1970; Ndemere, 1991) and as an expression of productivity at the cost level (Haarlaa, 1981, Ndemere, 199), as shown in Figure 3.

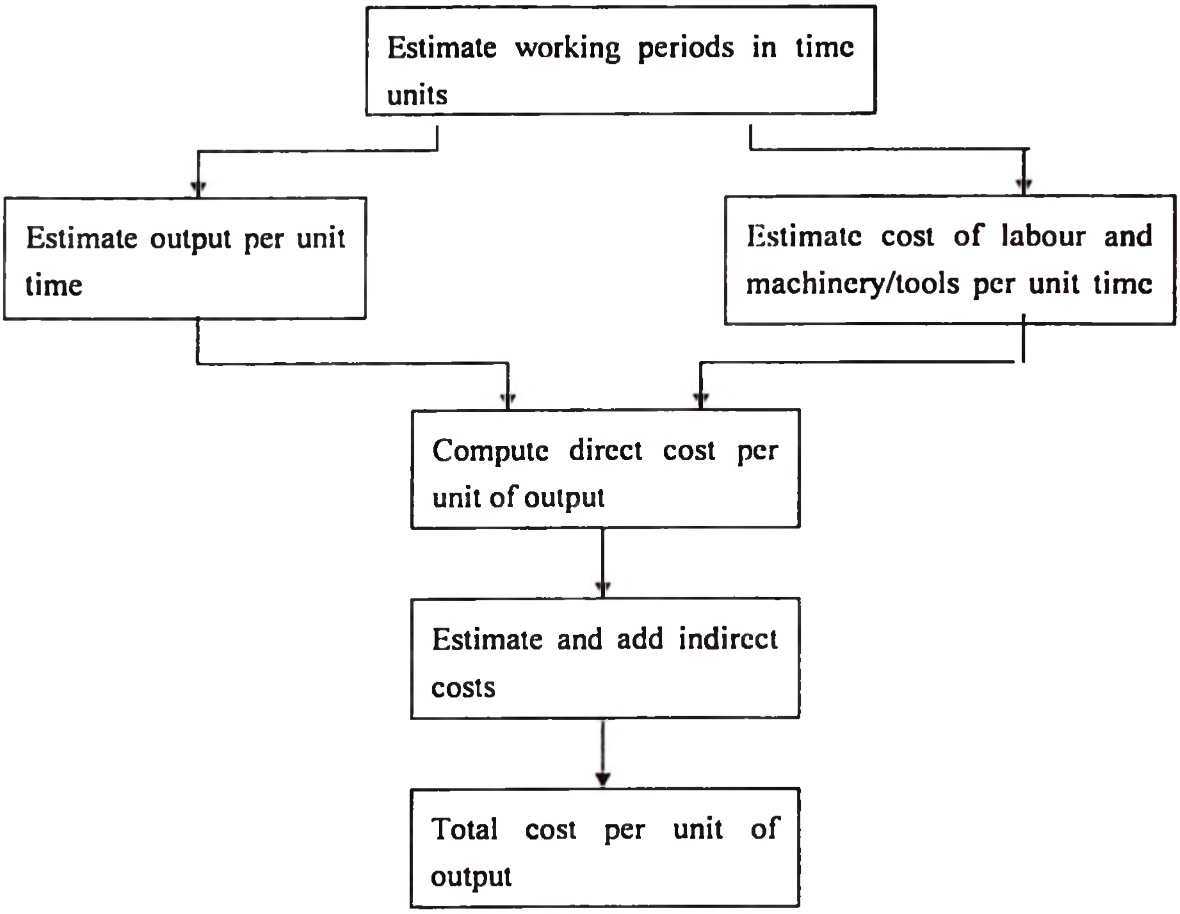

Figure 3. System for derivation of cost of delivered wood.

3.2.6.2 Productivity study

Tree volume was calculated using volume tables (Ackhurst and Micski, 1971) and log volume was calculated using Huber's formulae (Philip, 1994) as shown in equation (2).

$$Lvol = \frac{\pi \, md^2 \, L}{4} (m^3) \qquad (2)$$

Where;

Lvol = Log volume (m^3)

π = pi=3.142857143

md = Log mid-diameter (cm)

L = Log length (m)

Tree and log volumes with their respective data collected in the field were used to compute productivity in m^3 / hr. as shown in equation (3).

$$P = \frac{(Tvol)(F)(60)}{T} = \left(m^3 / hr \right) \quad (3)$$

Where;

P = Productivity in (m^3 / hr.) for a given operation

Tvol = Total volume of all trees or logs for a given operation (m^3)

60 = Number of minutes per workplace hour

F = Proportion of productive time to work place time

T = Total productive time (minutes)

$$F = \frac{100 - D}{100} \quad (4)$$

Where;

F = a fraction measuring the proportion of productive time determined as in equation (4).

D = Delay time expressed as a percentage of workplace time.

The mean cycle times were calculated and used in estimating mean production volumes.

Functional relationships of time to specified dependent variables in each operation were established by regression techniques. This will facilitate prediction of productivity in a set of conditions comparable to those studied.

3.2.6.3 Production Cost

Production costs were based on machine/ tool costs and operating labour. Annual costs in (UShs) per year were converted into hourly costs as follows (equation 5);

$$Hourly\ costs = \frac{Annual\ costs(Ushs/year)}{Working\ days/year \times working\ hours/day(hrs/yr)} = \left(\frac{Ushs}{hr}\right) \quad (5)$$

Working days per year for all operations were assumed to be 250. Working hours per day used for computing production rates in this study were 5 and 8 hours for cutting and rolling operations respectively. These were work place times which included effective working times, scheduled breaks and delays.

Using calculated production rates, representative logging costs were developed for determination of the alternatives, which minimise logging cost in conditions similar to those studied. Production cost (P/C) was computed using equation (6):

$$P/C = \frac{Owning\ and\ running\ costs(Ushs/hr)}{Production\ rate(m^3/hour)} = \left(\frac{Ushs}{m^3}\right) \quad (6)$$

3.2.6.4 Wood waste

The volume of wood lost or wasted in the logged compartments was determined by taking measurements of all merchantable logs left over and the heights and diameters of stumps.

3.2.6.5 Soil surface disturbances

The depths of ruts developed on disturbed soil points and the total area disturbed by rolling logs in logged compartments were determined and measured for estimation of the percentage of disturbed areas in the logged compartments.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The current methods and techniques described in this study (CL) are those currently being used in Uganda logging operations in soft wood plantations. Given the time they have been in use, one can say that there is little chance of them changing unless something drastic happens in the forest industries development programme.

4.1 Time and production data

The time and production data in this study are based on empirical data collected during July 2003 – June. 2004. The production figures below are based on actual output of workers and hand tools used for a work place time of 5hrs. (08.00-13.00) for the cutting crew and 8hrs for the log rolling crew (0800-1600) per day. Trees were felled by chainsaws, limbed or debranched by axes, and cross cut into 4.2m lengths by powersaw. The logs were rolled manually to the nearest mobile sawmill log yard or to a standby trailer, before being transported to a semi-permanent mill.

During the application of the improved logging methods referred as Reduced Impact Logging (RIL), the researcher supervised and controlled all the logging operations. This is why unnecessary delays were minimized or even eliminated in most activities. With such close supervision of the operations, and elimination of unnecessary activities, the dependency of actual operation time to common independent variables was highly significant, which resulted to increase of the regression coefficient (R^2) as can be seen on time distribution function graphs.

Walking time between trees to bc felled and bucked in Katugo plantation was rather constant in both cases basically because of thc equal distance between trees and generally clear ground. In Mafuga plantation walking between trees during the felling operation varied and consumed more time than in Katugo because of the steepness of the terrain, rough ground and unequal spacing of the trees.

4.1.1 Felling time and production rate for Mafuga forest plantation

In this study a total of 69 trees were felled with a power saw averaging 0.773 m^3 of merchantable volume per tree using the current methods, and 60 trees were felled using thc improved methods, averaging 0.784 m^3 per tree.

4.1.1.1 Felling time

Stump site operations were studied, with the following breakdown:

(i) Effective time; Walking and Felling

(ii) Delay time; Necessary delay and Unnecessary delay

Felling time varied with tree size in an increasing manner in both cases. Total felling work-place time for the current methods was 2.03 minutes per tree, of which productive time was about 89.9% and delay time resulting from spontaneous rests and workers talking with by-passers constituted about 10.1%. For the improved methods total felling time per tree was 2.74 minutes, all of which was productive time as shown in Table 3. This new system applied a directional felling technique as required in Reduced Impact Logging (RIL). With the improved methods felling operation consumed more time than in the current conventional methods (CL). Similar results have been reported by Pinard *et al.* (2000) and Sist *et al.* (2003) where reduced impact logging took longer time than conventional logging (CL). The reasons for this is that directional felling requires making decision on the direction of tree fall after considering several factors like, ground obstacles (i.e. hills and valleys, which are known for breaking the trees) and those other factors affecting the subsequent operations (bucking and rolling). For example, a tree has to be felled in the direction that will not hinder bucking (i.e., felling trees on top of each other) and rolling (trees are felled perpendicular to the rolling direction) operation.

As pointed out in FAO (1991), felling especially on steep slopes requires skill and expert handling as the ground surface is generally uneven. In such case trees must fall in a specific direction in order to facilitate conversion and avoid damaging the log. Considering all these factors, it consumes a certain amount of operation time (which is not the case in conventional operations) especially to operators who have just been introduced to the system. This is why the new improved system consumed more time performing the same operation than the conventional system. This also explains the low felling production rates of the improved system in performing this operation.

Table3. Felling time distribution for Mafuga plantation when using CL and improved logging methods

Time element	Current logging methods (CL)						Improved logging methods (RIL)					
	Time, (min/ tree)				As Percentage of		Time, (min/tree)				As Percentage of	
	Mean	Std	Min.	Max.	Prod. time	Total time	Mean	Std	Min.	Max.	Prod. time	Total time
Sawing time	0.814	0 269	0.380	1.410	53.52	40.30	1.727	0.303	1.21	2.620	63.08	63.08
Walk-ing time	0.707	0.392	0.230	2.080	46.48	35.00	o.440	0.141	0.200	0.82	16.07	16.07
Effect-ive time	1.521	0.499	0.610	3 490	100.00	75.30	2.161	0.432	1.41	3.44	79.15	79.15
Neces-sary delay	0.295	0.431	0.180	2.450	-	14.60	0.572	0.097	0.45	0.87	20.85	20.85
Produ-ctive Time	1.816	0.639	0.920	4.010	-	89 90	2 738	0.525	1.86	4.31	100.00	100.0
Unnece-ssary delay	0.204	0.098	0.180	0.520	-	10.10	-	-	-	-	-	-
Total delay	0.499	0.452	0 180	2.970	-	24.70	0.572	0.097	0.45	0.87	20.85	20.85
Total time	2.030	0.694	0.920	4.530	-	100.00	2.738	0.525	1.86	4.31	-	100.0

Productive felling times for both systems were all dependent on tree Dbh. and can be estimated by quadratic equations 7 and 8.

Current: $PRFT = - 0.143 + 0.0511\ Dbh^2$ $\qquad R^2 = 83.7\ \%$ (7)

Improved: $PRFT = - 0.143 + 0.0511 Dbh^2$ $\qquad R^2 = 97.4\%$ (8)

Where;

Dbh = Tree diameter at breast height, cm.

PRFT = Productive felling time, min.

Delays occurred at random averaging 0.499 minutes per tree for the current method and 0.572 minutes per tree for the improved method and were not dependent on Dbh.

Productive felling time distributions as a function of Dbh for both methods are presented in Figures 4 and 5.

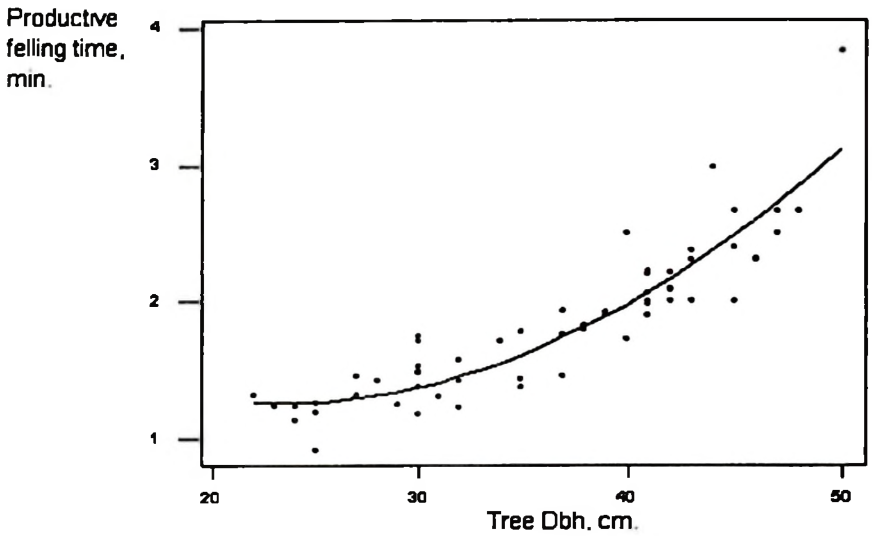

Figure 4. Productive felling time as a function of dbh for the current method.

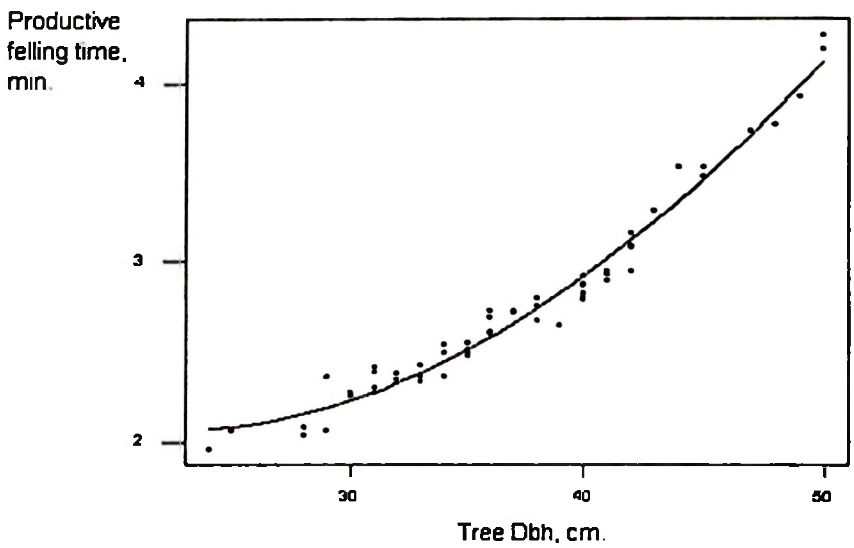

Figure 5. Productive felling time as a function of Dbh, for the improved logging method.

4.1.1.2 Felling production rates

Average felling production rates per productive times of both methods are presented in Table 3. Both depend on tree Dbh and they can be estimated by equations 9 and 10.

