COMPARISON OF PRODUCTIVITY, COST AND ENERGY EXPENDITURE WHEN SAWING ON PITSAWING AND PORTABLE PLATFORMS IN AGROFORESTRY FARMS IN KILIMANJARO

BY

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ABSTRACT

Although future increase in timber supply in many countries is expected to come from agroforestry, the problem of on farm timber sawing, physical strain on sawyers caused by “Pitsawing” has to be addressed, to increase timber sawing productivity. This study was aimed at analyzing the productivity and energy expenditure by sawyers when using Traditional Pitsawing Platforms (PSP) and Portable Steel Log Sawing Platforms (PLSP) in agroforestry farms in Kiruweni and Nduweni villages in South Kilimanjaro. Pitsawing productivity data was obtained using time studies of the pitsawing operations on the respective platforms and data on energy expenditure was obtained through heart rate measurements using heart rate monitor. Results indicated that the site preparation production rate, using PSP, was 0.1m^3/h and the structure assembling production rate, using PLSP, was 2.9m^3/h. The skidding production rate, using PSP, was 3.5m^3/h and the production rate, using PLSP, was 11.9m^3/h. Loading productivity improved from 4.97m^3/h, using PSP, to 7.27m^3/h, using PLSP. Productivity of sawing work element improved from 0.055m^3/h, using PSP, to 0.057m^3/h, using PLSP. In sawing, Energy Expenditure (EE) was 12.69kJ/min and 12.4 kJ/min using PSP and PLSP respectively. During pit excavation/structure assembling, EE was 14.05kJ/min, using PSP, and 2.61kJ/min using PLSP. The physical workload was classified as unduly heavy for PSP and light for PLSP. For the skidding work element, the EE decreased from 5.88kJ/min, using PLSP to 4.48kJ/min, using PSP. For the loading work element, the EE was decreased from 5.20kJ/min, using PSP to 3.55kJ/min, using PLSP. The sawing cost was TAS 205 320/m^3, using PSP and TAS165 350/m^3, using PLSP. In conclusion, PLSP is a technically more appropriate technology for reducing EE and sawing costs as well as increasing productivity during timber harvesting in agroforestry farms.

DECLARATION

I, FELIX ANVERS RURANGWA, do hereby declare to the SENATE of Sokoine University of Agriculture that the work presented here is my original work, and that it has neither been submitted nor being commercially submitted for degree award in any other Institution.

Felix A. Rurangwa (M.Sc. Candidate)	Date

The above declaration is confirmed by

Prof. George A. Migunga (Main Supervisor)	Date
Prof. Amini E. Kweka (Co-Supervisor)	Date

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DEDICATION

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LIST OF ABREVIATIONS AND SYMBOLS

ARecHR	Average Recovery Heart Rate
ARHR	Average Resting Heart Rate
Av	Average
AWHR	Average Working Heart Rate
CCR	Cardiac Cost of Recovery
CCW	Cardiac Cost of Work
cm	Centimeter
FAO	Food and Agriculture Organization
h	Hour
HR	Heart rate
IAWHR	Increased Average Working Heart Rate
ILO	International Labour Organization
kcal	Kilocalorie
kJ	Kilojoules
m	Meter
m^3	Cubic meter
MAP	Maximum Aerobic Power
METS	Metabolic Equivalents
min	Minute
PLSP	Portable Steel Log Sawing Platform
PSP	Traditional Pitsawing Platform
TAS	Tanzanian shilling
TCCW	Total Cardiac Cost of Work
URT	United Republic of Tanzania
Vol	Volume

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

In recent years, demand for timber and other forest products has been and keeps on increasing at local, national and international levels (Nilsson, 2007).Timber supply from natural forests is dwindling because of conservation, environmental and social concerns while expansion of industrial plantations is limited by competition from alternative land uses. This implies that future increase in timber supply in many countries will come from other sources such as agroforestry farms (Haynes, 2006; Enters and Durst, 2007). Most agroforestry farms are often established with the thought of improving agricultural yield but with little consideration about how tree harvesting operations will be carried out when trees mature. Apart from the fact that, these farms are small in size compared to other forest plantations, tree harvesting must be done selectively which lead to higher cost of timber extraction for every tone of logs. Due to small volumes of timber extracted from these farms and the transportation complications arising from maintenance of residual trees and other useful plants in the same fields, the practice has been to process the logs for timber on-farm (Hall, 1990). The common method used for on farm timber processing in many developing countries is ‘’pitsawing”.

Pitsawing is done by a crew of two men using a pitsaw (pitsawing crosscut saw). A log to be sawn is positioned horizontally on wooden poles across a pit or on a platform (scaffold) above the ground. One man stands on top of the log and pulls the saw up while the second man stands in the pit below the log being sawn and pulls the saw down (Butera and Klem, 1983; Richards, 1993; Philip, 2001 and Kweka *et al*,. 2007).

According to Kweka and Mganilwa (2004) digging of the pit takes about two man-days and the process causes a lot of soil disturbances and damage to the environment. Erection of a wooden platform takes about two man-days and it necessitates cutting nearby small trees for erection of the platform or scaffold purposes which cause wood waste and destroys future trees. When using ‘pits’ or ‘log platform’, logs to be sawn are first rolled on the ground to the site before being pushed manually on to the ‘pit’ or platform’. In agroforestry farms, rolling of logs (skidding the logs to be sawn) causes damages to agricultural crops, residual trees and the ground surface. Besides heavy physical workload and stress to pit sawyers as reported by Ole Meiludie *et al.* (1988) and Strehlke (2007), accidents resulting from using this technique are common. To minimize these negative consequences of using ‘pitsawing’ technique, Kweka *et al*. (2007) designed a Portable Steel Log Sawing Platform (PLSP). Studies done on PLSP showed that, the platform reduces most of environmental damages, occupational accidents and increases workers productivity. However, the question remains whether the reported increased production rate when using PLSP goes hand in hand with reduction in physical workload (i.e. energy expenditure).

1.2 Problem Statement and Justification

Among the interventions claimed to increase productivity and reduce physical workload, accidents, damages to growing trees, agricultural crops and the ground surface, associated with pitsawing is the introduction of Portable Steel Log Sawing Platforms (PLSP) (Kweka *et al*., 2007a). Although the new technique has been shown to increase productivity (Kweka *et al.*, 2007b) and reduce some of the adverse effects of traditional pit or wooden platform log sawing methods (Kweka, 2007) the effects of the PLSP on associated physical workload or energy expended by sawyers is not known. Thus the aim of this study was to assess and compare two sawing platforms by evaluating productivity, cost and physical workloads which will be used as a basis for choosing the most appropriate method for use in sawing logs in agroforestry farms.

1.3 Objectives

1.3.1 Main objective

To assess and compare productivity, costs, and energy expenditure of sawyers when using Traditional Pitsawing (PSP) and the Portable Steel Log Sawing Platforms (PLSP) in agroforestry farms.

1.3.2 Specific objectives

1. To determine the production rates and costs of pitsawing operations when using the Traditional Pitsawing (PSP) and the Portable Steel Log Sawing Platforms (PLSP).

2. To determine the energy expenditure by sawyers during log sawing operations when using both Traditional Pitsawing (PSP) and Portable Steel Log Sawing Platforms (PLSP)
3. To compare the performance and physical workloads and cost of sawing operation when using the both methods.

1.3.3 Research questions

1. What are the production rates of pitsawing workers when using the traditional pitsawing versus the portable steel log sawing platforms?
2. What are the costs involved when using the two types of log sawing platform?
3. What is the physical workload on sawing workers while using the traditional pitsawing and the portable steel log sawing platforms?
4. Which of the two log sawing platforms is the best based on productivity and physical workload on sawing workers?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global Timber Supply and Demand

Timber from natural forests is increasingly less available because of conservation, environmental and social concerns. Industrial plantations make up only about 5 percent of the total forest area but provide 35 percent of the world's wood supply (FAO, 2008). Expansion of industrial plantations, however, is limited because of competition from alternative land uses. Yet the demand for timber and other forest and tree products is increasing at the local, regional and international levels. In response of this, many small-scale agroforestry systems have evolved market orientations.

Trees on farms or agroforestry trees have long been recognized as protecting and often enhancing soil fertility, assisting in soil and water conservation and providing fodder, fuelwood and construction materials for rural households. They also help maintain biodiversity (by diversifying plant cover and providing habitat for other plants and animals) and enhance the landscape. In addition, commercial production of timber on farms in the tropics, either as scattered trees or as small-scale woodlands is a potentially important element of farm livelihoods (Dewees and Saxena, 2007). The potential of small-scale timber producers in providing raw materials in both contractual (corporate-smallholder partnerships) and open-market situations looks promising.

2.2 Agroforestry and Timber Production

Agroforestry is a symbiosis of tree growing, crop and livestock production on the same piece of land (or area) where each component is beneficial to another (Bandyopadhyay, 2007). This definition implies that in an agroforestry system: 1) There are two or more species of plants/animals at least one of which is woody perennial 2) There should be biological and economical interaction within the components; 3) The cycle of an agroforestry system is always more than one year (Mesele, 2007).

In other words "Agroforestry" refers to a dynamic, ecologically based natural resources management system that, through integration of trees in farms and in the landscape, diversifies and sustains production for increased social, economic and environmental benefits for land use at all levels (Leakey, 2008). Farmers plant or conserve trees on their farms for a variety of products and services – not only timber, but also fuelwood, fruits, vegetables, fodder, medicines, resins, shade (for livestock or under storey crops), and soil and water conservation.

