ASSESSMENT OF PRODUCTIVITY AND COSTS OF THREE WHEELED LOADER: CASE STUDY OF SAO HILL FOREST PLANTATION –MUFINDI IRINGA, TANZANIA.

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ABSTRACT

In recent years logging operations are either semi-mechanized or full mechanized. This has emerged due to shortage of labour in logging operations and the presence of new technology which simplifies work and increases productivity. Loading equipment such as three-wheel loaders have been used in logging operations in Tanzania but their productivity and costs are not documented. This study was done at Sao Hill Forest Plantations to determine productivity and costs of three wheel loaders used in loading operations. The study focused on determination of total time taken for the whole operation of the loader, the production rates of the loader, fuel consumption rate and unit costs of the three wheeled loader. Purposive sampling technique was used in making 244 observations. Primary data were collected by the use of snap-back time study. Secondary data were collected through interviews, office records and reading published journals and articles. The findings indicated that total average time taken for the loading operation was 1.56 minutes while total average productive time was 1.33 minutes. Production rate of the three wheeled loader was estimated to 59.71 m^3/h when only necessary delays were considered and 43.03 m^3/h when all delays were considered. This showed that the loader had high production rates but omission of unnecessary delays increases productivity. Fuel consumption rate was estimated to be 0.0027 litres/min which was very economical in comparisons to other loading equipment. Total cost of using the three wheeled loader was estimated to 21 153 000.00 TZS/year hence the unit cost of production was 10 922.01 TZS/m^3 when all delays were considered and 7 872.30 TZS/m^3 when only necessary delays were considered. This illustrated that unit costs of production reduces when unnecessary delays were omitted. It was concluded that the three wheeled loader has high loading production rates and reasonable unit costs of production.

DECLARATION

I, Edson Dennis Kaniki, do hereby declare to SENATE of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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This work is particularly dedicated to my family especially my parents and my aunt Mrs. Happyness Justinian Agape. I want to thank them for their prayers, assistance of any kind, guidance and especially fees payments and living allowances.

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LIST OF ABREVIATIONS AND SYMBOLS

FAO	Food and Agriculture Organization of the United Nations
FCR	Fuel consumption rate
GR	Grappling cycle time element
Ha	Hectares
LO	Loading cycle time element
MNRT	Ministry of Natural Resources and Tourism
MV	Maneuverability time cycle element
NEC	Necessary delays
SHFP	Sao Hill Forest Plantations
TANWAT	Tanganyika Wattle Company
TFS	Tanzania Forest Service Agency
TPT	Total Productive Time
TZS	Tanzanian Shillings
UC	Unit cost
UN	Unloading time cycle time element
UNEC	Unnecessary delays
URT	The United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Logging is defined as the process of cutting, processing, and moving trees to a location for transport at the least possible cost (Conway, 1976). Logging operations involves tree felling, bucking, bunching, skidding, loading and hauling of logs. Some logging operations are semi mechanized or fully mechanized with the use of equipment and machines. This has increased as a result of high costs and shortage of labour and the need for economic wood production (Schaeffer *et al*., 2001). In recent years, even the fully mechanized system based on the combined use of harvesters and forwarders has been spreading with the use of heavier and more suitable machines for working on steep terrain (Cadei *et al*., 2020). A combination of machineries used in timber harvesting operation increases productivity and reduces overall operational cost (Noriziah *et al*., 2016).

Various studies have been performed to analyze the efficiency (productivity and costs) of mechanized machines in logging operations. A study done by Mauya *et al*. (2011) to determine productivity and costs of using grapple skidders at Sao Hill forest plantations in Tanzania showed that the grapple skidder productivity was reduced exponentially with increasing skidding distances. The productivity for skidding operations ranged from 42.2 m^3/h to 15.4 m^3/h when the skidding distances were 10m to 125m respectively. Analysis of cost data indicated that, average skidding cost for grapple skidder was 1875 TZS/m^3 (1.4USD/m^3). Another study done by Silayo (2015) to model productivity and costs of timber harvesting in plantation forests using two man crosscut saws under learning experiments, showed that there is an increase in production rate of the crews after training with a subsequent fall in production rates as the crews resumed cutting after the break and there is an average of 40% production increase after training and about 23% production fall after the break for all crew categories. Further the production costs were relatively lower after training as compared to other experiments in the study. A study done by Mousavi and Naghdi (2013) to investigate time consumption and productivity analysis of timber trucking using two kinds of trucks in northern Iran, showed that average productivity of log transportation was 2.84m^3/h and 3.4 m^3/h for the dump truck and chassis truck, respectively. The average hauling unit cost was 18 USD/m^3 (24107 TZS/m^3) and 15 USD/m^3 (20089 TZS/m^3) in the dump truck and chassis truck, respectively.

In Tanzania, timber harvesting in forest plantations has been practiced since 1970s and it is progressing as more plantations reach maturity (Ntalikwa, 2019). Timber harvesting operations in Tanzania is changing from labour intensive and semi-mechanized methods to fully mechanized operations especially for felling and skidding operations (Mauya, 2011). However, for loading operations such trend was observed but little was documented which led to the need of this study. Before the introduction of mechanized loading machines in Tanzania, loading was done manually where by labourers were used in loading and unloading operations. Through the use of labourers time taken and efficiency were very low, leading to the introduction of mechanized loading machines. The mechanized loading machines used in Tanzania include three wheel loaders and front end loaders.

Three-wheel loader is very useful in plantation logging operations by loading and unloading of the logs onto trucks and sometimes usefully for skidding in small plantations area (Stokes *et al*., 1993). They are called three wheel loaders because they use three wheels/tires with one front wheel and two rear wheels. The front wheel is very useful for turning in different directions and different movements while the rear wheels are very usefully for stability of the loader. Three wheel loaders have been introduced in Tanzania in different places including; Sao Hill Forest Plantations (SHFP) in Mufindi and TANWAT forest plantations in Njombe Districts respectively.

No study had been reported to analyze the productivity and costs of three wheeled loaders in Tanzania and there was little information about productivity and costs of using three wheeled loaders. This called for the need of this study as productivity and costs information are needed for efficient planning of wheeled loader operations in plantation forests.

1.2 Problem statement and justification

Three wheeled loaders in Tanzania are used in some forest plantations including Sao Hill forest plantations in Iringa and TANWAT forest plantations in Njombe. However, little information was available on their efficiency focusing on productivity and costs. There was a knowledge gap on their productivity and costs as this is a new technology in Tanzania. Different studies have determined productivity and costs of other logging equipment's such as forwarders, skidders, tractor trailers and harvesters but there were no studies focusing on three wheeled loaders thus leading to this study. Effective planning and control of three wheeled loaders requires detailed information on every aspect (productivity and costs) of wheeled loader operations. Such data were not presently available for Tanzania. This study was designed to obtain and analyze data for the three wheel loaders used in logging operations at Sao Hill Forest Plantations (SHFP).

This study will assist forester engineers and logging managers to understand how the three wheel loader performs it's work in terms of its daily productivity, time taken for the whole operation of grapping logs and unload the logs onto the truck, the delays, the problems faced by the technical personnel and drivers on how to control the loader and the amount of logs in terms of volume that a three loader can carry which minimizes the problems that makes a loader to flip or go down. Also production costs of using a three wheeled loader available are going to help managers and foresters on better planning and control of loading operations by using the three wheel loaders.

1.3 Research objectives

1.3.1 Main objective

To assess productivity and costs of three wheeled loader in plantation forest logging operations.

1.3.2 Specific objectives

i. To determine time taken for loading operations using three wheeled loader.

ii. To determine production rates of the three wheeled loader in loading operations.

iii. To determine fuel consumption rate of the three wheeled loader when used in logging operations.

iv. To determine total loading operation unit costs when using three wheeled loader.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Logging operations in Tanzania

Tanzania has 48.1 million hectares of forest area which is 55% of the total land area of Tanzania main land which is 890 000 km^2. Forest plantations are estimated to cover about 554 500 ha (MNRT, 2015). The major part of the industrial forest plantations are owned and managed by the Government through Tanzania Forest Service (TFS) of the Ministry of Natural Resources and Tourism (Ngaga, 2011).The Government forest plantations include; Sao Hill (SHFP), North and West Kilimanjaro, Meru/Usa, Shume, Ukaguru, Ruvu, Rubya, Rubare, Kawetire, Kiwira, Wino-Matogoro, Rondo, Longuza, Buhindi, Mtibwa, Mpepo, Wino Ifinga, Mbizi, Rongai, Ukaguru, Iyondo, Mswima, Korogwe, North Ruvu, Buhigwe and Silayo (MNRT, 2021).

Timber harvesting comprises all technologies required to convert a forest from a community of trees into consumer products. It involves an aggregation of man and machine components (Silayo, 2007). Industrial timber harvesting in plantation forests in Tanzania started in the 1970’s after most plantations attained their rotational age. Harvesting operations were solely performed by public agencies with all the crews or workers being public servant of the government of Tanzania (Silayo *et al*., 2010). Logging operations in Tanzania were done by the government through Logging and Road Building Project (LRBP) agency under the Forest and Beekeeping Division (FBD) (Mauya *et al*., 2011). Most of the logging operations during this period were labour intensive and semi mechanized (Silayo *et al*., 2010). During that period the Government also owned most of the wood processing industries. However, due to the structural adjustment program where the government detached itself from doing business, most of the wood industries were sold to private companies through privatization which aimed at improving production, safety, quality and to reduce operational costs (Ngaga, 1998). As a result, some of the privatized companies, including Mufindi Paper Mill, revolved their operations (Mauya *et al*., 2011).

The whole process of timber logging involves a complex of interrelated activities which needs to be clearly planned in order to optimize profitability of the operations. Tree cutting, log skidding, loading and unloading are the key activities that are done in any timber logging process (Conway, 1976). Timber harvesting operations in Tanzania are changing from semi-mechanized and labour intensive methods to fully mechanized operations. To be cost effective, such operations must be carefully planned and controlled (Migunga, 1982). One of the contributing factors is due to the efficiency and improved safety of the mechanized logging operation (Clark and Monieba, 2004).

The management of Sao hill forests plantations is authorized to sell trees to customers, due to high harvesting costs (felling, skidding, and transportation costs). The management sells logs to clients as standing volume; meaning the trees are sold while still on land (MNRT, 2018). The purchasing price of timber from Sao Hill Plantation involves royalty fees paid depending on the volume produced (Ntalikwa, 2019). The costs involved are establishment costs, operational costs, overhead costs for one hectare to give the total royalty, on average the costs of producing $1m^3$/ha at Sao Hill is 37,387.82 TZS (MNRT, 2018). When buying logs from the plantation other fees which must be paid involve Logging and Miscellaneous Deposit Account (LMDA), CESS, Value Added Tax (VAT), Tanzania Forest Fund (TaFF), transit pass and the application fee (Ntalikwa, 2019). The above additional costs highly depend on the royalty paid which on average is 59,341.61 TZS/m^3 (MNRT, 2018). The management estimates the volume of the stand while the trees are not yet harvested by measuring the DBH and height of the trees. Tariff tables and the volume estimated are used to determine the price the client has to pay with respect to the harvesting volume obtained (MNRT, 2018).

2.2 Logging planning

Logging planning is mainly based on available information (data) on productivity and costs (Migunga, 1996). These can be estimated through detailed work studies of operations similar to the one being considered for a particular area. In planning three wheel loaders working in plantations forests, detailed time studies are needed to accumulate the data required in planning and control of its operation.

2.2.1 Work studies of logging operations

Work study can be defined as a systematic examination of the methods of carrying an activity in order to improve effective use of resources leading to high productivity. Work studies are commonly used to study production rates and costs of logging systems. Work studies are imperative for establishing productivity and costs of logging machines working under plantation conditions. Among these, method and time studies are commonly used in logging studies. Application of methods and time studies in establishing efficiency of logging machines is a prerequisite to planning and control of the operations (Dykstra, 1981).

2.2.1.1 Method studies

Method study is a technique in which work or an operation is critically and systematically examined in order to develop more efficient and easier ways to accomplish the task (Rathod *et al.,* 2015). It involves systematic recording and scrutinized inspection of existing and proposed ways of doing work for developing more effective methods and thereby reducing the overall cost. Simplification of work or the working methods to achieve higher productivity is the basic motive of method study. Method study uses symbols in recording different facts rather than written words (Rathod *et al*., 2015).In this technique, the methods of production are studied in detail in order to improve the method used in production. Studies by method studies done in logging operations include studies by Ronnquist *et al*., (2015); Lantin *et al*. (2009).