Current: Prod.RPRFT = $-22.1 + 1.41\ Dbh^2$ $R^2 = 64.9\%$ (9)

Improved: Prod.RPRFT = $-20.6 + 1.27\ Dbh^2$ $R^2 = 93.1\%$ (10)

Where; Prod.RPRFT = Production rate per productive felling time, m^3

Table 4. Felling production rate for Mafuga plantation

Production Element	Current logging methods				Improved logging methods			
	Average	Std	Mini-mum	Maxi-Mum	Average	Std	Mini-mum	Maxi-mum
Tree diameter, cm	36.55	7.638	22.000	50.000	36.767	6.193	24	50
Tree volume, m^3	0.773	0.454	0.101	1.752	0.784	0.366	0.16	1.754
Production rate, m^3/hr								
-per productive time	28.65	13.29	5.77	62.51	16.385	5.004	4.90	25.09
-per total time	25.780	12.890	4.380	61.450	16.385	5.004	4.90	25.09

The current (conventional) methods obviously seemed to be more productive than the improved methods. This agrees with results, which were recorded by Ahmad *et al.* (1999) and Pinard *et al.* (2000) while applying reduced impact logging in Malaysia. The reasons for the low production of the new system in this operation have been mentioned already. To perform controlled felling on steep slopes is not an easy task as mentioned in FAO (1991). The production figures for the improved system are expected to increase if operators will undergo further training and practice those techniques for some time.

Production rates per productive felling time distributions as a function of Dbh are presented in figures 6 and 7.

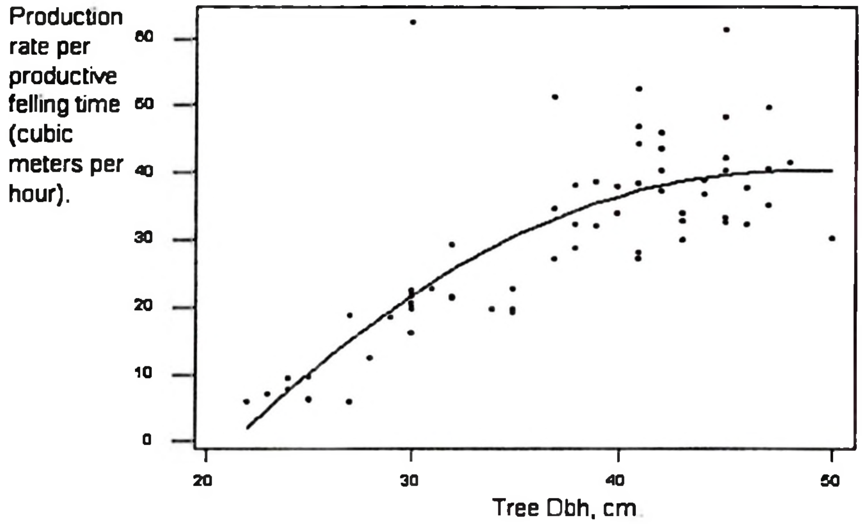

Figure 6. Production rate per productive felling time for the current logging method as function of Dbh.

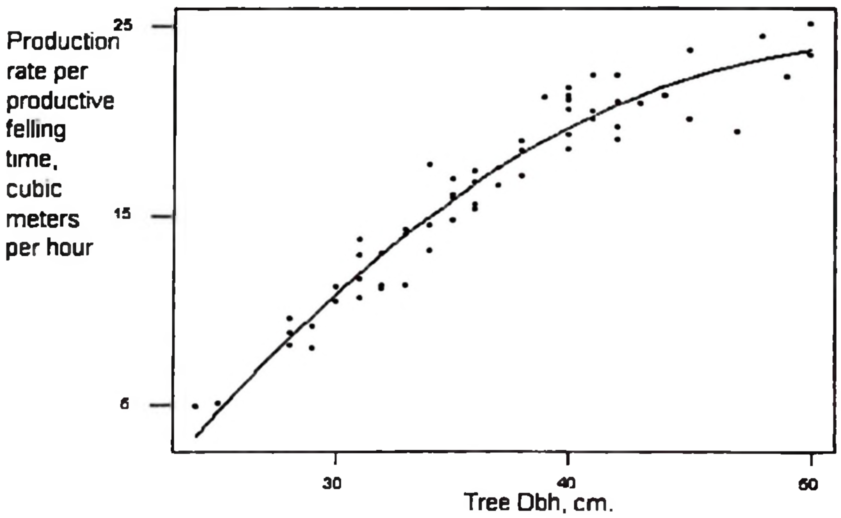

Figure 7. Production rate per productive felling time for the improved logging method as a function of Dbh.

4.1.2 Felling time and production rate for Katugo forest plantation

In this study a total of 70 trees were felled with a power saw averaging 0.696 m^3 of merchantable volume per tree using the current logging methods and 75.trees were felled while applying the improved logging methods. These trees averaged 0.686 m^3 per tree, and volume was dependent on tree Dbh as expressed by equation (11).

$V = -1.10 + 0.0535\ Dbh$ $\qquad R^2 = 91.9\ \%$ $\qquad$ (11)

4.1.2.1 Felling time

Felling time varied depending on the tree size. Felling work-place time for the current methods was 1.204 minutes per tree, of which productive time was 97.50% and delay time resulting from chain maintenance, saw jamming, spontaneous rests and workers disputes about correct working techniques constituted 2.5%. During the application of the improved methods, felling work-place time was 2.582 minutes per tree of which productive time constituted 100% as indicated in Table 5.

Productive felling times were all dependent on tree Dbh and can be estimated by equations (12 and 13).

Current: $PRFT = 0.177 + 0.0264Dbh$ $\qquad R^2 = 62.50\%$ $\qquad$ (12)

Improved: $PRFT = 0.957 + 0.045\ Dbh$ $\qquad R^2 = 80.9\%$ $\qquad$ (13)

Where;

Dbh = Tree Dbh, cm.

PRFT = Productive felling time, min.

During the study on the current logging methods, delays were not dependent on Dbh and were caused by workers urguing on the correct working techniques with the logging supervisor, talking to rolling crews and passers-by. Since the researcher took over the supervisory role of the operations during improved operations, this explains why unnecessary delays were eliminated during the felling operation. As was the case in Mafuga, in Katugo, conventional felling also proved to be more productive than improved felling in terms of time per tree and its production rates per hour. In terms of felled volume, conventional method was higher than that of the improved methods. The reasons for the low productivity in the improved methods have been given already. During the study period, the new system was not designed to make production higher than that of the conventional methods currently used, but rather it was designed to improve on the quality of the logs produced while reducing the amount of wood waste and ground disturbance as per Reduced Impact Logging objectives.

Table 5. Katugo forest plantation felling time distribution

Time element	Current logging methods						Improved logging methods					
	Time, min/ tree				As percentageof		Time, min/tree				As percentage of	
	Mean	Std	Min.	Max.	Prod. time	Total time	Mean	Std	Min.	Max.	Prod. time	Total time
Sawing	0.566	0.291	0.26	1.35	51.04	47.05	0.907	0.202	0.34	1.47	71.52	55.35
Walk-ing	0.543	0.143	0.23	0.92	48.96	45.14	0.569	0.066	0.40	0.65	28.48	22.04
Effect-tive time	1.109	0.301	0.74	2.04	94.46	92.19	1.476	0.161	0.74	2.12	77.38	77.39
Neces-sary delay	0.064	0.087	0.00	0.22	05-50	05.32	0.284	0.068	0.08	0.49	22.62	22.62
Produ-ctive time	1.173	0.305	0.74	2.26	100.00	97.51	2.050	0.225	0.82	2.61	100.0	100.00
Unnec delay	0.030	0.091	0.000	0.640	-	02.49	-	-	-	-	-	-
Total delay	0.094	0.117	0.000	0.860	-	07.81	0.284	0.068	0.08	0.49	22.62	22.62
Total time	1.203	0.345	0.800	2.540	-	100.00	2.050	0.225	0.82	2.61	100.0	100.00

Functional relationships of productive time to tree Dbh for the improved method can be viewed in figure 8.

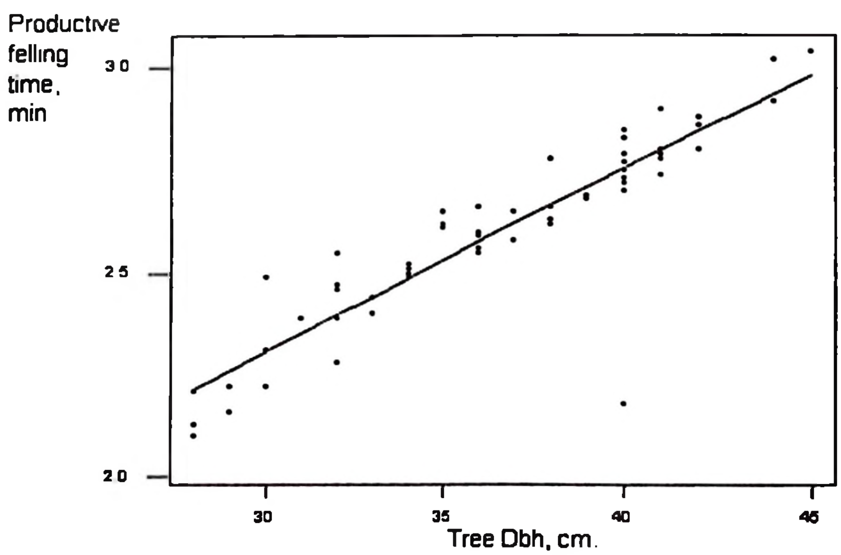

Figure 8. Productive felling time as a function of Dbh for the improved logging method.

4.1.2.2 Felling production rates

Average felling production rates per productive time for the current methods was 36.88 m^3/hr and 19.95 m^3/hr for the improved methods as presented in Table 6 and both depended on tree Dbh and can be estimated by equations (14 and 15).

Current: Prod.RPRFT = -45.7 + 2.34 Dbh R^2 = 74.2% (14)

Improved: Prod.RPRFT = -20.7 + 0.998 Dbh R^2 = 95.6% (15)

Where;

Prod.RPRFT = Production rate per productive felling time, m^3/hr.

Table 6. Katugo felling production rate

Production	Current logging methods				Improved logging methods			
Element	Mean	Std	Min.	Max.	Mean	Std	Min.	Max.
Tree diameter (cm)	35.257	6.635	22.00	50.00	36.370	4.498	28.000	45.000
Tree volume (m^3)	0.697	0.396	0.101	1.75	0.686	0.256	0.241	1.309
Production rate, m^3/hr								
-per productive time	36.880	18.040	8.080	81.14	20.400	4.593	6.790	51.840
-per total time	34.470	17.530	6.310	81.14	20.400	4.593	6.790	51.84

The workers' attitude towards controlled felling in Katugo was a bit negative; they didn't receive training with enthusiasm as was the case in Mafuga and that is reflected in the difference in production among the two systems. Similar results were recorded by Van der Hout (2000), when RIL reduced the felling performance by 37%.

Katugo felling production rates distributions as functions of Dbh are presented in figures 9 and 10 for both the current and improved methods..

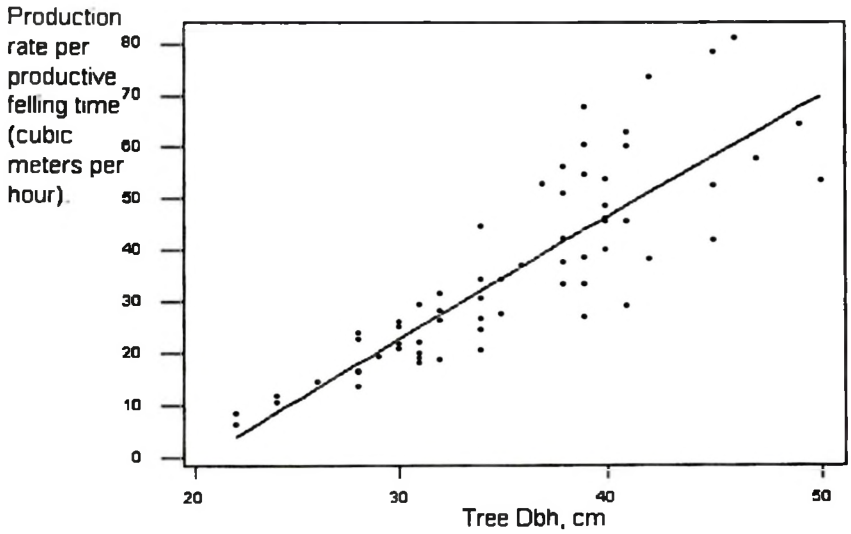

Figure 9. Production rate per productive felling time as a function of Dbh for the current logging method

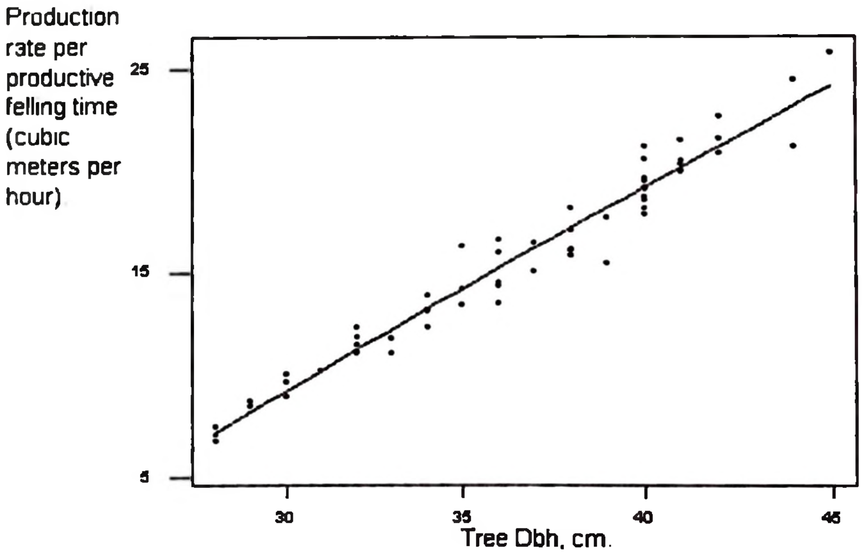

Figure 10. Production rate per productive felling time as a function of Dbh for the improved logging method

To obtain higher production in felling while applying the improved methods, there must be an increase in worker's wage payments and other incentives, such as provision of safety clothes and training. Training was also recommended by Andrewartha (2002) and Aulerich and Sirait (2002) when comparing the two harvesting systems (RIL and CL). There is also a need to provide workers with food at the work-place. A few fruits and water taken at midday break is not adequate for supplying enough energy needed for very strenuous work such as felling. The worker's health condition does not look impressive either and safety gears are completely absent.