Tree species used in agroforestry are diverse and can be either indigenous or exotic. In North Lampung, Sumatra, home gardens, averaging 0.75 ha, contain as many as 21 tree species excluding the understorey component (Roshetko *et al*., 2006). In farms around Mount Kenya, it is common to find up to 19 different tree species on one farm. In a survey conducted around eastern Mount Kenya, approximately 200 different tree species were identified on farms (Oginosako *et al.*, 2007).

In Tanzania the importance of agroforestry systems and tree farms to produce timber is increasing and is now widely promoted at all levels from national down to individual households (URT, 2001). The recent National Forest Policy (URT, 1998) has established the legal framework for the promotion of private and community-based ownership of forests and trees. Through the policy, the government intends to intensify and harmonise extension as well as to provide financial incentives to promote sustainable management of private and community tree farms including agroforestry farms (URT, 1998). Despite these efforts, considerable obstacles which include extraction of timber from farm, market access, tree management and species selection have to be overcome if farms are to produce timber of the quality and quantity sought by markets, and if timber production is to enhance incomes of farm families.

One possible solution to aforementioned obstacles is on-farm processing of timber which enables tree growers to provide products to the broader community market, and gives them access to added value at the point of sale (Hall, 1990).

2.3 Timber Harvesting in Small Scale Tree Farms and Agroforestry Farms

The common forest harvest and sawmilling practices include static sawmilling which are either circular or band saw mills. Static sawmills are likely to be most viable, with a highly mechanized and efficient operation able to process tens or hundreds of cubic meters of timber per day. Other common sawmilling practice is mobile sawmills which range from small, portable saws to trailer mounted saws. Mobile sawmills are useful for cutting round timber over 25 cm in diameter and 2 m in length. Power can be from the mill’s own engine or from a tractor power take-off (Eldred, 2006). However, due to low tree stock densities and volumes these harvesting and sawmilling practices are not viable for on site timber processing in agroforestry and tree farms. Sawmilling machinery suitable in situations with such low production must be very portable, able to cut small diameter, short and sometimes crooked logs efficiently, cause less damage to useful plants and of low capital cost if they are to be economical in such farms with few cubic meters of logs (Pasiecznik, 2006). These factors have resulted in portable sawmills becoming popular in many countries (Smorfitt *et al*., 2007). In developed countries, mechanized portable sawmills which include circular saws and band saws are very popular (Pasiecznik, 2006; Smorfitt *et al*., 2008), while manual or hand sawing commonly known as ‘pitsawing and is the most common on farm timber sawing system used in developing countries (Richards, 1993; Madira and Krassowska, 2006).

2.3.1 Pitsawing technology

Pitsawing is a method of cutting trees into planks by human labour alone. The tree is felled, crosscut into logs and the log is then positioned on a platform over a pit or on wooden platform above the ground level. It is sawn into planks by two men, one standing in the pit and the other on the platform above, using a two handed saw. During pitsawing, a pit of 1.5m wide, 2.5 to 5.5m long and 1.5m deep is normally dug near the felled tree(s). Decision on the length of a sawing pit depends on the length of planks to be cut. Where ‘wooden platforms’ are used, rectangular or triangular scaffold constructed by wooden poles are erected near the felled tree(s) before the actual sawing operation starts.

Digging of a sawing pit (Plate 1) takes about two man-days. However, rolling of logs to the pit (skidding the logs to be sawn) causes damages to agricultural crops, residual trees and the surface ground in general and the process cause a lot of soil disturbances and damages to the environment (Kweka *et al.*, 2006b).

In his study (Kweka, 2007) found that the overall conversion rate, productivity and recovery rate of pitsawing were 0.032 m^3/hr, 0.014 m^3/hr and 45.2% for Kilimanjaro and 0.033 m^3/hr, 0.072 m^3/hr, 55% for Iringa, respectively. Kijoti and White (1981) did similar studies in Pare mountains and obtained productivity of 0.011m^3/hr and recovery rate of 49% while (1986) obtained productivity of 0.0238 m^3/hr and the recovery rate of 42% at Sokoine University of Agriculture Training Forest, Olmotonyi. Butera and Klem (1983) did similar studies in Rwanda and obtained a recovery rate of 46%. Lower recovery rates observed in studies in Pare mountains by Kijoti and White (1981) and in Rwanda by Butera and Klem (1983) and in Kilimanjaro by Kweka (2007) were for hardwoods species sawn in agroforestry farms which are probably not cared for professionally to ensure the trunk matures in good form.

Plate 1: A sawing pit excavated in a tree farm (Kweka, 2007)

2.3.2 Traditional wooden log sawing platform

This log sawing method uses tree logs for construction of a sawing platform (scaffold). Therefore, the basic prototypes (triangular type or inverted V-shaped) platforms are fabricated from tree logs with two rear log poles inclined, horizontal and two frontal log poles inclined, vertical poles inserted in holes dug in the ground to ensure the stability of logs on the platforms (Plate 2). As pitsawing construction or erection of wooden platforms takes on average about two man-days and necessitates cutting nearby small trees for construction purposes which causes wood waste and destroys the future trees (Kweka and Mganilwa, 2004).

Therefore, to minimize these negative consequences of using 'pitsawing' technique and traditional wooden sawing method, Kweka *et al.* (2007) designed Portable Steel Log Sawing Platform (PLSP). Studies done on PLSP showed that, the platform reduces most of environmental damages, accidents and increases workers productivity productivity (Kweka, 2007).

Plate 2: Traditional wooden log sawing platform (Kweka, 2007)

In their studies, Kweka and Mganilwa, (2004) and Kweka *et al*. (2006) recommended adoption of Portable Steel Logsawing Platform (PLSP) and abandonment of the traditional wooden platforms and sawing pits, due to their serious cause of environmental damages, damage to agricultural crops, loss of biodiversity, low productivity and accidents.

2.3.3 Portable steel log sawing platforms (PLSP)

Portable Steel Log Sawing Platform (PLSP) (Plate 3 and 4) is made of steel pipes which were used to replace the wooden poles because, they are readily available; light and strong and their shape resembles that of wooden poles which are circular. Therefore, the basic prototypes (triangular type or inverted V-shaped) were designed and fabricated from steel pipes with two rear inclined steel pipes, one horizontal and two frontal inclined pipes.

To ensure the stability to the conventional platforms, the vertical poles are inserted in holes dug in the ground and supported firmly with wooden wedges. Since no holes are dug on the ground to support the prototype platform, stability is achieved by inclining the vertical members so that they can absorb forces in three dimensions. Again, since the forked ends of the traditional vertical poles are replaced by joints, these joints must be designed for strength and also facilitate easy assembly and dismantling of the platform. Moreover, development of a log raising mechanism onto the steel platform was meant to reduce stress/workload and injuries caused by pushing up heavy logs manually (Kweka, 2007). However, there is no documented information on physical workload (energy expenditure) on sawyers when using the (PLSP) method.

Plate 3: Portable steel log sawing platform (Kweka, 2007)

Plate 4: The PLSP at the logging site (Sawyers posing for a photo before starting sawing)

2.4 Physical Workload

Physical work load is the amount of muscular and mental energy converted into work (Grandjean, 1980). Physical work is performed as a result of muscle action. During aerobic combustion, those muscles use oxygen to transform food into mechanical energy. The more energy required in carrying out a given task, the more oxygen is needed, a process that necessitates increased blood circulation and consequently a higher heart rate. Andersen (1971) has reported a close relationship between heart rate and oxygen consumption, with the rate increasing in proportion to work intensity. Therefore, the physical workload can be estimated by comparing heart rates measured at rest and while working. Under strenuous conditions, information about heart-beat rates not only indicates the load on the cardiovascular system to carry oxygen, but also the extra effort required to transfer excess heat from the interior of the body to the skin. Thus, the higher the heart rate, the greater the physiological workload.

2.4.1 Factors that influence the physical workload on forest workers

Factors that influence the physical workload of the forest workers can be grouped into three categories as follows (Edholm, 2007 and Langerlorf, 1979):

i. **Human factors:** among human factors that affect physical workload cause on forest workers include age, gender and work experience, motivation and payments system. Juvenile workers, partly because of their undeveloped physique, inexperience and risk taking, tend to have much probability to get accidents; however, as people get older the chances of getting accidents increase since they become less physically active and take longer time to make decision in critical situations. A study conducted in Sweden on chainsaw operators (Petterson *et al*., 1983) showed that a change from piece rate payment system to monthly salaries payment led to lowering of accidents in forest operations (Van Loon and Spoelstra, 1971). Besides the accident being low, the change-over also resulted to workers respecting accidents prevention rules and listening to advices and instructions on new working methods (Edholm, 2007; Langerlorf, 1979).

ii. **Work place factors:** the level of perception, decision making, strength and precision required in performing critical work tasks will lead to fatigue and there after to accidents. Poorly designed, faulty machines and poorly operated and maintained machines can be a great source of high workload and accidents. Therefore, when a workplace is tidy and workers have enough experiences, less energy is likely to be expended as compared to untidy workplace (Edholm, 2007; Langerlof, 1979).

In developing countries like Tanzania the use of poorly designed tools, incorrect working techniques and inadequate and deficient nutrition for forest workers usually results into low productivity and high physical stress to workers (Apud *et al.*, 1989). As a general rule, many of the workers in the developing countries are characterized by the vicious circle of low production, malnutrition and low working capacity. This circle sometimes called the “Economic cycle of disease (Elgstrand, 1979) starts with low production due to low physical capacity, poor tools and working techniques. Low production leads to low income which leads to malnutrition, poor health and unhygienic living conditions. Malnutrition, poor health and unhygienic living conditions lead to diseases which reduce ones physical working capacity.