2.2.1.2 Time studies

Various "gross" and detailed time study techniques are commonly used in studying logging operations. Studies done by the use of time studies in logging operations include studies by Dykstra and Howard , (1980); Dykstra, (1981); Migunga, (1982); Migunga, (1996); Silayo *et al*., (2010); Mauya *et al*. (2011);   Migunga *et al*. (2014); Silayo (2015) and Ntalikwa (2019). The results of such studies are used in planning, forecasting, and control of forest operations. Ground based logging systems have also been studied by using time studies, specifically continuous time study methodology (Migunga, 1996; Silayo, 2014).

Time study methods may be used for scheduling and planning of work activities, determination of standard costs useful in budgeting, cost appraisals, determination of machine and labour effectiveness and judging productivity of labour and machine over a range of operating conditions (Migunga, 1982).

2.2.1.3 Detailed time study

Detailed time study are done when in-depth study is needed to obtain operating productivity and costs and determining factors affecting productivity and costs. Work operation must be split into short and well defined work activities known as elements. The work activities or elements forms a work cycle. Work cycle is the sequence of work elements which are required to perform a job or yield a unit of production (Migunga, 1982). Work elements must be easily identifiable with definite beginnings and endings. The work elements are then studied by recording the times for performance of each work element by the use of cumulative timing method or snap-back timing methods and productivity is estimated in accordance to time taken for each work element. Among the methods used in a detailed time study are discussed in the sections below.

(a) Continuous timing

Continuous timing method is when the operation is timed continuously from the start until the end of a working shift is performed (Dykstra and Howard, 1980). Usually stopwatches are used in recording the time taken for each activity. This can be done as cumulative timing or snapback timing methods.

(b) Cumulative timing

Cumulative timing method is when an observer uses a stop watch to determine how much time is used on productive and non-productive time elements (Anderson, 1976; Dykstra, 1975). Cumulative times are recorded from the start to the end of each element in the work activity without stopping or calibrating the stopwatch and each element times are obtained by subtraction. This method keeps the records of the sequence of operations observed (Migunga, 1982). It's advantageous in a way that it doesn't require much manipulation of the stopwatch, regular and irregular elements can be easily distinguished and elements are not easily omitted. Its main disadvantage is that it requires the presence of a skilled observer which may be costly (Migunga, 1982). Another disadvantage is that it involves subtraction in order to obtain individual elements which may lead to errors.

(b) Snap-back (Repetitive) timing

Snap-back (Repetitive) timing technique is when the net times for each work event are recorded directly on the study form. The observer uses a stop watch and starts the stop watch at the beginning of each activity and stops the watch at the conclusion of each activity. Elapsed time is recorded and the watch reset to zero. The advantage of this method is that it requires no subtraction hence it is less prone to errors. However it doesn't normally permit the analyst to reconstruct the sequence of a day's activity (Migunga, 1982).

(d) Work Sampling

Work sampling techniques are often used when the observer observes the operation at intervals rather than continuously based on sampling of activities. Fixed or random intervals are used in observing the work elements. It has been indicated that it offers economy at no theoretical sacrifices (Gardner and Shillings, 1969). Stopwatches may or may not be used in this method. Observations are recorded at interval such as 1 minute, 5 minutes or 30 minutes depending on the type of work, the level of precision desired and number of operations being timed by a single observer (Migunga, 1982). The method does not generally permit regression analysis due to the nature of the data.

(e) Shift level ("Gross") time study

Gross time studies technique records the production levels achieved by a work system, crew or machine working for every shift (Dykstra, 1977). A single data record is prepared for each shift. It does not require a trained time study analyst (Anderson, 1976). Data collected are such as total working time per shift, quantity of output per day, number of workers, working conditions, slope, distances, stand and terrain conditions, equipment used and machines used. This method is useful in monitoring day to day productivity and costs and monitoring long term trends in productivity and cost. Shift level time study is advantageous in determination of work elements that may require detailed time studies to improve efficiency. The method is not reliable when details of operations must be obtained (Dykstra, 1977).

2.2.2 Production rates and costs

Production rates and costs are always major concerns in choosing a harvesting system (Wang *et al.*, 2004). Many studies have used productivity and costs models as a way to estimate and compare productivity and costs of different harvesting systems (Cadei *et al.*, 2020). Production rates and costs for yarding by cable, balloon and helicopter in clear cutting and partial cuttings have been determined by time studies and costs analysis (Dykstra, 1976). Tree cutting operations by crosscut saw versus chainsaws were compared and production rates and costs estimated (Migunga, 1982). In Tanzania, studies that have used these productivity and costs models include Migunga, 1982; Migunga, 1996; Silayo *et al.*, 2010; Mauya *et al.*, 2011; Migunga *et al.*, 2014; Silayo, 2015 and Ntalikwa, 2019.

2.2.2.1 Production rates

Harvesting productivity can be defined as volume of logs produced per hour during harvesting operations (Ponsse, 2005). Time studies are frequently used to determine the productivity of a harvesting system, the rate of productivity however differs depending on various conditions such as the system being used, machines technology, the harvesting area (location) and the timber volume involved (Pajkoš *et al.*, 2018).

2.2.2.2 Production costs

Good cost and production records are needed for determining whether actual rates exceed or fall below bid rates and for identifying areas of high cost or low production, therefore areas needing improvement (Bushmen and Olsen, 1998). Estimation of the cost and benefits of the timber harvesting are necessary to ensure the profitability of the operation (Jones, 1993). Most of cost analysis of harvesting operation deal with the cost per unit of output (unit cost) and include the costs of labour and machines (Hancock, 1991). These costs can be found as hourly and unit cost of equipment's taking into account the two categories of costs which are fixed and variable costs.

2.3 Factors affecting efficiency of logging operations

Efficient logging operation is the one with low production cost but with high productivity leading to high profit of the logging operation (Mauya *et al*., 2011). Logging operational control plans must be done in order to increase productivity and reduce cost (Migunga, 1982). There are several factors affecting efficiency of logging operations, some of these include;

2.3.1 Climate

Climate plays an important role in determining logging productivity and although it cannot be influenced by man, logging plans must consider its effects in productivity and costs (FAO, 1977, 1978). Climatic factors that have been identified as being material importance in this regard include different seasons, temperature, humidity, wind, timing and distribution of rainfall and fog (Migunga, 1982). There are some period when logging operations cannot take place due to unforeseen climate instability leading to low productivity.

2.3.2 Slope

Terrain slopes can be adverse or favorable. Extreme slopes may preclude by the use of either tractors or skidders. Crawler tractor may be able to operate in some of the steeper slopes, but will result into environmental damages such as soil erosion and difficulties in regeneration due to building of skid trails and cost increase. The rule is to skid downhill to the landing whenever possible. If it is necessary to skid uphill, the payload should be lightened (Ntalikwa, 2019).

2.3.3 Machine factors

Unmaintained machines and equipment tends to increase the cost of logging operation (Bushmen and Olsen, 1998) which leads to low productivity. Machines used in logging operations should be well maintained and checked from time to time in order to increase their efficiency.

2.3.4 Labour

Labour factors to be considered are such as labour skills, trainings, experience, physical work capacity, nutrition, health and work attitude (FAO, 1977; Migunga, 1982; Abeli and Ole-Meiludie, 1990). These factors influences performance of forest workers either directly or indirectly leading to low productivity of the logging operation concerned.

2.3.5 Tree volume

Volume is determined by tree height (length) and diameter, a critical variable which affect productivity and costs in harvesting operation. The smaller the tree, the higher the variable operating cost per unit of production. The reason for this is that, in the brush small logs are more difficult to handle than large ones, hence more pieces are required to make up a payload, so that productivity per unit time actually will be lowered (Ntalikwa, 2019). A number of studies have identified tree volume to significantly influence machine operating time and thus productivity (Ghaffariyan *et al*., 2015; Pajkos *et al*., 2018).

2.4 Wheel loaders

A wheel loader is a mobile piece of earthmoving equipment capable of loading any type of bulk soil (stripping) or rock (ore) or log in production operations or support capacity in conjunction with another production loading piece of mobile equipment and machines. Additionally, wheel loaders are capable of transporting their payload over short distances, typically less than 183 meters, in order to achieve a productive cost (Achelpohl, 2018).

Wheel loaders have been introduced in many countries in order to assist in loading, unloading, and skidding. In Iran, wheeled loaders are commonly used for loading logs onto log trucks (Mousavi1 and Naghdi, 2013). Wheel loaders are used as a preferred loading tool for their mobility, operational flexibility, and comparatively low capital costs (Achelpohl, 2018). A wheel loader is designed to load logs into other equipment or machines such as forwarders, skidders and transport trucks. In grappling of the loads the bucket tends to hold the logs up to destination point in the landing or the respective truck. A wheel loader is very mobile and capable of tramming speeds of 17 - 25 kilometer per hour compared to other earthmoving loading equipment which generally have maximum tramming speeds of up to 5 kilometer per hour (Achelpohl, 2018) hence wheeled loader can move quickly around the area. Wheel loaders can be used to complete tasks in virtually any industry that deals with heavy loads in logging, carpentry, construction, quarrying and demolition (Wagner, 2020).

Failures in wheeled loaders such as overturning tends to occur due to machine design or overloading of the loader. The potential of elimination of all failures from a design is not realistically possible (Noriziah *et al.*, 2016). However, following proper working procedures with a wheeled loader taking into account the total weight it can carry and the maintenance done such failures can be omitted.

According to Tomlinson (2019), wheel loaders were classified into two groups such as light wheel loaders and heavy wheeled loaders. The light wheeled loaders are of smaller size and are used to carry light materials and are preferred for their compact size and the versatility they provide. These are such as compact wheel loaders, small wheel loaders and medium wheel loaders. Heavy (Large) wheeled loaders have powerful engines and are designed specifically for industrial purposes. Large wheeled loaders are heavy and provide optimum efficiency and According to Wagner (2020), wheel loaders were classified depending on the carrying capacity of the front-mounted bucket and the engine horsepower. A wheel loader was categorized into four classes referred to as compact, small horsepower, medium horsepower, and large horsepower.

Wheel loader costs can be broken down into ownership and operational costs, and these costs account for the machines total costs. Ownership costs include cost of purchasing the loader and operational costs include the fuel costs, operator labour cost, maintenance cost and repairing cost. Supervision and good maintenance of the wheeled loaders leads to increase in production hence increase in efficiency (Tomlinson, 2019).

2.4.1 Three wheeled loader

Three wheeled loader as one of the wheel loaders is remarkably versatile, being able to perform the following functions; pre-bunching (for other extraction units), extraction, loading and unloading (Stulen and Gleason, 1983). They are called three wheeled loader due to having three tires one front tire and two rear tires .The loader is being marketed to interface with existing harvesting equipment such as between a feller buncher and skidder or skidder and processor (Stokes *et al*., 1993). Three wheeled loader is known for its simplicity, low operating costs, maneuverability and high production capacity in comparison to other loaders. Three wheel loader does not have a steering wheel, clutch or brakes; instead there are two large independent hydrostatically powered and controlled drive wheels in front and one small castor wheel in the rear (Stokes *et al*., 1993). The direction and speed of the drive wheels are controlled through bidirectional foot controls. The machine has excellent maneuverability since it is possible to have one drive wheel rotating forward while the other is in reverse (Stulen and Gleason, 1983). A boom and grapple assembly is hinged above the cab on a cross member. When traveling forward the operator has excellent visibility. However, when traveling backward as in skidding, the operator visibility is reduced due to the location of the fuel tank (Stokes *et al*., 1993).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of Study Area

This study was conducted at Sao Hill Forest Plantations (SHFP) at Mufindi District, Iringa Region within the Southern highlands of Tanzania. Data were collected from Irundi division farm located about 29 km east from Mafinga town were trees are sold by the management to one of their client known as Mr. Abdi Shekivuli. Mr. Abdi had two three wheeled loaders, one of which was used in the collection of data needed.

