The effect of tree and bundle size on the productivity and costs of Cut-To-Length and multi-stem harvesting systems in *Eucalyptus* pulpwood

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

A.M. McEwan

Date

Note: Annexure D contains the official University of Pretoria declaration of originality.

DEDICATION

To my wife Ronalda. Thank you for your encouragement, patience, support and most importantly love. Also to my girls, Chanté and Annabelle, you mean the world to me.

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ABSTRACT

There is currently a global increase in *Eucalyptus* pulpwood plantations. Harvesting systems traditionally utilised in the northern hemisphere are being used in *Eucalyptus* pulpwood plantations worldwide. However, the small tree size and complexity of debarking *Eucalyptus* have provided harvesting with productivity and cost challenges not previously experienced in northern-hemisphere conditions. Much research has been invested in these two harvesting methods in northern-hemisphere species and conditions. There is little research available on mechanised processing-machine productivity and costs in *Eucalyptus*.

This investigation aimed to quantify the effect that tree and bundle size has on the productivity of different processing machines in *Eucalyptus* plantation pulpwood. This was done through regression analysis, whereby productivity models that included tree size and bundle size were constructed. The research also aimed to determine whether or not the multi-stem systems were more cost-effective in smaller tree sizes.

The research investigated five mechanised harvesting options that forestry managers could use in *Eucalyptus* pulpwood plantations. These systems consisted of one CTL system, one full-tree system with single-stem processing and three full-tree systems with multi-stem processing. The CTL system used a harvester to process the trees into logs and to extract them. The full-tree system with single-stem processing used a dangle-head processor (DHP) to process trees into logs. The first full-tree system with multi-stem processing used a chain-flail debrancher debarker (CFDD) to produce debarked and debranched tree lengths, which were slashed into logs. The remaining full-tree, multi-stem systems both produced chips. The first used a chain-flail debrancher debarker chipper (CFDDC) and the second, a CFDD feeding into a stand-alone disc chipper (CFDD&C).

The productivity data, measured as m^3 per productive machine hour (PMH), was then statistically analysed using regression techniques. Productivity equations were formulated, considering tree size and bundle size, as well as the quadratic functions of these two variables and the interaction between them. Bundle size was only applicable to the multi-stem processing machines. The productivity equations successfully predicted processing-machine productivity, using tree size and bundle size as input variables. Apart from the 0.075 m^3 tree size class, the CFDD had the highest overall productivity.

The costs of the five systems were then calculated for different tree sizes. No single system was more cost-effective than the others across all tree sizes. In 0.075 m^3 trees, the CFDDC system proved the most cost-effective. All systems evidenced high costs in the 0.075 m^3 trees, ranging between \$19.43 per m^3 for the CFDDC system to \$28.84 for the harvester

system. In 0.40 m^3 trees, the cost differences between systems were lower, ranging from \$6.91 per m^3 for the DHP system to \$11.84 per m^3 for the CFDD&C.

This study confirms that the CTL system was very expensive to operate in the small tree sizes (0.075 m^3). There is a cross-over point at 0.25 m^3 per tree, where the CTL system costs become lower than those of the full-tree system. At the 0.40 m^3 tree size, the full-tree system is slightly more expensive than the CTL system.

Key words: Processing, Debarking, Bark-wood bond strength, Debranching, Chipping, Chain-Flail Debrancher Debarker, Chain-Flail Debrancher Debarker Chipper, Productivity, Costs, Harvester, Dangle-Head Processor

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cmin	centiminutes
CFDD	Chain-flail debrancher debarker
CFDDC	Chain-flail debrancher debarker chipper
CFDD&C	Chain-flail debrancher debarker and chipper
CTL	Cut-to-length
DBH	Diameter at breast height
DHP	Dangle-head processor
FEL	Front-end loader
MAI	Mean annual increment
ODT	Oven-dry tonne
PMH	Productive machine hours
SMH	Scheduled machine hours
BWBS	Bark-wood bond strength

1 Introduction

This introduction presents the motivation for the research, followed by an outline of the research problem. Thereafter, a short description of the research design and methodology is offered and, finally, the structure of the document has been summarised.

1.1 Motivation for the research

Historically, indigenous forests have supplied the world's timber needs. However, there is increasing pressure to reduce the amount of timber flowing from these forests. Reasons for this include preserving the biodiversity values that indigenous forests offer; maintaining forest ecosystems, particularly as these provide carbon storage areas to help prevent further climate change and protecting local communities who depend on these forests. Plantation forests have been established to meet increasing global demand for timber products (Food and Agricultural Organisation [FAO], 2009).

Many different species are grown in the plantations mentioned above, depending on site characteristics and market requirements. The predominant plantation genera include *Pinus, Eucalyptus* and *Acacia* (FAO, 2009). Specific species are selected, based on aspects such as their growth potential, resistance to pests and diseases, fibre properties and potential for yield improvements. *Eucalyptus* plantations have become increasingly important in the global supply of round timber for pulp and paper (FAO, 2009) and are expected to continue to expand (Spinelli, Ward and Owende, 2009). This is due to various factors, including the large number of species from which plantation owners can choose, depending on their local conditions; the generally good fibre properties of *Eucalyptus*; and, most importantly, rapid growth characteristics. Most of these *Eucalyptus* plantations are concentrated in the southern hemisphere counties of Brazil, Chile, Uruguay, Argentina, South Africa and Australia. However, new *Eucalyptus* plantations are currently being established in other African countries, and the Far East, especially China, which is increasing the global supply even further (FAO, 2009).

Bakker and Nel (2000) commented that, unlike trees planted for sawn-timber products, which need to grow until they have reached a certain physical dimension, trees for pulpwood or biomass should only be harvested at the culmination of the Mean Annual Increment (MAI) or when sufficient mature wood has been produced as per the specification of the pulp- and paper-making process. The physical size of the tree is only a consideration for maintaining low harvesting and transport costs. Therefore, *Eucalyptus* trees grown for the pulp and paper/biomass industries are usually much smaller in size than trees grown for sawn-timber products. Conventional harvesting methods used in the past do not adapt well to high density, small-sized trees, resulting in poor tree and log handling, high harvesting costs and low levels of fibre recovery per hectare (Lambert and Howard, 1990). These high costs, especially for debranching and debarking, have been the main barrier to using smaller trees for products of lower value, such as pulpwood (Selby and Iff, 1986).

Many different harvesting methods and systems are available to fell, transport to a suitable location and convert a standing tree into a product (Brink and Kellogg, 2000). The reasons for choosing one system over another depend on factors such as client requirements, stand conditions and terrain. Forest engineering can make up 60 to 80 per cent of the annual forestry budget (Brink and Conradie, 2000). Forest engineering operations are also more capital intensive than silviculture operations. This is because of the machines and equipment that are used in the production process. Ultimately, the method and system selected should be low cost per cubic metre of delivered timber, but, at the same time, uphold silvicultural, environmental, social and customer values.

While much work has been done on tree species such as pine, scant harvesting productivity information is available on *Eucalyptus* (Spinelli, Owende and Ward, 2002a). Also, most *Eucalyptus* pulpwood has to be debarked in the plantation (Spinelli et al., 2009). Removal of the bark takes place either in the compartment or on the roadside, utilising various technologies and techniques, and is expensive. The bark-wood bond strength (BWBS), a measure of the strength of the wood-to-bark bond, varies between species, sites, seasons, soil moisture and the amount of time elapsed between felling and debarking. Therefore, the process of removing bark increases the costs of harvesting small trees even further.

An unwillingness across the world of the labour force to carry out difficult and menial manual tasks, as well as the inherent safety risks associated with manual- harvesting, is pushing companies to become increasingly mechanised (Spinelli et al., 2009). The felling and processing of *Eucalyptus* pulpwood in South Africa has traditionally been carried out using manual systems. This was due to relatively low labour costs, coupled with the high capital outlay and running costs of mechanised equipment (Mack, 2010). The low labour-cost scenario has now changed and harvesting operations are finding it increasingly challenging to find labour prepared to carry out these difficult tasks, even at a wage premium (FAO, 2009). This has also forced the South African forestry industry to investigate alternative methods of *Eucalyptus* pulpwood harvesting.

This research was conducted on sites across the southern hemisphere (South Africa, Chile and Australia) where the different harvesting systems were operating in order to compare these systems and measure the key factors that influence the investment decision and produce timber at the lowest cost. The sites had similar *Eucalyptus* species, site conditions and terrain characteristics, which made direct comparisons possible.

The harvesting systems having the most potential to cost-effectively process *Eucalyptus* pulpwood selected. Four full-tree harvesting systems and one cut-to-length (CTL) system were researched. Harvesting technologies included chain-flail debrancher debarkers (CFDDs), chain-flail debrancher debarker chippers (CFDDCs), a combination of CFDDs and chippers (CFDD&C), dangle-head processors (DHPs) and harvesters. The other equipment that was used and needed to be considered in the cost calculations included feller bunchers, grapple skidders, three-wheeled loaders, forwarders, slasher loaders, log truck loaders, log trucks and chip trucks.

1.2 The research problem

Forestry companies across the world are struggling to identify systems that can be used to harvest *Eucalyptus* pulpwood cost effectively (Spinelli, et al., 2009). This is because many of the harvesting technologies are new to *Eucalyptus* pulpwood harvesting. Most mechanised harvesting technologies were originally developed and used in northern hemisphere forestry conditions, specifically North America and Europe, owing to increasing challenges with regard to labour costs, an escalating demand for timber and changes in forestry management (Akay and Sessions, 2004). Even where labour is still available and cost competitive, there is a trend towards mechanisation. This is due to the streamlining of the timber supply chain and predicted labour shortages (Spinelli, et al., 2009). Although mechanised systems are now being applied in plantation forestry in the southern hemisphere, much information needs to be digested before systems decisions of this nature can be made.

As indicated by Spinelli et al. (2009), high labour costs are contributing to the increased use of mechanised harvesting systems. Globally, the mechanised harvesting methods with potential for productive, large scale *Eucalyptus* pulpwood harvesting operations include cut-to-length (CTL), where harvesters and forwarders are used, and full-tree or tree-length methods, where a skidder conveys the tree length to the landing for processing (Spinelli, et al., 2009). Various derivatives of these methods are being used in *Eucalyptus* pulpwood plantations around the globe. They are not widely or consistently used because of uncertainty with regard to their application, productivity and cost under different circumstances. Very little research has been carried out on the individual mechanised harvesting systems operating in *Eucalyptus* and no scientific study has compared the various systems.

Tactical harvesting plans, which allow the balancing of terrain conditions with harvesting equipment and annual timber volumes, should be professionally scheduled over a three-to-five year period. Sound information is required to compile these tactical plans. This will allow decisions to be made on alternative harvesting systems (Akay and Sessions, 2004). However, *Eucalyptus* pulpwood forestry companies are generally unsure as to what the ideal system for their plantation situation would be, as key information regarding productivity is not readily available. The most important of this type of information that is missing deals with the various processing machines for different tree sizes (Spinelli, et al., 2009). There is also no information available that indicates the optimal number of trees to process for a given tree size when utilising equipment that processes multiple trees simultaneously. If this information were readily accessible, it would be easier to make informed decisions about systems, allowing for correct productivity determination.

Whatever the system is that has been selected, it must be able to overcome the high costs associated with harvesting and debarking the small trees usually encountered in *Eucalyptus* pulpwood. Incorrect system decisions are expensive and may lead to timber rejections at the mill because of quality constraints. It is also possible that the system could cause unacceptable environmental damage to the site. Forestry managers strive to select the most cost-effective harvesting systems for their plantations. Lack of information about tree and bundle size hampers their decisions.

To summarise, the research needs to answer the following questions regarding mechanised *Eucalyptus* pulpwood harvesting:

1. What productivity factors, cost and operating variables need to be considered for the CTL and multi-stem systems?
2. Which system should be used to accommodate different tree sizes?
3. For multi-stem processing machines, what are the optimal bundle sizes for different tree sizes?

1.3 Research design and methodology

Various sites (South Africa, Chile and Australia) were identified where the applicable harvesting systems and processing technologies were operating and these sites were visited. Individual standing trees were measured to determine the tree size and work studies were carried out on the processing machines. The work study data, which included information on tree and bundle sizes, were collected from each site, initially analysed using descriptive statistics and then subjected to regression analysis.