It can be stated that ergonomics in developing countries should be considered as a fundamental subject and an essential part in improving the working conditions and the human work relationships. To achieve these objectives, information about the work place conditions and those human characteristics that contribute to human behavior and performance has to be available through research undertakings.

iii. **Environmental factors**: Environmental factors like temperature, noise and vibration have direct influence on human working ability and safety (Grandjean, 1980). For example, both high and low temperatures have negative impact on physiology of the human body. A study in Britain has shown that when temperatures fell from normal (18-21^{o}C) to 12.7^{o}C the physical workload increased (Edholm, 2007). The same applies to high temperatures which will result to heat stress and fatigue (Grandjean, 1980).

The type of work activity being performed also determines the heaviness of work. For instance where there is a balance between harvesting, silviculture and other forest activities, harvesting have been found to be more energy demanding and account about 70 percent of the total accidents (ILO, 1981)

2.5 Energy Expenditure Measurement

Due to the costs involved and the difficulty of obtaining valid physiological data in remote and often environmentally extreme areas while trying not to interfere with work tasks, limited research has been conducted in the field on the energy cost of forestry workers (Apud *et al.*, 1989; Scott and Christie, 2007). The techniques available to directly assess energy expenditure, such as direct and indirect calorimetry are well known (McArdle *et al.,* 2007). Both methods depend on the principle that all energy utilised by the human body is ultimately degraded into heat (Eston and Reilly, 2001). As such, it is well accepted that since the energy provided by food can only be used because of oxidations utilizing oxygen, measurement of steady-state oxygen uptake by the human body through open-circuit spirometry provides an accurate estimation of energy expenditure (McArdle *et al.*, 1996; Eston and Reilly, 2001).

During open-circuit spirometry an analysis of the difference in composition between inhaled and exhaled air reflects the body's constant release of energy (McArdle *et* *al.*, 1996). Modern ergospirometers are portable, weigh very little (less than 1.0 kg) and are attached to the individual’s trunk which facilitates easy use within a field setting. However, as the measurement of oxygen uptake *in situ* has proved problematic for several practical reasons, regression models have been established so that direct measures are not necessary. For example, Garg *et al.* (2008) argued that if the metabolic cost of sub-tasks were assessed, then totaling these could establish the net metabolic cost of the activity, although other researchers (Taboun and Dutta, 1989) have not confirmed this assumption. These latter authors argue that the approach does not consider other aspects of the overall job such as small periods of housekeeping or walking between tasks. Another problem is that this equipment is costly and only one subject can be attached at any given time. While the use of this method in a laboratory or field setting is well suited for assessing energy expenditure of specific activities over a short duration, it is not suitable for measuring energy expenditure over long periods and especially in remote areas and on a large sample such as the present study, hence other method have been employed “HEART RATE MONITOR”. The use of various commercially available electronic activity monitors and heart rate monitors can provide an estimation of the metabolic cost of different tasks. Compared to the difficulties associated with indirect calorimetry, this equipment is inexpensive and several researchers have attested to their validity (Haskell *et al.*, 1992; Strath *et al.*, 2007; Keytel *et al.*, 2005).

The most common method used to predict energy expenditure is heart rate recording. This is based primarily on the strong association between increasing heart rate and increasing energy expenditure during large muscle, dynamic exercises (Haskell *et al.*, 1992). Ceesay *et al.* (1989) found that the within-person correlation between heart rate and oxygen uptake during increasing exercise intensity on a treadmill or cycle ergometer frequently exceeds 0.95.

However, the limitations in using heart rate to predict energy expenditure include the slope of the relationship between heart rate and oxygen uptake, which varies from individual to individual, and between upper and lower body activities and the ratio of dynamic and static contractions (Maas *et al.*, 2009; Haskell *et al.*, 1992). Consideration should also be given to the fact that heart rate is influenced by other factors such as emotional status, posture and environmental conditions. Therefore, recording heart rate only for the estimation of the metabolic cost of a physically demanding task has not generally been accepted as an accurate method, although Kirk and Sullman (2007) showed that heart rate indices provided an effective means of determining the physiological strain of forest harvesters. To improve the accuracy of estimating oxygen uptake from heart rates recorded *in situ* during a wide range of activities, individualized heart rate oxygen uptake regressions are used (Haskell *et al.*, 1992; Strath *et al.*, 2007; Strath *et al.*, 2006; Keytel *et al.*, 2005). From these recent studies it was evident that establishing individualized heart rate-oxygen uptake regressions is the most reliable indirect measure of energy expenditure. In order to achieve this each worker needs to perform a progressive, sub-maximal test with at least three workloads, achieving a range of heart rates similar to that which was recorded in the field (Scott and Christie, 2007). The individual nature of the heart rate/VO_2 relationship makes it necessary to establish a regression equation for heart rate and VO_2 for each subject at several levels of work intensity, while recognizing that factors other than oxygen uptake, such as ambient temperature, food intake, body posture, and muscle groups active may influence heart rate (Barbara *et al.*, 2007). The VO_2 refers to the Maximal aerobic capacity which is referred to as the maximum rate of oxygen uptake or $VO_{2\ max}$. Assessing $VO_{2\ max}$ assists in establishing the relative level of exertion during manual work, expressed as a percent of maximum (Christie and Scott, 2007). The $VO_{2\ max}$ is measured by doing the sub maximal step test for the purpose of establishing individual or group heart rate-oxygen uptake (HR/VO_2) regressions for predicting oxygen uptake from working heart rate responses.

In order to establish a setting as close to the natural working ambience as possible the sub-maximal test should preferably be done during or after the work shift on the same day of recording heart rate while working (Apud, 1983; Lambert *et al.*, 2008; Scott and Christie, 2007). Heart rate measures taken in the field can then be converted to VO_2 by means of individual regression equations (Lambert *et al.*, 2008). Apud (1983) calibrated forestry workers on a cycle ergometer, and before applying the heart rate method, simultaneous measures of heart rate and VO_2 were carried out during different forestry activities. Following this, heart rate was converted into VO_2 using each individual regression equation. The results revealed no significant difference between the estimated VO_2 and the actual VO_2 measured in the field, although in other studies it has been found that the predictive values tend to overestimate actual measures of VO_2 between 10% and 20% (Nielsen and Meyer, 2007; Scott and Christie, 2007). However, as Scott and Christie (2007) argue, this is not necessarily a weakness as the overestimation may provide a safe index for workers in developing countries who tend to be over taxed during work. Although it has been suggested that this relationship be established in an activity representative of the task under investigation, many have argued that it does not make a significant difference (Apud, 1983; McArdle *et al.*, 1996). This need to individually calibrate subjects was acknowledged in the present study.

Additionally, the accuracy of estimating energy expenditure is further improved when heart rates and body movements are analyzed simultaneously during work (Haskell *et al.*, 1992; Strath *et al.*, 2007; Strath *et al.*, 2006). There are numerous motion sensors available including pedometers which measure distance walked (Washburn *et al.*, 1980), motion sensors which count the number of times a limb or the trunk moves and accelerometers which monitor the acceleration of the body during an activity (Meijer *et al.*, 1989). Similar to heart rate monitors, used in isolation these monitors do not provide meaningful information about the energy demands of tasks, but when used in combination with heart rate monitoring they have been shown to provide an accurate reflection of the energy cost of an activity.

2.5.1 Heart rate responses

Although literature on physiological work limits is inadequate, Kilbom (2007) argues that if heart rates are below 90 beats.min^{-1}, the strain on the cardiovascular system is "light". Heart rates, ranging from 90-110 beats.min^{-1} indicate a "moderate" strain; while those between 150-170 bt.min^{-1} suggest "extremely heavy" strain is being placed on a worker (Kilbom, 2007). These responses are average heart rate responses over extended work periods so at times, heart rate may be high (for example 150 beats.min^{-1}), while at other times it may be as low as 85 beats.min^{-1}. However earlier, Åstrand and Rodahl (1986) suggested that heart rates ranging between 110 beats.min^{-1} and 130 bt.min$_{-1}$ are the upper limit for continuous work, while more recently Kumar *et al.* (2006) argued that acceptable, rather than the upper limit for continuous work, is a heart rate range of 104 beats.min^{-1} to 114 beats.min^{-1}.

2.5.2 Oxygen consumption and energy expenditure

The most widely accepted limit for oxygen consumption during extended work is that it should not exceed 33% of the worker's maximum oxygen uptake (Waters *et al.*, 1993; Dempsey, 2008; Christie and Scott, 2007). Wu and Wang (2008) extend this further by providing recommendations for shifts varying in length, specifically 28.5% $VO_{2\ max}$ for 12-hour shifts, 31% for 10-hour shifts, 34% for 8-hour shifts, and 43.5% for 4-hour shifts.