Similar findings have been found by Aluma (1976) who observed that forest operations have not kept pace with basic developments found in other industries in improving labour input, mechanization for greater efficiency and reducing the physical work load of the workers. Ndemere (1991) has also stated the importance of the effect of work-load on performance in felling operations and strongly recommended its consideration in determining production standards, "fair days' task". Flat rate daily/monthly wage payments could also be replaced by piece-work wages based on Dbh using equation (5) for determining a fair wage for different diameters cut. In all areas, serious attempts should be made towards implementing reduced impact logging.

4.2.4 Limbing

During the study on the current logging methods in both plantations, limbing was not treated as a separate work activity. Limbing was performed poorly in three stages as explained below: -

Stage 1. As soon as a tree falls down, a man with a machete cuts the branches half way leaving branch stumps varying in length from 20 - 85 cm.

Stage 2. Limbing done during bucking when one of the two-man crew severs only those branches, stumps which could obstruct sawing with a power saw.

Stage 3. Limbing done by one of the rolling crew. For smooth log rolling, all branch stumps on the log are removed.

Limbing in this sequence resulted in delays in bucking and rolling activities/ operations and misuse of the labour force for undertaking unnecessary unplanned activities. In such situation it was impossible for the researcher to perform a time study on limbing in that form. During the application of the improved methods, limbing was carried out as a separate operation on its own with its own crew as in Ahmad *et al.* (1999).

Limbing operation was performed using axes. Limbing time ranged from 2.16 min/tree to 2.43 min/tree in Katugo plantation and ranged from 2.15 min./tree to 2.56 min/tree for Mafuga plantation operations. The production rates for this operation averaged 17.94 m^3/hr for Katugo and 19.93m^3/hr for Mafuga. There was correlation between limbing time and tree Dbh in both cases. Equations (16) and (17), and figures 11 and 12 show the dependence of limbing time on tree Dbh.

$LT = 1.77 + 0.0153Dbh$ $R^2 = 81.0\%$ (Katugo) (16)

$LT = 0.0873 + 0.0319\ Dbh.$ $R^2 = 87.5\%$ (Mafuga) (17)

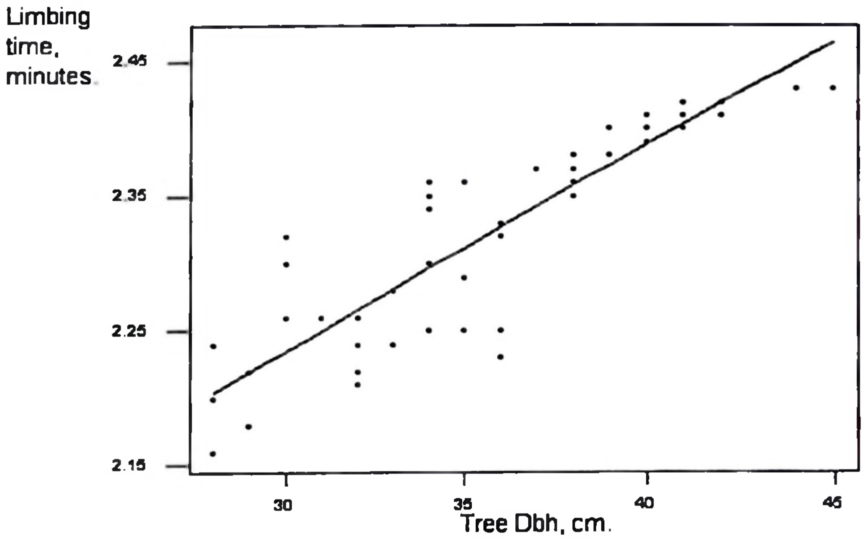

Figure 11. Limbing time as a function of Dbh for Katugo plantation operations

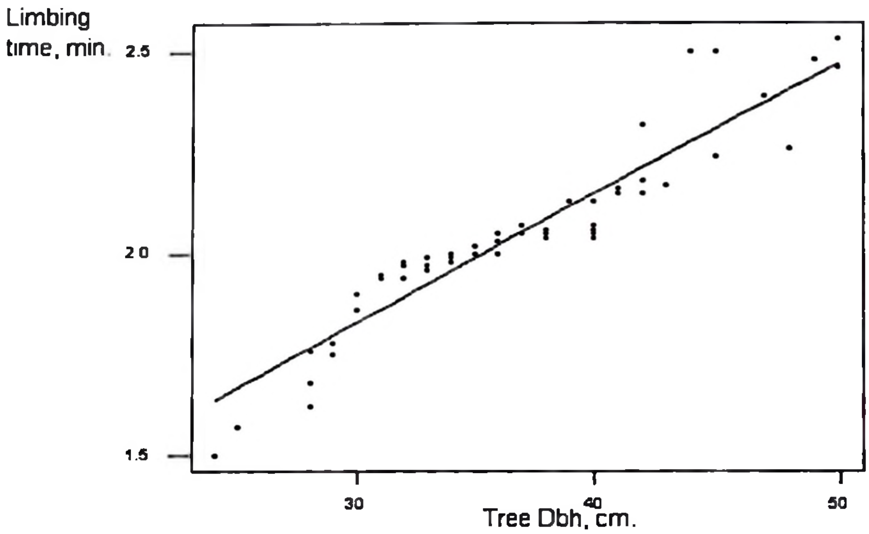

Figure 22. Limbing time as a function of Dbh for Mafuga plantation operations

For organizational improvements and efficiency limbing activity should be carried out as a separate operation in order to improve on the quality of logs produced. The Ugandan type of axe is still suitable for the size of branches cut in plantations, but heavier types of Scandinavian axes could be better because their steel quality enables them to be made sharper than the local type and their handles too provide better grip.

4.1.4 Mafuga bucking time and production rates

Bucking was carried out at the stump site using the same power saw used for felling. The standard log length (4.2m) was bucked on trees during the current system and a running meter system (1.5m-4.2m) was used for bucking logs when using the improved method. During the current logging methods a total of 69 trees averaging 0.773 m^3 per tree were bucked and 60 trees with an average of 0.784 m^3 per tree were bucked during the improved logging methods.

4.1.4.1 Bucking time

Bucking time was broken down as follows:

(i) Effective time; Scaling, Sawing and Walking

(ii) Delay time; Necessary delay time and Unnecessary delay time

Average bucking work-place time per tree for the current method was 3.843 minutes, of which productive time was 95.02% and delay time caused by saw jamming, short breaks, and chain maintenance accounted for 13.99 % (Table 6). For the improved method, work-place time per tree averaged 4.396 min., of which, 98.03% was productive time due to improved supervision and the time distribution is shown in Table 7.

Table 7. Distribution of Mafuga bucking time

Time element	Current logging methods						Improved logging methods					
	Time in minutes				As % of		Time in minutes				As % of	
	Mean	Std	Min.	Max.	Prod time	Total time	Mean	Std	Min.	Max	Prod. time	Total time
Scaling	1.355	0.573	0.53	2.70	40.89	35.17	1.438	0.565	0.94	2.463	33.37	32.71
Sawing	0.994	0.562	0.25	2.18	30.18	25.96	1.295	0.492	0.45	2.151	30.05	29.46
Walking	0.953	0.478	0.20	2.15	28.92	24.88	1.050	0.269	0.77	1.332	24.37	23.89
Effect. time	3.301	1.288	0.98	7.03	100.0	86.01	3.783	1.153	2.66	5.945	87.79	86.06
Necessary delay	0.349	0.163	0.13	0.85	-	09.01	0.526	0.213	0.19	0.920	12.21	11.97
Prod. time	3.650	1.356	1.93	7.33		95.02	4.309	1.320	2.85	6.867	100.00	98.03
Unnec, delay	0.193	0.266	0.00	0.80	-	04.98	0.087	0.024	0.00	0.179	-	1.98
Total Delay	0.542	0.298	0.13	1.65	-	13.99	0.613	0.135	0.19	1.099	-	13.95
Total time	3.843	1.462	1.11	8.68	-	100.0	4.396	1.604	2.85	7.966	-	100.00

As can be seen in Table 6, the improved bucking method consumed more time per tree than the current method. This agrees with results recorded by Boltz *et al.* (2003), when comparing RIL and CL. This is because during the application of the improved methods the Researcher tried to produce more wood from felled trees (maximum utilization) in terms of volume bucked per tree as was the case by Ahmad *et al.* (1999), Killman *et al.*(2002) and Hinrichs *et al.* (2002), when they were comparing RIL and CL in natural forests. Productive bucking times for both systems were all dependent on tree-length mid-diameter and number of bucking cuts as presented in Figures 13, and 14, and can be estimated by the following equations (18) and (19) for the current and improved methods respectively.

Current: $PRBT = -1.94 + 0.0798\,D + 1.03\,N^2$ $\quad R^2 = 82.9.\%$ (18)

Improved: $PRBT = -1.56 + 0.0691\,D + 1.10N$ $\quad R^2 = 81.1\%$ (19)

Where;

PRBT = Productive bucking time, min.

D = Tree length mid-diameter, m.

N = Number of bucking cuts.

Unnecessary delays occurred at random with an average of 0.193 minutes/tree for the current methods and 0.087 min/tree for the improved methods and they were not dependent on any independent parameter (see Table 7).

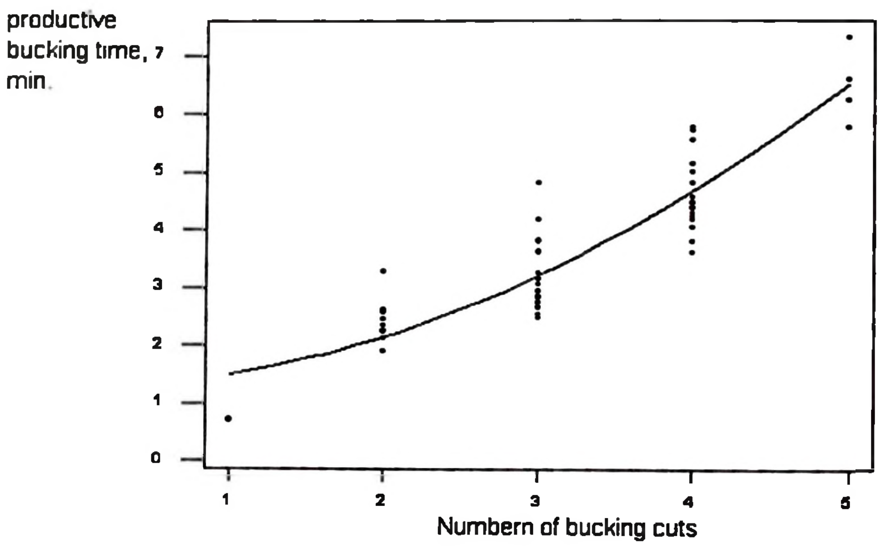

Figure 33. Productive bucking time as a function of number of bucking cuts for the current logging method.

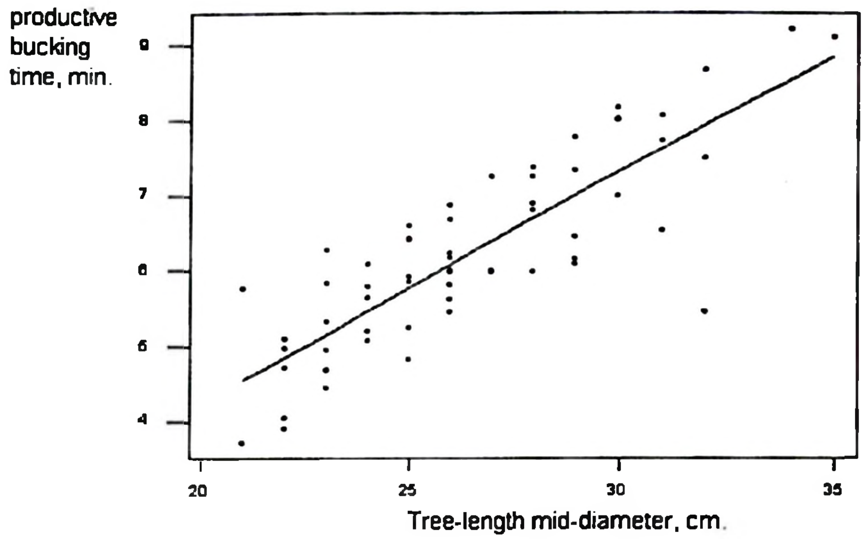

Figure 44. Productive bucking time as a function of tree-length mid diameter, for the improved logging method.

4.1.4.2 Bucking production rates

The number of bucking cuts for the current bucking methods varied from 1 to 4 buckings and for the improved methods it could go up to five bucking cuts per tree. Volume bucked using the current methods varied from 0.078 m^3/tree to 1.226m^3/tree and the volume extracted from trees bucked using the improved bucking methods ranged between 0.16 m^3/tree and 1.752m^3/tree. In both cases volume bucked was dependent on tree-length mid-diameter and number of bucking cuts and can be estimated by equation (20):

$V = -0.954 + 0.039\,D + 0.183\,N$ $\qquad R^2 = 78.7\,\%$ $\qquad$ (20)

Where; V= Volume bucked, m^3.

D = Tree-length mid-diameter, cm.

N= Number of bucking cuts.

A running meter system, which was used in the improved bucking methods, requires observing a tree for defected and crooked parts and scale it. The defected and crooked parts are not scaled but the remaining part of the log is utilized so long as it is more than 1.5m., a case, which is different from the standard length system where pieces of 4m are left in the plantation because its 0.2m is either crooked or defected. This maximum utilization of felled trees though time consuming proved to be more productive than the conventional standard length method. Production rates per hour of bucking time were higher in the improved methods than in the current methods (Table 8). Similar results have also been recorded by Hinrichs and Ruslim (2001) and Hinrichs *et al.* (2002), where bucking productivity of RIL was higher than that of CL. This means that the recovery factor at the stump site plays a significant role on production rates.

Table 8. Mafuga bucking production rate

Production element	Current logging methods				Improved logging methods			
	Mean	Std	Min.	Max.	Mean	Std	Min.	Max
Tree length-mid diameter, cm.	24.23	2.474	21	30	26.433	3.367	21	35
Number of bucking cuts	3	0.941	1	5	3.533	0.812	2	5
Volume bucked/tree (m^3)	0.773	0.318	0.078	1.226	0.784	0.343	0.16	1.58
Production rate, m^3/hr								
-per Productive time	9.882	3.799	4.590	21.158	10.290	2.530	4.96	23.18
- per total time	9.291	3.561	4.301	17.709	10.086	2.332	4.83	20.36

Production rate in bucking can be estimated using the bucked volume equation (20) and time equations (21) and (22) for any tree-length mid-diameter and number of bucking cuts. Production time distribution as a function of mid-diameter is shown in Figure (15).