Productivity models were developed for the processing technologies within the different systems that considered tree size (volume) and bundle size. This information, along with existing information on the productivity of the other machines in the various systems studied, was included in costing models to determine which system had the lowest cost for specific tree size.

1.4 Outline of dissertation

Chapter one provides the introduction, and outlines the motivation for the research, the research problem and the research design and methodology.

Chapter two serves as a literature review. It defines key concepts relevant to the research. It also identifies systems and machines that could have an application in mechanised *Eucalyptus* pulpwood harvesting. The systems and machines are described according to their costs, the factors that influenced their productivity, their advantages and disadvantages, and other general factors influencing the application. Future trends in mechanised harvesting of *Eucalyptus* are investigated and available literature on this subject is then described.

Chapter three explains the research design and methodology. It commences with the two research hypothesis. The different research sites are described, followed by analysis of productivity data, which includes the sample design, sampling method, methods of data collection, the initial data analysis and regression analysis. An analysis of cost data follows the productivity data analysis.

Chapter four contains the results and discussion. The different results with regard to processing technology productivity are provided, followed by results outlining system costs. The system-cost results are discussed per tree size to determine the optimal system for a specific tree-size class.

Chapter five provides the conclusions of the research and recommendations for future scientific investigation.

All photographs in this document were taken by the author, unless indicated. The Anglia Rusken Harvard Method of referencing was used.

2 Literature review

The literature review defines key concepts, provides a literature discussion and a summary of the main conclusions.

2.1 Demarcation of literature covered

Much of the information on the CTL systems was obtained from European journals. The material on full-tree systems was principally drawn from North American research publications. Two particularly useful sources of the latter were the Forest Engineering Research Institute of Canada (FERIC – now FPInnovations) and the United States Department of Agriculture (USDA – Forest Service). Much of the information on full-tree systems with CFDDs and infield chipping are from the early 1990s, an indication of when most of the research into these systems in North American conditions took place. Now, there is renewed interest in these systems from companies harvesting *Eucalyptus* pulpwood because of their potential to reduce costs in harvesting small trees: most other systems exhibit debarking constraints. A great deal of the research on CTLs is from the early 21st century, when these systems ventured into *Eucalyptus* harvesting. Indeed, much development has taken place to accommodate harvesting smaller trees.

The following aspects were extensively investigated in the literature:

- the general operation and management of CTL and full-tree systems;
- the advantages, disadvantages, productivity and costs of these harvesting methods;
- detailed accounts of the specific processing technologies pertaining to CTL and full-tree systems.

2.2 Definition of key concepts

The key concepts that follow need to be understood clearly to obtain maximum benefit from the research process and results.

2.2.1 Harvesting methods

A harvesting method is defined by the form in which timber is delivered to the roadside landing. It depends on the amount of processing which has taken place inside the compartment (Pulkki, 2011). The following harvesting methods, as described by Pulkki (2011), are commonly used for harvesting *Eucalyptus* pulpwood:

- **Cut-to-length (CTL)**

After felling takes place, the trees are debranched, debarked, cross-cut and topped in the immediate vicinity of where the tree was felled. All harvesting residue is left spread across the site. A CTL mechanised system usually consists of harvesters that fell and process trees and forwarders that load the logs onto a bunk and transport them to a roadside landing (Pulkki, 2011). Figure 1 shows an example of a CTL system consisting of a harvester and forwarder.

Locality / Activity	Stand	Extraction route	Roadside landing	Forest road	Millyard
Harvester					
Forwarder					

Figure 1: **Example of a CTL system showing a harvester and forwarder**

- **Tree length (TL)**

After felling has taken place, the branches and tops are removed from the tree, either in the immediate vicinity of where the tree was felled or at a point before the roadside. It is also possible that the tree will be debarked. Harvesting residue is left spread across the site. The remaining stem is then transported to a roadside landing. The tree is usually skidded to the roadside, using a cable, grapple or clambunk skidder. Processing into logs could take place on the landing or the entire stem could be transported to a remote processing facility or mill (Pulkki, 2011). Figure 2 shows an example of a tree-length system. The debranched and topped tree lengths are extracted using a grapple skidder.

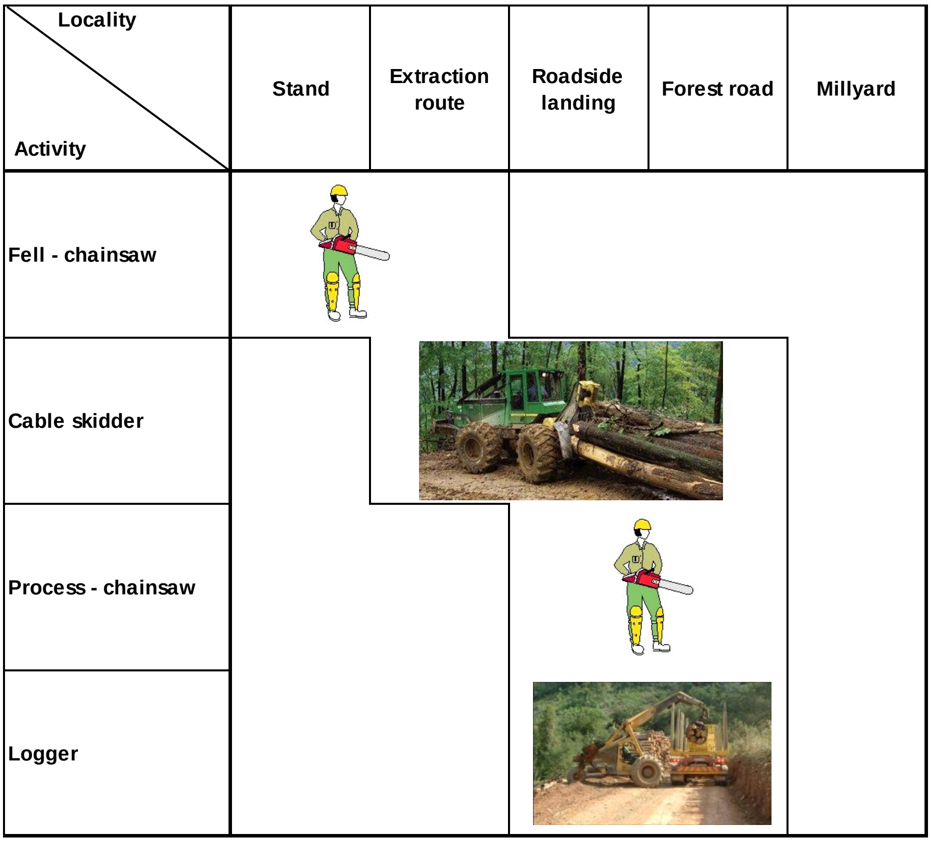


Figure 2: Example of a tree length system with cable skidder extraction

- **Full-tree (FT)**

Full-tree harvesting is termed whole-tree harvesting in the United States of America (USA). After felling, the entire tree is extracted to a roadside landing with its branches, bark and top still intact. Extraction is usually with a skidder: cable, grapple or clambunk. The full tree is processed at the roadside or is loaded and transported to a centralised processing area or a mill. Depending on mill requirements, different levels of processing can take place at the roadside, such as debranching and debarking or full-tree chipping. If roadside processing takes place, then harvesting residue needs to be handled, either by stockpiling and burning it, returning it to the compartment or transporting it away for another use, such as for biofuel (Pulkki, 2011). Figure 3 shows an example of a full-tree system. The trees are extracted with a grapple skidder, with branches and tops still attached.

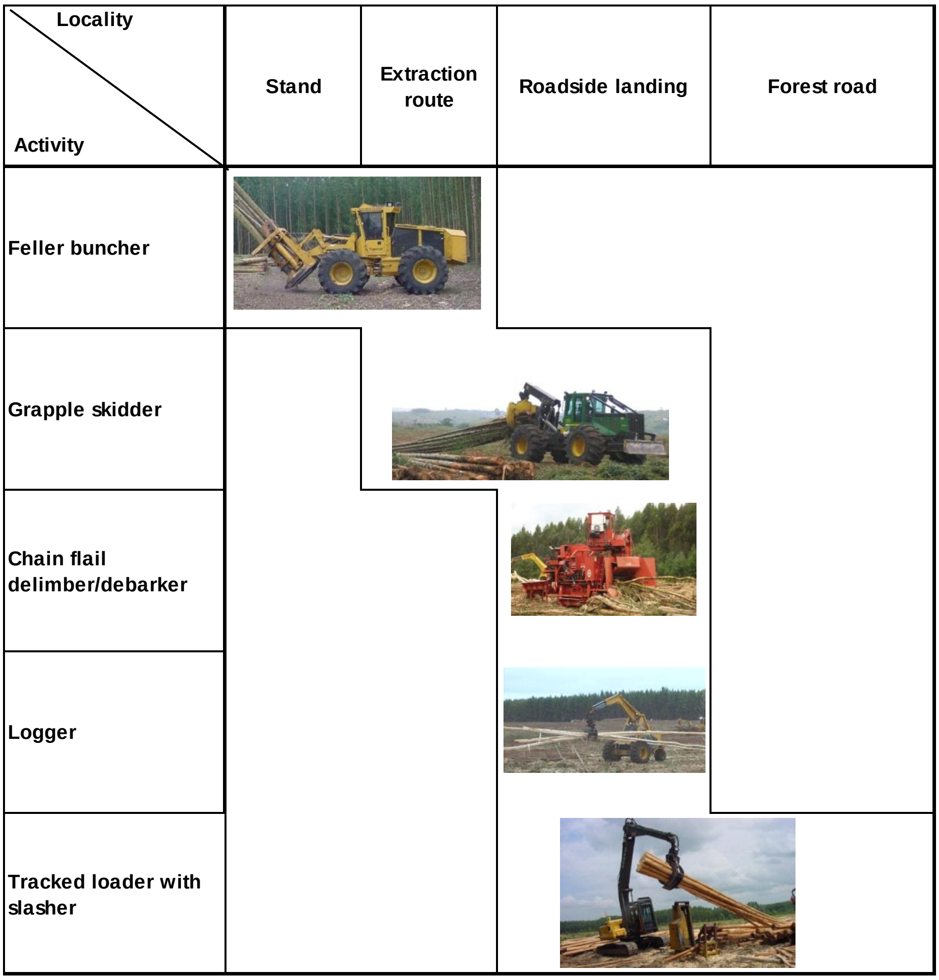


Figure 3: Example of a full-tree system with grapple skidder extraction

2.2.2 Harvesting equipment

A combination of harvesting equipment constitutes a harvesting system. A harvesting system is not the same as a harvesting method. A harvesting system refers to all the machines, equipment, people and tools required to harvest a certain site or group of sites (Pulkki, 2011). Therefore, there may be many combinations of systems that can make up one harvesting method. Mechanised harvesting may be defined as any operation during which at least one single or multi-function machine is used for felling, debranching, cross-cutting or chipping where the trees or logs are found in bunches prior to extraction (Kellogg, Bettinger and Studier, 1993). A brief description of harvesting equipment relevant to this research follows.

- **Harvester**

A harvester, as shown in Figure 4, is a tracked or wheeled machine with an attachment that is capable of felling the tree, removing the branches and possibly the bark, and then cross-cutting the stem into the log lengths desired by the customer (De Wet, 2000). All these activities take place within the compartment where the tree was felled. When harvesting *Eucalyptus*, the feed rollers of the harvester heads exert high pressure on the bark to break the bark-wood bond and thus remove the bark (McEwan, 2010). The harvester head is attached to the boom through a free swinging linkage and hydraulic rotator, and is commonly referred to as a dangle head. After the felling cut, the harvester head has limited control over the tree and drops it to the ground. Figure 4 shows a harvester operating.

Figure 4: Harvester operating, and Figure 5: Dangle-head processor

- **Dangle-head processor (DHP)**

This is a processing head mounted at the end of a boom. Depending on the system in which it operates, the DHP can carry out two or many functions. It does not fell the tree, but operates within the compartment where the tree was felled or on a landing. Its processing functions can include debranching, debarking and cross-cutting (MacDonald, 1999). Figure 5 above shows a DHP operating.

- **Feller buncher**

A feller buncher fells and and simultaneously bunches trees together for a skidder (Lambert and Howard, 1990), which extracts the trees to a landing for processing (Adebayo, Han-Sup and Johnson, 2007). They can be tracked or wheeled machines and reach the tree either by swinging a boom to it or by driving to each individual tree. The felling attachment normally used for smaller pulpwood trees is the accumulating or side-pocket type. The felling part of the head usually consists of continuous disk saws or shears (De Wet, 2000). Figure 6 shows a feller buncher operating.