Mital *et al.* (1993) proposed that there are two problems associated with physiological design criteria based on relative exercise intensity. Firstly, specifying the upper limit of VO_2 as a percentage of oxygen uptakes which can be sustained without undue fatigue, and secondly deciding on what kind of oxygen uptake test should be used to express this percentage. This has proved to be problematic in that the recommendation of 33% $VO_{2\ max}$ for extended work has been predicted using values obtained by running workers on a treadmill or cycling workers on a cycle ergometer (McArdle *et al.*, 2007; Bales *et al.*, 2006; Christie and Scott, 2005). This brings into account the concept of specificity which argues that the best measures are those that are obtained when testing subjects in their chosen exercise mode (McArdle *et al.*, 2007), for example testing runners on a treadmill and cyclists on a cycle ergometer. This implies that someone trained in manual work should be tested during an activity which closely simulates the predominant activity during work. More specifically, this is related to the total muscle mass activated during a maximum oxygen uptake test. In general, $VO_{2\ max}$ tests aim to maximize the muscle mass used, which is the reason for the popularity of the treadmill and cycling ergometer protocols, although arm-crank and all-extremity tests are not uncommon (Reybrouck *et al.*, 2006; Glaser *et al.*, 1980; Louden *et al.*, 2007). It has been found that $VO_{2\ max}$ values obtained during arm cranking exercise and all-extremity protocols are 68% and 60% respectively of those measured during treadmill running (Reybrouck *et al.*, 2006; McArdle *et al.*, 2007). Furthermore, Kumar (2007) found lifting to be more physiologically demanding than cycling for every workload. Recently Christie and Scott (2005) found that although most physiological responses were higher during lifting than during running, VO_2 was significantly lower during lifting. The accuracy of this measure is important for making recommendations for work as a measure done on a treadmill for example, may result in a worker being taxed beyond what they are capable for if their mode of work is completely different. Absolute values and classification of oxygen consumption and energy expenditure recommended for manual work can be seen in (Table 1). Otherwise the high physical workload lead to accidents in forest workers and sometimes it can cause injuries.

It can be stated that energy expenditure, work environment and productivity are mutual exclusive since when the work environment is conducive, the workload will be low and eventually the productivity will increase. Therefore in this comparative study, work study methods were used in order to compute and compare the productivity from both traditional pitsawing and portable steel log sawing platforms. Kweka (2007) in his studies used time study methods to assess the efficiency of log sawing operations in agroforestry in accordance with generally accepted forest work-study procedures (IUFRO, 1995).

Table 1: Five-level classification of physical activity based on intensity of effort

Level	**Energy Expenditure**			
	MEN			
	kcal.min^{-1}	l.min^{-1}	ml O_2.kg-1.min^{-1}	METS
Light	2.0-4.9	0.40-0.99	6.1-15.2	1.6-3.9
Moderate	5.0-7.4	1.00-1.49	15.3-22.9	4.0-5.9
Heavy	7.5-9.9	1.50-1.99	23.0-30.6	6.0-7.9
Very Heavy	10.0-12.4	2.00-2.49	30.7-38.3	8.9-9.9
Unduly Heavy	>12.5	>2.50	>38.4	>10.0
	WOMEN			
Light	1.5-3.4	0.30-0.69	5.4-12.5	1.2-2.7
Moderate	3.5-5.4	0.70-1.09	12.6-19.8	2.8-4.3
Heavy	5.5-7.4	1.10-1.49	19.9-27.1	4.4-5.9
Very Heavy	7.5-9.4	1.50-1.89	27.2-34.1	6.0-7.5
Unduly Heavy	>9.5	>1.90	>34.5	>7.6

(Adopted from McArdle *et al.* (2007): *kcal: kilocalories. O_2: oxygen. METS: metabolic equivalent).*

2.6 Work Study

Work study is defined as a method of intensive inquiry into the use of human and material resources in carrying out a specified activity in forestry or in any other work operation. The purpose is to increase productivity and the effectiveness of the labour and management (ILO, 1989). In work study, both method study and time study techniques are used to study the operations.

2.6.1 Method study

This is the procedure for systematic recording, analysis and critical examination of existing and proposed way(s) of doing work, and the development and applications of easier and more effective methods (ILO, 1979). Method study can be used to compare different logging methods employed in the logging production process. Method and time study are imperative if large and small scale planning and control of logging operations are to be effective (Migunga and Dykstra, 1983).

2.6.2 Time study

Time study is one of the most commonly used methods of work measurement (Björheden, 2007). It is a technique for making continuous observations and recording of the times and the units of production work in the performance of specific job for analysis, evaluation and appropriate decision making in order to improve the work process (González, 2005).

Time study data enables establishment of critical and non critical work elements, effective and ineffective times so that appropriate standard time for each work element and complete work cycle, can be determined with full consideration of the prescribed methods and due allowances for essential personal requirements (FAO, 2006).

Stopwatch time study which was used in this study is the most commonly used method for measuring work. Stenzel *et al.* (1985) and Sarikhani (2006) have reported stop watch time study as the most useful and most important approach used in determining the input element of productivity, in studying the factors affecting productivity and in developing work methods by eliminating ineffective time. Time studies can also be used in assessing the different harvesting methods for finding the most profitable one (González, 2005).

There are two broad categories of time studies; shift level time study (or gross data analysis) and detailed time studies. Each of these techniques differs in purpose, methodology, and type of analysis to which data will be subjected (Wittering, 1973).

2.6.3 Shift-level time study

This method is used to measure and record productivity and costs of operations over a day, season, shift or working period. Shift level or gross time study makes use of data on time spent by an operator and resulting production, the data being the normal operating records kept by management (Wittering, 1973). Shift level time studies are most useful in showing where detailed time studies are needed. ILO (1989) has thus pointed out that they can be of major benefit whenever long-term and lengthy operation system data are desirable. Gross time studies are useful in assessing long-term trends in productivity and costs.

2.6.4 Detailed time study

Detailed time study is used to obtain information on operating times and costs beyond the level of details available from shift level time study (Abeli, 1985). Two common timing procedures used in detailed time study are continuous timing methods and activity sampling.

2.6.4.1 Continuous time study method.

When using continuous timing techniques, timing is done continuously from the beginning to the end of a working shift. Under this method, both regular and irregular events are recorded. Two timing methods are distinguished under continuous timing method; these are cumulative timing and snap-back (zero-reset) timing (Abeli, 1985).

Cumulative timing keeps a record of the sequence of events or activities while for the snap back timing, the stop watch is started at the beginning of each activity and stopped at the end of the activity, and the elapsed time for performing the activity is recorded and the stop watch is reset to zero (Saarilahti and Isoaho, 1992). Snapback timing is more suitable in the time study of timber harvesting since it is less prone to record keeping errors than cumulative timing although it does not reveal the sequence of day’s activities (Migunga and Dykstra, 1983; Sarikhani, 2006).

2.6.4.2 Activity sampling

Activity or work sampling involves observing the operations at fixed time intervals or at random intervals (Olsen and Kellogg, 1983) established from a table of random numbers. Depending upon the type of work, the level of precision desired and the number of operations being timed by the observer, observations are usually recorded at intervals of 1 minute, 5 minutes or 30 minutes. Activity sampling measures the proportion of the workday that individual machines and people spend at each of a series of activities. Its primary disadvantage is that the data are generally not suitable for regression analysis since the link between causal factors cannot be associated with each other (Smidt, 2002).

2.6.5 Work study data analytical techniques

2.6.5.1 Quantitative data analysis

In the context of time study evaluation, quantitative analysis involves the development of histograms, frequency distributions and summary tables of dependent and independent variables observed during the time study period (Dykstra, 1975). In their studies Dykstra (1975, 1976a and 1977), Ohmstede (1977) and Schneider (1978), established production rates per day in terms of the production units being studied such as m^3 per day, number of logs per day, and trees per day. Frequency distributions for productive and delay times for different logging systems were plotted for each individual element of the system in these studies. Gabriel and Nissen (1974) and Gabriel *et al*. (2007) quantitatively analysed time study data to give summaries in form of tables for both productive and non-productive times and independent variables collected during the period. Delays have been analysed qualitatively in Dykstra (1976b). Quantitative analysis is therefore useful in the understanding of factors that influence productivity and delays. And therefore its operation use should permit forest managers to design any forest operation more efficiently including log sawing operation.

2.6.5.2 Regression analysis

Regression analysis has been widely used in research data analysis. Both simple and multiple regression analysis are commonly used in scientific research. Multiple linear regression is commonly used by researchers in many different professions to quantify relationships between one or more independent and dependent variables (Steel and Torrie, 1960). It has been widely applied in logging systems analyses (Rodenberg and Gibson, 1975; Hartsough and Cass, 1979). Such analyses have enabled derivation of models and equations relating logging productivity to stand and environmental factors pertaining in particular situation. The models and equations developed by regression analysis have been used to develop nomographs and cost curves for logging productivity and cost forecasting (FAO, 2006; Legault and Powell, 2006; Abeli and Dykstra, 1981). These have facilitated the use of research results in forest operations in the field as managers and researchers can easily obtain the readily available data in the field (Migunga, 1982).