Current: Prod.RPRBT= 8.68 + 1.85 D – 22.5 N R^2= 56.1% (21)

Improved: Prod.RPRBT= 8.73– 2.22.N + 1.27 D^2 R^2=72.3% (22)

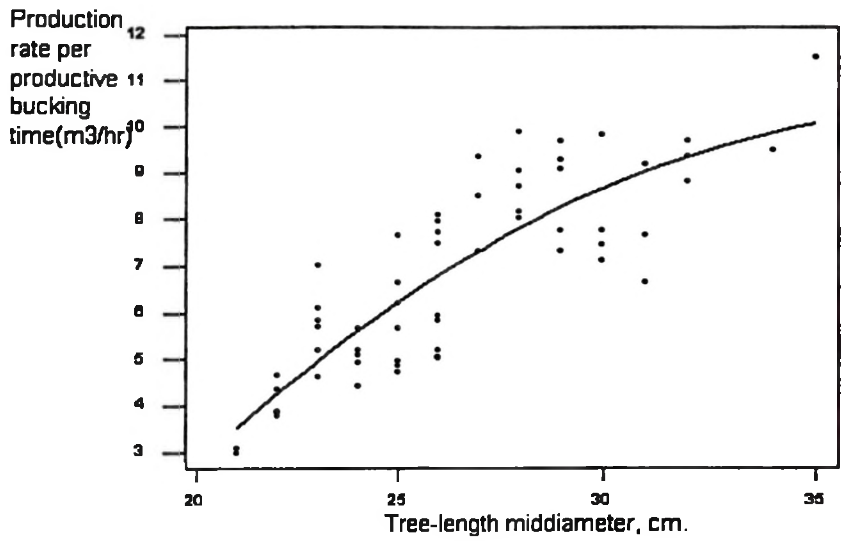

Figure 55. Production rate per productive bucking time as a function of tree-length mid-diameter for the improved logging method.

4.1.5 Bucking time and production rates for Katugo plantation

Bucking was carried out at the stump site with a power saw, which was used for felling. A total of 70 trees were bucked using the current methods with an average of 0.554m^3 (bucked volume) per tree while 60 trees were bucked applying the improved methods, which were averaging 0.692 m^3 per tree.

4.1.5.1 Bucking time

The time break down for bucking was as follows:

Effective time: Scaling, Sawing / bucking and Walking

Delay time : Necessary and Unnecessary delay time

Average bucking time for the current methods per tree was 3.436 minutes, of which effective time was 84.13% and the unnecessary delay time caused by saw jamming, short breaks of talking and chain maintenance constituted 15.87%. The average bucking time for the improved methods per tree was 4.12 minutes of which, 97.72% was productive time (see Table 9).

Table 9. Katugo bucking time distribution

Time element	Current logging methods						Improved logging methods					
	Time in minutes per tree				As % of		Time in minutes per tree				As % of	
	Mean	Std	Min.	Max.	Prod. time	Total Time	Mean	Std	Min.	Max.	Prod. time	Total time
Scaling time	1.303	0.462	0.420	2.130	39.77	37.92	1.282	0.258	0.526	2.078	31.84	31.12
Sawing time	1.116	0.327	0.220	2.100	34.07	32.48	1.537	0.309	0.321	2.373	38.18	37.31
Walking time	0.472	0.490	0.110	0.720	14.41	13.74	0.653	0.171	0.282	1.143	16.22	15.84
Total effective time	2.891	0.779	0.650	4.950	88.25	84.13	3.472	0.630	1.129	5.594	86.24	84.27
Neces-sary delay time	0.385	0.112	0.160	0.620	11.75	11.21	0.554	0.188	0.260	0.840	13.76	13.45
Produ-ctive bucking time	3.276	0.829	0.810	5.57	100.0	95.34	4.026	0.713	1.389	6.434	100.0	97.72
Unnece-ssary delay time	0.160	0.179	0	0.700	-	04.66	0.094	0.024	0.000	0.23	-	2.28
Total delay time	0.545	0.223	0.160	1.320	-	15.87	0.648	0.215	0.260	1.07	-	15.73
Total time	3.436	0.934	0.710	6.270	-	100.00	4.120	0.753	1.389	6.664	-	100.0

For the current methods, unnecessary delays occurred at random with an average of 0.160 minutes per tree, while it was minimized to 0.094 min/tree during the application of the improved methods and this was managed through proper supervision of the operation by the Researcher. Productive bucking time was dependent on tree-length mid-diameter and number of bucking cuts for both cases and can be estimated by equations 23 and 24 and as illustrated in Figure 16.

Current: $PRBT = 0.123 + 0.0113\ D + 0.851\ N$ $R^2 = 74.3\ \%$ (23)

Improved: $PRBT = 0.366 - 0.0029\ D + 1.07\ N^2$ $R^2 = 93.5\%$ (24)

Where; PRBT = Productive bucking time, min.

D = Tree-length mid-diameter, cm.

N = Number of bucking cuts.

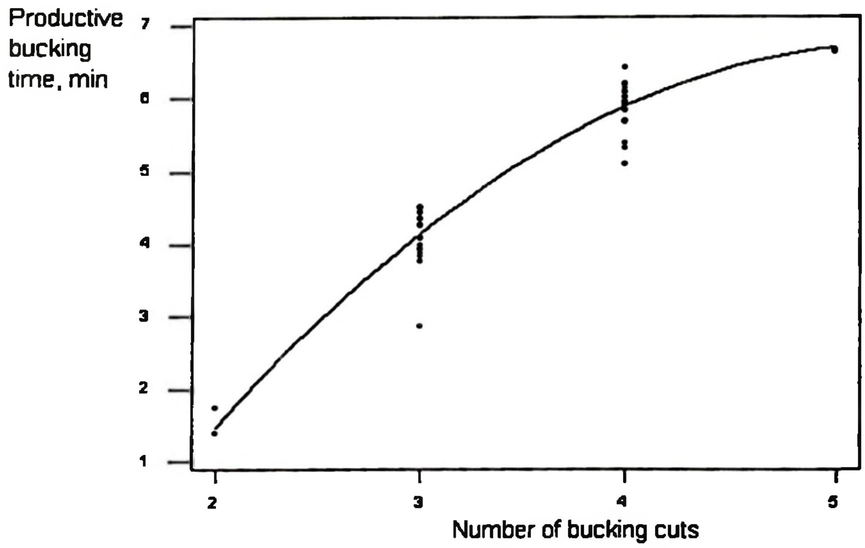

Figure 16. Productive bucking time as a function of number of bucking cuts for the improved logging method.

4.1.5.2 Bucking production rates

The number of bucking cuts varied from 1 to 5 per tree for both methods. Volume bucked was dependent on tree-length mid-diameter, number of bucking cuts and can be estimated by equation 25.

$V=-1.09 + 0.049D + 0.198N$ $R^2=93.3\ \%$ (25)

Where;

V = Volume bucked m^3.

D = Tree-length mid-diameter, cm.

N = Number of bucking cuts.

Bucking production rates per productive time is presented in Tables (10) for both systems and were all dependent on tree-length mid-diameter and number of bucking cuts.

Table 10. Katugo bucking production rate

Production element	Current logging methods				Improved logging methods			
	Mean	Std	Min.	Max.	Mean	Std	Min.	Max.
Tree-length mid- diameter (cm)	24.211	4.183	20.00	31.00	26.117	2.358	21	32
Number of bucking cuts	3	0.785	1	4	3	0.893	2	5
Volume bucked/ tree (m^3)	0.550	0.320	0.0768	1.500	0.692	0.231	0.185	1.067
Production rate, m^3/hr								
-per Productive time	12.610	8.960	1.490	46.390	10.31	2.380	6.453	29.892
-per total time	10.606	7.435	1.235	36.437	10.08	1.793	6.231	29.894

Despite a running meter system being more time consuming, the mean production rates were almost at the same levels, though for the improved system should have been higher if the operators trained to apply the system in this plantation were not slow learners. Production rates per productive times were all dependent on tree-length mid-diameter and number of bucking cuts and can be estimated by the following equations (26 and 27).

Current: $Prod.RPRBT = 28.9 - 0.054\ D - 5.05\ N$ $R^2 = 62.5\%$ (26)

Improved: Prod.RPRBT = 24.2 – 0.029 D – 4.36 N R^2= 62.7% (27)

For the current methods bucking was poorly performed as an operation, due to excessive splitting of logs. As observed by McCaughan and Carvalho (2003), splitting of logs and excessive saw jamming in plantations seems to be a, difficult problem to overcome. In addition to application of proper bucking techniques, it could be helpful if the fellers apply bench-felling techniques to provide a slight lift of the felled trees to facilitate bucking operation. As reported by Winkler and Nobauer (2001), 90% of the wood loss is due to poor felling and bucking techniques. Some of the splits were caused by bucking trees when they are unevenly supported and bucking of logs under tension without first making a cut at the compression side. Training in proper bucking techniques would definitely improve the quality of bucked logs and reduce the amount of wood waste. As pointed out by Heinrich (1995), training of forest workers is very important from both forest sustainability and industrial accidents.

4.1.6 Log rolling by hand

Since terrain conditions did not favor tractor skidding in Mafuga forest plantation, terrain transport was achieved by hand rolling the logs down the hill. For Katugo forest plantation, despite the terrain being good for tractor skidding, hand-rolling was the method applied. The log rolling technique used was simple and similar in both two forest plantations. Each log on average required 2-8 people to push it to the landing using wood levers. At Mafuga since most logs lay down slope due to trees falling down stream, this resulted in a lot of delays in turning the logs to the rolling position. Obstacles such as high stumps were avoided by laying across them smaller logs to form "spring boards" for the rolling logs. In steep slopes like Mafuga forest plantation, control of rolled logs was difficult. For example, logs could roll in any direction and could stop rolling on the way or overshoot the landings because of the high rolling speed. The whole operation was dangerous especially for those using the roads below.

During the study on the current logging methods, work organization appeared to be very poor. Logs were rolled haphazardly so long as logs were rolled to the nearest landing. The size of the rolling crew kept on changing from 2-8 people per log and when there were many people per log they spent more time arguing rather than pushing the log. Rolling operation itself was very slow in both plantations, in Mafuga this was caused by the high stumps and uncontrolled felling direction while in Katugo though the terrain is flat and rolling is slower than on steep slopes, the main problem was lack of supervision in the field.

During the application of the improved logging method, work was organized in such a way that log rolling crews worked systematically from the lower to the upper slopes. Since during the improved logging methods stumps were shorter (15-20cm), a "spring board" method was used to protect the ground from rolling logs and give the logs a smooth rolling speed.

4.1.6.1 Log rolling time and rolling production rate for Mafuga forest plantation

During the current logging method a total of 90 logs were rolled/ skidded manually over an average distance of 42m. On the other hand 70 logs were rolled manually during improved logging method and the average rolling distance was 47m. In the improved system, log rolling operation was improved by trees being felled in the extraction direction.

4.1.6.2 Log rolling time

Log rolling time was broken down as follows;

(i) Effective time;Hooking (preparing the log for rolling), Actual rolling and Piling

(ii) Delay time; Necessary delay and Unnecessary delay

As indicated in Table 11, productive rolling time represented 72.26% of the total rolling time for the current methods and more than half of this time was used for turning the log into a rolling position and piling. Productive rolling time for the improved methods was 96.55% as unnecessary delays constituted 3.45%.

Table 11. Time for hand log rolling in Mafuga plantation

Time element	Current logging methods						Improved logging methods					
	Time in minutes per log				As percentage of		Time in minutes per log				As percentage of	
	Mean	Std	Min..	Max.	Prod. Time	Total time	Mean	Std	Min.	Max.	Prod. time.	Tot. time
Hooking	1.689	0.715	0.450	3.44	30.96	26.63	0.48	0.12	0.28	0.70	19.11	15.67
Actual rolling	1.966	0.921	0.300	4.63	36.04	31.00	1.64	0.83	0.5	3.83	65.75	53.89
Pilling	0.928	0.838	0.150	3.44	17.01	14.63	0.38	0.21	0.12	0.81	15.14	12.61
Effective time	4.583	1.570	0.900	11.51	84 01	72.26	2.50	1.05	0.79	5.33	84.90	82.17
Neces-sary delay	0.872	0.523	0.120	2.530	15.99	13.75	0.44	0.34	0.00	1.24	15.10	14.58
Produc-tive time	5.455	1.754	1.020	14.04	100.0	86.01	2.94	1.26	0.79	6.57	100.0	96.55
Unneces-sary delay	0.887	1.614	0.170	2.37	-	13 99	0.11	0.22	0.00	0.58	-	3.45
Total delay	1.759	0.867	0.290	4.90	-	27.74	0.55	0.47	0.00	1.82	-	17.83
Total time	6.342	1.901	1.190	16.41	-	100.0	3.05	1.48	0.79	7.15	-	100.00

Productive rolling time was dependent on rolling distance, load size and slope and can be estimated by equation models (28 and 29)

Current: $PRRT = 3.43 - 0.0474S - 0.882\,V + 0.0531DIST^2 \quad R^2 = 65.3\ \% \quad (28)$

Improved $PRRT = -0.04 + 0.0347\,S + 0.542\,V + 0.0414\,DIST^2 \quad R^2 = 75.2\% \quad (29)$

Where;

PRRT = Productive rolling time, min.

DIST = One way rolling distance, m

S = Slope, %

V = Load size per trip, m^3.

Productive rolling time distribution as a function of rolling distance for both systems is presented in Figures 17 and 18.

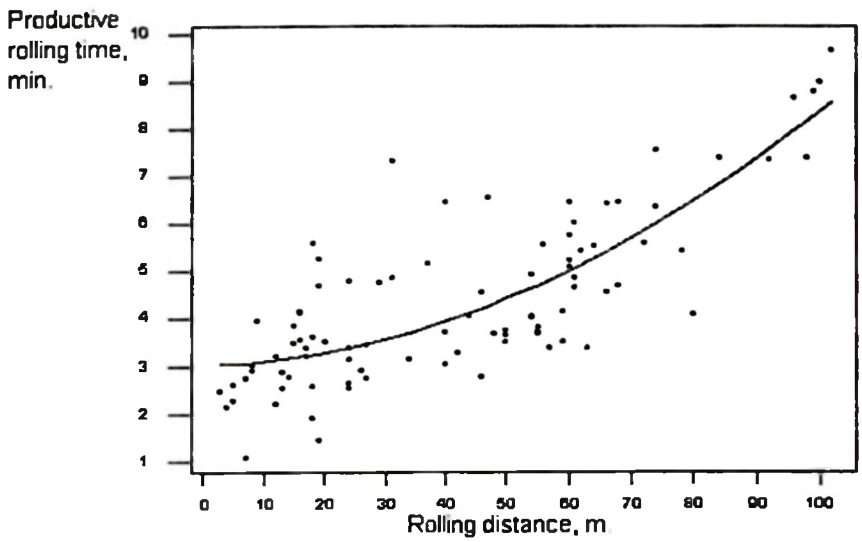

Figure 67. Productive rolling time as a function of rolling distance for the current logging method

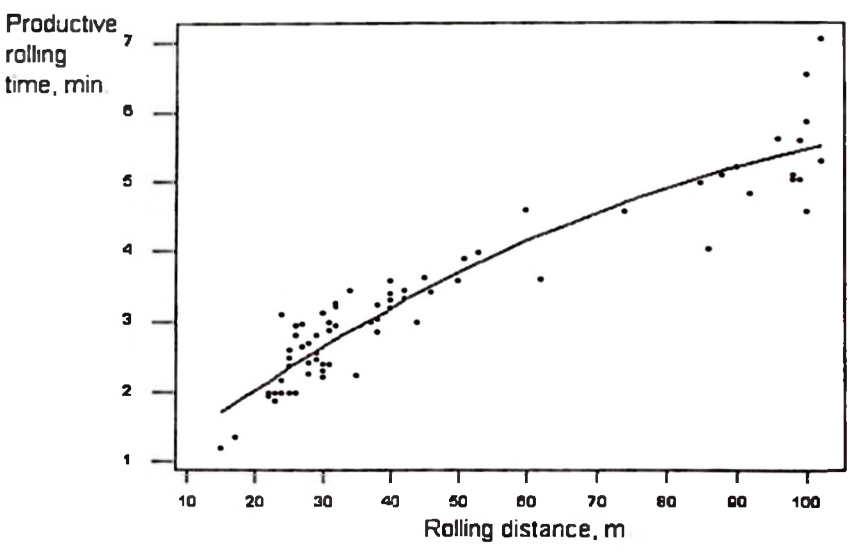

Figure 78. Productive rolling time as a function of rolling distance for the improved logging method.