Figure 6: Feller buncher, and Figure 7: Grapple skidder

- **Grapple skidder**

A grapple skidder is a rubber-tyred, articulated machine designed for transporting trees by lifting the butt ends off the ground in a hydraulic grapple (Kellogg, Bettinger, Robe and Steffert, 1992). A bunching grapple, as opposed to a sorting grapple, is usually used to carry large loads of small trees. Figure 7 above shows a grapple skidder operating.

- **Forwarder**

Kellogg, et al. (1992) described a forwarder as a rubber-tyred, articulated machine designed to carry logs in a bunk from compartment to roadside. It has a crane with a grab attachment to lift the logs from the ground in the compartment and load them, then to offload them at the roadside. Forwarders can have four, six or eight wheels, some now even having ten wheels. Different tyre configurations are available, including wide, flotation tyres. The tyres can also be fitted with chains or band tracks for increased traction or flotation (Kellogg, et al., 1992). Figure 8 shows a forwarder operating.

Figure 8: Forwarder, and Figure 9: Chain-flail debrancher debarker

- **Chain-flail debrancher debarker (CFDD)**

Figure 9 above shows a CFDD operating. This portable machine operates in stationary positions (Wingate-Hill and MacArthur, 1991; MacDonald, 1999). It removes bark and branches from full-tree lengths by using hardened chain links, mounted on rotating drums (rotors) that make contact with bark and branches, knocking them off. This action results in debarked and debranched tree lengths (Sessions and Kellogg, 1994). The bark, branches and leaves fall to the bottom of the debarker and are expelled by a hydraulic bark discharger. There are integral knuckle-boom cranes that feed the trees into the machine (MacDonald, 1999). In the context of this research, the CFDD is a machine that is fed with multiple trees, not the small, mobile CFDDs mounted on front-end loaders. These small, mobile CFDDs do not meet the quality requirements of the mills as they cannot debark effectively (Mooney, Boston and Greene, 2000).

- **Chain-flail debrancher debarker chipper (CFDDC)**

With a CFDDC, the operation of debarking and debranching is similar to that of the CFDDs above. However, the tree lengths are chipped by the same machine, using a disk chipper (a combination or integrated machine), immediately after the debranching/debarking. It is also possible to have stand-alone CFDDs feeding into stand-alone chippers (CFDD&C). The resultant chips are fed into chip trucks (MacDonald, 1999; Pulkki, 2011). Figure 10 shows a CFDDC operating.

Figure 10: Chain-flail debrancher debarker chipper, and Figure 11: Disc chipper

- **Disc chipper**

The debarked and debranched tree is chipped, using sharp knives mounted onto a rotating disk (Lambert and Howard, 1990). In the context of the research, the debarked and debranched trees are fed straight from the CFDD into the chipper, although the chipper does have a crane to help feed if necessary. Chips are fed directly into chip trucks (MacDonald, 1999). Figure 11 above shows a disc chipper.

- **Loader**

A loader is a machine that can lift logs or trees in a grapple and place them on a log truck or an area for temporary storage (Lambert and Howard, 1990). Figure 12 shows a knuckle-boom loader.

Figure 12: Knuckle-boom loader, and Figure 13: Three-wheeled loader

- **Three-wheeled loader**

A three-wheeled loader is a small, rigid machine, with hydrostatic power driving and steering the two large, front tyres (see Figure 13 above). There is a single, high flotation dolly wheel at the rear. It has a boom and log grab for taking hold of logs or tree lengths (Langenhoven, 2000).

- **Slasher loader**

This consists of a tracked excavator operating with a hydraulically powered slasher (MacDonald, 1999). The tracked knuckle-boom excavator has a hydraulically operated joint at the midpoint of the boom, with a log grab at the end (Donovan, 1988). The slasher incorporates a cradle and a hydraulic power take-off from the excavator supplies the slasher with power. The slasher cuts tree lengths into logs, using a hydraulically operated chainsaw to cross-cut. The excavator can pick up the slasher and move it to the next slashing location.

The logs are then stacked on the roadside for transport. In some systems, the same excavator also loads log transport trucks. The ability to cross-cut many stems at once makes slasher loaders cost effective when harvesting small trees (McEwan, 2008). Figure 14 below shows a slasher loader in operation.

Figure 14: Slasher loader

2.2.3 Activity concepts

The following activities need to be clearly understood in the context of the research

- **Accumulation** – this applies to feller bunchers and some harvester heads when more than one cut is made per machine cycle by holding the previously felled tree vertically in the head (Johansson and Gullberg, 2002).
- **Debarking** – the process of removing the bark from the tree or log length (Stokes, Ashmore, Rawlins and Sirois, 1989).
- **Debarking quality** – achieving the levels of bark on the tree or in the chips that satisfies the customer. Debarking quality is measured by determining the residual bark left on a tree/log or in the chips after debarking has taken place and is measured as a percentage. Debarking quality also considers the amount of useful wood fibre lost while debarking. This is also measured as a percentage of the stem wood or chips (Raymond, 1989).
- **Debranching** – the removal of branches flush with the stem so that there are no protruding stubs, also called delimbing. There should be no damage to the bole of the tree where the branch was attached (Mooney, et al., 2000).

- **Multiple stem/tree (multi-stem) handling –** the ability of a machine to fell, process, handle or extract more than one tree or stem at a time. Many smaller stems and tree lengths are handled together in an attempt to overcome the costs of handling these individually. A multi-stem system is one where all the machines within the system are capable of handling more than one tree at a time (Dahlin, 1991). Examples of this type of machine would be feller bunchers, grapple skidders and CFDDs.

- **Tree-length bundles** – trees that have been placed parallel to and on top of each other in a condensed pile format. This facilitates multiple handling or gives the following machine easier access to these trees (McEwan, 2010).

- **Bark-wood bond strength (BWBS)** – the ease or difficulty with which bark can be removed from the tree. It reflects the strength of the adhesion between the bark and the wood (Baroth, 2005).

- **Hot-deck** – an area where tree lengths or logs are processed or loaded immediately after being placed there (Stokes, et al., 1989).

- **Cold-deck –** an area where logs or tree lengths are stored for later processing or loading (Stokes, et al., 1989).

2.2.4 Location concepts

Some important definitions:

- **Compartment** – a territorial unit of land which is permanently demarcated and defined for record keeping and description. Different management, silvicultural and harvesting prescriptions are formulated per compartment, based on site characteristics. The trees within a compartment should be uniform with regard to species, age, stems per hectare and site quality. Separate income, expenditure, yield and treatments are recorded per compartment (Louw, 2000).

- **Landing** – a processing area adjacent to the harvesting area and an accessible road (Lambert and Howard, 1990). It should be accessible to both the extraction machines and log or chip trucks.

2.2.5 Time and productivity concepts

The following concepts regarding machine management are important to the understanding of this report:

- **Scheduled machine hours (SMH)** – the time in which machines are scheduled to carry out their productive work (Hogg, et al., 2009).
- **Productive machine hours (PMH)** – the time that the machine is available and is actually working, determined as a percentage of SMH (Hogg, et al., 2009).
- **Machine utilisation (MU)** – the ratio between PMH and SMH is known as machine utilisation. Machine utilisation indicates how well the SMH are being used (Hogg, et al., 2009).

2.3 Literature discussion

Development and use of mechanised harvesting systems in global forestry have increased rapidly over the last two decades (Jiroušek, Klvač and Skoupý, 2007). This has been due to labour shortages and the need for cost-effective harvesting operations (Schäffer, Hartmann and Wilpert, 2001). There has also been renewed interest in CTL ground-based mechanised harvesting systems in North America and Europe. There are several reasons for this renewed interest, among them: the ability of these systems to leave tops and branches in the compartment, better partial cutting (or thinning) abilities, the need for smaller landing areas and improved labour productivity (Akay and Sessions, 2004).

Mechanised ground-based machines have traditionally operated on slopes of less than 35 per cent and in trees with diameters of less than 50 cm (Bettinger, et al., 1993). However, new technologies and modifications to machines are allowing ground-based mechanised systems to operate on increasingly steeper slopes and handle and process larger trees (Amishev and Evanson, 2010). Mechanised systems can be difficult to manage owing to equipment breakdowns, seasonal access restrictions, the inability of the equipment to work on very steep terrain and possible environmental impacts. The expectation that more processing would be carried out at centralised locations with machines that are less complex has proved incorrect. Indeed, increasingly sophisticated machines are processing timber in the compartment or on the roadside (Gellerstedt and Dahlin, 1999).

Traditionally, CTL methods were popular in Europe and full-tree systems were used in North America. The full-tree method is based on the concept of handling as many stems as possible to compensate for small tree sizes in an attempt to maintain competitive harvesting costs (Spinelli, Hartsough, Owende and Ward, 2002b). The trees are normally bunched during felling to optimise multiple-stem or downstream handling.

2.3.1 General costs of mechanised harvesting systems

The total cost of producing a unit of timber is determined by machine costs and system efficiency (Stokes and Hartsough, 1993). When calculating machine rates, which are the hourly costs of running a machine, the most important input factors in the costing are the purchase price of the machine and the fuel cost – the fuel price and fuel consumption rate (Akay and Sessions, 2004).

2.3.1.1 Machine purchase price

The purchase price is particularly important because it plays a role in determining the annual investment cost, depreciation, the repair cost factor and insurance. Machine life is also important as it can help dilute the ownership costs (Akay and Sessions, 2004).

2.3.1.2 Fuel costs

The fuel component will always be important in forestry because large, heavy machines are required to pull or carry heavy loads. Harvesting costs of mechanised systems are usually sensitive to the diesel price per litre. Spinelli, et al. (2009) simulated the impact of the change of the diesel price on the cost of a full-tree system (with CFDDC) and a CTL system. Even though both systems were impacted, the full-tree system with infield chipping was more sensitive to an increase in the diesel price owing to the high fuel consumption of the CFDDC. However, when chipping infield, there are no energy costs for chipping at the mill, and this needs to be considered in fuel-use calculations.

2.3.2 General factors influencing the productivity and cost of mechanised harvesting systems

The machine rate on its own is not sufficient to determine whether a machine or system is suitable. The productivity of the machine in relation to the machine rate is the most important consideration (Akay and Sessions, 2004). Adebayo, et al. (2007) found that full-tree systems had a higher overall productivity than CTL systems. They attributed this to the full-tree system having dedicated machines for specific tasks in the forest engineering value chain, whereas the CTL machines carry out multiple functions. As indicated below, the general productivity of mechanised harvesting systems is dependent on three key factors, namely tree size, operator skill and extraction distance.

2.3.2.1 Tree size

Average tree volume is very important when determining the productivity of mechanised harvesting machines and systems (Kellogg and Spong, 2005; Jiroušek, et al., 2007). As tree DBH increases, harvesting productivity increases. Harvesting small trees one tree at a time has always been comparatively unproductive (Johansson and Gullberg, 2002). Harvesting small trees requires efficient felling and bunching, as the bunching process facilitates log or tree removal (Stokes and Hartsough, 1993). Adebayo, et al. (2007) found that as tree size increased, the productivity of feller bunchers increased non-linearly more than that of a harvester. This is consistent with the findings of Li, Wang, Miller and McNeel (2006), who observed that the productivity of a feller buncher could be four times higher than that of a harvester. Andersson (1994) commented that even though tree size affected both feller bunchers and processors, size influenced processors more. The explanation offered was that a feller buncher could accumulate trees, whereas a processor was only able to process one tree at a time. Although felling with a chainsaw might cost very little, the inability to bunch may actually increase total system costs (Stokes and Hartsough, 1993).

Thus, as explained in the literature mentioned above, all forestry machines are affected by tree size in one way or another. While machine productivity slows as the tree size being harvested increases, the unit cost per tree drops substantially (Spinelli, et al., 2002b).

Only a few research articles indicate CTL costs as being similar to full-tree system costs. Gingras (1994) did find that CTL costs were lower in tree sizes averaging between 0.15 and 0.25 m^3. However, in Gingras's 1994 research, the ground was very wet, which resulted in the grapple skidder travelling with reduced payloads and often getting stuck. A considerable travel distance between felling areas, which favoured the CTL systems, also contributed to the results recorded.