2.6.5.3 Economic analysis

The objective of the forest manager is presumed to be an economic one: choice of appropriate harvesting technologies, which are cost effective, cause minimum environmental degradation and encourage biodiversity need to be developed, applied and adopted in agroforestry farms to contribute to the sustainable development and to the well being of the rural people (Kweka, 2007). To contribute to sustainable development, the activities associated with tree utilization must not irreversibly compromise the potential of the farms to regenerate and continue to provide timber and non-wood products, environmental services, social benefits and global values (such as carbon sequestration and maintenance of biodiversity) that are essential for the well-being of both current and future generations. This implies that where timber is to be removed from agroforestry farms and tree farms, harvesting operations must be carried out in such a way as to leave the farm in a condition that favours rapid recovery to its pre-harvest state or to some other state that is agri-silviculturally, ecologically and socially desirable (Dykstra and Heinrich, 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study Area

The study was done within the agroforestry zone on the Southern slopes of Mountain Kilimanjaro (3 ^{0}00'-3^{0} 20'S and 37^{0}00'-37^{0}40 E), in Northern Tanzania. Two villages namely Kiruweni and Nduweni were selected for the study due to their participation in an earlier study to test the designed Portable Steel Log Sawing Platforms (PLSP). Population statistics indicates that most villages on the Southern slopes of the Mount Kilimanjaro have a population density of 500 per km^{2} and an annual population growth rate of at least 1.6 per cent (URT, 2004). Rainfall pattern is bimodal with short rains and long rains with an annual average of between 1,000 to 1,700 mm. In general, the soils are fertile volcanic ash with a high base saturation and high cation exchange capacity. The agricultural crops grown in the area include coffee, maize, sweet potatoes, cassava, beans, yams and bananas. Timber species grown in agroforestry farms in Kilimanjaro region include *Grevillea robusta, Albizia* spp., *Cordia africana*, *Acrocarpus flaxinifolius*, *Olea europea* spp., *Croton macrostachyus* and other natural forest species.

3.2 Data Collection

3.2.1 Energy expenditure

Four male workers performing manual timber sawing activity regularly were selected for the study. Physical characteristics (height and weight) were measured using anthrop meter and weighing balance (scale) respectively. Heart rate monitor was used to record the heart rate minute by minute during the sawing operation. Before starting working, subjects were requested to sit on a chair for approximately 15 minutes and their resting heart rate recorded. Heart rate per minute was recorded on each work element as it proceeded. At the end of work for the working day, the subjects were requested to seat on a chair again and rest for 15 minutes and the recovery heart rate per minute was recorded. At the end of the session, the heart rate monitor was detached from the subjects and data was transferred to a computer and analyzed.

3.2.2 Time study and productivity studies

3.2.2.1 Time study

Time studies to assess the efficiency of log sawing operations in small scale timber production in agroforestry farms when using both pitsawing and portable steel log sawing platforms were conducted in accordance with generally accepted work study procedures described in IUFRO (1995) using time study data sheet. Cumulative timing methods by the Snap-back or Zero reset timing method was used to collect production data for each work element. Log sawing was comprised of a set of activities depending on the method; the activities were segregated into the following work elements: pit excavation and platform construction; skidding the log to the pit; loading and sawing for traditional pitsawing method. The PLSP work elements were: platform assembling; skidding; loading and sawing. Apart from productive times, delay times were also recorded. These are interruptions in the production process that use time for non productive activities. Delays were subdivided into necessary delays (changing position, saw sharpening, wedging, adjusting the log, resting, eating, etc.)

and unnecessary delays (smoking and discussions not related to work). The work elements mentioned above were studied to establish time consumed on each work element and to estimate the production rate of each work element. Tally sheets were used for recording time study data during the sawing operations (Appendix 1).

3.2.3 Labour **costs**

Direct labour costs were obtained from the pitsawyers (self employed sawyers). The sawyers are paid according to the number of planks they have produced no matter the time consumed during their work. Therefore, their wages were based on productivity.

3.3 Data Analysis

Data were summarized by descriptive statistics using Microsoft Excel Software spread sheet. Based on the collected data, valid statistical models for estimating energy expenditure on sawyers and physical workload classification were developed.

3.3.1 Descriptive statistics

Statistical summaries were developed showing the mean, standard deviation, minimum, maximum values and percentages for each work element of the studied sawing methods.

Based on the heart rate records the following parameters were calculated.

i. Average heart rate during rest, work and recovery period.

   The energy expenditure per minute (kJ/min) was estimated from average heart rate (Av HR in beats/minute) using the following formula and the classification of work load was done based on (McArdle *et al.,(* 2007) work.

ii. $$Energy\ Expenditure = 0.159\ x\ (\text{Av HR } - 8.72)$$

The Total Cardiac Cost of Work (TCCW) per minute was also estimated based on the Cardiac Cost of Work (CCW) per minute and Cardiac Cost of Recovery (CCR) per minute where:

$$\text{CCW min} = \text{IAWHR} = \text{AWHR} - \text{ARHR}$$

Where:

IAWHR = Increase Average Working Heart Rate

AWHR = Average Working Heart Rate

ARecHR = Average Recovery Heart Rate

$$\text{CCR (min)} = \text{IARecHR} = \text{ARecHR} - \text{ARHR}$$

Where:

IARecHR =Increased Average Heart Rate during recovery

ARecHR = Average Recovery Heart rate

ARHR = Average Resting Heart Rate

iii. To avoid fatigue it was desirable to determine the amount of rest required for the sawing task. Rest allowance time was determined with knowledge of the work force Maximum Aerobic Power (MAP) using the following equation (Bridger, 2006):

$$\text{MAP} = 200 - (0.65\text{Age})$$

Where:

Age = average age of the subjects.

Using Rohmert (1973) formula for dynamic work, rest allowance was determined as percentage of the actual task time.

$$\%\ \text{rest allowance} = 1.9 \times (\text{Task time min})^{0.1450} \times \left(\frac{\text{Task energy expenditure/min}}{\text{Standard energy expenditure/min}} - 1\right)^{1.4} \times 100$$

3.3.1.1 Productivity

Mathematical models based on time study data were used to calculate the average production rates and generate productivity model for each work element of sawing methods both traditional pitsawing and portable steel log sawing platforms.

Log volume was computed using Huber's formula as shown in the following equation which was then used to determine the sawing production rates of both traditional pitsawing and portable steel log sawing platforms.

$$Lvol = \frac{\pi md^2 L}{4}$$

Where:

Lvol = Log volume (m^3)

π = pi ≈ 3.14159654

md = log mid-diameter (m)

L = log length (m)

3.3.1.2 Production rate equation

$$P = \frac{(Tvol)(F)(60)}{T}$$

Where:

P = productivity in (m^3) for a given sawing operation, m^3/h

Tvol = total volume of all sawn logs for a given sawing operation, m^3.

60 = number of minutes per workplace hour,

F = proportion of productive time to workplace hour,

T = the average productive time (minutes) (can also be estimated using a regression model developed for the productive times)

$$F = \frac{100 - D}{100}$$

Where:

F = a fraction measuring the proportion of productive time.

D = delay time expressed as percentage of workplace time

This formula was used to determine the sawing production rates of both traditional pitsawing and portable steel log sawing methods.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Results of data analysis of the study data and a discussion are presented and discussed in this chapter. Detailed results and discussions are presented based on productivity, costs and energy expenditure data analysis for both Traditional Pitsawing Platform (PSP) and Portable Steel Log Sawing Platforms (PLSP). The main goal of the analysis was to compare these two methods based on productivity, costs and energy expenditure.

4.1 Energy Expenditure and Physical Workload

The mean age of the respondents selected for the study was 40 ± 4.54 years, height was 1.66 ± 0.05 m and weight was 59.75 ± 2.72 kg. The mean resting heart rate (RHR) was 64.75 ± 5.13bits/min, (Table 2).

Table 2: Physical characteristics of the subjects selected for ergonomic evaluation of log sawing activity with hand saw(N=4)

S. No.	Physical characteristics	Mean	S. D.
1.	Age(yrs)	40	4.54
2.	Height (m)	1.66	0.05
3.	Weight (kg)	59.75	2.72
4	Resting heart rate (RHR) (beats/min)	64.25	5.13

4.1.1 Peak heart rate and energy expenditure of the sawyers

4.1.1.1 Traditional Pitsawing Platform (PSP)

The results in Table 3 show that the average heart rate recorded while performing the pit excavation was 143.21 beats/min while energy expended was 14.05 kJ/min and the workload was classified as unduly heavy workload. For skidding when using PSP method the average heart rate was 91.86 beats/min which consumed about 5.88 kJ/min, thus skidding work element was classified as moderately heavy. Slightly less energy was required for loading (5.2kJ/min) at the heart rate of 87.55 beats/min and hence classified as moderately heavy since there was assistance from no crew members. Energy demanded to perform the core activity of sawing was high (12.69 kJ/min) at the heart rate of 134.68 beats per minute. The sawing work element was classified as very heavy workload. These results show that sawing was the second activity to pit excavation with respect to energy expenditure on sawyers. After the sawing activities, workers were given 15 minutes for recovery heart rate recording which was 2.95 kJ/min and classified as a light workload.

Table 3: Peak heart rate and energy expenditure of the sawyers while using Traditional Pitsawing Platform (PSP)

Activity	Working heart Rate (beats/min)		Energy Expenditure (kJ/min)		Classification of work load	
	Average	**Peak**	**Average**	**Peak**	**Average**	**Peak**
Pit/platform	143.21	159	14.05	16.56	Unduly heavy	Unduly heavy
Skidding	91.86	120	5.88	10.36	moderate	heavy
Loading	87.55	127	5.20	11.47	moderate	heavy
Sawing	134.68	150	12.69	15.13	Very Heavy	Unduly Heavy
Recovery	73.4	98	2.95	6.86	Light	moderate

4.1.1.2 Portable steel log sawing platform (PLSP)

The results in Table 4 show the energy expenditure on each work elements when using the portable steel log sawing platform. Compared to the traditional pitsawing method (PSP), this method is less energy demanding. Therefore, the results revealed that 2.61 kJ/min was spent for the structure assembling activity and the workload was classified as light workload, on skidding work element, workers spent 4.48kJ/min which is light workload, loading and sawing consumed 3.55 and 12.4 kJ/min and were classified as light and very heavy workload respectively. After performing the work, the same as in traditional pitsawing method, the workers were also given 15 minutes for heart rate recovery and therefore the results show that the energy expenditure of resting for recovery heart rate was 2.43 kJ/min. In this method, sawing is the only energy demanding activity since the sawyers spent 133.74 beats/min which is higher than the allowable HR for eight hours (108.15 beats/min). The decrease of energy expenditure when using PLSP is due to the use of a pulley block when loading and the fact that this structure can be erected near the log to be sawn since it is portable, so all of these parameters reduces the workload on sawyers and it cuts down the time needed for the whole operation which increases the productivity.