Walking and unnecessary delay times resulting from log rollers getting involved in discussions with fellers and passers-by were not dependent on load size and were more or less constant for both methods.

4.1.6.3 Log rolling production rates

The improved logging system proved to be more productive than the current methods with an average of $8.08m^3$ per productive hour as compared to $6.6m^3$ per productive hour of the current methods (Table 12). Similar results were recorded by Van der Hout and Leersum (1998) and Holmes (2002), where production rates during skidding operation were higher under RIL than under CL. In this case improvement in log rolling production was achieved through close supervision and by use of a spring board system. Also since stumps were shorter this time, logs rolled without finding any obstacles on their way.

Table 12. Mafuga rolling production rate.

Production Element	Current logging methods				Improved logging methods			
	Mean	Std	Min.	Max.	Mean	Std	Min.	Max.
No. of men	3	0.524	2	8	3	0.605	2	4
Distance, M	18.00	26.48	3.00	102	47	28.18	15	102
Slope, %	26.62	7.55	6.00	36.00	28.357	3.301	25	36
Load size, m^3	0.396	0.328	0.124	1.026	0.299	0.147	0.076	0.694
Production rate, m^3/hr								
-Per Productive time	6.61	4.18	1.27	19.39	8.082	4.931	3.622	31.26
-Per total time	5.79	3.61	1.27	16.74	6.994	4.921	1.713	30.394

Production rates of the productive times for the log rolling operations were dependent on load size and can be estimated by equations (30) and (31);

Current: Prod.RPRRT $= 1.29 - 0.076DIST - 0.0799S + 16.1\ V$ $R^2 = 75.9\ \%$ (30)

Improved: Prod.RPRRT $= 3.47 - 0.112\ DIST + 0.034\ S + 26.2\ V$ $R^2 = 77.8\ \%$ (31)

4.1.6.4 Rolling time and production rate in Katugo plantation

During the study of the current logging method, a total of 64 logs were rolled by hand over an average distance of 20m. A total of 70 logs were rolled over an average distance of 21.23m when applying the improved methods.

4.1.6.5 Log rolling time

Log rolling time was broken down as follows;

Effective time; Log preparation, actual rolling and piling

Delay time; Necessary delay and Unnecessary delay

Productive rolling time for the current methods was 93.08% and more than half of this was used for turning (preparing) the log into rolling position and for the improved method, productive time was 98.35% of the total work-place time per tree (see Table 13).

Table 13. Time for hand rolling in Katugo plantation

Time Element	Current logging methods						Improved logging methods					
	Time in minutes per log				As percentage of		Time in minutes per log				As percentage of	
	Mean	Std	Min.	Max.	Prod. time	Total time	Mean	Std	Min.	Max.	Prod. time	Total time
Log preparation	2.134	0.800	0.850	4.08	62.54	53.66	1.534	0.122	0.44	3.98	50.61	49.77
Actual rolling	0.970	0.449	0.300	1.95	28.44	24.4	0.874	0.829	0.28	1.54	28.83	28.36
Pilling	0.308	0.128	0.128	0.67	9.02	7.74	0.419	0.177	0.18	0.88	13.82	13.60
Effective time	3.412	1.173	1.270	6.70	92.19	85.8	2.829	1.587	0.80	6.40	93.34	91.79
Necessary delay	0.289	0.138	0.110	0.62	7.81	7.28	0.202	0.109	0.00	0.48	6.67	6.55
Productive time	3.701	1.321	1.370	7.32	100.0	93.08	3.031	1.936	0.80	7.78	-	98.35
Unnecessary delay	0.275	0.190	0.080	0.84	-	6.92	0.051	0.035	00.0	0.13	-	1.66
Total delay time	0.564	0.280	0.190	1.46	-	14.20	0.253	0.149	00.0	0.61	-	8.21
Total time	3.976	1.342	1.46	8.16	-	100.0	3.082	1.167	0.8	8.12	-	100.0

Productive rolling times for both systems were dependent on load size, slope and rolling distance and can be estimated by equations (32) and (33);

Current; PRRT $= 0.286 + 1.48\ V + 0.079\ S + 0.146\ DIST^2$ $\quad R^2 = 73.9\ \%$ (26)

Improved; PRRT $= -0.557 + 0.077\ V + 0.359\ S + 0.202\ DIST^2$ $\quad R^2 = 89.4\ \%$ (27)

Where; PRRT = Productive rolling time, min.

S = Slope, %

Walking (returning) and unnecessary delay times resulting from log rollers getting involved in discussions with fellers and passers-by were not dependent on load size and were more or less constant in all cases. Productive rolling time distribution as a function of rolling distance for the respective methods is presented in Figures 19 and 20.

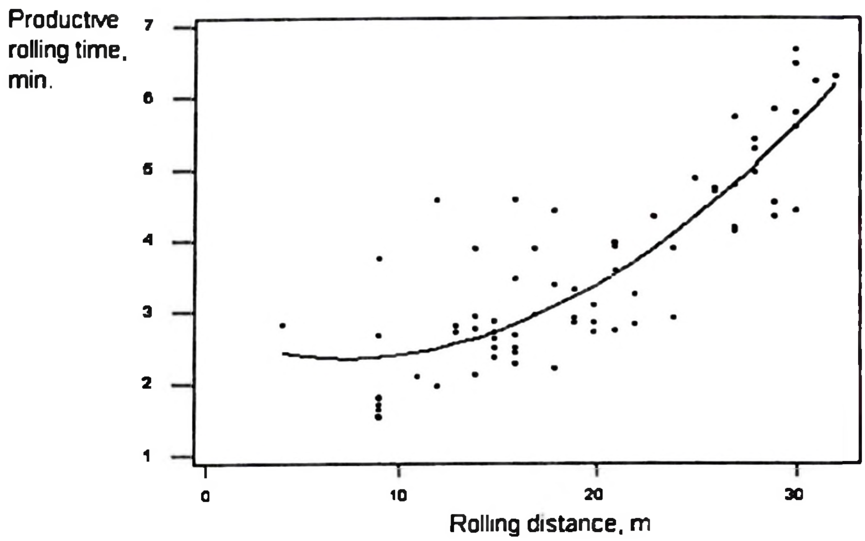

Figure 89. Productive rolling time as a function of rolling distance for the current logging method.

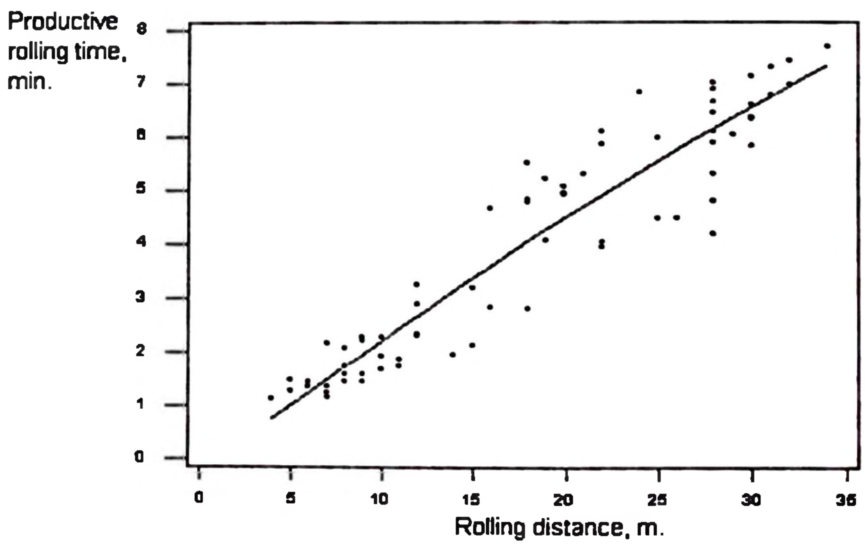

Figure20. Productive rolling time as a function of rolling distance for the improved logging method.

4.1.6.6 Katugo log rolling production rates

In Katugo also the improved methods of rolling proved to be more productive than the current methods as can be seen in Table 14. The reason for higher production is the same as for Mafuga, improved supervision, shorter stumps and a "spring board" method. On average the improved system produced 5.217m^3 per work-place time as compared to 4.04 m^3 per work-place time for the current method.

Table 14. Rolling production rate for Katugo plantation

Production Element	Current logging methods				Improved logging methods			
	Mean	Std	Min.	Max.	Mean	Std	Min.	Max.
No. of men	5	1.005	2	8	3	0.61	2	4
Distance, M	20	6.693	4	32	21	9.02	4	34
Slope, %	2	0.614	1	3	2	0.65	1	3
Average load size, m^3	0.231	0.112	0.095	0.541	0.268	0.106	0.101	0.504
Production rate, m^3/hr								
-Per productive time	4.322	2.113	1.353	11.267	5.305	4.183	2.07	20.00
-Per total time	4.042	1.977	1.251	9.833	5.217	3.865	1.98	20.00

Production rates per productive times for both systems can be estimated by the following equations (34 and 35);

Current; Prod.RPRRT = 4.27 – 0.18 Dist.+15.4 V–0.098 S R^2 =74.3 % (34)

Improved; Prod.RPRRT = 7.66. + 22.4 V – 0.814 S– 0.321 $Dist^2$ R^2 = 73.9% (35)

Production rates per productive rolling time as functions of rolling distance for the improved system is presented in Figure 21.

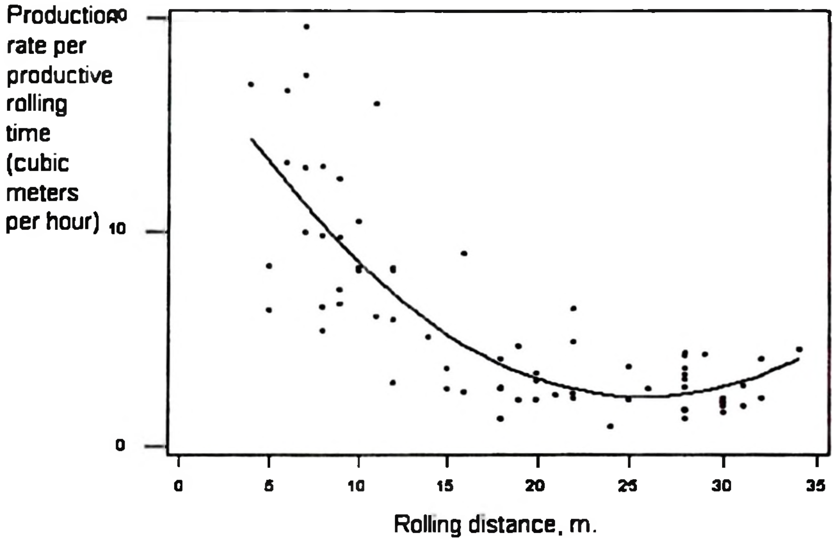

Figure 91. Production rate as a function of rolling distance for the improved logging method

The terrain conditions of Katugo are suitable for tractor winch skidding because of the flat terrain while at Mafuga, tractor skidding and the current hand rolling are not suitable. Hand rolling at Mafuga is too slow besides being dangerous and uncontrollable. Even if log production could be increased by better work organization and men working on task work basis, the ultimate desire should be towards the introduction of tractor winching in Katugo and cable yarding in Mafuga.

4.1.7 Logging production costs

There is very little public knowledge of logging and transport costs of the commercial forest operations in Uganda. This is surprising in view of their crucial importance in such matters as assessment of the contribution of private firms and determination of royalty fees.

Equipment/tool costs included purchasing prices, depreciation, interest, taxes, fuel, oil and lubricants and insurance. Most of this information was unavailable from the logging companies' records as they are either not known or not recorded. To supplement on this equipment/tool data, Husqvarna and STIHL (U) Ltd were consulted so as to get the actual values of equipment/tools.

Labour costs were obtained from the accounts sections of the logging companies. Wages were on monthly basis for sawmill managers and supervisors while for logging crews, the terms of payment were either on a daily basis (in Mafuga) or on task (in Katugo). There was no information obtained on other forms of costs like fringe benefits, free medical care in case of injury at work-place (indirect costs) and overhead management costs. Overhead costs were difficult to determine because there was virtually no separation of logging overheads from mill overheads. Therefore the costs presented here, were computed using the little information from the company's records and standard engineering formulas (FAO, 1976) (see Appendix 6).

A study on the production costs of the two harvesting systems showed that the current (conventional) system generally was slightly cheaper on the felling operations than the improved system. For the conventional methods the total felling production cost was 456.40Ushs/ m^3 and 531.16.30Ushs/ m^3 for Mafuga and Katugo respectively. While for the improved system the felling operation production cost was 484.68Ushs/m^3 and 560.13Ushs/ m^3 for Mafuga and Katugo respectively. In Mafuga the improved bucking system was more cost effective than the current bucking operation costing 1062.34Ushs/m^3 as compared to 1073Ushs/ m^3 (CL). For Katugo the improved bucking method did cost 972.28Ushs/ m^3 as compared to the current bucking cost of 964.39Ushs/ m^3 (CL). This difference in cost was due to the technical application of the improved system, which made it a bit slower during the cutting time because of the aforementioned reasons. For the log rolling operation, the improved system proved to be cheaper, costing 160.94Ushs/ m^3 and 223.88Ushs/ m^3 as compared to 194.30Ushs/ m^3 and 259.74Ushs/ m^3 of the current methods for Mafuga and Katugo respectively. The decrease in costs for rolling operation was achieved through improved supervision and application of a spring board system as mentioned earlier. The total logging cost per m^3 delivered at the mill was slightly higher under RIL than under CL (see Table 14). Similar results were obtained by Dadang *et al.* (2002), when the harvesting cost was 28% higher under RIL relative to CL, Ruslim *et al.* (2000) and Hinrichs *et al.* (2002), when harvesting costs were \$1/m^3 higher under RIL relative to CL, and Tay *et al.* (2002), who also reports of RIL being more expensive as compared to CL. But as reports Boltz *et al.* (2003), RIL can generate competitive profits relative to CL if the financial costs of wood wasted in the harvesting operation are fully accounted for. So, the slight difference of 0.8% in this case can be outweighed by the increase of 30% in wood recovery.