Three investigative publications indicated CTL systems were between 15 and 30 per cent more expensive than full-tree systems. The researchers were Gingras (1994; 1996) and Li, et al. (2006), analysing a sample of trees between 13 and 21 cm DBH. Richardson and Makkonen (1994) calculated that the costs of CTL systems were 10 to 75 per cent higher than full-tree mechanised systems in tree sizes ranging between 0.30 and 0.05 m^3. Hartsough, et al. (1997), found CTL stump-to-mill costs to be 25 per cent higher than full-tree costs.

2.3.2.2 Operator skill

The more complex a machine is to operate, the more important operator skill becomes. Complex machines occur mostly in CTL systems, where single machines can carry out multiple functions. Differences in operator performance can result in machine productivity variations of between 20 and 50 percent (Bergstrand, 1987). Bergstrand found that it would be necessary to include nearly 400 operators in a machine-productivity research exercise to achieve a 95 percent confidence level. This is not economically justifiable. It may be possible to overcome skill differences between operators while carrying out work research by using operator ratings. However, it has been discovered that ratings can only be used when the work is simple – for example, manual tasks. Ratings would not be an effective tool with the complexity of tasks carried out by most forestry machines (Samset, 1990). A second option considered by Bergstrand (1987) was to replicate the research, but, as Glöde (1990) observed, this is also not economically feasible in most situations. Bergstrand (1987) did conclude, however, that even though the operators' skills played a key role in all comparative research, the results could still be used as productivity indicators, offering guidance for the evaluation and development of new systems and methods. Operators must be experienced and trained to obtain acceptable machine productivity. Purfurst (2010) found that harvester operators begin their careers at between 50 and 60 percent of mean operator performance.

2.3.2.3 Extraction distance

The largest component in the primary transport of both harvesting methods is extraction distance (Adebayo, et al., 2007). Kellogg, et al. (1992) indicated that there was much information on how harvesting productivity and stand variables affected the productivity of mechanised harvesting systems. However, there are still many discrepancies surrounding cost differences of CTL and full-tree systems (Adebayo, et al., 2007).

In research conducted by Adebayo, et al., (2007), the extraction costs of both full-tree and CTL systems accounted for between 36 and 54 percent of the total system costs, the greatest proportion of any of the components of the harvesting systems. Adebayo et al found that full-tree harvesting was more cost effective than CTL systems, but the differences between the systems were sensitive to machine productivity and stand variables.

2.3.3 CTL systems

Mechanised CTL systems usually consist of harvesters and forwarders. However, they can also consist of a feller buncher operating with an infield processor and a forwarder. Karjalainen, et al. (2001) affirmed the wide use of these systems in many countries, among them, Sweden, Ireland and Finland. Percentages reflecting the extent to which the systems are preferred in these three countries are 98, 95 and 91 respectively.

2.3.3.1 Advantages of CTL systems

CTL systems have been favoured in many countries owing to their requiring less labour, less road construction and fewer and smaller landing areas than other ground-based harvesting systems (Bettinger and Kellogg, 1993; Meek, 1993; Gellerstedt and Dahlin, 1999).

There is less traffic in the compartment because there are fewer machines in the system and forwarders can carry larger payloads (Gellerstedt and Dahlin, 1999). The lower road construction requirements arise because forwarders are able to carry timber over a longer distance economically.

Because the logs are carried off the ground, they normally have much less soil contamination and fewer stem breakages (Gellerstedt and Dahlin, 1999; Pulkki, 2011). The logs can be offloaded directly onto log trucks, or trailers if necessary. CTL systems also usually have lower annual volume requirements to sustain good utilisation levels than full-tree systems. If there are many different log assortment classes, CTL systems are often preferred, as less space is needed to process the tree (De Wet, 2000). The different log assortment classes can also be more easily stacked along the roadside by the forwarders (Pulkki, 2011). CTL systems are normally versatile, as they can be used in clearfelling and thinning operations (Gellerstedt and Dahlin, 1999). They tend to cause less damage to residual trees in thinning operations (Richardson and Makkonen, 1994; De Wet, 2000).

Harvesting residue is left scattered in the compartment, which can result in fewer soil nutrient problems (Spinelli, et al., 2002a) because of the high levels of nutrients found in bark and foliage. Poor soil can cause severe complications on intensively managed sites. Higher residue levels also retain soil moisture effectively, especially during drier periods (Hartsough and Cooper, 1999).

The forwarder can travel over residue mats created by the harvester, reducing soil compaction (Meek, 1993; Gellerstedt and Dahlin, 1999; Hartsough and Cooper, 1999). Owing to its lower ground pressures, a forwarder has the ability to extend the harvesting season where this is a limitation, and sometimes even achieve year-round logging (Gellerstedt and Dahlin, 1999). This also results in less soil damage.

Another benefit is that CTL systems can usually operate on steeper terrain than full-tree systems (Gellerstedt and Dahlin, 1999) and perhaps one of the most important advantages is that the forwarder is less sensitive to tree size (De Wet, 2000).

2.3.3.2 Disadvantages of CTL systems

One of the greatest disadvantages of CTL systems versus tree-length and full-tree systems is the high capital cost of individual machines (Gellerstedt and Dahlin, 1999; De Wet, 2000; LeDoux and Huyler, 2001). In a similar vein, the cost of repairs and maintenance of the onboard computer system in CTLs is usually high

Gellerstedt and Dahlin (1999) observed that a great deal of training was required before high operator proficiency could be achieved and commented that the operators' natural ability still played a large role in their ability to control these machines.

CTL machines are often not mechanically available because of machine breakdowns. CTL machines utilise highly intricate technologically: hence, the skills required to maintain them have to be equally sophisticated (Gellerstedt and Dahlin, 1999; McEwan, 2010).

Because of the nature of the felling and processing equipment, there is a specific diameter range in which CTL systems are forced to work (De Wet, 2000). This diameter range varies between different processing heads and carrier machines (Richardson and Makkonen, 1994) and is being increased at both the lower and upper limits in new machines (McEwan, 2010).

Fowarders are limited by the strength and hydraulic power of the crane, as well as by the stability of the machine while loading. The log length that a forwarder can carry is limited by the length of the log bunk (Hartsough and Coooper, 1999). Hartsough and Coooper (1999) found that forwarders are very sensitive to crooked logs, with up to half the nominal payload of the forwarder being lost in severe cases. Variable log lengths within a load can also reduce the payload of a forwarder by increasing the air-space factor within the load. Fowarders are relatively unstable when travelling on side slopes and over rough terain (De Wet, 2000), owing to their higher centre of gravity compared with grapple skidders.

Site preparation costs can be higher for CTL systems as there is more residue left scattered within the compartment. These higher residue levels can also create a fire hazard (Hartsough and Cooper, 1999).

2.3.3.3 Productivity of CTL systems

Focusing specifically on CTL systems, the main factors affecting productivity include the forest stand, site, ground conditions, slope, operator motivation, operator skill, branch size, operational layout, tree size, tree form, log assortments produced, number of merchantable and unmerchantable trees, hauling distance, undergrowth density and machine design (Andersson, 1994; Jiroušek, et al., 2007). Richardson and Makkonen (1994) found that harvester productivity depended primarily on average tree size, operator skill and the ratio of merchantable to unmerchantable stems. Tree volume was found to be the most important of these three factors. CTL systems are very senstive to changes in tree size (Richardson and Makkonen, 1994). Richardson and Makkonen (1994) also found that branchiness, stem form, multiple-stem handling, length accuracy requirements and the technical characteristics of specific harvesters all affected productivity, but not significantly. Operator skill and difficult terrain conditions do have an influence as well (Richardson and Makkonen, 1994). Some of these factors affecting harvesters are discussed in more detail under **Harvesters** in Section 2.3.3.4.

With the extraction component of CTL systems, fowarder productivity is mostly influenced by extraction distance and forwarder size. Richardson and Makkonen (1994) agreed with Jiroušek, et al. (2007) that forwarder productivity primarily depended on extraction distance. Forwarder productivity is also affected by the piece size of the logs, the size of the log stack, the amount of slash in the stack and the neatness of the stack (Andersson, 1994). Table 1 contrasts the approximate annual production capabilities of the harvester, DHP and fowarder CTL machines for different tree sizes, as researched by Richardson and Makkonen (1994).

Table 1: Annual production capabilities of CTL machines
(adapted from Richardson and Makkonen, 1994, pg 7)

Production per year (m^3)	**Average tree volume (m^3)**			
	0.10	**0.15**	**0.20**	**0.25**
Harvester	26,000	35,000	42,000	49,000
DHP (cutting felled trees into logs at the stump)	39,000	49,000	56,000	62,000
Forwarder @ 100 m average extraction distance	51,000	60,000	75,000	84,000
Fowarder @ 400 m average extraction distance	38,000	45,000	51,000	59,000

Note the DHP in this research was cross-cutting the trees and that debarking was not included. What is clear is the rapid increase in the productivity of the harvester and DHP with increasing tree size. Forwarder productivity does not increase as rapidly as it is less sensitive to piece size. When considering only ownership and operating costs, the harvester-based CTL system only started to become competitive when tree volume approximated 0.15 m^3 or more (Richardson and Makkonen, 1994).

Jiroušek, et al. (2007) divided harvesters and forwarders into three different classes when comparing their productivity:

- Class I (small) – harvesters with an engine output of up to 80 kW and forwarders with a payload of up to 10 tonnes.
- Class II (medium) – harvesters with an engine output ranging between 80 and 120 kW, and forwarders with a payload of between 10 and 12 tonnes.
- Class III (large) – harvesters with an engine output of more than 120 kW and forwarders with a payload greater than 12 tonnes.

Jiroušek, et al. (2007) found that even though larger forwarders cost more to own and operate per machine hour, their higher productivity made the cost per m^3 lower when compared with that of smaller forwarders in clearfell operations. Therefore, larger forwarders should be selected for such operations. However, the size of harvester utilised was determined by the average tree size and the technical capabilities of the machine. The smallest harvester technically capable of harvesting the required tree size should be selected.

2.3.3.4 Harvester

The single-grip harvester head originated from the need to make thinning profitable (Gellerstedt and Dahlin, 1999). Gellerstedt and Dahlin (1999) identified the design reasons for the different parts of a harvester and these are summarised in Table 2.

Table 2: Design reasons behind the Nordic harvester
(Gellerstedt and Dahlin, 1999, pg 18)

Machine part or quality	Reasons behind the construction or quality
Ten-metre boom	20 m between strip-roads in thinning
Weight of harvester head under 1,200 kg	Ten-metre boom – machine stability and weight
Small size of the harvester head	Felling diameter of most trees is less than 65 cm
Confined debranching capacity	Trees with small and uniform limbs
Good terrain accessibility	Rocky terrain; most slopes less than 40%; great variation in ground strength
Multi-functional machine	Thinning and smaller clear cut areas; must be easy to plan, supervise, control and transport; shortage of labour; less ground damage
The flexibility of the harvester concept	The variation in tree size and terrain factors
The high safety and ergonomic standard	The few operators are key persons; a multi-functional machine requires an easy-to-use and comfortable work area as part of the machine

Various factors to be considered with regard to harvesters include:

- *Tree size*

The reason tree volume plays such an important role in harvester productivity is that these machines can only process one tree at a time. The cycle time to harvest one small tree is similar to that required to harvest a large tree. Therefore, the additional volume of a large tree enables proportionately higher productivity (Richardson and Makkonen, 1994). The debranching/debarking and cross-cutting time elements are significantly affected by the length of the tree (Richardson and Makkonen, 1994).

Harvester producivity is negatively affected when operating in compartments with highly variable tree sizes and poorly managed coppice compartments (M. Brink, Ass. Prof. Univeristy of Pretoria, South Africa, personal communication [Conversation], 17 September 2010).

A harvester is unable to fell and process trees over a certain butt diameter. Unmerchantable trees in the compartment reduce productivity by forcing the harvester to move around them, reducing visibility. Further productivity reduction occurs if the operator attempts to process such trees. If unmerchantable, stems can be manually felled before harvesting. In Richardson's research (1992), harvester productivity was shown to increase by between 22 and 37 percent. Harvester operators can take up to two years to reach their full potential, although the most productivity gain takes place in the first six months (Richardson and Makkonen, 1994).

- *Fibre utilisation*

Leaning trees can cause high stump heights and therefore lower fibre utlisation, as the operator lifts the head due to the risk of the chain cutting into the ground (Hartsough and Cooper, 1999).