Table 4: Average and peak heart rate and energy expenditure of the sawyers while using Portable Steel Log Sawing Platform (PLSP)

Activity	Working heart Rate (beats/min)			Energy Expenditure (kJ/min)		Classification of work load	
	Average	**Peak**	**Number of. observations**	**Average**	**Peak**	**Average**	**Peak**
Structure							
Assembling	71.26	99	80	2.61	3.78	Light	light
Skidding	83.08	99	78	4.48	5.98	Light	moderate
Loading	77.23	97	67	3.55	5.39	Light	moderate
Sawing	133.74	174	105	12.4	18.94	Very Heavy	Unduly Heavy
Recovery	70.16	92	73	2.43	5.90	Light	moderate

4.1.2 Estimated limit of work for the subjects over an eight hours day

It is generally argued that individuals can work at level of 40% of their maximal aerobic power for 8 hours without suffering undue fatigue (Kukkonen and Raurama, 2006). From Table 5, the average working heart rate of the subjects on each work elements was compared to the 40% of average maximal aerobic power (108.15 beats/min) which indicated that if the physiological cost to workers was greater than that which is appropriate for 8-hours; it then indicates that this operation should not be performed without rest pauses. The sub-elements pit excavation and sawing of logs with the physiological cost was 143.21 and 134 beats/minute respectively need to have rest pauses if the work is to be sustained for 8 hours.

Table 5: Estimated limit of work for the subjects over an eight hours day

Average Age (years)	Estimated MAP (beats/min)	RHR (beats/min)	IAWHR (beats/min)	40% x IAWHR (beats/min)	Allowable HR for 8hrs (beats/min)
40	174	64.25	109.75	43.9	108.15

4.1.3 Cardiac cost of work, physiological cost of work and classification of work load of pit-excavation/Platform assembly and sawing using PSP

The results in Table 6 represent the Cardiac Cost of Work (CCW) and recovery per minute and the classification of workload of pit excavation, platform assembly and sawing activity based on heart rate and energy expenditure. Therefore, the results from the calculated CCW show that the two activities impose high physiological cost of work on the sawyers. As per McArdle *et al.* (2007), the average heart rate and energy expenditure of the pitsawing activity was classified as unduly heavy workload while sawing activity (pit excavation and platform assembly) was classified as heavy activity and based on peak heart rate it was classified as very heavy workload activity.

Table 6: Total cardiac cost of work, physiological cost of work and classification of work load of pit excavation and sawing activity during PSP (N=4)

Physiological Parameters	Pit excavation and platform assembling	Sawing Activity
Cardiac Cost of Work (beats/min)	78.96	70.43
Cardiac Cost of Recovery (beats/min)	13	9.15
Rate of Exertion	Very heavy workload	Heavy workload

4.1.4 Physiological cost of work and classification of work load of sawing activity when using PLSP

The results of CCW calculations when using PLSP Indicated in Table 7 indicate that the sawing activity can be classified as heavy workload. However, the results by McArdle *et al.* (2007) revealed that the average heart rate and energy expenditure on sawing activity was classified as very heavy activity and based on peak heart rate, it is classified as unduly heavy activity. These differences could be explained by the way that the sawing activities are arranged.

Table 7: Total cardiac cost of work, physiological cost of work and classification of work load of sawing activity using PLSP (N= 4)

Physiological Parameters:	Sawing Activity
Cardiac Cost of Work (beats/min)	69.94
Cardiac Cost of Recovery (beats/min)	13.44
Rate of Exertion	Heavy workload

4.2 Comparison of Energy Expenditure when Using PSP and PLSP

The average energy expenditure of platform assembling when using PLSP decreased to (2.61kJ/min) (Fig. 1) compared to the energy spent on the same work element when using PSP (14.05 kJ/min) (Fig. 2), this difference is due to the fact that PSP involves the pit excavation/platform assembly which poses a high physiological cost of energy on sawyers whereas for PLSP, this particular work element is about assembling the steel platform structure only which consumes less energy. So long as this platform is portable, sawyers can erect it near the log to be sawn to thus reducing the skidding distance. Therefore, this study revealed that log skidding for this new method (PLSP) demanded 4.48 kJ/min while for traditional pitsawing platform (PSP) this work element consumed 5.88 kJ/min. In addition PSP required two extra two helpers in log skidding and loading operations.

For the PLSP the loading operation was done by the sawing crew without an additional assistant or helper and consumed less energy (3.55 kJ/min) since it involved raising the log on to the scaffold using two pulley blocks. It was observed that for PSP, loading process was done by pushing the log manually until it reached the sawing position and therefore it demanded higher energy (5.02 kJ/min) than on PLSP (Fig. 1). Energy expended for performing the core activity of sawing was 12.69 kJ/min (Fig. 2) when using traditional pitsawing platform (PSP) while it was 12.4kJ/min when using PLSP. The PSP and PLSP were using the same sawing technique. The energy expenditure was not significantly different during the recovery. The energy expenditures were 2.95 kJ/min and 2.43 kJ/min for PSP and PLSP respectively for the sawyers during the recovery.

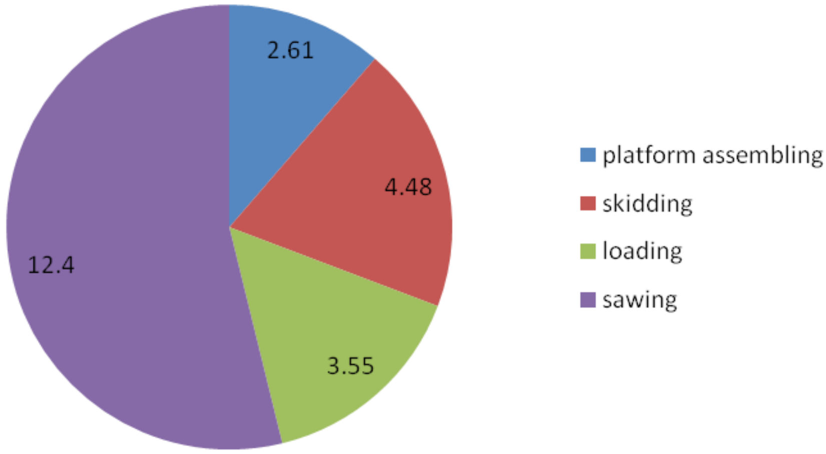

Figure 1: Energy expenditure for portable steel log sawing platforms (PLSP)

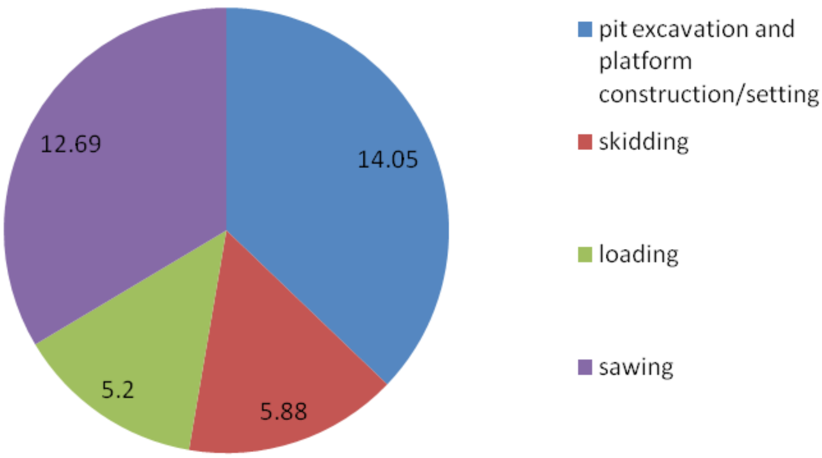

Figure 2: Energy expenditure for traditional pitsawing platform (PSP)

4.3 Rest Allowance

Rest allowance time was determined as percentage of the actual task time. Fig. 3 shows the variation of rest time as percentage of the task time. The Rohmert algorithm produces higher resting percentages as the task duration and/or work intensity increases. For the 30 minutes task duration used in this study the rest allowance was 90% of the task time which is equivalent to 27 minutes. This implies that if the subjects perform the actual task for 30 minutes they have to have a rest of 27minutes to minimize fatigue. These results are similar to those conducted by Kweka and Mauya (2009). They argued that if the sawyers perform the task for 30 minutes, they have to rest for 28.8 minutes. This indicates that once these rest allowances are implemented, workers will be able to work for long time (sustained period without undue fatigue and the productivity will be sustainable and increased.