SHFP is the largest industrial forest plantation in Tanzania, covering about 135 000 ha. Currently, 58 079 ha are covered with planted trees mainly softwood (Pines (e.g.*Pinus patula*, *Pinus elliotiii*, *Cupressus lusitanica*) and hardwoods Eucalyptus (e.g. *E. Saligna, E. grandis*), 48,000 ha are covered with natural forests, 1700 ha covered with buildings, while 27,221 ha is set aside for plantation extension (Ntalikwa, 2019). SHFP consists of four divisions with different sizes, namely Irundi, Ihefu, Ihalimba and Mgololo, their respective areas are shown on Table 1 (SHFPR, 2017).

3.1.1 Geographical location

Sao Hill Forest plantation (SHFP) is located between latitudes 8^0 18’ – 8^0 13’ S and longitudes 35^0 06’ - $35^0$20’E in the southern highland of Tanzania in Iringa region. The plantations are on rolling terrain interacted with some low hills and wide flat-bottom valleys at an altitude varying from 1400 to 2000 m above sea level (Mauya *et al*., 2011). At SHFP, forests are being harvested in large numbers by variety of clients using different methods and machines such as the use of skidders, forwarders, loaders (three wheel loaders) and trucks. This study was done at Irundi division. Figure 1 is a map of a study area showing the location and four divisions of SHFP

Table 1: Four divisions of Sao Hill Forest Plantation and its appropriate area (ha)

S/N	Division Name	Total area (ha)	Tree species
I	Irundi	13,266.89	*Eucalyptus spp* and *Pinus patula*
II	Ihefu	9,712.1	*Pinus patula* and *Pinus elliotii*
III	Ihalimba	15,137.06	*Pinus patula and Eucalyptus. grandis*
IV	Mgololo	7,884.27	*Eucalyptus spp, Cupressus lustanica,* and *Pinus patula*

3.1.2 Climate

The climate of Sao Hill is characterized by rainy season from November to April and dry season from May to late October. The mean annual rainfall is 1300 mm ranging from 725 mm to 1400 mm. Temperatures are fairly cool, the mean monthly temperature vary between 10^0C to 18^0C and maxima varying between 23 to 28^0C (Migunga, 1996).

3.1.3 Soils and vegetation

The area has deep soils with poor drainage and an acidic pH ranging from 4.4 to 5.4 (Ntalikwa, 2019). Apart from the planted trees there is also natural vegetation, which is determined by the amount of rainfall received in the area. The predominant natural vegetation is grassland with trees widely scattered. The planted trees for commercial use in the plantation are: *Pinus patula, Pinus eliotii, Cupressus lusitanica* and *Eucalyptus spp*.

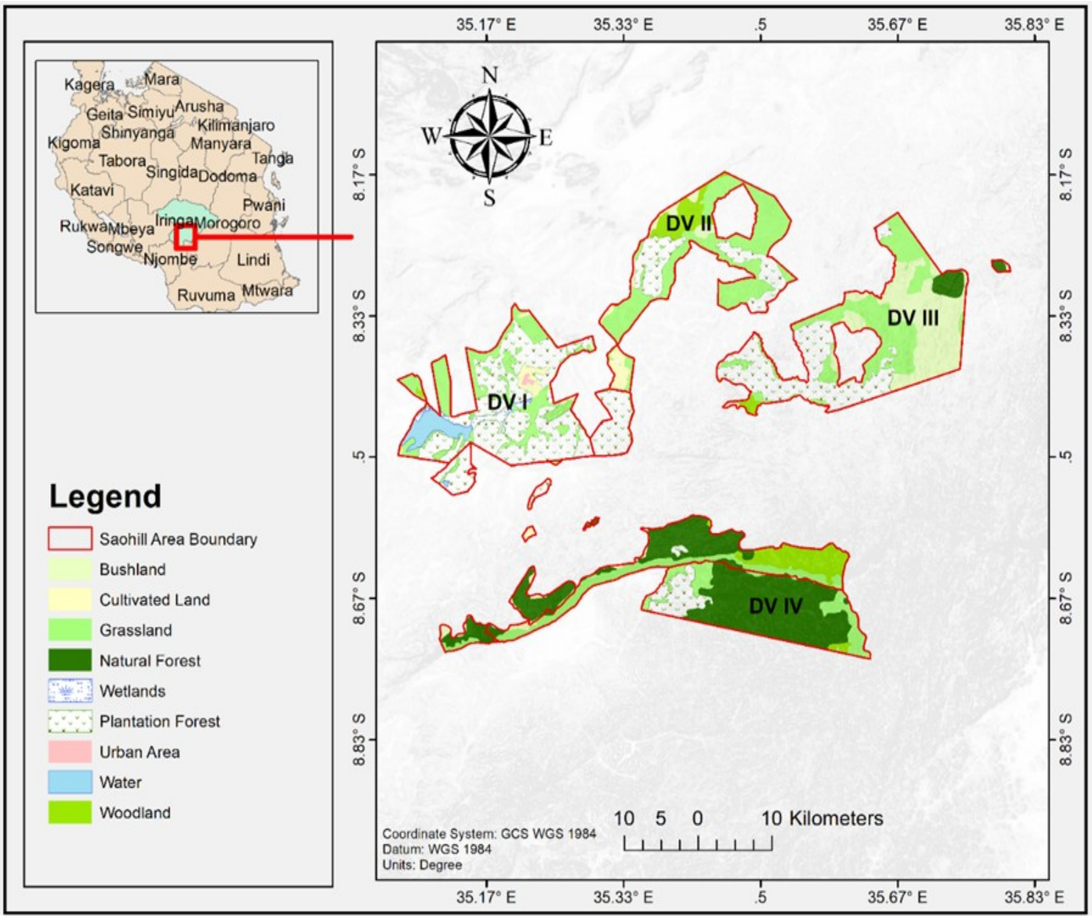

Figure 1: Map of Study Area.

3.2 Data collection

3.2.1 Research design

This study was designed to assess productivity and costs of three wheeled loader loading logs to log trucks. A case study research design was conducted at Sao Hill Forest Plantation (SHFP) in Mufindi district, Tanzania. The design was useful for determination of time taken for loading operations and description of dependent and independent variables relationship.

3.2.2 Materials and Equipment

3.2.2.1 Main Equipment

(a) Three wheeled loader

Three wheeled loader (Figure 2) known as bell logger by the operator and workers was the main equipment in the study. The loader was operated by single operator from the start to the end of data collection. The loader was very useful as all work elements were well observed during loading operations. Three wheel loader contains one front tire and two rear tires. The front tire is mainly useful in direction operation at which it helps the loader to turn in any direction with or without the load. The front tire tends to maneuver around the area when the loader is loading or grappling logs. The front tire is smaller in size in comparison to the rear tires. The rear tires are large in size and they are very useful in withstanding the load and maintain the stability of the loader when in movement or in static motion.

The loader does not have a steering wheel, clutch or brakes; instead there are two large independent hydrostatically powered and controlled drive wheels in front and one small castor wheel in the rear (Stokes *et al.*, 1993). The loader tends to overturn or slip when the load is heavy in comparison to its capacity. The direction and speed of the drive wheels are controlled through bidirectional foot controls. The operator controls the amount of load to carry through the use of the grapple handle boom hinged on a cab above the cross member. The machine has excellent maneuverability since it is possible to have one drive wheel rotating forward while the other is in reverse (Stulen and Gleason, 1983). When traveling forward the operator has excellent visibility. However, when traveling backward as in skidding, the operator visibility is reduced due to the location of the fuel tank and framework of the machine. Their simple design has resulted in a comparatively modest capital investment and this means the end-users benefit from the lowest cost per tonne solution for a machine (Ntalikwa, 2019).

(b) Truck

Trucks were used in transporting logs from the stump area to the landing area were measurements such as log diameter and length were done. The capacities of trucks were different in accordance to their maintenance and the weight of the given truck. The larger truck was able to carry about 10 to 20 logs per trip and the smaller truck which was a tractor was able to carry about 5 to 10 logs per trip in accordance to the volume of the logs per trip. Tree length harvesting method for most of the logs was employed by the management. Figure 3 shows arrangement of labelled logs by their number of observation (batch number) in the truck after loading by the three wheeled loader.

Figure 2: Three wheeled loader in action at SHFP

Figure 3: Labelled logs arrangement in truck before transportation

3.2.2.2 Time studies materials and equipment

- Stopwatch was used in determination of time taken for each work cycle element and delays.
- Tape measure was used in measuring of log’s length to the nearest meters.
- A caliper was used in measuring of the top and bottom diameter in cm at landing area.
- Chalks were used in labelling the logs loaded into the truck in their respected loaded batch number before independent variable measurements at landing area.
- Field forms were used for recording the data collected.
- A board, pens and pencils were used for writing and recording data into the field forms.

3.2.3 Sampling design and Sample size determination

Purposive sampling was employed in determination of the landing area to be used, number of logs to be loaded and three wheel loader to be used in order not to interfere with the workers and management plans. This sampling technique favored the nature of the study in reduction of errors which could have incurred if the logs harvested were done by different methods and not the tree length method used. This study followed a study design (Figure 4) in data collection which did simplify the work of the data needed and where and how to be collected. The pilot study was done to determine the sample size of the study by the use of equation (1);

$$N = \frac{t^2C^2}{E^2} \quad \text{......} \quad (1)$$

Whereby:

N = number of observations,

t = the value of t obtained from the student's t distribution table at n-1 degree of freedom,

E = allowable error acceptable to the time study in percentage,

C = Coefficient of variation computed as ratio of standard deviation to mean and

n = pilot number of observations.

Sampling error (E) at 5% was used in estimation. From the formula the number of observations were estimated to be around 200. As the result number of the observation estimated, the collected number of observation were 244 for the study. Cost of the three wheel loader were divided and assessed as variable costs and fixed costs which were very significant in determination of hourly costs (HC) in TZS/hr. Hourly cost were used in determination of Unit cost (UC) in TZS/m^3.

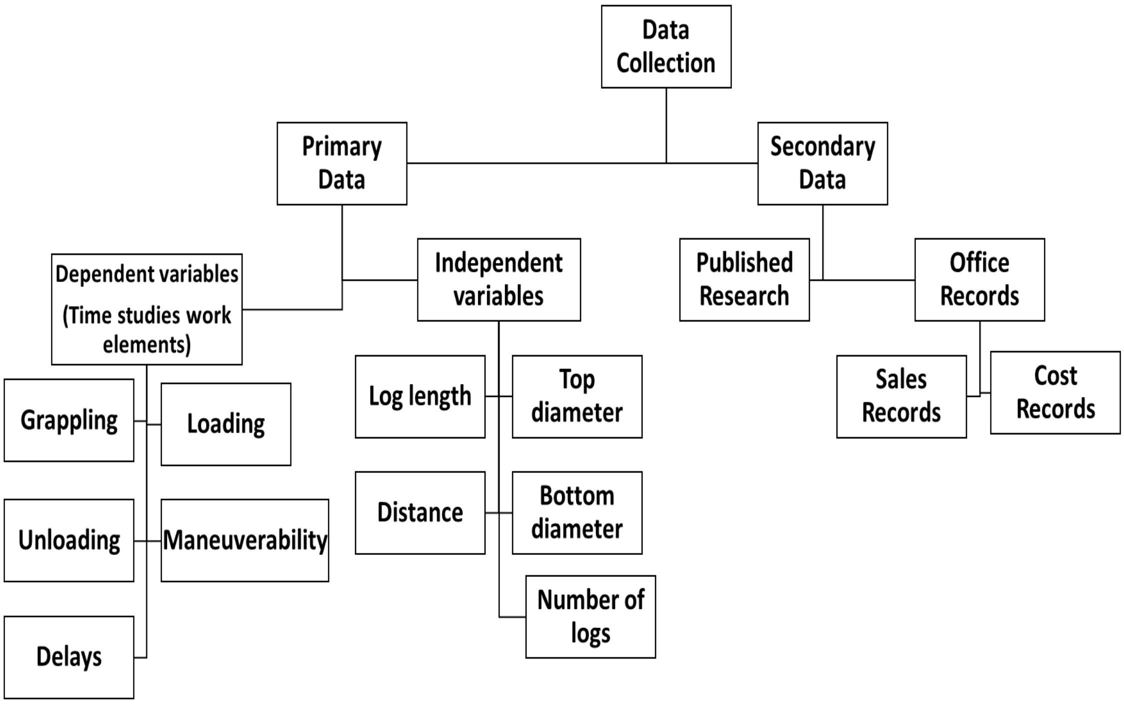

Figure 4: Data collection design

3.2.4 Primary data

Primary data were collected directly from the field through time studies of loading operations by three-wheel loader. Time studies of loading operations by using three wheeled loader were performed by the use of continuous time study method. Productive and delay times for each work element were recorded by the use of stopwatches. Snapback time study was used in determination of time taken for each work time element. Dependent variables included work time elements for the operation and independent variable were such as log length (L), number of logs (Nlogs), bottom diameter (BD), top diameter (TD) and distance between the loader and the logs to be loaded (D). Independent variables were used in determination of Volume per log (m^3).