- *Multi-tree harvester heads*

One way of trying to reduce the costs of harvesting small trees with a harvester is to fell and process many trees simultaneously. Gringas (2004) explained how multi-tree harvester heads are capable of processing more than one tree at a time, as well as being able to handle trees of different sizes and length simultaneously.

The key technologies allowing more than one stem to be processed at a time utilise:

- accumulating arms, which keep trees vertical in the head while additional trees are being felled;
- extra feed rollers (normally four in total), which help prevent slippage during processing; and
- a wider-than-usual measuring wheel, which allows contact with the trees to be maintained.

In research conducted by FERIC in 0.10 m^3 trees, a comparison between the multi-tree and conventional harvester heads showed the former was able to improve productivity by between 21 and 33 per cent (Gingras, 2004). Cycle times increased by between 30 and 40 percent, but the mean processing time per stem was lower and the heads were not able to calculate production output with any level of accuracy.

The benefits of multi-tree harvesting heads are most pronounced in very small trees in dense stands (Johansson and Gullberg, 2002; Gingras, 2004) As average tree size increases, the benefits gained from multi-stem handling decrease. Bergkvist (2003) reported an 18 per cent productivity gain in slightly larger trees. In Gringas's research (2004), the debranching quality and accuracy of log length was good. However, there was no debarking element.

Bergkvist's research (2003) indicated that six per cent of the logs produced were rejected because of poor debranching quality or because the log diameter was below the mill specification. Gingras (2004) did specify that if there were large differences in the diameter of the trees being processed (greater than 4 cm), the top ends of the trees might not be topped at the correct diameter. He concluded by stating that quality problems posed a real risk and had to be carefully managed (Gingras, 2004).

None of the above research included a debarking element. Indeed, this technology is not yet able to debark adequately owing to the reduced contact between the feed rollers and the trees. The mutli-tree machine is unable to spin the trees, an action that is required during the debarking element.

- *Terrain*

To obtain the lowest cost operation when using a harvester, the terrain needs to be flat (Spinelli, et al., 2002a). On steeper terrain, the cost will increase, owing to productivity reductions and more expensive machine requirements.

- *Log lengths*

Richardson and Makkonen (1994) found there was up to 20 per cent difference in harvester productivity when using longer log lengths.

- *Construction excavators versus purpose-built carriers*

Construction excavators, rather than purpose-built forestry excavators, have become more popular as carrier machines in forestry, especially for smaller tree sizes, roadside processing and easier terrain. However, matching the harvester or DHP head to the carrier can be difficult, specifically with regard to the hydraulic systems. Richardson and Makkonen (1994) identified problems with hydraulic flow capacity, inadequate filters, small reservoirs and inadequate cooling systems. They also observed that the stick boom normally had to be extended to allow processing close to the excavator. Safety can also cause concern, particularly with roll-over protection structures (ROPS), operator protection structures (OPS) and fall-over protection structures (FOPS).

Many of these problems have been overcome, but not all. The hydraulic power of construction excavators was found to be less than that of purpose-built wheeled forestry harvesters (Nakagawa, Hamatsu, Saitou and Ishida, 2007). This is important for machines operating in *Eucalyptus* as a great deal of hydraulic power is required for the debranching and debarking elements.

Johansson (1995) studied productivity in and other variables of four construction-based excavator harvesters and found no difference between their productivity and that of Nordic-type wheeled harvesters. The excavators had increased boom reach and had higher lift, which enabled more trees to be harvested from one position. This resulted in a higher concentration of logs being prepared for the forwarder. However, the ergonomics of the wheeled harvesters was better.

Spinelli and Visser (2008) observed that mechanical problems in purpose-built wheeled harvesters were often assumed to cause fewer delays than those in tracked excavators. However, they found the opposite to be true: excavator-based harvesters were less susceptible to mechanical breakdowns than their wheeled counterparts.

2.3.4 Full-tree systems

This section examines the advantages, disadvantages and productivity of full-tree systems. Different processing technologies that occur in full-tree systems are also included.

2.3.4.1 Advantages of full-tree systems

- *Tree size*

When harvesting small trees, such as is often the case with *Eucalyptus* pulpwood, it is often better to handle multiple stems throughout the system to reduce costs. Full-tree systems lend themselves more towards multi-stem handling, which improves the handling efficiencies of each stem (Boprey, 1988; Stephenson, 1989). Multi-stem handling is most feasable when harvesting small trees of a uniform size, where the trees do not have excessively large branches (Richardson and Makkonen, 1994). Even though length-measuring accuracy is not that good, they found between 5 and 25 per cent increases in productivity by handling multiple stems. If the tree needs to be accurately optimised, the entire stem is now available in a more controlled location (Gellerstedt and Dahlin, 1999).

- *Fibre utilisation*

As timber resources become increasingly scarce, the harvesting system selected must be able to optimise as much useful fibre from a tree as possible. Fibre recovery was deemed so important to FPInnovations of Canada (then FERIC), that the cost models developed to investigate systems and system alternatives included fibre-recovery efficiency (Favreau, 1992). When a full tree is debarked and debranched with chain flails, large branches are left intact and the flails do not completely remove the top. When these stems are then fed directly into a chipper, there is the opportunity for increased fibre utilisation.

CFDDCs can even use trees that would be considered unmerchantable for roundwood systems (Favreau, 1993). Rodden (1994) indicated that low grade trees, tops, twisted trunks and other deformed pieces that might have been left in the compartment previously can now be processed into clean chips. Furthermore, there is no wastage from cross-cutting operations (Favreau, 1992). Full-tree systems using CFDDCs could therefore substantially increase the fibre yield from a given site by 10 per cent or more. Favreau (1992) indicated that the greatest opportunities for increased fibre yields and, therefore, lower costs, came from low volume stands.

Favreau (1992), Flanders (1994), Hartsough, Spinelli, Pottle and Klepac (2000) and Mooney, et al. (2000) conducted research which showed or inferred increased fibre yields. Their findings indicated that over 95 per cent of the potentially available wood culminated in the chip truck. This figure decreased slightly when processing trees of less than 0.05 m^3, as there was a proportionately large percentage of smaller breakable material.

Markham (1995) and Rodden’s (1991) research also indicated greater fibre yields. Markham (1995) found that the yield per tree and per hectare increased because previously unmerchantable trees could be processed. The increase was by 1.5 per cent in spruce, by between 10 and 12 per cent in jack pine, over 25 per cent in poplar and over 5 per cent per hectare. Rodden (1991) reported yield increases ranging from 1.6 to 16 per cent in poplar. Even short lengths of 1.22 m tops of trees were flailed in Rodden’s research.

Buggie (1991) conducted research on two sites with black spruce of very small tree size (0.05 m^3). By including stems that other systems were not able to harvest, fibre yields were increased by between 20 and 56 per cent. Much of the additional fibre came from the tops of merchantable stems and trees as small as 2.5 cm in diameter. When considering the improvement in fibre yield from only the merchantable stems on the same research sites, the gains on the two sites were 7.2 and 8.4 per cent. The main reasons for this improvement are:

- the use of tops down to much smaller diameters,
- the chipping of large branches,
- there were no cross-cutting losses as is usual with most systems that produce logs.

It must be noted that these trials only achieved bark percentages of 3.3 and 2.3, which would be unacceptable to many mills. However, the technology used in the trial was that of the first Peterson Pacific 5000 built and much development has taken place since then.

In 1991, Stokes and Watson conducted a trial on 21-year-old *Pinus elliottii* and found that infield CFDDCs produced 4.3 tonnes of acceptable chips per hectare more than a method sending full trees to the mill for processing. Interestingly, the CFDDCs generated a tonnage of 9.6 more than a tree-length method that attempted to remove branches with a gate debrancher in the compartment and then transport the tree lengths to the mill. The increased breakages of this latter method were mainly responsible for the lower chip production. The mill also had to deal with increased residues when the full-tree and tree-length methods were used.

Stephenson (1989) showed 25 per cent increases in fibre utilisation when harvesting small pine with CFDDs compared with log production. This was due to the ability to process tops and previously unmerchantable stems. Simultaneously, bark contents, silica levels and debris contents were reduced.

Feller bunchers are normally able to cut stumps to a lower level than harvesters, which improves fibre utlisation (Favreau, 1997). Hartsough and Cooper (1999) showed that the stumps left by a harvester averaged 26 cm in height, whereas those remaining after a feller buncher with a shear-felling attachment had been through the compartment were only 12 cm high. In 1992, Shaffer's summary of literature focusing on stump height revealed that the quantum of the height difference was not normally so large. Most research showed an eight centimetre height difference (Shaffer, 1992), which is still substantial.

- *Harvesting residue for energy production*

Full-tree systems enable the more economical use of harvesting residue as material to generate energy (Spinelli, et al., 2009). The material is concentrated on the landing and can either be processed and transported simultaneously with the timber product or stockpiled for later processing and transportation. Spinelli, et al. (2009) calculated that if harvesting residue were valued at between €10.00 and €15.00 per tonne on the roadside landing, the costs should be divided by three (the proportion of harvesting residue generated per tonne of pulpwood) to obtain the value of the additional income that could be added to the conventional harvesting product. Therefore, an additional income of approximately €4.00 per tonne of pulpwood can be achieved by utlising harvesting residue.

In addition to the economic benefits of using the plantation residue, reduced fuel loading in the compartment would lessen the fire risk. Re-establishment activities, such as site preparation and planting, would also be easier and more productive with lower harvesting residue loads (Spinelli, et al., 2009).

- *Harvesting residue handling if returned to compartment*

Even though full-tree systems result in harvesting residue at the landings, a grapple skidder is still more effective at returning this residue than other extraction equipment (Rodden, 1991). If properly supervised, most of the residue can be returned into the compartment to the place desired. The grapple skidder can leave the slash in windrows, large residue stacks, scattered piles across the compartment or accumulate it on a landing for bio-energy use. Grapple skidders can also be fitted with debris attachments on the front, which further assist with residue handling (Rodden, 1991). Front-end loaders (FELs) with timber grabs or forks have also been used for extracting small trees successfully. They lift bunches completely off the ground in their grabs and carry the trees out of the compartment. The tree lengths are carried perpendicular to the extraction route (Spinelli and Hartsough, 2001). Although FELs are slower per cycle than grapple skidders, their ability to take larger payloads of very small trees makes them competitive (Spinelli and Hartsough, 2001; Spinelli, et al., 2002b). The FEL is also more versatile than the grapple skidder and is better when working on landings, specifically when handling harvesting residue (Spinelli, et al., 2002b).

- *Equipment robustness*

The equipment used in full-tree systems is inclined to be more robust (Pulkki, 2011). Operator training is also likely to be easier and quicker, and spare parts for the equipment are usually more readily available.

- *Other advantages of full-tree systems*

    - **Reduced inventory** – If carrying out infield chipping of tree lengths, the amount of inventory in the plantation can be reduced (Favreau, 1992).
    - **Uniform moisture content of chips –** Product with a more uniform moisture content is offered to the mill, as the time from felling to chipping is normally similar to that of infield chipping systems (Favreau, 1992).

- **Public perception of chip trucks –** The chips are usually transported in an enclosed chip truck that looks very similar to other trucks on public roads. The negative public perception of log trucks is not attached to these vehicles (Boprey, 1988; Stephenson, 1989; Rodden, 1991).

- **Larger chip-truck payloads with small trees** – By converting small trees into chips, it is also possible to achieve larger and more uniformly distributed truck payloads more easiy and this reduces transport costs (Mooney, et al., 2000).

- **Low capital option for new mills –** For new mills, having the trees chipped in the plantation could also offer a lower capital option.

- **Multi-functional machines** – CFDDs also eliminate the need for a separate machine to execute debranching, one of the problem areas that needed addressing (Stokes and Watson, 1991). Flanders (1994) reported that CFDDCs could eliminate the need for debarking at the mill. By carrying out chipping in the plantation, there is the possibility of producing a chip product of higher value, as well as using a larger portion of the tree.

2.3.4.2 Disadvantages of full-tree systems

A disadvantage of full-tree systems is that they normally require high annual volumes to utlise the system fully (Gingras, 1994). Full-tree systems can also cause more soil compaction and disturbance, as the tree length being extracted tends to sweep organic material off the extraction route, leaving the soil exposed (Hartsough, et al., 1997). This also creates more dust (Hartsough and Cooper, 1999). If full-tree systems are going to be used, the inadequate return of plantation residue to the compartment could result in site nutrition problems on sensitive sites (Spinelli, et al., 2009). This could be compounded if plantation residue is removed from the site for energy production.