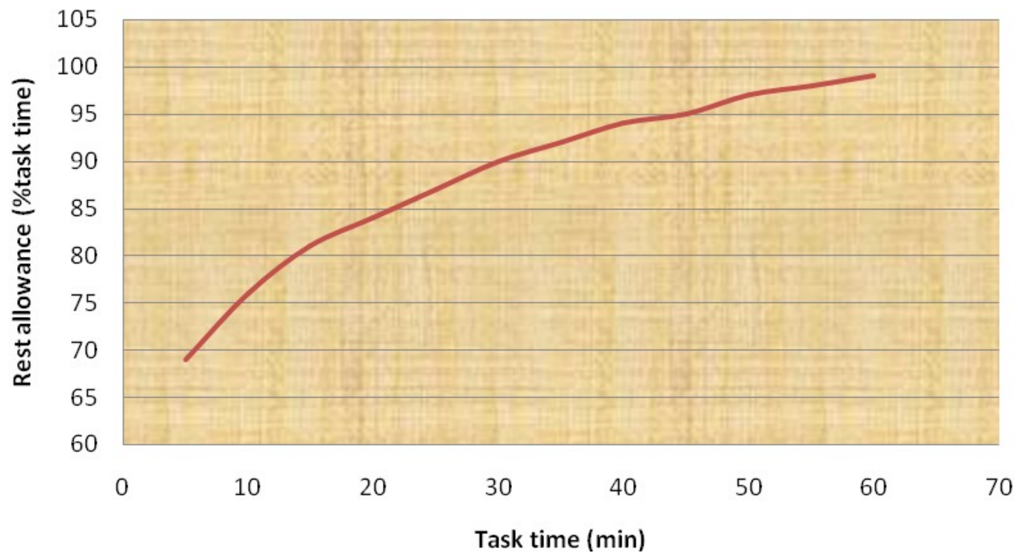

Figure 3: **Rest allowance**

4.4 Time Study and Productivity

4.4.1 Time study

4.4.1.1 Time spent on each work element of pitsawing in Nduweni Village

In Nduweni village, 67% of the total time was effectively used to perform the intended activity, while 22% was used for supportive activities, and about 12% of the workplace time was wasted on activities not associated with pit or platform sawing method (Table 8).

The total productive time consumed per log from site preparation to sawing, in Nduweni Village was 30 hours (about 4 working days of 8 hours/day). Sawing consumed more time than any other operation averaging at 22 hours (74% of the total time) per log of 2.7 m length and 0.75 m mid diameter which produced 23 planks of 28 cm x 2.5 cm.

Table 8: Distribution of time spent on each work element of pit sawing in Nduweni village

S/N	Work Element	Effective working time %	Necessary delays %	Unnecessary delays (%)
1	Pit/platform preparation	61	36	3
2	Skidding	100	0	0
3	Loading	27	20	53
4	Sawing	74	24	2
% Total		70	27	3
% Average		67	22	12

4.4.1.2 Time spent on each work element of Portable Steel Log Sawing Platform in Nduweni Village

At Nduweni village, 75% of workplace time was used as effective working time and the necessary and unnecessary delays consumed 13% and 2% of the total workplace time respectively (Table 9).

The total time consumed per log from structure assembling to sawing, at Nduweni village was 11 hours (about 1.5 working days of 8 hours). Sawing consumed more time than any other operation averaging at 10.6 hours (94 % of the total time) per log of 2 m and 0.63 m of mid diameter which produced 12 planks of 25 cm x 2.5 cm (10 x 1 inches each)

Table 9: Distribution of time spent on each work element of Portable Steel Log Sawing Platform in Nduweni Village.

S/N	Work Element	Effective Working time (%)	Necessary delay (%)	Unnecessary delay (%)
1	Platform preparation	100	0	0
2	Skidding	100	0	0
3	Loading	71	29	0
4	Sawing	78	18	4
% Total		78	18	4
% Average		75	13	2

4.4.1.3 Time spent on each work element of Portable Log Sawing Platform in Kiruweni Village

At Kiruweni village when using the portable steel log sawing platform, 64% of the total time was effectively used to perform the intended activity, while 31% was used for supportive activities. Whereas about 5% of the workplace time was wasted on activities not associated with pit or platform sawing (Table 10).

Table 10: Distribution of time spent on each work element of Portable Steel Log Sawing Platform in Kiruweni village

Work Element	Effective Working time (%)	Necessary delay (%)	Unnecessary delay (%)
Platform preparation	100	0	0
Skidding	29	71	0
Loading	60	20	20
Sawing	66	31	3
% Total	65	32	3
% Average	64	31	5

4.4.2 Time spent on each work element of traditional pitsawing method (PSP) in Kiruweni Village

At Kiruweni village while performing pitsawing by the traditional pitsawing method (PSP), 88% of workplace time was used as effective working time and the necessary and unnecessary delays consumed 11% and 1% of the total workplace time respectively (Table 11).

The total time consumed per log from site preparation to sawing, in Kiruweni village by using traditional pitsawing method was 7.4 hours or about one working day of 8 hours while by using portable log sawing platform, the total time was 5.9 hours. In both sites sawing consumed more time than any other operation averaging at 5.13 hours (69.3% of the total time) per log of 2 m length and 0.41 m log mid diameter when using pit sawing and 5.6 hrs (95.4%) per log of 2 m log length and 0.39 log mid diameter when using PLSP. These two methods produced 9 planks and 8 planks of (27.5 cm x 3 cm) each respectively with the recovery of 0.0165 m^3 each plank.

Although log skidding and loading elements consumed less of the total conventional time at both Nduweni and Kiruweni villages, the activities are tedious and energy demanding which necessitate hiring of extra labour to assist. Depending on the size of the logs, two to four people were hired to assist the sawing crews which are normally made up of two people. These hired people plus the sawyers moved the logs from the felling sites to the sawing sites and loaded them on the pits or platforms.

Table 11: Distribution of time spent on each work element of pit sawing in Kiruweni village

Work Element	Effective working time (%)	Necessary delays (%)	Unnecessary delays (%)
Platform preparation	82	15	3
Skidding	100	0	0
Loading	100	0	0
Sawing	76	22	2
% Total	78	20	2
% Average	88	11	1

4.5 Productivity

4.5.1 Productivity of traditional pitsawing platform (PSP)

The productivity for PSP method was 0.055 m^3 per hour. These results are similar to those reported by Kijoti and White (1981), Migunga (1986) and Kweka (2007), whose pitsawing productivities were 0.054, 0.088 and 0.06 m^3/h, respectively. Pit excavation work element productivity was 0.1 m^3 per hour (Fig. 4).

Skidding and loading work elements productivities were much higher than those of pit preparation and sawing. In PSP method, the skidding and loading productivities were 3.5 and 4.97 m^3/h respectively.

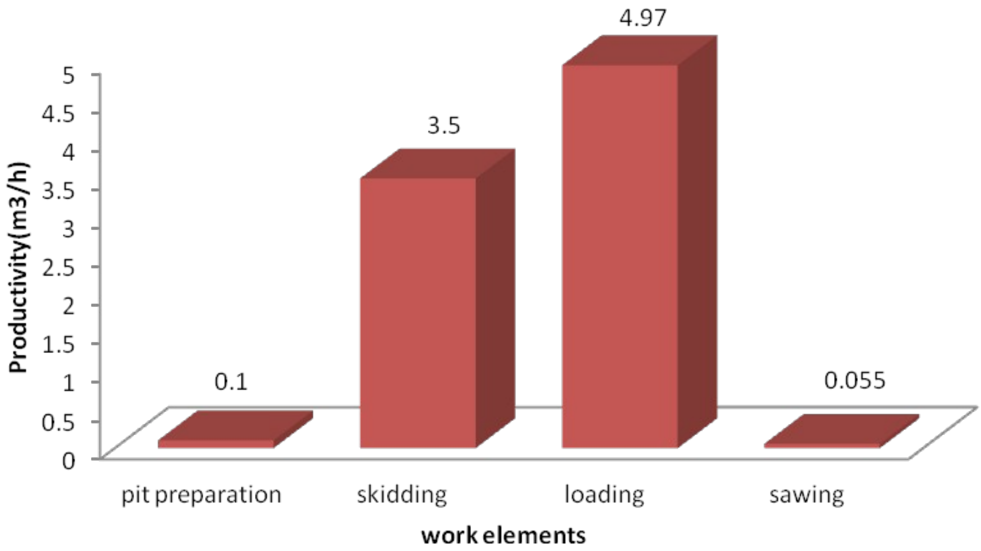

Figure 4: Productivity of each work element when using pitsawing platform (PSP)

4.5.2 Productivity of portable steel log sawing platform (PLSP)

The sawing productivity for portable log was 0.057 m^3/h. Structure assembling work element productivity was 2.9 m^3/h (Fig. 5).

Skidding and loading work elements productivities were much higher than those of Structure assembling and sawing. In portable log sawing platforms, the skidding and loading productivities were 11.9 and 7.27 m^3/h respectively.