The wheel loader loading operation productive cycle time were recorded in minutes and sub divided into following work elements;

Grappling (GR): This was the time required to hold the logs by the loader, it began when the loader started holding the logs and it ended when the loader couldn't hold anymore logs;

Loading (LO): This was the time required to load logs onto the truck, it began when the loader lifted the logs and it ended when the logs were on the truck;

Unloading (UN): This was the time required to release logs into the truck, it began when the logs are released and it ended when the loader was empty;

Maneuverability (MV): This was the time when the loader started to rotate (maneuver) after releasing the logs to when it started grappling the logs, it began when the loader was empty to when it started holding the logs.

Delays: These were all interruptions during the wheel loader operations which were observed and their times were recorded. Delays were classified as necessary delays (NEC) and unnecessary delays (UNEC). NEC were such as refueling, arranging of logs, eating, repairing, short breaks (urinating) and oil check and UNEC were talking, removal of rubbish/debris, travelling and smoking (Figure 5). All delays times were recorded in minutes.

Fuel consumption data were obtained from field for each day under study, used fuel was recorded and their data were useful in determination of fuel consumption by the loader.

Data collected were recorded on field forms in Appendix 1 and 2.

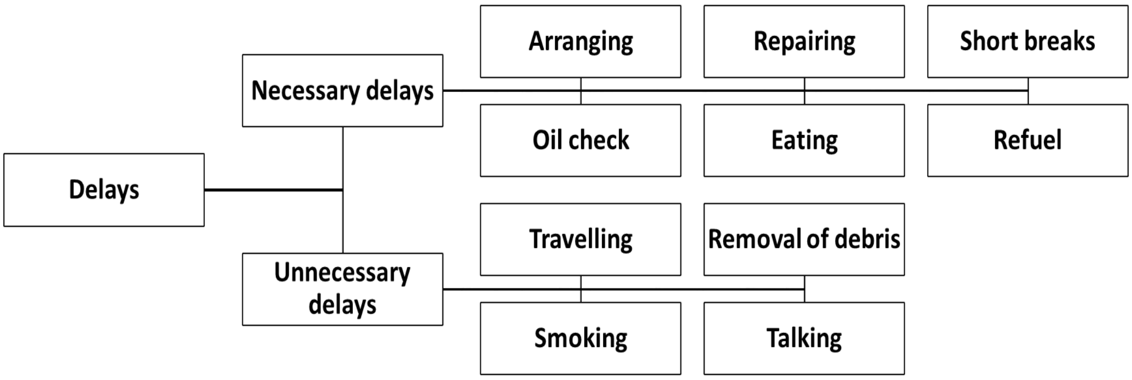

Figure 5: Observed delays during three wheeled loader operation

3.2.5 Secondary Data

Secondary data were obtained from (i) the office of Mr. Abdi Shekivuli the owner of the loader where three-wheel loader costs and maintenance costs were obtained (ii) the operator and workers through oral interview where fuel costs, fringe benefits and operational labour costs were obtained (iii) Sao Hill forest plantation offices where tax payments were obtained (iv) from previous published research conducted in the area. Data obtained were collected and recorded in field form on Appendix 3.

3.2.6 Limitations of the study

i. The study was done at landing place chosen by the management of Mr. Abiud Shekivuli which was in a gentle slope leading to the difference between slopes being very low hence the slope of the area was negligible.

ii. Trucks used in loading conditions were of different sizes and they changed in daily to daily work that could affect loading productivity.

iii. Climate of the area was not controlled during data collection, it was a rainy season which led to the data collected during wet and some dry days hence the collection of data followed that pattern.

iv. The study was done by using only one three wheel loader manufactured by Bell Company known as Bell logger.

v. Independent variables such as length of logs were not controlled during data collection due to the fact that it was in accordance to the management decisions on the intended output.

3.3 Data Analysis

Analysis of data was done to reflect the following: (i) time taken for loading operations using a three-wheel loader (ii) production rates for the use of three wheel loader (iii) fuel consumption rate of the three-wheel loader (iv) total loading unit costs of the use of three-wheel loader. Data were analyzed by the use of Microsoft excel and R software.

3.3.1 Time taken for loading operations using three wheeled loader

Time taken for loading operations were determined through the use of stopwatches by recording the time taken for each work cycle element. The work cycle time elements included;

Grappling time (GR): Grappling time was analyzed in terms of descriptive statistics and regression analysis. Descriptive analysis was used in determination total and average time taken for the grappling time. Regression analysis was done for testing the following hypothesis;

Ho: Grappling Time = f (Number of logs, Length of logs, Volume of logs)

Loading time (LO): Loading time was analyzed by descriptive statistics to find the average and total of loading time. Regression analysis was done by using the following hypothesis;

Ho: Loading Time = f (Volume of logs, Number of logs, Length of logs, Distance)

Unloading time (UN): Unloading time descriptive statistics was done to express the total and average time taken for the operation. Regression analysis was done in consideration of the following hypothesis;

Ho: Unloading Time = f (Number of logs, Length of logs, Volume of logs)

Maneuverability time (MV): Maneuverability time descriptive statistics as others was done to find the average and total time taken for the operation. Regression analysis hypothesis was given as;

H_O: Maneuverability time (MV) = f (Distance)

Delays: Delays described as Necessary delays time (NC) and Unnecessary delays time (UNEC) were analyzed by descriptive statistics to find the average and total time taken for these operations.

Microsoft excel software was used to compile the data for the time taken for each work cycle element observed and recorded.

3.3.2 Production rates of using three-wheel loader

Data collected for independent and dependent variables were summarized in Microsoft excel software. Descriptive data analysis was used to find how work cycle elements contribute to productivity. Total volume (T_{vol}) computed from the use of equation (ii) and total time taken were used in determination of productivity. Volume was computed by the use of Smalian formula (equation ii). Smalian formula was used as it is accurate when the logs are in piles and the mid diameter cannot be identified (León and Valencia, 2013). Volume for each observation was computed leading to computation of total volume (T_{vol}) by the use of regression analysis.

$$V = \frac{A_1 + A_2}{2} \times L \qquad (2)$$

Whereby:

V is the volume of the log in cubic meters, m^3,

A_1 and A_2 are the area of the log small end and large end respectively in m^2 and

L is the length of the log in m.

Production rates (Productivity) of the use of three-wheel loader was computed by the use of the following equation (iii);

$$P = \frac{(T_{Vol})\,(F)\,(60)}{T} \qquad (3)$$

Whereby:

P = Productivity in m^3/hr for the logging operation

T_{Vol} = Total volume of all logs for the logging operation, m^3

60 = Number of minutes per workplace hour

F = Proportion of productive time to workplace hour

T = Total productive time (minutes) from the regression equation.

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

Whereby:

F = A fraction measuring the proportion of productive time

D = Delay time expressed as percentage of workplace time.

3.3.3 Fuel consumption rate of the use of three-wheel loader

Data collected for fuel consumption were analyzed by the use of descriptive analysis. Fuel consumed rate was computed by the use of equation (5);

$$FCR = \frac{TFC}{T} \quad \text{.............} (5)$$

Whereby:

FCR = Fuel consumption rate (l/min)

TFC = Total fuel consumed (litres) and

T = Total productive time (minutes) from regression equation.

3.3.4 Total loading unit costs of the use of three-wheel loader

Three wheeled loader costs were divided into fixed and variable costs. Total cost was computed as summation of variable and fixed costs. Fixed costs include depreciation, insurance costs and salary costs. Variable costs consisted of operating labour cost, hourly machinery cost and repair and maintenance cost.

These costs data collected were analyzed to determine unit cost in TZS/m^3.

3.3.4.1 Fixed costs

a) Insurance costs

Insurance costs was estimated by the use of equation (6) and (7);

$$AAI = \frac{(P)(L+1) + (S)(L-1)}{2L} \quad \text{.............} (6)$$

Whereby:

AAI = Average annual investment in the asset

P = Purchase price of the asset, TZS.

L = Expected useful life time of the asset in years.

S = Salvage value of the asset at the end it's useful life, TZS.

Annual insurance was then estimated as a fraction annual investment by the use of equation (7);

$$Ins = (AAI)(r) \qquad (7)$$

Whereby:

Ins = Annual insurance cost, TZS.

r = Insurance rate, %.

b) Depreciation costs

Depreciation cost was computed using straight-line method represented by equation (8);

$$Depreciation = \frac{P - S}{L} \qquad (8)$$

Whereby:

P = Purchase price of the asset, TZS

S = Salvage value, TZS

L = Expected useful life time of the asset in years.

3.3.4.2 Variable costs

a) Repair and maintenance costs

Repair and maintenance costs were collected from office records and recorded in data forms in appendix 3 and they were computed with other variable costs to get total variable costs.

b) Labour costs

Data payments to labour and the cost of social benefit were collected through face to face interview and office records which were used to determine annual labour costs.

3.3.4.3 Total annual and unit costs

Total costs as annual cost was determined as a summation of variable costs and fixed costs (equation 9);

Total annual costs = Variable costs + Fixed costs ……………………………………… (9)

Annual costs (TZS/yr) was converted to hourly costs (TZS/hr) by using equation (10);

$$\text{Hourly cost (TZS/hr)} = \frac{\text{Annual costs (TZS/yr)}}{\text{Working days per year * working hours per day}} \quad \ldots\ldots (10)$$

The hourly cost together with production rates was used to calculate unit costs in Equation (11)

$$\text{Unit cost (TZS/m}^3\text{)} = \frac{\text{Hourly costs (TZS/hr)}}{\text{Production rate (m}^3\text{/hr)}} \quad \ldots\ldots (11)$$

3.3.5 Data analysis matrix

The analysis matrix (Table 2) shows the output for each specific objective and the analysis used to reach to final output. Statistical tools such as Microsoft excel and R software were useful in analysis of data.

Table 2: Data analysis matrix

Required	Data required	Analysis	Output
Objective 1	Time taken for loading operation	Descriptive analysis (mean, Standard error, Max and Min, Confidence level) Regression analysis	Time taken for loading operation
Objective 2	Length of logs (L) Bottom diameter of logs (BD) Top diameter of logs (TD) Time taken for each work element Volume of logs (Smalian's formula Equation ii)	Regression analysis Equation (iii) and (iv)	Productivity of the three wheeled loader
Objective 3	Daily fuel consumed	Computation of fuel consumption rate (Equation v)	Fuel consumption rate of three-wheel loader
Objective 4	Fixed costs Variable costs	Cost analysis using acquired data (Equation vi, vii, viii, ix, x and xi)	Operational unit cost of three-wheel loader

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter discusses the results of productivity and costs of the three-wheel loader operations in terms of descriptive and regression analysis results of the whole loading operation.

4.1 Descriptive data statistics

This section presents and discusses summary statistics for the dependent and independent variables. Dependent variables includes discussion on total loading time for the whole operation which summarizes the loading time cycle elements, delays distributions and total productive loading time of the loader. Independent variables includes discussion on summary statistics of all independent variables collected from the field.

4.1.1 Time taken for loading operations using three wheeled loader

Total average time taken for the whole operation was estimated as 1.5 minutes. The minimum total time taken for the whole operation was 0.27 minutes and maximum total time taken 24.88 minutes as seen in Table 3. Among all loading operation time elements and delays, necessary delays had the highest mean of 0.56 minutes which was equivalent to 35.65% of total operation time of the loader. This was due to the fact that there were some fixed time for necessary delays such as eating breaks which ranged from 2 to 10 minutes per day and their schedule was in the form that couldn't be altered. The least time taken among all loading operation time elements and delays was maneuverability time as it had an average of 0.13 minutes which was equivalent to 8.56% of the total operation time.