Full-tree and tree-length systems also require much larger landing areas than CTLs for the storage and processing of trees (Raymond, 1990; Gellerstedt and Dahlin, 1999; Spinelli, et al., 2009; Pulkki, 2011). Because of the additional slash brought to the landing by the full-tree system, landing requirements can be even higher than for the tree-length system.

Full-tree systems usually have many different types of machines that work in close proximity to each other. In order for the system to work most effectively, there needs to be sufficient buffers between machines (Pulkki, 2011). The reason is that breakdowns in a full-tree system can result in the entire system stopping production relatively quickly. This will vary with the species being harvested, the type of processing equipment used and mill requirements. The hot nature of most full-tree systems can result in system inefficiencies because of congested landings, longer extraction distances, interference between machines and problems with debris disposal (Raymond, 1990).

Skidding full-tree lengths can result in dirt contamination and more stem breakage during the extraction process (Gellerstedt and Dahlin, 1999; Spinelli and Hartsough, 2001; Wang, LeDoux, Vanderberg and McNeel, 2004). The amount of damage depends on ground roughness, felling direction, operator technique, operator visbility and extraction route layout (planning). In a *Eucalyptus* harvesting operation, dirt contamination is less problematic, as the tree is extracted with the bark on, which is then removed by the processing equipment on the landing.

If dry wood or trees with a low basic density are chipped infield, it could happen that it is not possible to achieve payload on the chip trucks. The payload can vary between 15 and 20 per cent less than that of log trucks (Favreau, 1992). Naturally, this will increase transport costs.

The safety risk is also considered to be higher, as there are many machines working in close proximity to each other (Gellerstedt and Dahlin, 1999).

2.3.4.3 Productivity of full-tree systems

Productivity levels of some of the equipment used in full-tree systems is discussed below.

- *CFDDs and CFDDCs*

Thompson and Sturos (1991) reported productivity figures of 30 to 60 tonnes per PMH in research conducted in North American indigenous hardwoods, using a two-flail Peterson Pacific 4800 CFDD. Even though the species were different to *Eucalyptus*, debarking still took place and, therefore, an indication of the productivity levels possible in *Eucalyptus* could be provided. In research conducted by Hartsough, Spinelli and Pottle (2002), it was discovered that the productivity of the CFDDC gradually reduced over the course of each day. In the small, hybrid poplar being studied, the drop amounted to half an oven-dried tonne (ODT) per hour. This was attributed to operator fatigue, but a dulling of the chipper knives could also have contributed to the diminished productivity.

- *Feller bunchers*

Tree size is the major factor that affects the productivity of a feller buncher. The number of trees per accumulation has a smaller influence on productivity than tree size. Thereafter, factors such as bunch size, spacing between corridors and the average distance between trees come into play (Johansson and Gullberg, 2002). The proportion of fallen and leaning trees could also influence productivity. Drive-to-tree machines are more affected by poor terrain than other machines (Spinelli, et al., 2002a).

Three-wheeled feller bunchers can be used effectively for clearfelling under the correct terrain conditions. These machines work better on flat areas with few obstacles. The wheeled drive-to-tree machines are effective on flatter terrain, while the tracked levelling machines are needed for steeper slopes (Spinelli, et al., 2002a).

When handling trees with a diameter smaller than 56 cm, continuous disk-saw feller bunchers have been found to be more productive than bar-saw feller bunchers (Adebayo, et al., 2007). However, bar-saw feller bunchers have a much lower investment and maintenance cost and can handle a wider range of tree diameters, although this is not really important in pulpwood operations involving small tree sizes. The shear felling attachment is less productive than a continuous disk saw, but is able to cut at ground level, even cutting below this level at times. It has a narrower kerf, which increases fibre utilisation further (Adebayo, et al., 2007). Adebayo, et al. (2007) also indicated that shear heads were more reliable and had lower capital, fuel consumption and maintenance costs than continuous disk felling heads.

- *Extraction equipment*

As with CTL extraction equipment, extraction distance affects grapple skidder productivity most, but load size and average tree size are also important (Andersson, 1994). The skidder’s load capacity is influenced by its grapple area and the drag force of the trees being extracted (Spinelli and Hartsough, 2001). It should be noted that a grapple skidder is not the only option for full-tree timber extraction for small trees.

In their research on *Eucalyptus* pulpwood and with tree sizes of less than 0.1 m^3, Spinelli, et al. (2002a) established that a FEL could carry two-thirds more payload than a grapple skidder. The FEL, operating in tree sizes of 0.058 m^3 and with an extraction distance of 201 m, carried 61.2 trees per cycle, with an average payload of 3.54 ODTs. The grapple skidder, operating in tree sizes of 0.087 m^3 and with an extraction distance of 251 m, carried 17.1 trees per cycle, with an average payload of 1.49 ODTs. The FEL productivity was higher than the grapple skidder over the entire range of extraction distances (up to 400 m) in the research. Even though the FEL is slower, it does not have drag on it the way the grapple skidder does.

Stability is a concern with large loads. As the extraction distance increases, the average travel speed increases as well because the operator becomes more comfortable with the load stability. In the research conducted by Spinelli, et al. (2002a), the FEL had much spare capacity and was able to carry out the work at the landing as well. However, the grapple skidder had very little spare capacity and a second machine was necessary for landing work (Spinelli and Hartsough, 2001). It is interesting that the number of trees per cycle being carried by the grapple skidder was very low and the reasons for this were not indicated.

Spinelli, et al. (2002) observed that the use of a larger capacity grapple should increase the skidder payload and make it more competitive in comparison with the FEL on longer extraction distances. They also observed that the FEL:

- operated best in compartments with small, uniform-sized trees;
- resulted in less dirt contamination of the trees during extraction;
- was more expensive than the grapple skidder;
- was less robust and had poorer terrain-handling capabilities than the grapple skidder. The latter is a purpose-built forestry machine and is able it to work on steeper and softer ground with more obstacles (ground clearance 450 versus 700 mm);
- when travelling loaded, was approximately 30 per cent heavier than the grapple skidder and would not be capable of extracting immediately after heavy rains on clay soils.

There is the possibility that there could be more soil compaction owing to higher axle loads, so the FEL would be restricted to areas with gentle slopes, low ground roughness (Spinelli and Hartsough, 2001) and good soil conditions in the wet – indeed, it would only be able to operate in areas that were not waterlogged. These authors also stated that the FEL operates best in compartments with small, uniform-sized trees.

- *Systems planning*

With full-tree and tree-length systems, proper planning of the landing area before harvesting will ensure that imbalances caused by interaction between system machines are minimised (Adebayo, et al., 2007). When carrying out system balancing for a compartment, the spare capacity of all systems should be examined. The lowest overall cost for the system has to be achieved. If it takes a long time to set up the landing, then spare capacity of the extraction equipment should be used to extract longer distances than usual (Favreau, 1992; Spinelli, et al., 2002). This could apply when using processing equipment such as CFDDs or CFDDCs.

Favreau (1992) indicated that due to longer extraction distances, extraction costs to feed these processing machines can be 15 percent higher than for other full-tree methods. Longer extraction could reduce the total road requirements for this full-tree system as well. However, as stated above, it should not compromise the overall system cost. When considering CFDDCs as part of full-tree harvesting for small *Eucalyptus* trees (<0.1 m^3), Spinelli, et al. (2002b) recommended three-wheeled drive-to-tree feller bunchers for felling and a FEL for extraction on easy terrain. For difficult terrain, Spinelli, et al. (2002b) advocated tracked swing-to-tree feller bunchers for felling and grapple skidders for extracting.

Hot-deck operations, where the tree lengths are brought to the landing by the extraction equipment and immediately processed by the processing machine, incur more delays than cold-deck operations, where the trees are brought to the landing and then processed at a later stage (Spinelli and Visser, 2008). Most literature reports delays as a percentage of the total scheduled time (SMH). Spinelli and Visser (2008) found that delays can vary between machine types, stand conditions and terrain variables. Therefore, delay categories need to be identified for machines operating under specific stand and terrain conditions. It is not possible to use standardised factors to measure delay for different technologies.

- *Costs of full-tree systems*

In Favreau's research on softwood (1992), two full-tree systems were compared with each other. One system included a CFDDC and the other a stroke-boom debrancher with subsequent slashing and loading of logs. The stroke-boom debrancher system could be most closely correlated to the DHP full-tree system researched as part of this dissertation (see Section 2.3.4.4 below). Favreau (1992) found that when the tree size was lower than 0.22 m^3/tree, the CFDDC system was cheaper. Total system costs were discussed in Favreau's research (1992), including debarking of logs produced by the stroke debrancher system at the processing plant. These research results indicated a cost reduction of more than 10 Canadian dollars per cubic metre in small trees (0.1 m^3/tree) if the roundwood system was converted to a CFDDC system. The main savings came from reductions in log handling, chipping and chip handling at the mill. Even in larger trees (0.3 m^3/tree), the cost of the CFDDC system was still lower.

2.3.4.4 Dangle-head processors (DHP)

Richardson and Makkonen (1994) found processor productivity generally higher than harvester productivity, but this was greatly affected by average tree size. They found that tree size was the most important factor determining the DHP productivity. As with factors that influence harvesters, operator skills, branchiness and accuracy requirements also played a role in DHP productivity (Richardson and Makkonen, 1994).

In research conducted by Spinelli and Visser (2008), it was found that DPHs working on a hot deck evidenced delay factors of 62.6 percent. This indicates how difficult it is to balance systems in ‘hot’ tree-length or full-tree operations. This high percentage could also apply to other processing equipment working on a hot deck. However, the inherent reliability of the processing equipment should be considered as well. While it is hypothesised that CFDDs would give a lower delay percentage because they are more robust, they are also more sensitive to a shortage of trees being placed at the infeed because of their high production rates. Long extraction distances or breakdowns of the grapple skidders will very quickly result in the CFDD or CFDDC being delayed.

DHPs are also much easier to operate than harvesters as there are two fewer functions to perform (felling and cross-cutting/topping).

2.3.4.5 Chain-flail debrancher debarker (CFDD), Chain-flail debrancher debarker chipper (CFDDC) and Chain-flail debarker debrancher & chipper (CFDD&C)

CFDDs are commonly used in the western half of North America to process trees. They produce clean wood chips of high quality on short-rotation (fewer than 10 years) poplar plantations (Sessions and Kellogg, 1994; Hartsough, et al., 2000). Because the trees are so small, it is necessary to find systems that are economical (Stokes and Watson, 1991). A CFDD is most commonly used with infield chipping (Mooney, et al., 2000), offering a cost-effective method of producing chips in the plantation from full trees (Stokes and Watson, 1991). The eastern half of North America does not need this equipment as debarking generally takes place at the mills. This is discussed further below under *Chip quality* below.

The reasons for the implementation of CFDDCs are varied. Certainly, this machine’s ability to process multiple small trees with possible poor form and BWBS into chips of the correct quality, ready for further mill processing, may be offered as the main reason. Secondary reasons for utilising a CFDDC include the following:

- the high productivity levels of the system in which it operates enable areas to be clearfelled quickly with minimal labour;
- quicker re-establishment opportunities;
- the robustness of the processing equipment;
- the reduction of equipment requirements for the total system; and
- the system's ability to utilise plantation waste for biofuels in the future (McEwan, 2010).

CFDDCs can result in increased tree utilisation as the entire tree is chipped, including tops and branches that have not been debranched, without saw-kerf wastage. It should be borne in mind that the investment costs for these machines are very high (Spinelli, et al., 2009).

The cost of CFDDCs as a percentage of the total system cost can be as high as 50 per cent (Favreau, 1992). The system must therefore be set up to reduce the operational delays that might affect this machine. However, no additional loaders are needed to remove material, stack it and load trucks, thus reducing the complexity to some degree. Proper truck scheduling and system management are prerequisites for operating the CFDDC system successfully, but these do increase the complexity of the scheduling immensely. In order to plan and coordinate properly, the chip-truck fleet is often considered part of the harvesting system when operating CFDDCs (Favreau, 1992).

- *Tree size*

CFDDs are processing machines able to process a much wider spread of trees sizes and species than most other processing methods (Creelman, 1989). CFDDs with chippers have the potential to cost effectively produce chips in the plantation, utilising small trees more effectively than other log production systems (Stokes and Watson, 1991). These CFDDCs can process smaller trees cost effectively as they handle many trees simultaneously.