Table 15. Comparison of logging production costs for boths systems

Operation	Forest plantation			
	Mafuga logging costs (in UShs/m^3)		Katugo logging costs (in UShs/m^3)	
	Current	Improved	Current	Improved
Felling Operation	456.40	484.68	531.16	560.13
Bucking Operation	1073.14	1062.34	964.39	972.28
Limbing operation	-	30.37	-	38.86
Log rolling Operation	194.30	160.94	259.74	223.88
Total logging cost	1724.11	1738.33	1755.30	1795.15

4.1.8 Wood waste

During the study on the current logging methods, the wood waste in the logged areas was alarming, averaging 12.48m^3/ha. in Mafuga and 7.26m^3/ha in Katugo respectively. This was in form of logs bucked and not rolled because of being less than the minimum diameter (20cm) a swivel head mill can saw. The other forms of wood waste were those logs abandoned in the plantations (photo 7) averaging 7 logs/ha for Mafuga and 2.5logs/ha for Katugo, logs rejected because of splits and undersize and the high stumps (see photo 1) which were averaging 53cm. and 41cm. high for Mafuga and Katugo respectively. The other big cause of wood waste was the standard log length system used in soft wood plantations, which is 4.2m. No matter how big the log is in terms of diameter, it cannot be rolled or be sawn if it does not meet the 4.2m minimum standard length (see photo 2).

Photo 1. Cut without a notch nor a back cut resulting to wood split.

Photo 2. Logging wastes in form of abandoned logs in Mafuga plantation.

During the application of the improved logging system, the amount of wood wasted was minimised by, controlled felling (by making notch and back cuts) , short stumps and a bench felling method to facilitate bucking. When a running meter system was applied in the bucking operation, this managed to reduce wood waste significantly. Due to improved supervision, there were no logs left or abandoned in the logged areas, Tables 16 and 17 compares the changes in wood waste in the two cases for Mafuga and Katugo respectively.

Table 16. Merchantable stem volume and log waste in Mafuga.

Item	Mafuga - Current logging system.				Mafuga – Improved logging system.			
	Merchan-table Stem/log volume, (m^3).	Volume utilized, (m^3)	Volume Wasted, (m^3).	Wood waste in (%)	Merchan-table stem/log volume, (m^3)	Volume utilized, (m^3)	Log waste (m^3).	Wood waste in (%)
Trees felled, bucked and Rolled	0.773	0.427	0.346	44.87	0.784	0.674	0.110	14

Table 17. Merchantable stem volume and log waste in Katugo.

Item	Katugo – Current logging system.				Katugo – Improved logging system.			
	Merchantable stem/log volume, (m^3)	Volume utilized (m^3)	Volum e wasted (m^3).	Wood waste in (%)	Merchan-table stem/log volume (m^3)	Volume utilized (m^3).	Log waste (m^3).	Wood waste in (%)
Trees felled, bucked and rolled	0.697	0.425	0.272	39	0.686	0.617	0.069	10

The amount of wood waste in both plantations when using Conventional Logging was higher than when using Reduced Impact Logging. By introducing proper supervision and proper cutting techniques, the amount of wood waste was reduced significantly. Similar results have been recorded by Ahmad *et al.* (1999), where RIL significantly reduced wood waste relative to CL. Hinrichs *et al.* (2002), also found that logging waste was reduced by 20% under RIL. While Killman *et al.* (2002), recorded 60% reduction of wood loss under RIL relative to CL.

4.1.9 Soil surface disturbances

4.1.9.1 Soil surface disturbance in Mafuga forest plantation

There were three main forms of soil disturbance observed during the hand log rolling operation: organic matter displacement, mineral soil displacement and rut formation. During the application of the improved methods, small branches and small logs were spread all over the rolling trails (spring board) to help minimize direct contact of the logs with the ground soil disturbance (see photo 3). This was the only manual method that can be applied on the steep slopes of Mafuga in absence of a sky line. The amount of soil disturbance was reduced as compared to the current (CL) methods. Table 18 summarizes the total area disturbed on the log rolling trails for both methods.

Photo 3. Limbing and log rolling techniques.

Table 18. Comparison of the disturbed and undisturbed areas on the rolling trails during log rolling operation in Mafuga forest plantation

Class	Current system (CL)		Improved system (RIL)	
	Total area disturbed (m^2)	Percentage by class (%)	Total area disturbed (m^2)	Percentage by class (%)
Undisturbed	112	50.22	136	69.04
Slightly disturbed	80.0	35.87	54.0	27.41
Deeply disturbed	31.0	13.91	7.00	3.55
TOTAL	223	100.00	197	100.00

Based on the information in Table 18, the following observations were made; the improved logging system managed to reduce the deeply disturbed areas by 77.42% as compared to the current logging methods, while slightly disturbed area was reduced by 32.5% and the undisturbed class was increased by 18.82% under RIL. Similar results were recorded by Jackson *et al.* (2002) and Killman *et al.* (2002), who reported that area disturbed under RIL was reduced by 50% as compared to CL. It was also observed that ruts, which on average were less than 4 cm deep, (see photo 4) were formed only in areas that were deeply disturbed, and these are areas where conventional logging took place.

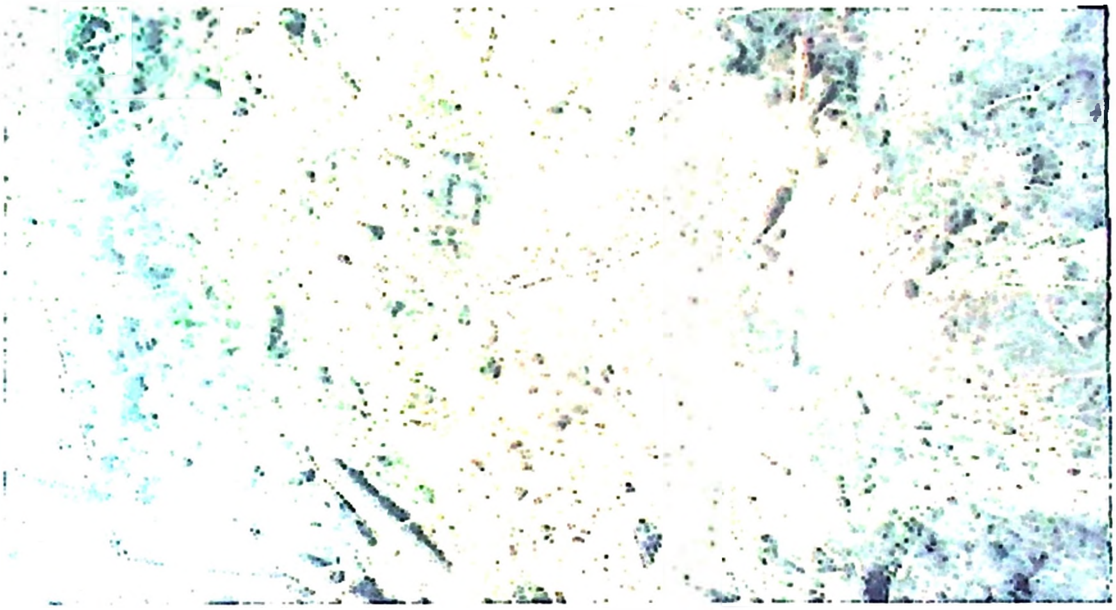

Photo 4. Ground disturbance in Mafuga.

4.1.9.2 Soil surface disturbance in Katugo forest plantation

There were no significant soil disturbances in Katugo caused by rolling logs because of the flatness of the terrain and vegetation cover in this plantation. The only ground disturbed was on landings and on tracks made by lorries that come to pick the timber and slabs from the plantation since these mobile sawmills are located in the forests.

4.1.9.3 Other impacts

Mafuga being a plantation situated on steep terrain, most mills are located in valley bottoms, as it is impossible to roll logs uphill. This practice was observed to cause water pollution and bring destruction of riparian zones. One mill was found set up in the river-bed, a practice, which should have a detrimental effect upon water quality to the disadvantage of those people living down stream. This is because most of the debris goes into the water system.

4.1.10 Working and living conditions

In the steep areas like Mafuga, mills must be set in valley bottoms as it is impossible to roll logs uphill to feed them. This practice encourages the removal of the topsoil, which brings erosion, water pollution, destruction of riparian zones and the indigenous forest belts always associated with them. During the study period some portable mills were set up in the river- bed itself, a practice, which has had a detrimental effect upon water quality to the disadvantage of those living downstream. To make matters worse, mobile mills encourage the establishment of temporary makeshift shelters around these saw mills. Besides causing environmental degradation, the quality of life of workers living in these makeshift shelters (in both plantations) is poor and sanitary arrangements are inadequate. (See photo 5)

Photo 5. Makeshift shelters near the mobile sawmill.

4.1.11 Safety

There was absolutely no evidence of safety precautionary measures being taken against injury. Workers were inadequately dressed and had no protective gear, which included helmets, boots and gloves. Nearly all workers were bare foot and some wore rubber sandals, which are not suitable for this type of job. The question of safety unfortunately seems not to be taken seriously by the supervisors or foremen as they neither wear nor provide or encourage workers to wear the protective gear.

The uncontrolled rolling logs in steep terrain of Mafuga appears to be a problem to overcome. Neither the loggers nor the people using the road down slope are safe from the rolling logs. The hygienic living conditions of the workers in the makeshift shelters are very poor. Sanitary conditions are not impressive, workers smoke and cook food (light fire) in these camps and the risks of fire are very high.

The conditions of the hand tools leave much to be desired. All had no protective guides and were carried and handled carelessly. Workers were not protected against physical injury from equipment / tools, trees and from rain and sun. Snakes though rare, were potential danger and to make matters worse, first aid facilities were not available at work places. Chain saw operators had no Personal Protective Equipment whatsoever (see photo 3 and 6), and in many parts of the world, this would not have been allowed in the plantations.

Photo 6. Bucking with no safety gear.

4.1.12 Fire

The current policy of undertaking sawmilling in plantations seriously increases the risk of plantation fires (one of the causes of wood waste). Due to the fact that these mobile sawmills are inside plantations, there are unnecessarily more human activities in the plantation forests. For example labour must be housed, they have to cook food and light fire, all of which greatly increase the risk of forest fires. As the National Forestry Authority (NFA) has no resources to fight plantation fires, they are (for the greater part) left to burn themselves out (see photo 7). The cost in terms of loss of timber is likely to be significant. In the course of the study, we noted numerous recent fires close to harvesting/milling sites, which is unlikely to be coincidence. In one case the whole compartment caught fire and all harvesting operations were shifted to that compartment to harvest those trees before they could dry out.

Photo 7 Abandoned logs and fire hazards at Mafuga forest plantation.

4.1.13 Control

With small independent Millers working in isolation, it is virtually impossible for Assistant Forest Officers (AFO) and District Forestry Officers (DFO) to exercise the required degree of control, particularly in the present circumstances where there is scarcity of vehicles and fuel.

Even though instructions have been given (but not uniformly heeded) to concentrate harvesting / milling operations in single compartments, this is not always possible, particularly when viewed from the safety perspective. Kabale District alone has 27 licensed mills. It is virtually impossible for this number of operations to be controlled by available staff, and concentrating them into a small area will greatly compromise safety.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 General conclusions

This study has produced information, which can be used to solve some of the problems in the logging systems in Ugandan softwood plantations. Interpretation of the results from the data analysis has given rise to a number of conclusions in this regard. These include general lack of information at the National Forestry Authority and the sawmilling companies on production and cost and environmental impact of existing methods and equipment /tools used in the various phases of plantational timber harvesting operations.

Sawyers receive no training in felling or bucking and there is considerable wastage due to poor trimming and poor felling techniques. This study has revealed that trained operators can reduce the incidence of wood loss significantly. Safety is more or less disregarded (e.g. many workers work in shorts, no helmets and no boots), no proper communication between fellers and other workers and fellers appear unaware of the need for preparing escape routes prior to felling trees. Due to the haphazard nature of the operation, almost 30% of the ground surface area is disturbed. Daily production rates in felling and bucking varied with different tree dimensions, yet labour payments were based on a flat rate.

The study compared information on the production rates and costs, wood waste and the ground disturbance of the two harvesting systems (the current and the improved) in

Mafuga and Katugo softwood plantations. The information collected was therefore used to develop models that can be used for prediction of production and costs in similar conditions.

The timber harvesting operations studied ranged from semi-mechanised (power saw used for felling and bucking) to purely manual (limbing with axes and hand rolling) logging methods. In the current logging methods, the felling and bucking crews were not supervised in both plantations rather, the operators were supervising themselves. The foremen who were also sawmill supervisors were always at the mill site supervising the sawing process. The observations made during the study revealed that they are more of sawmill supervisors than logging supervisors and they had no knowledge what so ever on logging operations. The logging operators too had no knowledge on directional felling nor on a running meter system until they were trained by the Researcher during the application of the improved logging methods.

5.2 Production rates and costs

5.2.1 Production rates

The average felling production rates of the current logging methods were 25.78 m^3/hr and 34.47 m^3/hr making an average daily production of 125 m^3 and 172.35 m^3 per crew for Mafuga and Katugo respectively. This was higher than 16.39 m^3/hr and 20.4 m^3/hr making daily production averaging 81.95 m^3 and 102 m^3 per crew for Mafuga and Katugo respectively during the improved logging methods. The low productivity during the improved system can be explained by the fact that directional felling is a more time consuming operation, which requires considering many factors before felling a tree as mentioned before. All these factors take a certain amount of operation time to observe. This time is not wasted at all as it is sacrificed for the sustainability of the forest resource. We don't have to meet the demand of timber by over felling trees since this demand can be met through proper utilisation of what is felled through improved felling system.

Productivity of the bucking operation during the application of the current methods was 9.29 m^3/hr and 10.61m^3/hr making a daily average of 46.45 m^3 and 53.05 m^3 per crew for Mafuga and Katugo respectively. For improved logging this was 10.08 m^3/hr and 10.09 m^3/hr averaging 50.45 m^3 and 50.50 m^3 per crew a day for Mafuga and Katugo respectively. This case was different from the felling operation. During the application of the improved system, a running meter system was used. Any merchantable piece of wood, which was 1.5m long and more was bucked as a log unlike in the current system where only a log with a standard length of 4.2m is considered to be the minimum log. When bucking using a running meter system, the scaling activity consumes more time by observing the whole tree and looking for the defected parts. The defected parts are eliminated and the rest of the log is utilised. This is aimed at sustainable utilisation of the forest resource, unlike in the current system where a log of 4m is left in the plantation as it doesn't meet the minimum 4.2m requirement. This high recovery factor seems to have a big influence on the production rates. Although a running meter system consumed more time, at the end of the day it proved to be more productive per work-place hour than the 4.2m standard length in Mafuga.