The mean grappling time was estimated as 0.27 minutes equivalent to 17.29% of the whole loading time operation ranging from 0.06 to 0.82 minutes. The mean loading time was estimated to 0.21 minutes equivalent to 13.58%. Unloading time averaged 0.16 minutes equivalent to 10.51% of the total loading time and Unnecessary delays averaged 0.22 minutes which was equal to 14.41% of the whole loading operation. The number of observation for all loading time cycle elements was 244 observations. The variation of the time consumed by the three-wheel loader based on their loading time cycles are presented in figure 5, summarized as Grappling (GR) had 17.29% of total time taken, Loading (LO) 13.58%, Unloading (UN) 10.51%, Maneuverability (MV) 8.56%, Necessary delays (NEC) 35.65% and Unnecessary delays (UNEC) had 14.41%.

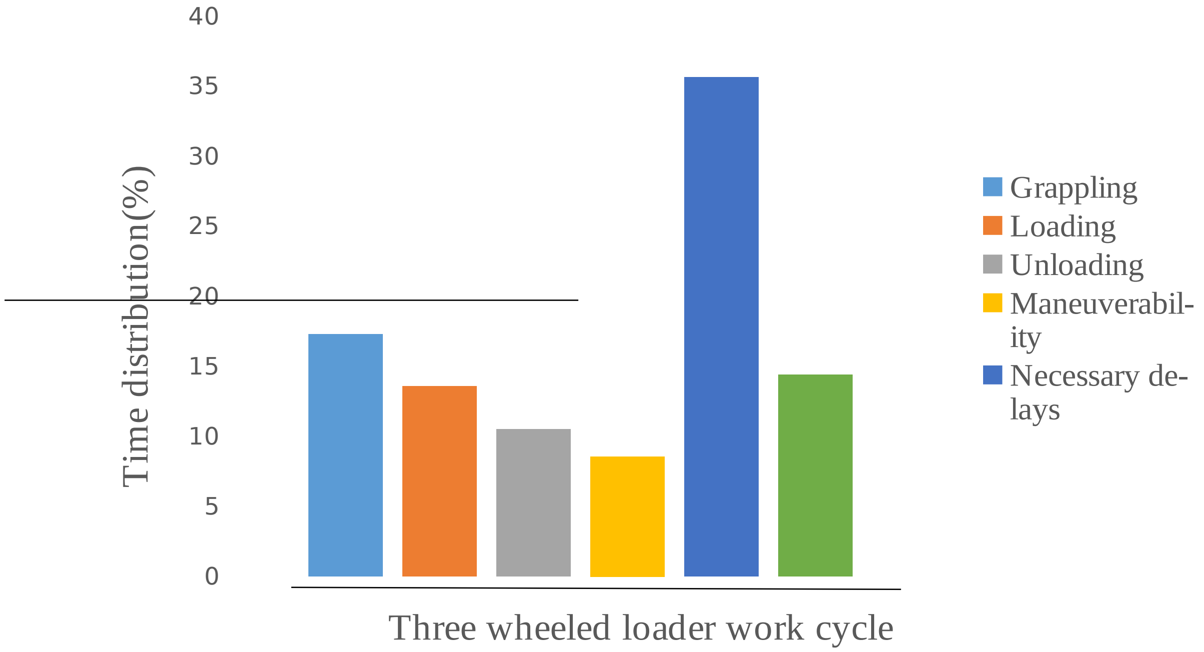

Figure 6: Three-wheel loader work cycle distribution time elements

Table 3: Summary statistics of Three-wheel loader work cycle elements and delays

Time elements	GR (min)	LO (min)	UN (min)	MV (min)	NEC (min)	UNEC (min)	TOTAL (min)
Mean	0.26	0.21	0.16	0.13	0.56	0.22	1.56
Standard Error	0.01	0.01	0.01	0.01	0.14	0.08	0.17
Standard Deviation	0.16	0.14	0.12	0.05	2.23	1.32	2.58
Minimum	0.06	0.02	0.04	0.04	0	0	0.27
Maximum	0.82	1.18	0.58	0.30	24.01	19.10	24.87
Percentage %	17.29	13.58	10.52	8.56	35.64	14.41	100
Count	244	244	244	244	244	244	244
Confidence Level (95.0%)	0.02	0.02	0.01	0.01	0.28	0.17	0.33

4.1.2 Delays distribution

Delays were classified as necessary delays (NEC) and unnecessary delays (UNEC). Necessary delays (NEC) included refueling, arranging of logs, eating, short breaks, repairing and oil check and unnecessary delays (UNEC) were talking, travelling, removal of rubbish/debris and smoking.

4.1.2.1 Necessary delays (NEC)

NEC average time taken was 0.56 minutes (35.65%) of total operation time of the loader. NEC had the highest time taken in consideration to other time taken elements. Among all NEC, eating break time had a highest time taken of about 45.83 minutes which was equivalent to 32.79% of all NEC time. Short breaks which included urinating or attending to nature call had the lowest time taken for the NEC which was about 8.15 minutes equivalent to 6.01% of all NEC as seen in Table 4. Arranging of logs before grappling took about 40.43 minutes which was 24.81% of all NEC followed by refueling which took about 16.02 minutes (11.81%) then oil check which took about 24.01 minutes (17.20%) and

repairing which had a time taken of 10.01minutes (7.38%). NEC took about 71.21% of all delay time. Figure 7 shows distribution of NEC in a pictorial bar graph indicating variations of the necessary delays discussed.

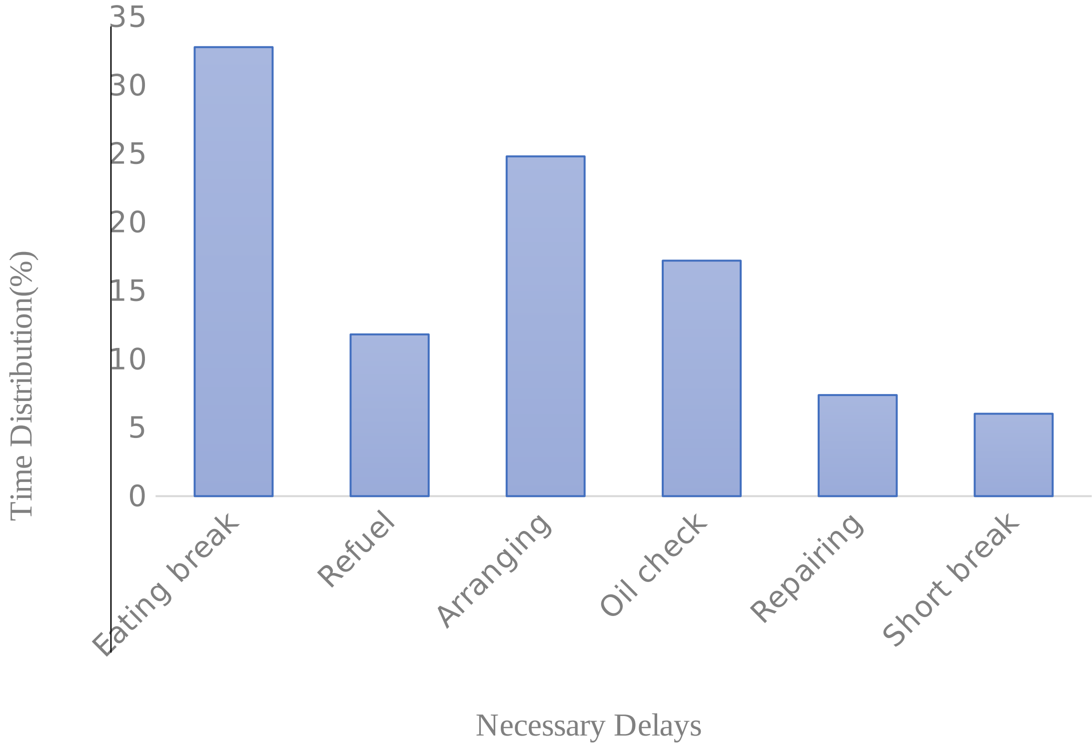

Figure 7: Time distribution for necessary delays

Table 4: Necessary delays Summary statistics

Necessary delays	**Eating Break**	**Refuel**	**Arranging**	**Oil check**	**repairing**	**short break**
Mean	6.55	8.01	1.06	24.01	10.01	2.04
Standard Error	1.39	1.99	0.29	0	0	0.78
Minimum	2.01	6.01	0.09	24.01	10.01	0.48
Maximum	11.24	10.01	10.01	24.01	10.01	3.42
Percentage	32.79	11.81	24.81	17.20	7.38	6.01

Confidence Level (95.0%)	3.41	25.39	0.58	0.00	0.00	2.48

4.1.2.2 Unnecessary delays (UNEC)

UNEC average time was 0.22 minutes which equaled to 14.41% of total operation time of the loader as seen in Table 3. Talking as one of UNEC took a lot of time in consideration to other UNEC which was equivalent to 65.79% of all UNEC (37.17 minutes). Talking was followed by removal of debris or unwanted materials which took about 8.01 minutes which equaled to 14.61% of all UNEC then unnecessary travelling of the loader which had 5.98 minutes (10.80%) and the least time taken was smoking which took about 4.85 minutes equivalent to 8.80% as seen in Table 5. UNEC were equivalent to 28.79% of all delays incurred during the use of three-wheel loader. Figure 8 shows a pictorial bar graph indicating the variation among UNEC discussed.

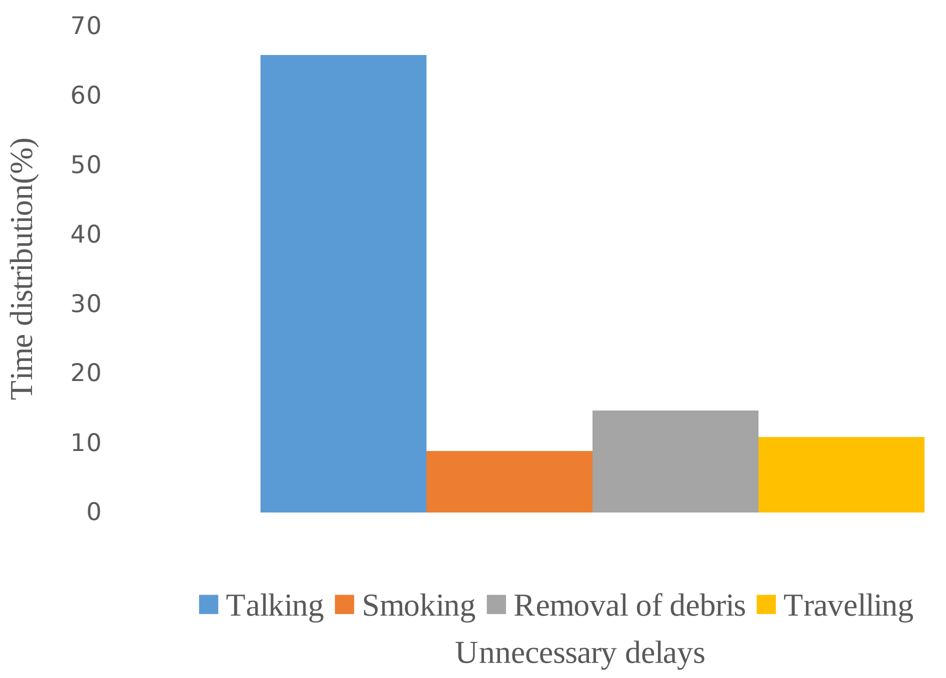

Figure 8: Time distribution for unnecessary delays

Table 5: Unnecessary delays Summary statistics

Unnecessary Delays	Talking	Removal of debris	Unnecessary Travelling	Smoking
Mean	3.38	0.89	0.60	1.62
Standard Error	1.62	0.07	0.13	0.83
Standard Deviation	5.36	0.21	0.40	1.43
Minimum	0.67	0.66	0.19	0.58
Maximum	19.10	1.31	1.31	3.25
Percentage	65.79	14.61	10.80	8.80
Confidence Level (95%)	3.60	0.16	0.29	3.56

4.1.3 Total loading productive time

Total loading productive times (TPT) comprised of the sum of the effective time (loading time cycle elements) and necessary delays of the loading operations. Good supervision can eliminate all unnecessary delays leading to better productive time (Jones, 1993). Total productive time ranged from 0.27 to 24.87 minutes with a mean of 1.33 minutes as seen in Table 5. Loading productive time showed how effective the loader was in terms of its loading time work elements and how unnecessary delays affected the loading time. It was seen that unnecessary delays had effect on loading operation of the loader whereby the total mean time which included unnecessary delays was 1.56 minutes (Table 3) and total loading productive time excluding unnecessary delays was 1.33 minutes (Table 6). This showed that unnecessary delays had an average of 0.23 minutes affection to the loading time production hence indicating why it should be eliminated for better loading operation of the three wheeled loader.