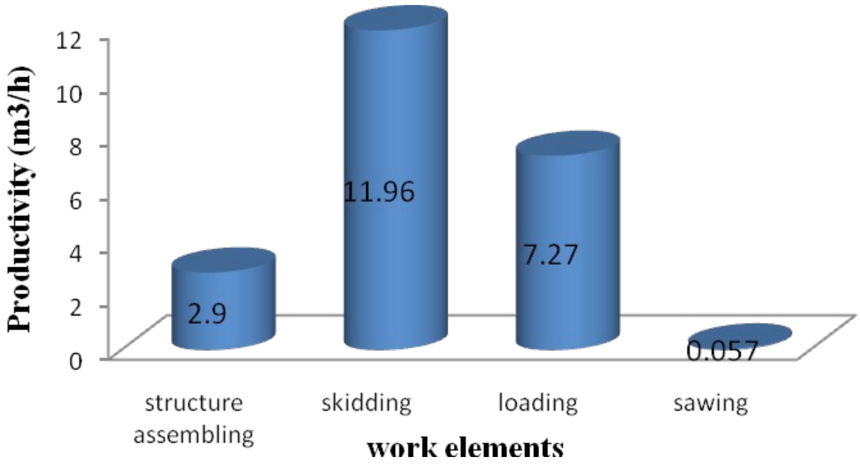

Figure 5: Productivity of each work element when using PLSP)

4.6 Productivity Versus Energy Expenditure

4.6.1 Productivity vs. energy expenditure when using traditional pitsawing platforms (PSP)

The results in Table 12 revealed that for pit preparation, 8,830 kJ is required, for pit excavation, to skid 1 m^3 in pit sawing method, 352.8 kJ is required while for loading and sawing, 312 kJ and 761.4 kJ are required respectively to load and saw one m^3. In other words, the most energy consuming work element on PSP is pit excavation followed by sawing and skidding and loading work element was the last.

Table 12: Productivity vs. energy expenditure when using PSP

Work element	Energy Expenditure (kJ/min)	Productivity (m^3/h)	Energy Expenditure (kJ/m^3)
Pit preparation	14.05	0.1	8,830
Skidding	5.88	3.5	352.8
Loading	5.20	4.97	312
Sawing	12.69	0.055	761.4

4.6.2 Productivity Vs energy expenditure when using PLSP

The results in Table 13 show that PLSP method is more economic than PSP method in terms of energy expenditure and production rates. 156.6 kJ/min is required to assemble the structure, 268.8 kJ/min is required to skid 1m^3 while 213 kJ/min is required to load 1m^3 of log and 744 kJ/min is required to saw 1 m^3.This is due to the fact that the structure is portable and easy to assemble (it can be erected wherever the log to be sawn is, loading of logs on the steel structure is done mechanically using pulley system by rolling the log on platform until it reaches the sawing position), therefore this method requires less energy more than traditional pitsawing method. Based on energy expenditure, the sawing work element consumed more energy followed by skidding and loading and structure assembling was the last.

Table 13: Productivity vs. energy expenditure when using portable steel log sawing platforms

Work element	E.E.(kJ/min)	Productivity (m^3/h)	E.E.(kJ/m^3)
Structure assembling	2.61	2.9	156.6
Skidding	4.48	11.96	268.8
Loading	3.55	7.27	213
sawing	12.4	0.057	744

4.7 Sawing Cost

4.7.1 Sawing costs for different tree species

As shown in Table 14, when using either PSP or PLSP, the sawing costs for the studied tree species varied despite all being hardwood species. For example, *Grevillea robusta* had the lowest sawing costs of TAS 1 800 per plank of (27.5 cm x 3cm x 200 cm or 0.0165 m^3) or TAS 109 091/m^3. The higher sawing costs for the other species such as *Albizia schimperiana* (TAS 2 500/plank of the same size or TAS 151 515/m^3) could be due to the anatomical structure of the wood (hardness), tree size, and different sizes of timber sawn. The study conducted by Kweka (2007) revealed that the sawing costs for the studied tree species varied depending on tree hardness.

Table 14: Sawing costs for different tree species

Vernacular name	Scientific name	Sawing cost/m^3 (TAS/ m^3)
Grevillea	*Grevillea robusta*	109 091
Mruka	*Albizia schimperiana*	151 515
Average sawing cost		130 303

4.7.2 Labor costs of traditional pitsawing platform (PSP)

Table 15 presents the average total labour cost of pit sawing which is calculated by adding up the pit excavation cost and the average sawing costs for the entire two tree species listed in the Table 14.

Compared to the traditional pitsawing method (PSP), portable steel log sawing (PLSP) method cost is lower than PSP cost. In the PLSP method the main cost is sawing cost only TAS 165 350/m^3 whereas the cost of PSP includes the cost of pit excavation which is TAS 40 000 per a pit, therefore the total labour cost of PSP is the summation of sawing, extra labour for skidding if necessary and pit excavation costs which was 205 320 TAS/m^3. In 2007 Kweka found that the total labour cost of pitsawing per a cubic meter was 58 300 TAS, this implies that the total labour cost of pitsawyers was very low that moment comparing to actual results. It was also noted that in this area there was no payment for extra labour required for skidding the heavy logs since there are different crews of sawyers in the same place and therefore they help each other in that particular work element.

Table 15: Total labor costs of pit sawing

Type of cost	Amount in TAS	% of Total labour cost
Pit excavation cost	40 000	19.48
Average sawing cost per m^3	165 350	80.52
Total labour cost	205 350	100

4.7.3 Cost, life span and depreciation of portable log sawing platforms (PLSP)

The current costs of buying equipments by which the portable steel log sawing platforms is made together with their useful life span were obtained from the interviews with the workshop technicians of Sokoine University of Agriculture. This formed the basis for the calculation of write-off time and depreciation per year (Table 16).The results from the Table16 revealed that the buying cost of the frames was TAS 450 000 and its write-off time was 15 years while the depreciation per year was 30 000.

For the pulley, which is used to log the log on the sawing position, the buying cost and depreciation were 150 000 and TAS 10 000 respectively and the total depreciation per year of the PLSP equipments was TAS 40 000. This implies that when using PLSP, sawyers have to save TAS 40 000 per year in order to be able to purchase a new structure after 15 years. The interview with the sawyers were also conducted to know the hiring cost of PLSP, they argued that the hiring cost ranges between TAS 3000 and 5 000 per m^3.

Table 16: Total cost of PLSP

Equipment	**Buying cost**	**Write-off time (Years)**	**Depreciation costs[1] (TAS/year)**
platform	450 000	15	30 000
Pulley system	150 000	15	10 000
Total	600 000		40 000

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Despite the fact that currently tree harvesting for timber production in agroforestry farms is a profitable venture, minimization of physical workload on sawyers could increase sawing productivity and minimize the sawing cost. As the aim of this study was to compare productivity, costs, and energy expenditure of sawyers when using Traditional Pitsawing Platforms (PSP) and the Portable Steel Log Sawing Platforms (PLSP), it can be therefore concluded that Portable Steel Log Sawing Platforms (PLSP), is more productive, economic and reduces the physical workload on sawyers than traditional pitsawing method according to the results of this study.

The findings of this study revealed that when using Portable Log Sawing Platform (PLSP), the productivity increased from 0.1 m^3 per hour to 2.9 m^3/h for the site and platform assembling work element, it increased also from 3.5 to 11.9 m^3/h for skidding and 4.97 m^3/h to7.27 m^3/h for loading due to the use of pulley block and tackle which reduced the workload on sawyers and eliminated the need for assistance from other people when loading on PLSP.

Like PSP, PLSP also used manual power during timber sawing operation. The sawing production rate for PSP and PLSP was 0.055 m^3/h and 0.057 m^3/h respectively. The similarity in productivity is attributed to the use of the same sawing technique on both structures. In contrast with PSP, PLSP minimized the cost from

205 320 TAS/m^3 to 165 350/m^3.Therefore, Portable Log Sawing Platform (PLSP) is productive and more economic than the Traditional Pitsawing Method (PSP).However; the equipments of PLSP (frames and pulley) are not free although its life span is high (15years). The total purchasing price of these equipments was TAS 600 000 while their depreciation was TAS 40 000 per year. This implies that the sawyer who own the structure has to save TAS 40 000 per year in order to purchase a new one after 15 years.

As for the energy expenditure, PLSP method was less energy demanding than PSP method when sawing the logs. During platform structure assembling, PLSP reduced the energy expenditure from 14.05 kJ/min to 2.61KJ/min and the physical workload were classified as unduly heavy workload and light workload respectively, for skidding work element PLSP also minimized the energy expenditure from 5.88 kJ/min to 4.48 kJ/min, the same applies to loading work element, the energy expenditure decreased from 5.20 kJ/min to 3.55 kJ/min, this difference is due to the fact that loading for PLSP is supported by the use of a pulley system while for PSP method the log is loaded manually. For the core activity which is sawing, there was no significant difference because of the similarity of sawing technique. The energy expenditure for this sawing work element for PLSP and PSP were 12.69 and 12.4 kJ/min respectively.

Based on overall findings of this study, it could be concluded that the Portable Log Sawing Platform (PLSP) is a better technology to be adopted for increasing productivity, minimize the sawing cost and reducing physical workload on sawyers during timber sawing operations in agroforestry farms.

5.2 Recommendations

In order to improve productivity of sawn timber and to reduce physical workload, costs associated with traditional timber sawing practices in agroforestry farms, the following are recommended:

- Portable Log Sawing Platform (PLSP) should be adopted for sawing tree logs,
- Portable Log Sawing Platform (PLSP) technology should be promoted in the agroforestry farms by providing information as to their benefits as compared to the traditional pitsawing method.
- Training of hand sawyers on the appropriate method of using the PLSP method.
- Efforts by Government should be made to avail loans for purchase of the PLSP structures so that they are accessible to all hand sawyers.
- Further studies on PLSP method has to be undertaken in order to improve them in order to reduce the energy costs and improve their efficiency

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APPENDICES

Appendix 1: Work and time study data sheet

Work element							
Date							
Name of recorder							
Tree number and specie	Independent variables			Time study			
	Log number	Log length (m)	Log diameter (m)	Working time (hh:mm:ss)	Necessary delays (hh:mm:ss)	Unnecessary delays (hh:mm:ss)	Remarks