Productivity studies on the log rolling operations showed the improved system performing better than the current methods. The production rates of the improved system were 6.99m^3/hr and 5.22 m^3/hr averaging 55.92 m^3 and 41.76 m^3 per crew per day for Mafuga and Katugo respectively. This was higher than the current 5.79 m^3/hr and 4.04 m^3/hr averaging 46.32 m^3 and 32.32 m^3 per crew per day. These improvements were achieved through proper and close supervision, which managed to eliminate the unnecessary activities during the operation time and the application of spring board method on the ground that allows a log to roll smoothly.

5.2.2 Production costs

A study on the production costs of the two harvesting systems showed that the current (conventional) system generally was slightly cheaper on the cutting operations than the improved system. For the conventional methods the total felling production cost was 456.40Ushs/ m^3 and 531.16.30Ushs/ m^3 for Mafuga and Katugo respectively. For the improved system, the felling production cost was 484.68Ushs/m^3 and 560.13Ushs/ m^3 for Mafuga and Katugo respectively. In Mafuga the improved system was more cost effective than the current for the bucking operation costing 1062.34Ushs/m^3 as compared to 1073Ushs/ m^3 (CL). While for Katugo the improved method was costing 972.28Ushs/ m^3 as compared to 964.39Ushs/ m^3 (CL). This difference in cost was due to the technical application of the improved system, which made it a bit slower during the cutting time because of the aforementioned reasons. For the log rolling operation, the improved system proved to be cheaper costing 160.94Ushs/ m^3 and 223.88Ushs/ m^3 as compared to

194.30Ushs/ m^3 and 259.74Ushs/ m^3 of the current methods for Mafuga and Katugo respectively. The decrease in costs of the rolling operation was achieved through proper supervision and application of a spring board system. The total logging cost per cubic meter delivered at the mill was 0.8% and 2.3% higher under the improved logging methods than under the current logging methods for Mafuga and Katugo respectively.

5.3 Wood waste

The level of wood waste was far higher in areas logged using the current methods than in those harvested using the improved system. The number of logs abandoned in areas logged using the current methods were seven logs/ha for Mafuga and 2.5 logs/ha for Katugo, while the merchantable pieces of wood left because of the splits and simple defects were 47 pieces together averaging 12.48 m^3/ha for Mafuga and 29 pieces averaging 7.26 m^3/ha for Katugo. The stump heights on average were 53cm in Mafuga and 41cm in Katugo instead of 20 cm and 15cm in Mafuga and Katugo as was the case during the application of RIL method. In Areas harvested using the improved system no abandoned logs were found. The only pieces of wood found there were left because of the splits and these amounted to 0.11m^3/tree (14%) for Mafuga and 0.069 m^3/tree (10%) for Katugo and this was an improvement as compared to the current wood waste rate of 44.48% per tree for Mafuga and 39% per tree for Katugo. This improvement was achieved by applying directional felling (avoiding damaging the tree when falling), a running meter system for bucking (sawing logs of less than 4.2cm) and proper supervision during the log rolling operation.

5.4 Soil surface disturbance

There were no significant soil disturbances in Katugo caused by rolling logs because of the flatness of the terrain and vegetation cover in this plantation.

The assessment of the ground disturbance in Mafuga revealed that the ground was more disturbed in areas logged using the current methods than in those harvested using the improved methods. In areas logged using the current methods 13.9% of the rolling trial was deeply disturbed and 35.87% of the rolling trail was slightly disturbed in Mafuga. During the application of the improved methods in Mafuga, the deeply disturbed areas were reduced to 3.55% and the slightly disturbed areas were reduced to 27.41% of the rolling trail. These improvements were achieved by using a springboard method during the rolling operation, which requires the spreading of small logs and branches along the rolling trail preventing the log from having direct contact with the ground cover as seen in Photo 3. Similar results were reported by Sist *et al.*, (2003), who concluded that reduced impact logging normally reduce wood waste and ground disturbance.

Since the new improved harvesting system was a new technology in Ugandan forest plantations, the researcher spent a big portion of work-place time instructing operators on the correct working techniques during the operations. The felling production rates were lower because the techniques applied in the new improved system were very new to the operators. On the other hand if the operators are given a chance to practice these techniques and undergo further training they will master these techniques and significantly improve their felling performance. This will leave no reason for not adopting this improved system, since the researcher spent a lot of time teaching them on the correct working techniques during the operations.

Improvements of logging practices will be sustainable if adopted by the private sector, since they are the ones engaged in logging activities. Whatever developmental efforts made, there will be a demand for a dynamic operational framework, capable of making the necessary adjustments in the ever- changing business environment. Directional felling techniques are applied to minimize damage to the tree, minimize damage to the ground and to facilitate extraction. Even though directional felling is more time consuming than haphazard felling but gains in these three areas will almost certainly outweigh the cost.

In general the present harvesting and extraction techniques used in the softwood plantations of Uganda are inefficient, dangerous and environmentally unsound. Poor practice has become the accepted norm. Supervision of sawmillers and their staff is generally poor. There are too many people with no valid reasons in the plantation, resulting in forest fires, which have caused considerable damage to the plantations.

The introduction of proper training of workers in reduced impact logging and better planning, organisation and supervision of work and proper maintenance of the equipment/tools will improve the situation.

5.5 Recommendations

Since the ultimate aim of this study was to analyse the current logging system and propose an optimum timber harvesting system for Ugandan plantation forests, the following recommendations are put forward;

To ensure efficiency in felling operation, training on the importance of directional felling should be initiated by the National Forestry Authority and logging companies together with close supervision. This will help minimise wood loses and haphazard falling of trees thus minimising breakage of trees. The payment system for operators should also be based on quality rather than volume alone. The best felling direction is towards or away from the skid trail at an angle of 30^0-45^0 (Herringbone pattern) for mechanised skidding operations. For the manual rolling operations, it is better to fell trees perpendicular to the rolling direction. This helps to minimise the time spent on turning the log into the rolling position. On steep slopes like Mafuga, the felling direction should be towards the side of the slope (along the contour) for safety of the operators and the falling tree itself. Stumps should be cut very low, 15cm or even less. A bench method should be used to facilitate bucking operation. The use of felling wedges is recommended to give additional control over the felling direction. The felling operation should be closely supervised and properly performed as it determines the efficiency of the other subsequent operations.

For the bucking operation, a running meter system should be introduced to replace the current wasteful standard 4.2m log length method. Before bucking, a stem should be measured and its log sections determined. Crosscuts should be not more than 10^0 from vertical to avoid under sizing of the logs. When cutting tension stems, a cut should be made on the compression side first then on the tension side to avoid splits (Elias *et al*, 2001). These techniques will help in production of better quality logs. By reducing the wood losses and improving on the quality of the logs produced, the production costs will obviously be reduced.

For efficiency of a log rolling operation, a spring board method should be applied. This method gives a log a smooth and faster rolling rhythm that helps to improve on the productivity of the rolling crew and at the same time protects the ground from having direct contacts with the logs (a practice, which causes a lot of ground disturbance). Close supervision and training are greatly needed for efficient performance of this operation.

Planning, organization and control of logging operations should be given priority, in order to increase production rate and reduce costs, wood waste and ground soil disturbance by eliminating unnecessary activities. For instance, tool maintenance should be carried outside work place time.

Many of the basic skills required for safe and productive harvesting are non-existent in the plantations, and there is much scope for training, both of supervisors and labourers. The following needs are by no means comprehensive, but are the most pressing:

1) Chainsaw use: Felling is the most dangerous job in the plantation, and yet no formally trained chainsaw operators were encountered during the study. This is reflected in the quality of the workmanship displayed. Felling direction was

uncontrolled and most operators were a danger to themselves and their colleagues. Poor felling direction makes all later operations unnecessarily less productive and is the key to inefficiency.

2) Log scaling and crosscutting. To achieve maximum utilisation of round wood, effort must be spent to train loggers on log scaling and crosscutting. Millers' present enthusiasm for 4.2m lengths must be changed, and trees must be assessed and scaled for maximum revenue. It is perfectly feasible to increase the value of any given tree by 30% by careful log scaling (MWLE, 2003).

If training exercises in reduced impact logging will be carried out for the operators and their supervisors, it will improve the situation on the quality of logs produced and reduce costs due to improved productivity and minimised wood waste. Worker training should be done professionally through a formal programme and repeated in refresher training so that safe and efficient working techniques can be sustained. A very practical solution to this, which can be recommended, is to make use of a mobile trainer, or logging extensionist. A mobile trainer travels to the logging sites with appropriate tools and provides training to a group of workers, at least for a period of one week. This is the most cost effective way of providing training to the workers in the field (APPRODEV, 1995). Close supervision is intended to eliminate unnecessary delay activities, which means improved production and reduced costs. The introduction of reduced impact logging techniques in these softwood plantations will ensure the sustainable utilisation of the forest resources.

Due to the fact that this study was carried out on a limited scale, it is recommended that more studies be conducted on the same subject (in the natural forests). These should include work and time studies aimed at improving economy in human efforts, optimal use of machines/tools and overall operational efficiency in forest production processes. And efforts should be made to put into practice the recommendations made from research findings. Accumulation of knowledge is not an end in itself, it must be followed by action to initiate and implement developmental programmes.

The Government (National Forestry Authority) and Funding Agencies need to place greater emphasis on the development and delivery of training and extension programmes for the forest industry.

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APPENDICES

Appendix 1 Cutting production field data form

Forest.........................

Date...... Start time........ Species......... Form No.......

Compartment No..... Stop time........... Tools/equipment......................... Crew size............................

Crew names................

Tree No.	Tree Dbh (cm)	Total tree Hgt (m)	Stump Diam. (cm)	Stump Hgt. (cm)	Cutting cycle time elements (centiminutes)																			Remarks
					Felling				Limbing			Bucking				Number of logs								
																1		2		3		4		
					Prepar-ation	Cut-ting	Nec. del.	Unn. del.	Cut-ting	Nec. del.	Unn. del.	Seal-ing	Cut-ting	Nec del.	Unn. del.	mid-diam	Log lgth.	mid-diam	Log lgth.	mid-diam	Log lgth.	mid-diam	Log lgth	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

NB: Tree hgt-Tree height, Log lgth-Log length, Nec. del.-Neccssary delay, Unn. del.-Unnecessary delay, Dbh-Diameter at breast height

Appendix 2 Log rolling production field data form

Forest…………

Date….. Start time…. Stop time….. Compartment No…………… Form No……..

Crew size…….. Crew names…………….

Log No.	No of men	Mid Diam. (cm)	Length (m)	Volume (m^3)	Rolling Distance (m)	Slope %	Ground condition	Log rolling time elements (centiminutes)						Remarks
								Rolling time (min.)	Pilling Time (min)	Necessary Delay (min)	Total effective time(min)	Unnec. delay (min)	Total time	

Appendix 3. Equipment/ tools operating cost estimates

Equipment/tools: Description ……………………………………

Gross hp…………… Delivered cost……………

Life in years……. Hours (days): per year…………

Fuel: Type…………….. Price per litre………………

Operators: Rate per hour (day)………… Fringe benefits…………%

<u>Cost components</u> (fixed)

(a) Depreciation

(b) Interest

(c) Insurance

(d) Taxes

(e) Overheads.

<u>Cost components</u> (variable)

(f) Fuel

(g) Oil and lubricants

(h) Repair and maintenance.

Appendix 4. Number and Volume of logs leftover in the forest

Forest…………………………………… Compartment No………………….. Form No……………………

Log No.	Mid Diameter (cm)	Length (cm)	Volume (m^3)

Appendix 5. Log rolling soil disturbance data sheet

Forest.......... Date................ Form No. ....

Compartment No. .... Species.....................

Trail No.	Total area of the rolling trail (LxW) (m^2)	Area of slightly disturbed soil (m^2)	Area of deeply disturbed soil (m^2)	Area of undisturbed Soil (m^2)	Remarks

Appendix 6. Logging production costs

Production cost of a felling operation in Katugo forest plantation

Machine; Descriptio n : Powersaw, STIHL 46 ; Delivery cost : 2,740,000 Ushs.
Life in years : 4; Days per year : 250
Hours per year : 1500;
Fuel type : Petrol; Price per litre : 2950Ushs.
Operator rate per (day) : 4500Ushs; Fringe benefits : 0%

1.Cost components (fixed)

$$(i) \quad Depreciation = \frac{Delivery\ \cos t}{Life\ in\ years} \times 0.9 = \frac{2740000}{4} \times 0.9 = 616500\ Ushs\ /\ year$$

$$= 411\, ushs\ /\ hr.$$

$$(ii) \quad Interest = \frac{Delivery\ \cos t \times 60 \times \text{int}\, erest\ rate}{Life\ in\ years}$$

$$= \frac{2740000 \times 0.6 \times 0.08}{4} = 32880\ Ushs\ /\ year = 29.92\, ushs\ /\ hr$$

$$(iii) \quad Insurance = Delivery\ \cos t \times 1.5\% = 2740000 \times 0.015 = 41100\ Ushs\ /\ yr$$

$$= 27.4\, Ushs\ /\ hr.$$

$$(iv) \quad Operational\ labour = 4500 \times 250 = 1125000\ Ushs\ /\ yr = 750\, Ushs\ /\ hr.$$

$$Total\ fixed\ \cos t = 181580\ Ushs\ /\ yr = 1210\ Ushs\ /\ hr;$$

$$Fixed\ \cos t: \quad For\ the\ current\ methods = \frac{1210}{34.47} = 32.11\, Ushs\ /\ m^3.$$

$$For\ the\ imrove\ methods = \frac{1210}{20.4} = 59.31\, Ushs\ /\ hr.$$

2. *Variable* cos *t components*

(i) *Fuel* : *Total consumptio n estimated by the company per* m^3 *was* $0.12\, ltrs$.

$$Total\ \cos t = 2950 \times 0.12 = 354\, Ushs\ /\ m^3$$

(ii) *Oil and* lub *ricants* : *No company estimate*, *applied* 15% *of fuel* cos t(*FAO*, 1976)

$$Oil\ \&\ Lubr. = 354 \times 0.15 = 53.1\, Ushs\ /\ m^3$$

$$(iii)\ \text{Re}\,pair\ and\ maitenance = \frac{0.4D + 0.03D}{100} = \frac{0.4 \times 2740000 + 0.03 \times 2740000}{100 \times 100hrs \times prod.rate} =$$

$$For\ the\ current\ methods\ = \frac{1178200}{344700} = 3.42Ushs/m^3$$

$$For\ the\ improve\ methods = \frac{1178200}{204000} = 5.78Ushs/m^3$$

$Total$ var $iable$ cos t : $For\ the\ curent\ methods\ = 410.52Ushs/m^3$

$For\ the\ improved\ methods = 412.88Ushs/m^3$

$Total$ cos t : $For\ the\ current\ methods\ = 32.11 + 410.52 = 442.63Ushs/m^3$

$For\ the\ improved\ methods = 59.31 + 412.88 = 472.19Ushs/m^3$

3. Ad min $istration$ cos t = 20% × $total$ cos t :

$For\ the\ current\ methods\ = 88.53Ushs/^3$

$For\ the\ improved\ methods = 96.94Ushs/m^3$

TOTAL FELLING PRODUCTION COST :

$For\ the\ current\ methods\ = 531.16Ushs/m^3$

$For\ the\ improved\ methods = 560.13Ushs/m^3$

Katugo Bucking Production cost.