Table 6: Summary statistics of total productive time (TPT)

Loading productive times	GR(min)	LO(min)	UN(min)	MV(min)	NEC(min)	TPT(min)
Mean	0.27	0.21	0.16	0.13	0.56	1.33
Standard Error	0.01	0.01	0.01	0.00	0.14	0.14
Standard Deviation	0.16	0.14	0.11	0.05	2.23	2.25
Minimum	0.06	0.02	0.04	0.04	0	0.27
Maximum	0.82	1.18	0.58	0.30	24.01	24.87
Count	244	244	244	244	244	244
Confidence Level (95.0%)	0.02	0.02	0.01	0.01	0.28	0.28

4.1.4 Independent variables

Independent variables included number of logs (Nlogs), distance (D), log length (L), top diameter (TD) and bottom diameter (BD). These variable were used in determination of volume of logs (V). These independent variables varied differently in affecting the dependent variables. Number of logs grappled and loaded by the loader ranged from 1 to 7 logs. Distance between the loader and truck ranged from 0.7 to 3 meters. The length of logs varied from 4.3 to 6.99 meters with an average of 5.87 meters. Mean bottom diameter was estimated to 0.32 meters ranging from 0.11 to 0.63 meters and mean top diameter was given as 0.29 meters ranging from 0.1 to 0.57 meters. The volume of logs was estimated to have an average of 1.06 m^3 with a minimum of 0.17 m^3 and a maximum of 2.72 m^3. Table 7 summarizes what has been discussed above about independent variables.

Table 7: Independent Variables summary statistics

Independent variables	BD(m)	TD(m)	L(m)	D(m)	Nlogs	V(m^3)
Mean	0.32	0.30	5.87	1.74	2.59	1.06
Standard Error	0.01	0.01	0.02	0.04	0.07	0.03
Standard Deviation	0.09	0.08	0.37	0.60	1.15	0.42
Minimum	0.10	0.10	4.13	0.70	1	0.17
Maximum	0.63	0.57	6.99	3.00	7	2.72
Count	244	244	244	244	244	244
Confidence Level (95.0%)	0.01	0.01	0.05	0.08	0.14	0.05

4.2 Multiple regression data statistics

Regression equations were developed for all loading cycle time elements and loading productive time. For each loading time element a hypothesis was developed related to the independent variable that would theoretically be expected to have influence on loading time. In the regression analysis results that follows:

a) R^2 is the coefficient of determination which measures the fraction of variance in the observed values of the independent variable which is explained by linear relationship between that variable and independent variable(s);

b) n is the number of independent observations;

c) the regression equations developed are estimated to have a maximum error of 5% (0.05);

d) numerical values entered below the regression coefficients in each equation are the standard errors of the respective coefficients.

4.2.1 Grappling operation regression results

Grappling time was the time taken to hold logs by three wheeled loader and it began as the loader started to hold the logs and it ended when the loader couldn't hold anymore logs. The loader was able to hold a minimum of 1 log to a maximum of 7 logs. As of this reason I formulated the following grappling time regression hypothesis.

H_O: Grappling Time (GR) = f (Number of logs (Nlogs), Length of logs (L), m, Volume of logs (V), m^3)

Regression equation for grappling operation was developed as;

GR = 0.1834 + 0.0332Nlogs………………………………………………………….. (12)
(0.008843)

R^2 = 0.9823 n= 244

Results indicated that among all the variables considered for grappling time, only number of logs had a significant variation in consideration to all other variables such as volume of logs and length of logs due to its R^2. Hence, Equation (12) generated above would be used with confidence to predict grappling time for the three wheeled loader if the number of logs grappled by the loader are known. Appendix 6 shows the linear relationship between grappling time and number of logs.

The results didn't vary much as what I expected because grappling time was highly affected by the number of logs grappled during data collection. The high the number of logs grappled by the loader the higher was the time taken and the vice versa. This shows that the results were not biased in any form as the way it was expected for grappling operation.

4.2.2 Loading operation regression results

Loading time was the time required to load logs into the truck. It started when the loader lifted the load and it ended when the load was on the truck. The regression hypothesis was formulated in consideration to the distance between the loader and the truck as it was seen that distance had an effect on loading time, also volume of logs, length of logs and number of logs were considered as they theoretically affected loading time.

Loading operation regression hypothesis;

Ho: Loading Time = f (Volume of logs (V), m^3, Number of logs (Nlogs), Length of logs (L), m, Distance (D), m)

Regression equation for loading time operation

LO =0.146373+0.011069L+0.024209Nlogs+0.010349V-0.04216D…………………. (13)
(0.024773) (0.008021) (0.022501) (0.014949)

R^2 = 0.067608 n = 244

Results indicated that among all variables, there wasn't any variable which was a good predictor of loading time because of small R^2 generated through regression equation (13). This concurs with Mauya (2011) results which indicated that grappling and unloading time elements in grapple skidder were not predicted by the variables in the study. These results could have occured because of other variables not studied such as the speed of the operator and operator experience. Therefore, the equation generated cannot be used with confidence to estimate loading time, the average loading time 0.21 minutes (Table 3) could be used instead.

4.2.3 Unloading operation regression results

Unloading time was the time required to unload logs from the truck, it began when the logs were released by the loader and it ended when the loader was empty. Unloading time regression hypothesis was estimated based on the null hypothesis below;

Ho: Unloading Time = f (Number of logs (N), Length of logs (L), m, Volume of logs (V), m^3)

Unloading operation regression equation:

UN = 0.132989 – 0.00956L + 0.026744Nlogs + 0.016626V ………………………… (14)
(0.020326) (0.006478) (0.018215)

R^2 = 0.78536 n=244

The results showed that all the variable considered affected unloading time as it had a considerable R^2 in multiple regression hence the variables were good predictor's of unloading time. The equation would be usefully in prediction of unloading time if distance from the loader to the truck, volume of logs and length of logs are known.

4.2.4 Maneuverability operation regression results

Maneuverability time was the time taken when the loader started to maneuver around the landing after releasing the logs to when it started grappling the logs again, it began when the loader was empty from the truck to when it started holding the logs. Maneuverability was considered to depend on the distance between the loader and the truck. As of this, regression null hypothesis was by consideration of distance only.

H_O: Maneuverability time (MV) = f (Distance (D), m)

Maneuverability equation was developed as seen below;

MV = 0.123951 + 0.005456D ……………………………………………………….. (15)
(0.00554)

R^2 = 0.003992 n = 244

Results showed that distance wasn't a good predictor of maneuverability time taken as it had a very low R^2. This could be caused by the other factors which weren't studied. These factors were such as; turning angle, slope, speed of the operator, age of the loader, operator experience and skill and trainings of the operator. The equation generated cannot be used in confidence in prediction of maneuverability time taken of the loader hence the mean maneuverability time 0.13 minutes (Table 3) can be used instead.

4.2.5 Total loading productive time regression results

Total loading productive time was considered to be affected by the following independent variables; number of logs, volume of logs, distance and length of log. Hence the total loading time null hypothesis was given as;

H_O: TPT = f (Length of logs (L), m, Volume (V), m^3, Number of logs (N), Distance (D), m)

Total loading productive time regression equation:

$$TPT = 0.3332L + 0.2562N + 0.0527D + 0.1688V - 1.559047 \quad \text{.............................} (16)$$

(0.41008) (0.05117) (0.82898) (0.64587)

$R^2 = 0.02446428$ n = 244

The results from the equation (16) above shows that all variables used were not good predictors of total productive time which was indifferent with the expectation of the study. This was due to low values of adjusted coefficient of multiple determinations (R^2) of a three-wheel loader. In determination of the model even the logarithmic coefficient were added to values in order to increase their chances of being a good predictor but the coefficient of determination R^2 remained very low.

This could be attributed to the fact that loading productive time either depended on factors that were not studied. The factors that were included in the study were highly variable and were not controlled during the study thus leading to low R^2 values. Three wheel loaders productive times is influenced by many factors that were not measured by the study. Factors that were not studied included operator experience, operator speed, slope, age of the loader, loader maintenance, operator payments, turning angle of the loader and skills and trainings.

Equation (16) generated would not be used to in confidence to predict total loading productive time hence using mean or average value of the total productive time 1.33 minutes (Table 6) would serve as a prediction of total loading time by three wheel loaders in this case.

4.2.6 Production rate

The general format for production rate was given as seen in equation 3 and 4. Volume was computed by the use of Smalian formula as in equation 2. Total volume (Tvol) of the three wheeled loader was influenced by log length, top diameter, bottom diameter and number of logs loaded hence leading us to find the relationship between total volume and these independent variables by using regression statistics.

Total volume of logs loaded by three-wheel loader null hypothesis was given as;

Ho: Total volume (Tvol) = f (Bottom diameter (BD), m, Top diameter (TD), m, Length of logs (L), m, Number of logs (Nlogs))

Volume regression equation:

$$Tvol = 0.316981Nlogs + 1.818375TD + 3.193706BD + 0.26393L - 2.86934 \quad \text{…………. (17)}$$

(0.014908) (0.993386) (0.950227) (0.036811)

$R^2 = 0.75914$ n = 244

Due to high R^2, it showed that the variables considered had a significant effect on volume hence if number of logs, top diameter, bottom diameter and length of logs are known volume of a three wheeled loader can be estimated.

The production rate equations developed considered the inclusion of all delays and exclusion of unnecessary delays. An estimate of Tvol for calculation of Production rate was estimated by regression equation 17. Total productive time (T) from Equation 3 was estimated as the mean average value for total loading productive time which was 1.33 minutes. 0.88 and 0.81 were the mean average value of F values for inclusion of necessary delays and inclusion of all delays respectively (Appendix 7).

Production rate equations for three-wheel loader derived by substituting the values and equations above were as follows;

a) With all delays included

$$P_{ALL} = \frac{11.41Nlogs + 88.37TD + 155.21BD + 12.83L - 139.4}{1.33} \quad \ldots\ldots\ldots 17$$

b) With only necessary delays included

$$P_{NEC} = \frac{16.73Nlogs + 96.01TD + 168.43BD + 13.94L - 151.5}{1.33} \quad \ldots\ldots\ldots 18$$

These production rate equations depended on number of logs (Nlogs), top diameter (TD), bottom diameter (BD) and length of logs (L). The inclusion of all delays and inclusion of only necessary delays shows the relationship between productivity and delays. Table 8 shows production rates by the use of equation 17 and 18 whereby top diameter, bottom diameter and length of logs were kept constant and their mean average values (Table 7) were used instead. Number of logs was used as varied independent variable at which sample of 1 to 10 logs was used to estimate production rates. The production rates summarized in Table 7 have been plotted in figure 10. The line graph (Figure 9) shows that as number of logs loaded increases productivity increases. The maximum value is achieved when the loader has loaded high amount of logs which showed that three wheel loader productivity highly depends on the number of logs grappled and loaded. Productivity while all delays are included shows low values in comparison to when unnecessary delays have been omitted hence reduction of all unnecessary delays leads to high productivity of the three-wheel loader. So supervision should be highly encouraged in order to decrease unnecessary delays and to have a maximum possible productivity of the three wheeled loader.