Because trees are processed as bundles, it is difficult to quantify the effect of tree size and stem form on the productivity of these machines (Spinelli, et al., 2002b). Mooney, et al. (2000) tried to develop transformations to explain the effect of a number of trees per cycle, but their results did not explain the significant variance in cycle times. They also commented that this was not an unexpected result when the method of debarking/debranching was taken into account.

With CFDDs, it is preferable to process trees of similar sizes. If very big trees and very small trees are found in the same bundle, the big trees tend to shield the small trees from the flail action, resulting in poor quality of debarking and debranching. Also, trees of the same size within a given compartment tend to have the same physical characteristics. For example, all the very small trees might have poor BWBS or all the very big trees might have big branches. The bundle then has to be fed through the machine at a rate that will achieve the desired quality for the most limiting tree. This results in an overall lowering of productivity (Mooney, et al., 2000; Hechem, pers. com., 08 March 2010).

In addition, when large and small trees are fed through together, the infeed rollers have no grip or control over the small trees. These small trees tend to be swept through the CFDD by the flails, with little debarking taking place (Araki, 1994). The chipping quality is affected as the small stems are not fed into the chipper at a controlled speed, a requirement for uniform chip sizes. Uniform stands are therefore ideal for optimising the productivity of CFDDs. If this is not possible, then, in extreme cases, it might be worthwhile attempting to sort stems by DBH, so that a bundle consists of uniformly sized trees before they are processed (Mooney, et al., 2000).

- *Fibre utilisation*

Even though fibre yields have been shown to be greatly improved, CFDDs still have the potential to waste fibre if not operated properly. Raymond (1989) showed that CFDDs can lose as much as five per cent of available fibre. However, with current knowledge and new CFDD technology, this amount is much lower and is more than offset by the additional fibre gains through tops, large branches and unmerchantable stems. Much other research has shown that CFDDs can achieve lower fibre losses than drum debarking and producing logs in the plantation (Raymond, 1989).

An additional area that could be focused upon to increase the fibre yields from CFDDCs and CFDD&Cs is the waste chute. Hartsough, et al. (2000) showed that most reject material from the chipper is wood and that 80 per cent of all the wood lost in the CFDDC process comes out of the waste chute. This percentage was influenced by tree size, with larger trees resulting in more waste wood. But, as explained in the paragraph above, if expressed as a ratio of waste from waste chute to tree size, smaller trees had more wood waste. As a comparison, only five per cent of the wood lost came out of the hydraulic bark discharge (0.8 dry kilograms per tree) and this was irrespective of tree size. This figure clearly indicates that wood material actually lost because of flail action was minimal.

It is not clear what causes the wood to be found at the waste chute. Researchers have suggested the following factors play a role in this: knife sharpness, knife design, number and size of branches, incorrect flail setup, incorrect feed speeds of the flails and chipper and damage from flails (Hartsough, et al., 2000). If technology advances to reduce the amount of wood from the waste chute, the overall percentage of fibre utilisation will naturally increase.

- *Harvesting residue*

Because debranching and processing frequently takes place on the roadside, it is often difficult to handle the large amount of plantation residue (bark, leaves, branches) generated (Hartsough, et al., 2002). The machine removes material from the bole of the tree, the residue consumes space in the infeed and thus reduces the capacity for additional trees. Some systems have chainsaw operators who top the trees and remove very big branches in the compartment. This results in reduced residue at the landing and higher CFDD productivity.

If plantation residue is utilised (for example, transported to a power generation plant), then this system is ideal as the residue can be fed straight from the CFDD into a transport vehicle or moved to one side of the landing for later processing and transport (McEwan, 2010). The residue that a CFDD or CFDDC produces is more compact and easier to handle than residue from other processing methods (Favreau, 1992). It is also possible to use a conveyor to feed the bark and branches into a plantation residue truck, another chipper or a grinder, which will process the residue for transport. However, there can be broken chain links in the residue. This needs to be considered when deciding on which grinder to use to process the residue (Stephenson, 1989).

With CFDDCs, residue can also block the waste chute if the hydraulic bark discharger is not able to remove all of it and some is fed through to the chipper with the debarked bole. Hartsough, et al. (2002) explained that large amounts of residue increase the operating costs of CFDDs and CFDDCs by increasing fuel consumption and chain wear. These are two of the most important operating costs of these machines. To reduce these costs, an attempt was made to debranch hybrid poplar trees with a pull-through static debrancher before the trees were flailed. Even though the productivity of the CFDDC did increase by 10 per cent, this was not sufficient to justify the additional costs incurred by using an additional machine. However, Hartsough, et al. (2002) did state that some form of debranching before flailing might still be an option in certain site-specific situations.

- *Debarking*

The ability of CFDDs to remove the bark from trees is dependent on species, temperature, moisture content, tree size, number of trees fed at the same time, branchiness, feed speed, flail speed, number of chains used and flail condition (Thompson and Sturos, 1991). Thompson and Sturos (1991) reported that branches could actually improve debarking quality as they slowed the movement of the tree through the flails, resulting in greater chain contact. Sauder (1990) recommended reducing the bark content of the chips produced from flailed trees by not feeding too many trees through at one time, with three to five tree lengths being considered acceptable. Other methods of reducing bark on chips included:

- adjusting flail infeed and rotation speeds;
- synchronising the CFDD outfeed and the chipper infeed so that the trees were not pulled in by the chipper faster than the flails could debark them;
- the operator's examining the specific dynamics of the trees being debarked and ensuring that the CFDD infeed rollers could grip small trees tightly so they were not propelled through the CFDD without being adequately debarked.

Stephenson (1989) also investigated feed speeds and arrived at the same conclusions as Sauder (1990). Creelman (1989) tested an infield CFDD and found that it was consistently able to produce chips with a bark content of less than one per cent if the feed speed was controlled.

The number of flail drums used to debark usually varies from two to four. More flail drums result in better debarking and debranching quality. Often the last flail drum is used as a sweep drum. This drum rotates in the opposite direction to the others, preventing bark from being expelled with the debarked timber. For stubborn bark, two chains per attachment on the drum and more attachment points can be used (McEwan, 2010). The number of chains per drum can vary, but most flails make provision for between seven and ten chains per row, and have eight rows of chains per drum. CFDDs are very good at handling crooked stems and forked trees, removing bark effectively where a harvester is not able to (Wingate-Hill and MacArthur, 1991; Hartsough and Cooper, 1999).

Even though CFDDs are able to handle many stems at a time, it is still possible to over-feed the machine. Too many stems being fed through at once will result in poor debarking and debranching quality because some stems shield others (Rodden, 1991). Stephenson (1989) found that overfeeding results in patches of bark being left on the stem. Rodden (1991) stated that feeding the correct number of trees through resulted not only in better debarking quality, but it also enabled all the bark to drop to the floor of the machine for expulsion.

When too many stems are fed at once, the chipper has to slow down, which causes the feed speed of the trees moving through the CFDD to decrease. The excessive flailing of the stems subsequently causes white fibre to be lost. This results in an excess of fines and pins in the chips, as well as brooming of the chip ends (Araki, 1994). Thompson and Sturos (1991) affirmed that if the machines were fed with too many trees at once, then debarking quality was lower. They also mentioned that faster flail speeds improved debarking, but could result in an excess of poor quality chips (most notably, fines) and decrease chain life.

Tree size plays a role in the effectiveness of debarking. In their pine research, Watson, Twaddle and Stokes (1991) observed that smaller tree sizes had a naturally high level of bark in proportion to the entire stem and producing low levels of bark content could be more difficult. However, in research on a CFDD in North American hardwoods conducted by Thompson and Sturos (1991), the small trees achieved better debarking levels. This was attributed to the smaller trees having thinner bark.

- *Chain life and performance*

Flail chains are listed as one of the items incurring the highest expenditure in CFDDs. Thompson and Sturos (1991) found that chain costs can account for up to one third of the total CFDD operating costs. This expenditure concerns many potential operators and contractors. Chain condition is very important to achieve the correct debarking quality levels (Thompson and Sturos, 1991). Only a few missing links from a key area on the drum can reduce debarking quality.

Worn chain tends to fold up easily, which reduces the debarking effectiveness (Jackson, Thompson and Sturos, 1993). The aggressive nature of the flailing process puts stress on the chains, which causes them to wear rapidly (Sessions and Kellogg, 1994). Sessions and Kellogg (1994) reported that the major factors affecting the action of flail chains were:

  - the amount of space within the link – too much space allowed the chain to fold up and it became less efficient;
  - link length – as the length increased, the chain bounced off the stem more easily, causing faster wear;
  - link mass – the comment about link length applies to mass as well; and

- link shape – round links folded up too easily.

The cost of chains for the CFDD varies with the species being processed, wood density, tree size, drum design, hardness and rotational speed, bunch size, the time of year (both in terms of BWBS and cold – the trees are sometimes frozen), the size and frequency of the branches, feed rate, number of chains per drum and specific chain characteristics (Jackson, et al., 1993; Sessions and Kellogg, 1994). Table 3 shows the factors that influence the performance of flail chains.

Table 3: Factors influencing the performance of flail chains
(Jackson, et al., 1993, pg 30)

Workpiece	Machine	Chain
Volume processed	Drum placement	Wire diameter
Tree species	Drum orientation	Link size
Tree size	Cavity design	Number of links
Branch size	Residue removal system	Link geometry
Number of branches	Feed rate	Composition
Bunch size	Drum speed	Heat treatment
Number of trees per bunch	Drum design	Hardness
Dirt and rocks on trees	Drum hardness	Toughness
Previously delimbed	Number of chain rows	Impact strength
Time of year	Number of chains per row	Working temperature
Temperature	Chain position on drum	Weld quality
	Link position in chain	Wear to present

Harder wood and bark puts more stress on the chains. The number of chain rows and the number of chains per row influence chain wear. The more chains there are per drum, the lower the individual chain wear is, as the load is spread and the chains support each other. The chains at the centre of the drum (in horizontal drums) also wear more quickly as they make most contact with the stem (Raymond and Franklin, 1990). Chain costs for processing hardwoods are more than those for processing softwoods (Jackson, et al., 1993). Jackson, et al. (1993) observed that a high density of branches per tree and large branches made chains wear faster.

The main source of wear has been identified as the aggressive action between chains, with the chain hitting the drum playing a minor role. The chain motion most responsible for the wear is the whipping and snapping action of the last three links after the chain has struck an object (the stem) and is trying to catch up (Sessions and Kellogg, 1994). The wear from the chain striking wood is insignificant compared to the chain-on-chain wear, and, to a lesser extent, from chain-on-drum contact. The third link from the end generally shows the highest wear, but link failure normally occurs with the two end links (Jackson, et al., 1993). It has happened that the anchoring device fails as well. Raymond (1990) discovered that certain operators would extend chain life by cutting off the last link once the third-last link showed wear. This would effectively create a new third-last link which doubled chain life. The link normally fails at the weld, as can be seen in Figure 15.

Figure 15: Chain link failure at the weld

Shorter link chains seem to exhibit the least wear. Jackson, et al. (1993) also reported that once an eight-link chain has lost two links, it becomes ineffective for debarking. However, if mounted next to another eight-link chain, it can provide stability and shock absorption which can actually reduce wear. Chains should be rotated as wear becomes evident. Chains should be rotated end-to-end and should be moved to areas on the drum or to another drum less likely to promote wear (Raymond, 1990; Carte, 1991).

New chains are normally placed on the first drum where the most wear takes place (Raymond, 1990). In extremely difficult conditions, such as difficult debarking with lots of branches, chains with welded studs can be used (Sessions and Kellogg, 1994). These should not be used continuously though, as they can cause high fibre loss and the chains are expensive. Quick-disconnect links have also been used successfully to reduce the time taken to change chains. Jackson, et al. (1993, pg 33), stated that “Good debarking chain starts with good quality wire.” Obtaining chains at a lower price makes no sense if they wear quickly.

Mooney, et al. (2000) reported obtaining 400 truckloads of chips (eight weeks' worth of production) from a set of flails in a *P. taeda* thinning. Thompson and Sturos (1991) obtained 25 loads (each load was 26 tonnes) of timber from a set of chains before the chains were rotated for another 25 loads, giving an average of 50 truckloads of chips per set of flails or 1,300 tonnes from a set of chains. Gehoski (1989) managed to process 2,500 tonnes of trees on average before the chains were replaced. Thompson and Sturos (1991) predicted two future methods of improving the life of the chains: the first was through improved chain technology and the second was to separate the debarking/debranching function from the chipping function. Twenty years on, chain technology has indeed improved, However, no research has been conducted to quantify this improvement.