The same powersaw was used for bucking as for felling so the fixed cost components values are the same.

1.Fixed costs

The total fixed cost :

$$\textit{For the improved methods} = \frac{1210}{\textit{bucking prod.rate}} = \frac{1210}{10.08} = 120.04 Ushs/m^3$$

$$\textit{For the current methods} = \frac{1210}{\textit{buckingprod.rate}} = \frac{1210}{10.61} = 114.04 Ushs/m^3$$

2. *Variable cost components*

(i) *Fuel*: *Total consumption estimated by the company per* m^3 *was* 0.2*ltrs.*

$$Total\ cost = 2950 \times 0.2 = 590 Ushs/m^3$$

(ii) *Oil and lubricants*: *No company estimate, applied* 15% *of fuel cost* (*FAO*, 1976)

$$Oil \& Lubr. = 590 \times 0.15 = 88.5 Ushs/m^3$$

(iii) $Repair\ and\ maitenance = \dfrac{0.4D + 0.03D}{100} = \dfrac{0.4 \times 2740000 + 0.03 \times 2740000}{100 \times 100 hrs \times prod.rate} =$

$$For\ the\ current\ methods = \frac{1178200}{106100} = 11.12 Ushs/m^3$$

$$For\ the\ improve\ methods = \frac{1178200}{100800} = 11.69 Ushs/m^3$$

Total variable cost: *For the curent methods* $= 689.62 Ushs/m^3$

For the improved methods $= 690.19 Ushs/m^3$

Total cost: *For the current methods* $= 810.23 Ushs/m^3$

For the improved methods $= 803.66 Ushs/m^3$

3. *Administration cost* $= 20\% \times$ *total cost*:

For the current methods $= 160.73 Ushs/^3$

For the improved methods $= 162.05 Ushs/m^3$

TOTAL BUCKING PRODUCTION COST:

For the current methods $= 964.396 Ushs/m^3$

For the improved methods $= 972.28 Ushs/m^3$

Mafuga felling production rates

$Machine: Description: Powersaw Husqvarna\ 365; Delivery\ cost: 2650000 Ushs$

$Life\ in\ years: 4 years; Days\ per\ year: 250 days$

$Hours\ per\ year: 1500 hours;$

$Fuel\ type: Petrol; Price\ per\ litre: 2950 Ushs.$

$Operator: Rate\ per\ day: 3000 Ushs; Fringe\ benefits: 0\%$

$1. Fixed\ cost\ components$

$$(i) \quad Depreciation = \frac{Delivery\ cost}{Life\ in\ years} \times 0.9 = \frac{2650000}{4} \times 0.9 = 596250 Ushs/year$$

$$= 397.50 ushs/hr.$$

$$(ii) \quad Interest = \frac{Delivery\ cost \times 60 \times interest\ rate}{Life\ in\ years}$$

$$= \frac{2650000 \times 0.6 \times 0.08}{4} = 31800 Ushs/year = 21.20 ushs/hr$$

$$(iii) \quad Insurance = Delivery\ cost \times 1.5\% = 2650000 \times 0.015 = 39750 Ushs/yr$$

$$= 26.5 Ushs/hr.$$

$$(iv) \quad Operational\ labour = 3000 \times 250 = 750000 Ushs/yr = 500 Ushs/hr.$$

$$Total\ fixed\ cost = 141800 Ushs/yr = 945.020 shs/hr;$$

$$Fixed\ cost: \quad For\ the\ current\ methods = \frac{1210}{prod.rate} = 36.66 Ushs/m^3.$$

$$For\ the\ imrove\ methods = \frac{1210}{prod.rate} = 57.69 Ushs/hr.$$

2. .*Variable* cost *components*

(*i*) *Fuel* : *Total consumption estimated by the company per* m^3 *was* 0.1*ltrs.*

$Total\cos t = 2950 \times 0.1 = 295 Ushs / m^3$

(*ii*) *Oil and* lub*ricants* : *No company estimate, applied* 15% *of fuel* cos*t*(*FAO*,1976)

$Oil \,\&\, Lubr. = 295 \times 0.15 = 44.25 Ushs / m^3$

$$(iii)\ \text{Re}\, pair\ and\ maitenance = \frac{0.4D + 0.03D}{100} = \frac{0.4 \times 2650000 + 0.03 \times 2650000}{100 \times 100 hrs \times prod.rate} =$$

$$For\ the\ current\ methods\ = \frac{1178200}{257800} = 4.42 Ushs / m^3$$

$$For\ the\ improve\ methods = \frac{1178200}{163850} = 6.96 Ushs / m^3$$

Total var*iable*cos*t* : *For the curent methods* $= 343.67 Ushs / m^3$

For the improved methods $= 346.21 Ushs / m^3$

Total cos*t* : *For the current methods* $= 36.66 + 343.67 = 380.33 Ushs / m^3$

For the improved methods $= 57.69 + 346.21 = 403.90 Ushs / m^3$

3. *Ad* min*istration*cos*t* = 20% × *total* cos*t* :

For the current methods $= 88.53 Ushs / ^3$

For the improved methods $= 96.94 Ushs / m^3$

TOTAL FELLING PRODUCTION COST :

For the current methods $= 531.16 Ushs / m^3$

For the improved methods $= 560.13 Ushs / m^3$

Mafuga Bucking Production cost.

The same powersaw was used for bucking as for felling so the fixed cost components values are the same.

1.Fixed costs

$$\textit{The total} - \textit{fixed}\cos t : \textit{For the improved methods} = \frac{1210}{\textit{bucking prod.rate}} = \frac{1210}{10.086}$$

$$= 93.71 Ushs / m^3$$

$$\textit{For the current methods} = \frac{1210}{\textit{buckingprod.rate}} = \frac{1210}{9.291}$$

$$= 101.73 Ushs / m^3$$

2. .Variable cost components

(i) Fuel: Total consumption estimated by the company per m^3 was 0.23ltrs.

$$Total\ cost = 2950 \times 0.23 = 678.5 Ushs/m^3$$

(ii) Oil and lubricants: No company estimate, applied 15% of fuel cost (FAO, 1976)

$$Oil\ \&\ Lubr. = 678.5 \times 0.15 = 101.78 Ushs/m^3$$

$$(iii)\ Repair\ and\ maitenance = \frac{0.4D + 0.03D}{100} = \frac{0.4 \times 2650000 + 0.03 \times 2650000}{100 \times 100hrs \times prod.rate} =$$

$$For\ the\ current\ methods = \frac{1178200}{92910} = 12.27 Ushs/m^3$$

$$For\ the\ improve\ methods = \frac{1178200}{100860} = 11.29 Ushs/m^3$$

Total variable cost: For the curent methods $= 792.55 Ushs/m^3$

For the improved methods $= 791.57 Ushs/m^3$

Total cost: For the current methods $= 894.28 Ushs/m^3$

For the improved methods $= 885.28 Ushs/m^3$

3. Administration cost = 20% × total cost:

For the current methods $= 178.86 Ushs/^3$

For the improved methods $= 177.06 Ushs/m^3$

TOTAL BUCKING PRODUCTION COST: For the current methods $= 1073.14 Ushs/m^3$

For the improved methods $= 1062.34 Ushs/m^3$

Limbing operation production cost for mafuga plantation

$Machine$: $Descrripti\ on$: Axe : $Delivery\ \cos t$: $37000\, Ushs$; $Lifeinyear\ s$: $2 years$

$Days\ per\ year$: 250; $Hours\ per\ year$: 1500

$Operationa\ l\ labour$: $2000\, Ushs\ /\ year$

1. $Cost\ components\ (fixed)$

(i) $$Depreciati\ on = \frac{Delivery\ \cos t}{Life\ in\ years} \times 0.9 = \frac{37000}{2} \times 0.9 = 11650\, Ushs\ /\ year$$

$$= 11.101 ushs\ /\ hr.$$

(ii) $$Interest = \frac{Delivery\ \cos t \times 60 \times \text{int}\ erest\ rate}{Life\ in\ years}$$

$$= \frac{37000 \times 0.6 \times 0.08}{2} = 8880\, Ushs\ /\ year = 0.59 Ushs\ /\ hr$$

(iii) $$Insurance = Delivery\ \cos t \times 1.5\% = 37000 \times 0.015 = 555 Ushs\ /\ yr$$

$$= 0.37 Ushs\ /\ hr.$$

(iv) $$Operationa\ l\ labour = 2000 \times 250 = 500000\, Ushs\ /\ yr = 333.33 Ushs\ /\ hr.$$

$$Total\ fixed\ \cos t = 518093\, Ushs\ /\ yr = 345.40 Ushs\ /\ hr;$$

$$Fixed\ \cos t: \quad For\ the\ improve\ methods = \frac{345.4}{19.93} = 17.33 Ushs\ /\ hr.$$

2. $Variable\ \cos t\ components$

(iii) $$\text{Re}\ pair\ and\ maitenance = \frac{0.4D + 0.03D}{100} = \frac{0.4 \times 37000 + 0.03 \times 37000}{100 \times 100\, hrs \times prod.rate} =$$

$$For\ the\ improve\ methods = \frac{14800 + 1110}{19.3} = 7.98 Ushs\ /\ m^3$$

$Total\ \text{var}\ iable\ \cos t$: $For\ the\ improved\ methods = 7.98 Ushs\ /\ m^3$

$Total\ \cos t$: $For\ the\ improved\ methods = 7.98 + 17.33 = 25.31 Ushs\ /\ m^3$

3. $Ad\ \text{min}\ istration\ \cos t = 20\% \times total\ \cos t$:

$For\ the\ improved\ methods = 5.06 Ushs\ /\ m^3$

$TOTAL\ LIMBING\ PRODUCTION\ COST$:

$For\ the\ improved\ methods = 30.37 Ushs\ /\ m^3$

Limbing operation production cost for Katugo forest plantation

$Machine: Descrription: Axe: \quad Delivery\ cost: 35500Ushs;\ Life\ in\ years: 2years$

$Days\ per\ year: 250;\ Hours\ per\ year: 1500$

$Operational\ labour: 2500Ushs/year$

1. $Cost\ components\ (fixed)$

(i) $$Depreciation = \frac{Delivery\ cost}{Life\ in\ years} \times 0.9 = \frac{35500}{2} \times 0.9 = 15975Ushs/year$$

$$= 10.65Ushs/hr.$$

(ii) $$Interest = \frac{Delivery\ cost \times 60 \times interest\ rate}{Life\ in\ years}$$

$$= \frac{35500 \times 0.6 \times 0.08}{2} = 852Ushs/year = 0.57Ushs/hr$$

(iii) $Insurance = Delivery\ cost \times 1.5\% = 35500 \times 0.015 = 532.5Ushs/yr$

$$= 0.36Ushs/hr.$$

(iv) $Operational\ labour = 2500 \times 250 = 625000Ushs/yr = 416.67Ushs/hr.$

$Total\ fixed\ cost = 642359.5Ushs/yr = 428.24Ushs/hr;$

$$Fixed\ cost: \quad For\ the\ improve\ methods = \frac{428.24}{17.94} = 23.87Ushs/hr.$$

2. $Variable\ cost\ components$

(iii) $$Repair\ and\ maitenance = \frac{0.4D + 0.03D}{100} = \frac{0.4 \times 35500 + 0.03 \times 35500}{100 \times 100hrs \times prod.rate} =$$

$$For\ the\ improve\ methods = \frac{14800 + 1110}{17.94} = 8.51Ushs/m^3$$

$Total\ variable\ cost: For\ the\ improved\ methods = 8.51Ushs/m^3$

$Total\ cost: \quad Fortheimprovedmethods = 8.51 + 23.87 = 32.38Ushs/m^3$

3. $Administration\ cost = 20\% \times total\ cost:$

$For\ the\ improved\ methods = 6.48Ushs/m^3$

$TOTAL\ LIMBING\ PRODUCTION\ COST:$

$For\ the\ improved\ methods = 38.86Ushs/m^3$

Log rolling production cost in Mafuga Forest plantation

Method applied: Mannual; Average men per crew: 3

Average working hours per day: 8 hours

Labour; Rate per day: 2500Ushs; Average load size: Current: 0.396m^3

Improved: 0.299m^3

1. Average production per hour: Current=5.79m^3; Improved=6.99m^3

2.Average production per day :

Current=46.32 m^3 per day per crew

Improved =55.92 m^3 per day per crew

3.Cost of a crew per day= 2500×3=7500Ushs per day per crew.

Log rolling production costs:

4. Administration: For the improved methods = 0.2 × 134.12= 26.82Ushs/m^3

For the current methods = 0.2 × 161.92= 32,38 Ushs/m^3

5.Total log rolling production cost:

For the current methods = 161.92 + 32.38 = 194.30 Ushs/m^3

For the improved methods=134.12+26.82 = 160.94Ushs/m^3

Log rolling production cost in Katugo Forest plantation

Method applied: Manual; Average men per crew: 4;

Average working hours per day: 8 hours;

Labour; Rate per log: 50Ushs; Average load size: CL: 0.231m^3

RIL: 0.268m^3

1. Average production per hour: CL=4.04m^3; RIL=5.22m^3
2. Average production per day :

   Current method =32.32 m^3 per day per crew

   Improved method =41.76 m^3 per day per crew

3. Average number of logs rolled per day per crew:

$$For\ the\ improve\ methods = \frac{41.76}{0.268} = 155.82\log s/day/crew$$

$$\Rightarrow 155.82 \times 50 = 7791Ushs/crew/day$$

$$\Rightarrow \frac{7791}{41.76} = 186.57Ushs/m^3$$

$$For\ the\ current\ methods = \frac{32.32}{0.231} = 139.91\log s/day/crew,$$

$$\Rightarrow 139.91 \times 50 = 6995.5Ushs/crew/day,$$

$$\Rightarrow \frac{6995.5}{32.32} = 216.45Ushs/m^3.$$

4. Administration: For the improved method = 0.2 × 186.57 = 37.31Ushs/m^3

   For the current method = 0.2 × 216.45= 43,29 Ushs/m^3

5.Total log rolling production cost:

For the current method = 216.45 + 43.29 = 259.74 Ushs/m^3

For the improved method=186.57+37.31 = 223.88 Ushs/m^3

TOTAL LOGGING PRODUCTION	Mafuga	Katugo
For the improved method=	1599.86Ushs/m^3;	1795.15Ushs/m^3
For the current method =	1611.11 Ushs/m^3	1752.30Ushs/m^3