Table 8: Production rate of the three wheeled loader

Nlogs	P_{ALL} (m^3/h)	P_{NEC} (m^3/h)
1	17.30	21.98
2	25.88	34.55
3	34.46	47.13
4	43.04	59.71
5	51.62	72.29
6	60.19	84.87
7	68.78	97.45
8	77.36	110.03
9	85.93	122.61
10	94.51	135.19

P_{ALL}= Production rate (m^3/h) with inclusion of all delays P_{NEC}= Production rate (m^3/h) with inclusion of necessary delays only Nlogs = Number of logs

In summary, production rate while including all delays was estimated as 43.04m^3/h while including only necessary delays was estimated as 59.71m^3/h. The high production rates indicated that the factors considered in the field affected the productivity of the three wheel loader. The results concurs with Stokes *et al.* (1993) who also found high productivity of Mor-Bell logger (three-wheel loader) for skidding operations in United States of America. The higher productivity may be as a result of good organization of the work in the field. On daily basis the loader could skid the logs in piles in one place before the work starts hence minimizing delays for loading operations. Also operator experience could be the other factor contributed to high productivity as the operator had an experience of three years

working with the loader. The relationship between experience and productivity is known as learning curves, it describes the level of performance through learning over time (Silayo, 2007).

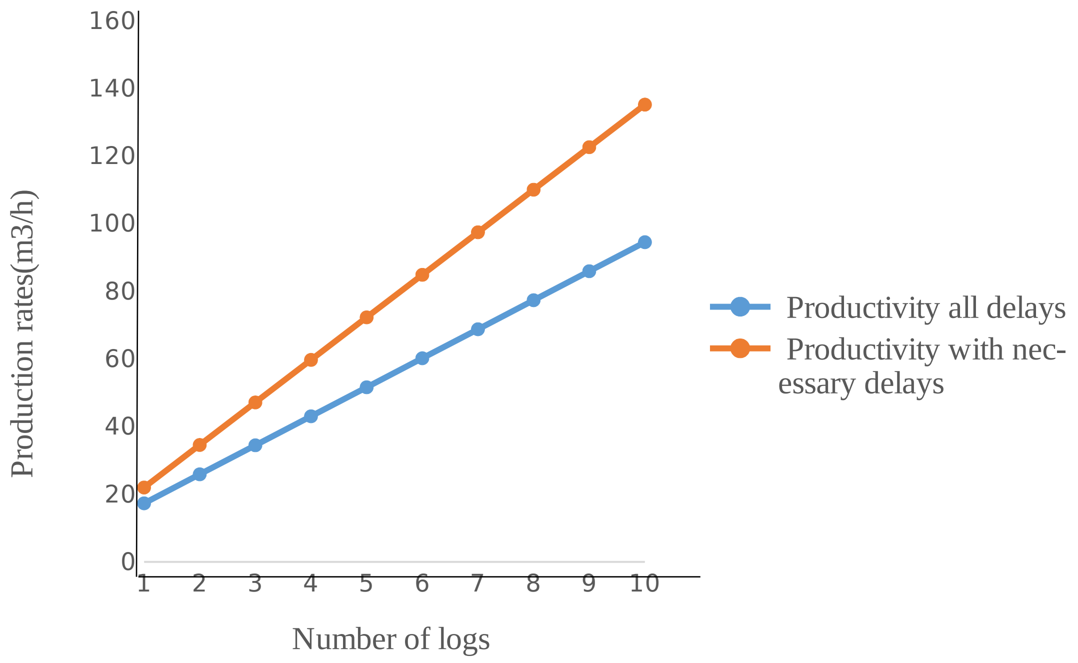

Figure 9: Production rates of the three-wheel loader as a function of number of logs

4.3 Fuel consumption rate

Three litres of fuel were used per day by the loader. Fuel consumption rate had an average of 0.0029 litres/min ranging from 0.00055 litres/min to 0.052 litres/min (Appendix 7). This indicated that the loader was very economical in daily to daily fuel consumption. Frank *et al*. (2012) suggested that fuel efficiency productivity depends on operator experience and skills. They suggested that the experience of wheel loaders operators tends to decrease the amount of fuel consumed by working without delays which increases fuel efficiency and productivity. The driver had an experience of three years which could be a factor as Frank *et al.* (2012) suggested.

Even maintenance of the loader could have affected how fuel was consumed. Good maintenance of the loader helped the loader to work properly hence decreasing the amount of fuel used per minute. Figure 10 illustrates the relationship between fuel consumption and total productive time.

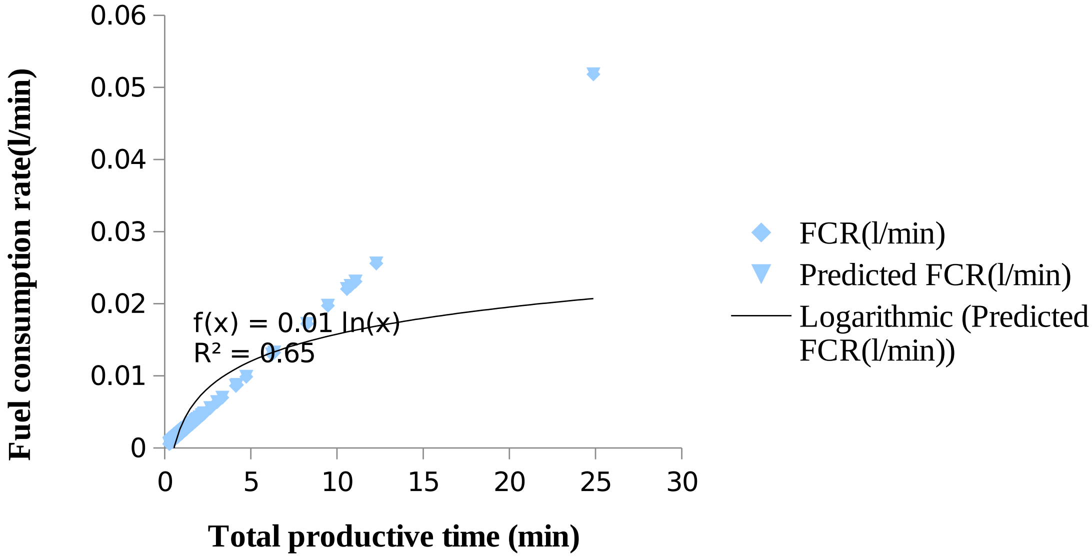

Figure 10: Fuel consumption rate as a function of total productive time

4.4 Three-wheel loader costs

Total annual fixed cost for the operational of three-wheel loader was estimated as TZS. 8 865 000 per year and total annual variable cost was TZS. 12 288 000 per year (Appendix 4 and 5). Then total annual cost as from Equation 9 was estimated as TZS. 21 153 000 per year. Hourly costs as estimated by Equation 10 was estimated to be 470 078 TZS/h (Appendix 5). Unit cost of production from equation 11 was estimated to 10 922.01 TZS/m^3 including all delays and 7 872.30 TZS/m^3 including only necessary delays. This showed that if unnecessary delays are omitted costs of production tends to decrease. The results agrees with Stokes *et al.* (1993) who found that the unit costs of bell logger (three-wheel loader) to be \$6.12/ft^3 (14192.28 TZS/m^3) in skidding operations.

This means that the unit costs of a bell logger in loading operations can be estimated as seen in equation 19 and 20.

Depreciation costs was the mostly costly cost of all costs comprising of 74.45% of total fixed costs which was equivalent to 31.2% of total annual costs, Insurance costs was estimated as 25.55% of total fixed costs which was equivalent to 10.7% of total annual costs. For variable costs, the costliest element was labour costs having 48.83% of total variable costs equivalent to 28.36% of total annual costs, followed by maintenance costs which had 28.97% of total variable costs equivalent to 16.83% of total annual costs, then fuel costs which had 16.93% of total variable costs equivalent to 9.83% of total annual costs and lastly oil and lubricants costs which had 5.27% of total variable cost equivalent to 3.06% of total annual costs. Figure 11 illustrates the different percentage costs incurred by three wheeled loader operations.

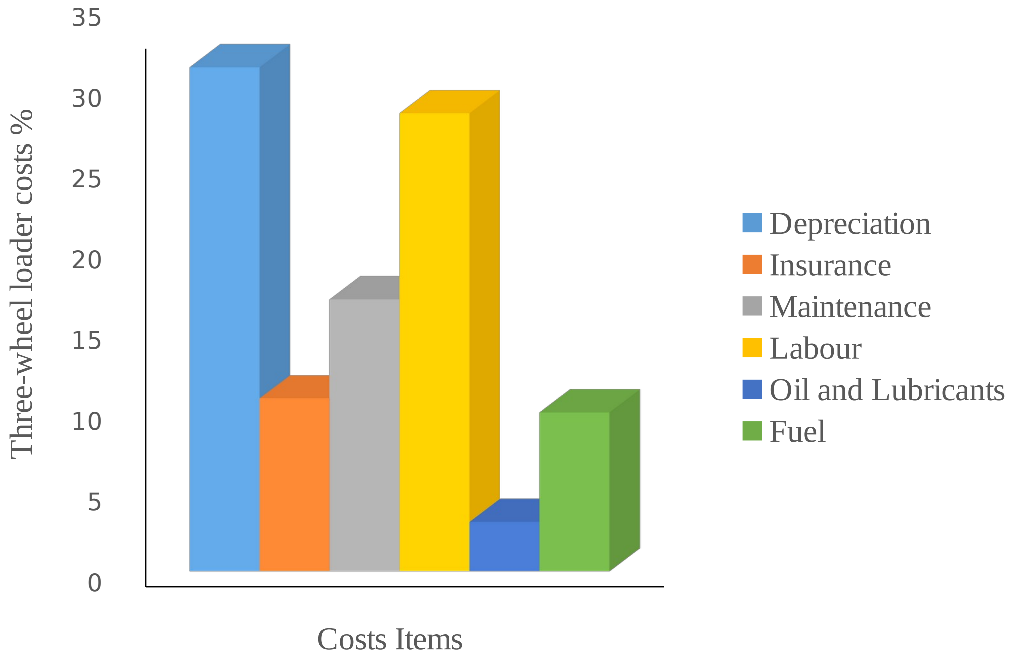

Figure 11: Percentage annual costs distribution of a three wheeled loader

4.4.1 Unit costs of production

Unit costs formulae from Equation 11 was used to estimate unit cost models which were used in estimation of unit costs. Equation 19 and 20 shows the unit costs equations taking into consideration all delays and only unnecessary delays respectively. Hourly costs used was estimated as 470,078 TZS/h (Appendix 5). Then from the unit costs formulae in equation 11 we emerged to the following equations:

a) With all delays included

$$UC_{ALL} = \frac{470,078\ (1.33)}{11.41Nlogs + 88.37TD + 155.21BD + 12.83L - 139.4} \quad \text{……. ……..………19}$$

b) With only necessary delays included

$$UC_{NEC} = \frac{470,078(1.33)}{16.73Nlogs + 96.01TD + 168.43BD + 13.94L - 151.5} \quad \text{………………………...20}$$

This showed that unit costs was affected by four independent variables namely; number of logs (Nlogs), top diameter (TD), bottom diameter (BD) and length of logs (L).

Different unit costs of production by using Equation 19 and 20 are showed in Table 10 whereby top diameter, bottom diameter and length of logs were kept constant and their mean values (Table 7) were used. Different number of logs were used from a sample of 1 to 10 logs loaded by the loader. Figure 13 illustrates the values in Table 9 in a line graph. The curves varied as the way the unit costs did. Figure 12 illustrates that as the number of logs increased unit costs of production decreased. So, the loader should grapple and load a large amount of logs in order to decrease the unit costs of production. Unit costs of production while including necessary delays only shows low costs in comparison to when all delays are included. This illustrates that unnecessary delays should be highly reduced or omitted in order to increase unit costs of production.

Table 9: Unit costs of production of a three-wheel loader

Nlogs	UC_{ALL} (TZS/m^3)	UC_{NEC} (TZS/m^3)
1	27167.94	21390.47
2	18162.62	13603.76
3	13641.04	9973.24
4	10922.01	7872.30
5	9106.78	6502.51
6	7808.94	5538.75
7	6834.88	4823.80
8	6076.87	4272.32
9	5470.21	3834.00
10	4973.68	3477.25

UC_{ALL}=Unit cost of production with inclusion of all delays UC_{NEC}=Unit cost of production with inclusion of necessary delays only Nlogs=Number of logs

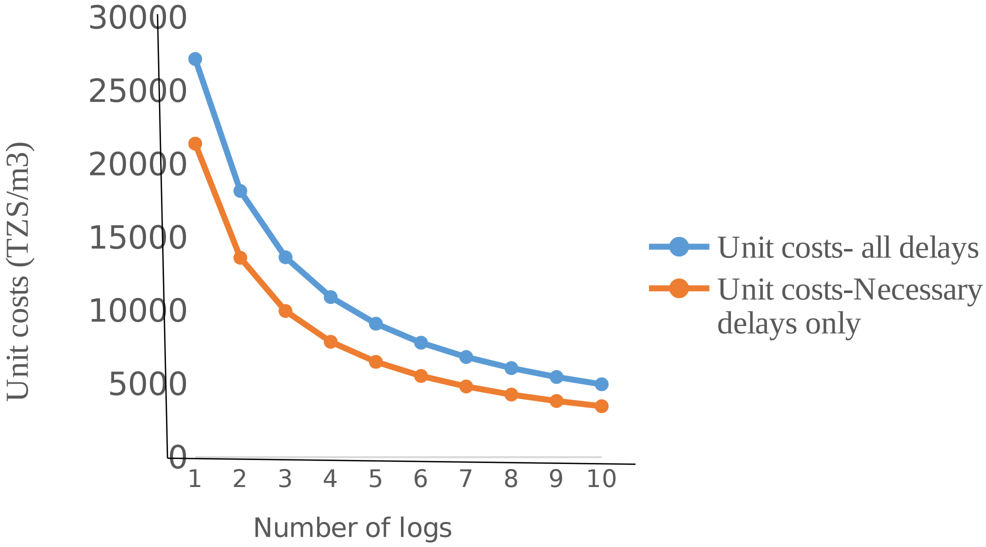

Figure 12: Unit costs of production of a three wheeled loader as a function of number of logs

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations from the presented and discussed research findings. From research findings; it was seen that productivity of using the three wheeled loader was good and reasonable and the unit costs were economical.

5.1 Conclusion

i. Total loading operation time averaged 1.56 minutes while the total average productive time was 1.33 minutes but the total productive time regression model lacked as all variables considered weren't good predictors of total productive time model.

ii. Production rate of the three wheeled loader when all delays were included was estimated to be 43.04 m^3/h and when only necessary delays were included was estimated to 59.71 m^3/h. This showed that if UNEC are omitted production rate increases hence there is a need to increase supervision in order to omit unnecessary delays leading to increase in production rate. The higher production rate's means that the loader was working very effectively in the field.

iii. Fuel consumption rate was estimated to 0.0028 litres/min. This meant that in every minute, 0.0028 litres were used by the loader which is very little in comparison to other machines who uses more than estimated fuel by the three wheeled loader hence the loader was very economical in fuel consumption.

iv. The costs data estimated total fixed costs to be 8,865,000.00 TZS/yr and total variable costs to be 12,288,000.00 TZS/yr while the cost per productive machine hour was 470,078.00 TZS/h. Unit costs of production by the loader was estimated to 10,922.01 TZS/m^3 in consideration of all delays and 7,872.30 TZS/m^3 in consideration of only necessary delays. This illustrated that for unit costs of production to decrease, unnecessary delays should be omitted or reduced hence good supervision is needed in the operation of the three wheeled loader.

v. Productivity and costs were influenced by number of logs, top and bottom diameter, length of logs and total productive time of the loader. However, regression models, production rate models and unit costs models presented here should be used only in a situation where the independent variables are within the range of the study data from which the numerical models were developed.

vi. This research showed that the load to be lifted by the three wheeled loader should be controlled in such a way that its weight or volume is less than that of the loader. This will include the reading of three wheeled loader operational manual which will help in decreasing accidents which occurs when the loader flips or goes down. The problem of the loader to flip or go down was not observed but through different interviews to the operator and the owner it was discovered that the loader tends to flip or go down when the weight is exceeded and when there is sleepy soil or obstacles such as residue stand trees. All of these can be minimized by adopting good cutting techniques and operators to drive the loader carefully during rainy season.

vii. The results reported should be useful to forests managers, loading supervisors and production planning personnel in deciding how to use three-wheel loader to its full capacity in order to increase production and reduce unit costs of production but also setting standard production rate of the loader when used in loading operations.

5.2 Recommendations

i. In order to improve loading production of a three-wheel loader, delays should be reduced. NEC such as eating should be given a little time per day by observing one meal and enough water during working time. UNEC such as smoking can be reduced by good supervision which can be adopted in order to reduce the time taken for the whole operation hence increasing production. Good supervision and planning of the whole loading operation can be useful in reducing the delays which will increase production.

ii. Three wheeled loader operators should be well trained before given the work of using the machine. Through given trainings, skills tends to increase hence the time taken for the operation decreases which increases productivity hence unit costs of production reduces leading to profit to the owners of the three wheeled loader.

iii. Daily maintenance of the three wheeled loader should be adopted to reduce unnecessary operation production costs. During data collection, the loader had some problem at which oil had finished and they had to go to town to bring oil which increased operational costs and increased the time for a given operation but if daily maintenance was done that problem could have been known prior to working time and dealt with. If daily maintenance of the loader is done and observed it might decrease some unforeseen problems which may occur during loading operation time hence increasing productivity and decrease costs of operation.

iv. Motivation through good payments and incentives to operators and other workers could be helpfully in motivating the workers to work fully in the field. There was little motivation given to workers hence too much complaints during loading operation which might have led to low production rates but if there were better motivation it could have happened that productivity would have been higher than what we got.

v. Further studies should be done to determine factors or variables affecting total productive time and factors affecting some loading operation time cycle elements which are maneuverability and loading time elements. These studies will be helpful in determination of models which can be used in prediction of total productive time, maneuverability and loading time as the variable chosen in this research were not good predictors.

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APPENDICIES

Appendix 1: Three wheeled loader work cycle field data form (Dependent variables)

Date……….……. Start time…………. Stop time………………. Form no………………..

Dependent Variables						
Batch no.	Grappling (GR)	Loading (LO)	Unloading (UN)	Maneuverability (MV)	Necessary Delays (NEC)	Un-necessary Delays (UNEC)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Appendix 2: Independent variables data form.

Date: ……………. Start time ………… Stop time ………….. Form no ……………

Independent variables						
Batch no	Top Diameter (TD) meters	Bottom Diameter (BD) meters	Length of logs (L) meters	No of logs (N)	Distance meters	Volume Of logs (V) (m^3)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Appendix 3: Machine operating costs field form.

Machine:

Description…………………

Gross KW…………………... Delivered cost……………

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

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

Tires: Size……………. Type……. Number…………

Cost of replacement set………………………….

Operator: Rate per hour (day)………… Fringe benefits…………. %

COMPONENTS COST (FIXED)

Depreciation:

Interest:

Taxes:

Operational labour:

COMPONENTS COST (VARIABLE)

Fuel:

Oil and lubricants:

Repair and maintenance:

Appendix 4: Operating costs data of three wheeled loader

- Purchase price (P): TZS. 75,000,000
- Salvage value (S): 12% of Purchase price
- Expected life in years (L): 10 years
- Insurance rate (r): 5%
- Operator salary: TZS. 300000/= per month
- Engine maintenance costs (EMC): TZS. 500,000 per year
- Hydraulic maintenance costs (HMC): TZS. 300,000 per year
- Tires maintenance costs (TMC): TZS. 650,000 per 5 month
- Other maintenance costs (Occasionally) (OMC): 100,000 per month
- Incentives (Fringe benefits): TZS. 50,000 per week
- Engine oil costs (EO): TZS. 35,000 per month (5 litres)
- Hydraulic lubricants (HL): TZS. 720,000 per 3-5 years
- Rim lubricants (RL): TZS. 48,000 per year
- Fuel costs : TZS 5700 per day (3 litres)

Appendix 5: Fixed and Variable costs estimations

Fixed costs

1. Depreciation:

Depreciation = (P - S)/L

Salvage value = 12/100 *75,000,000 = 9,000,000

Depreciation = (75,000,000-9,000,000)/10

Depreciation = TZS. 6,600,000 per year

2. Insurance costs

$$AAI = \frac{(P)(L+1) + (S)(L-1)}{2L}$$

AAI = (75,000,000(10+1) + 9,000,000(10-1)) / 2(10)

AAI = TZS. 45,300,000 per year

Ins = (AAI)(r) = 45,300,000*(5/100) = 2,265,000

Insurance costs = TZS. 2,265,000 per year

Total fixed costs = 6,600,000+2,265,000= TZS. 8,865,000 per year

Variable costs

1. Maintenances costs

Total maintenances costs = (EMC+HMC+OMC+TMC)

Total maintenances costs = (500,000+300,000+1,200,000+1,560,000) = TZS. 3,560,000 per year

2. Labour costs

Total labour costs = Operator salary + fringe benefits

Total labour costs = (300,000*12) + (50,000*4*12) = TZS. 6,000,000 per year

3. Oil and lubricants costs

Total oil and lubricants costs = EO+RL+HL

Total oil and lubricants costs = (35,000*12) + 48,000 + (720,000/4) = TZS. 648,000 per year

4. Fuel costs

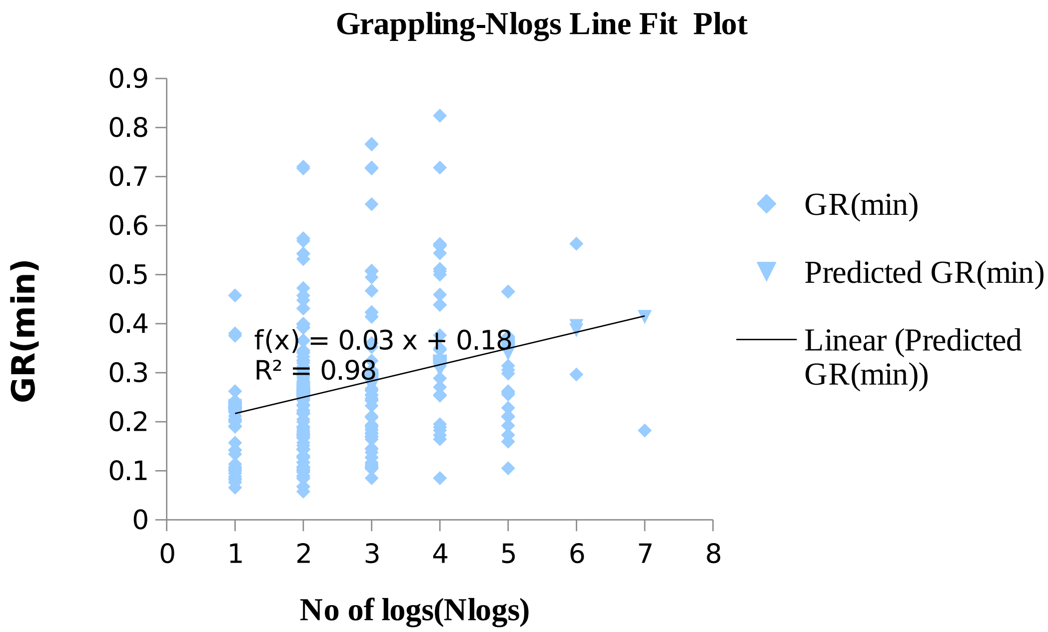
Total fuel costs = 5700*365 = TZS. 2,080,000 per year

Total variable costs: 3,560,000+6,000,000+648,000+2,080,000= TZS. 12,288,000 per year

TOTAL ANNUAL COSTS =8,865,000 + 12,288,000 = **TZS. 21,153,000 per year**

Hourly costs =21,153,500 TZS/YR / 5 days x 9hr/day = **470078 TZS/h**

Appendix 6: Grappling time-Number of logs linear regression plot



Appendix 7. F values and Fuel consumption rate summary statistics

	F-NEC	F-all delays	FCR(l/h)	FCR(l/min)
Mean	0.881956	0.810445	0.125	0.002781
Standard Error	0.016368	0.018845	0	0.0003
Standard Deviation	0.255669	0.294369	0	0.00469
Minimum	0.034734	0.034734	0.125	0.000554
Maximum	1	1	0.125	0.051822
Count	244	244	244	244
Confidence Level (95.0%)	0.03224	0.03712	0	0.000591

F-NEC=F value for Necessary delays F-ALL=F value for all delays

FCR=Fuel consumption rate