There is no rule as to how many chains should be mounted onto each drum. This is established by trial and error and fluctuates according to the variables mentioned above and in Table 3 (Jackson, et al., 1993). The minimum number of chains required for debarking and chip production of suitable quality should be used. If the stem is too close or too far from the flail, debarking and debranching are not as effective. Trees are also tapered, which makes maintaining the distance from the drum to the stem difficult. At least one drum, usually the upper one, should be floating in order to maintain this distance (Franklin and McPhee, 1993). It takes approximately 20 minutes to change chains (Selby and Iff, 1986).

- *CFDDs feeding chippers*

CFDDs' feeding into stand-alone chippers (termed CFDD&Cs in this report) allows the flexibility of producing debarked and debranched tree lengths if desired, as opposed to chips only. The CFDD operator can concentrate fully on optimal tree intake, relieved of having to guide the chip chute and watch material exiting the waste chute. It can also result in cleaner chips as monitoring of debarking quality is easier. Further to this, bark that still escapes the CFDD outfeed can fall onto the ground instead of being chipped with the tree lengths (McEwan, 2008).

Stephenson (1989) stated that if debarking levels of less than two per cent are required, it is better to have the chipper and CFDD a little further apart to allow bark to drop to the ground. However, Stephenson's research was undertaken before integrated CFDDCs had become commonly used and further developed. Previous methods of debranching and debarking to feed infield chippers often had undesirable levels of bark and soil contamination. CFDDs have the ability to remove this debris successfully (Thompson and Sturos, 1991).

One of the problems with having separate machines is that the chipper often has a much higher potential for productivity than the chipper. One option is to use two CFDDs to feed the chipper (Thompson and Sturos, 1991). This would create a system of exceptionally high productivity and there would have to be sufficient yearly volume to utilise the machines fully. This has been experimented with in *E. globulus* in Western Australia (Cameron, personal observation, 30 September 2010), but has not been scientifically researched. Two or more separate machines increase the need for operators and feeding cranes, as well as requiring more engines, which, in total, consume more fuel. All of this has the potential to drive costs up instead of down (Thompson and Sturos, 1991).

- *Chip quality*

CFDDCs are able to debranch, debark and chip full-tree lengths to meet the strict quality requirements of international pulp mills (Stokes and Watson, 1991). Infield chipping is a cost-effective method of producing chips for the forests' customers (Thompson and Sturos, 1991). CFDDCs are capable of producing chips with a bark content of less than one per cent (Rodden, 1991; Markham, 1995; Hartsough, et al., 2000) and can remove bark to levels similar to those achieved by fixed millyard installations (Mooney, et al., 2000). In the research by Markham (1995), the CFDDCs achieved a lower debarking percentage than that obtained by debarking drums at a mill. Keeping the bark at levels below one per cent does, however, require specific focus (Rodden, 1991).

Research has also been carried out to investigate chip quality, both in terms of chip-size distribution and bark content (Saunder, 1990). Rodden (1991) investigated aspects such as the chip yields as a percentage of the total material, yield comparisons between a number of harvesting systems and the percentage of useful wood fibre lost in the flailing process. Rodden also examined chip yield as a function of tree size. It was discovered that the chip output per cubic metre of stem volume increased with tree diameter. With regard to considering the useful fibre lost in the flail process, Rodden's results varied between three and five percent. None of this research was conducted on short rotation species such as *Eucalyptus* or hybrid poplar.

Debarking before chipping improves chip quality, enables the knives to stay sharper for longer and makes it unnecessary to separate the bark from the clean fibre at a later stage (Stephenson, 1989). Sauder (1990), in research which included *Picae mariana* (black spruce), *Pinus contorta* (pine) and *Abies species* (fir), found that the chips produced from infield CFDDs were of the same quality as those produced by ring debarkers at a mill. Poor debranching quality reduces the quality of chips produced by increasing the amount of fines, bark and undersize/oversize chips (Mooney, et al., 2000). Proper setup of the machine, including chip-knife maintenance, is important to ensure that both high productivity and good chip quality is obtained (Rodden, 1991). Feed rate differences between the CFDD and the chipper can also affect chip quality, as the incorrect average-size chip will be produced (Thompson and Struos, 1991). Stephenson (1989) warned that quality monitoring was very important when a bark content of less than one per cent was produced. There is an inverse relationship between debarking quality and chip fines. If, in trying to achieve very low bark levels in the chips, excess chip fines are produced, it could become problematic for the digester screens in a pulp mill. If pre-screening at the mill takes place, then this problem is eliminated (Stephenson, 1989).

Jirjis (1995) found that chip quality was mostly influenced by moisture content, tree species and size distribution. Higher moisture content results in the production of a higher proportion of 4 mm to 8 mm acceptable chips (Araki, 1994). Araki (1994) added ambient temperature as an influencing factor. Rodden (1991) indicated that chip quality from a studied infield chipping operation continuously produced chips of a better quality than the mills could. Spinelli, Hartsough and Magagnotti (2005) indicated that moisture content and tree species were not influenced by processing machine characteristics, whereas the chip-size distribution could be largely influenced by machine design and setting. Therefore, chip-size distribution is a very good indicator of the quality of chips that a particular type of chipper is capable of producing. Chip screening has been attempted infield (Araki, 1997), but adds an additional degree of complexity to the operation. This is best carried out at centralised processing yards or at the mill itself.

Araki (1994) observed that overall chip quality was negatively influenced as stem size decreased. This is due to small stems already having a high proportion of bark surface area to solid wood than larger stems (Araki, 1994). Flailed tops of trees can also result in lower chip quality and can even discharge these chips out of the waste chute. Very small stems are also negatively affected when debarked at the mill by means of drum or trough debarkers. As Stephenson (1989) explained, small stems tumble and break which results in broomed ends and under- and oversized chips. When chipping at the mill, it is also difficult to chip large and small trees separately because of the high productivity rates and the mix of timber being processed. If small trees are processed with infield chipping, the chips can be stockpiled and processed separately. This can reduce pulping losses by about the 10 per cent that would normally be attributed to the increased amount of juvenile wood (Stephenson, 1989).

Even though increased fibre utilisation has been demonstrated as an advantage of CFDDCs, bigger branches can result in many chip slivers and oversize material because the angle of contact with the chip knife is not usually correct (McEwan, 2010). If the trees have many branches, these can cushion the effect of the flails on the tree, resulting in poorer debarking quality (Araki, 1994). Keeping chipper knives sharp will reduce the proportion of chips outside specification parameters and ensure that the overall fibre yield from the tree is kept high (Hartsough, et al., 2000).

Sauder (1990) stated that the counter knives should also be in good condition and the anvil properly adjusted. In research conducted in pine, Watson, et al. (1991) found that infield chippers working with CFDDs produced fewer pins and fines, but more oversize chips, than the mill installation chippers. These oversize chips were partly attributed to inexperienced operators and the situation was expected to improve. Measuring chip quality accurately infield would make the team aware of potential problems in this regard. However, these infield tests have been shown to be very unreliable. If infield tests are carried out, it is best to place a bucket under the chip spout very briefly, repeating occasionally until the bucket is full (Stephenson, 1989).

As the team operating the CFDDs, CFDDCs and CFDD&Cs becomes more experienced, so the productivity, debarking quality and chip quality improves (Rodden, 1991).

2.3.5 Future trends with mechanised harvesting systems

Even though the harvesting costs of one harvesting system over another may indicate significant differences, it does not necessarily mean that a system change will take place. If a certain type of harvesting method has been established in a country or group of countries for some time, it becomes difficult to introduce radically different harvesting methods, even if the cost advantages are large. Spinelli, et al. (2009) listed factors such as the market for machinery, the mechanical support network and operator training as being important issues that cause people to ignore the cost advantages of a new method.

When the possibility of changing from a full-tree system to a CTL system arises, sometimes impediments prevent this from occuring. Such obstacles include not finding trained and experienced operators, poor organsation of the work crew, lack of mechanical backup for the machines and insufficient funds because much capital is already tied up in existing systems (Gellerstedt and Dahlin, 1999).

Gellerstedt and Dahlin (1999) averred that future mechanised systems would have to handle trees of both large and small sizes. While this is true, the situation is different in southern hemisphere plantations and the variations in tree size are unlikely to be as large as in the natural forests in the northern hemisphere. Gellerstedt and Dahlin (1999) indicated that the environmental aspects surrounding the consumptions of fuels, lubricants, oils and metal would have to decrease, but, at the same time, not compromise the power efficiency of machines. Another important aspect which Gellerstedt and Dahlin (1999) raised was reduced storage of wood in the forest, rather increasing buffers of logging capacity and not logs. Increasingly, harvesting systems would have to handle and process plantation residues at the same time as processing the conventional product. It is even possible that harvesting systems might have to switch between harvesting conventional products and energy wood throughout the year (Gellerstedt and Dahlin, 1999).

Machine operators will increasingly be required to carry out basic repair and maintenance of their machines or a dedicated person within a contractor's or company operation will have to be appointed to deal with these tasks (Gellerstedt and Dahlin, 1999). With the depreciation life of machines moving from the 15,000-hour mark towards 20,000 hours, management of maintenance is becoming increasingly important. Sourcing a person who can repair a machine as well as operate it is becoming more difficult in many countries. The prime reason for this appears to be that working alone in an isolated plantation forest is not very attractive to young people, many of whom are already migrating to the cities. Increased operator training through simulators and training schools will assist with the skills base and shorten learning curves (Gellerstedt and Dahlin, 1999).

Even though new technology in some harvesting machines, such as computer and control systems, leads to cost increases, some of the costs have been reduced. This is due to increases in parts coordination across products and more efficient assembly lines in the factories (Gellerstedt and Dahlin, 1999).

When questioning operators about new technology that they see as potentially helping them become more productive and comfortable in their work, Courteau (1996) identified several factors, including diagnostic and monitoring systems, navigation aids, improved seat suspension and automatic levelling of the cab.

Globally, an overall trend embracing CTL systems is expected because of their silvicultural and environmental advantages (Gellerstedt and Dahlin, 1999).

2.3.6 Mechanised harvesting of Eucalyptus

Owing to the wide range of provenances, clones and species available, it is possible to plant *Eucalyptus* on most sites, including soft underfoot conditions and steep terrain. Different mechanised harvesting systems therefore need to be available to handle most of these conditions (Spinelli, et al., 2009). *Eucalyptus* is a very dense wood which can reduce productivity by causing higher levels of mechanical breakdown in harvesting machines. These machines should be designed or modified for a *Eucalyptus* application.

Different solutions need to be found for debarking infield, at the landing and at the mill. The debarking technology has to handle the variety of small and large trees that are produced from the same compartment or felling programme (Wingate-Hill and MacArthur, 1991). Wingate-Hill and MacArthur (1991) predicted that a number of different technologies would emerge to harvest small-sized *Eucalyptus*. However, Spinelli, et al. (2009) found that knowledge of *Eucalyptus* harvesting is fragmented and spread over many different research projects.

Spinelli, et al. (2002a) found very few productivity models for *Eucalyptus*: most are based on other tree species. BWBS could also play a role, but it was assumed it would prove of less importance than average tree volume. Debarking trees, however, will lower the productivity level across the entire range of tree sizes.

Spinelli, et al. (2009) were able to develop a cost model for mechanised harvesting of *Eucalyptus* with both full-tree (using CFDDCs) and CTL systems (using harvesters). The model was able to predict costs within the systems utilising these two processing technologies for various machines under different working conditions. This model would assist forest engineers to make system decisions that are specific to the conditions they face. It should be noted that these cost models only include two different processing options, a CFDDC and a harvester.

2.3.6.1 Tree size

Spinelli, et al. (2009) found full-tree harvesting systems that used CFDDCs in *Eucalyptus* to be much less sensitive to tree size when compared with CTL systems utilising harvesters. They attributed this to the multi-stem handling ability of these full-tree systems, which were able to overcome the problem of harvesting small trees individually. They found the cut-off tree size, where costs for the CTL became unacceptably high, to be less than or equal to 0.10 m^3 per tree. The full-tree system used in their research (using CFDDCs) would be the preferred system. However, this research did not include other full-tree systems, such as DHPs operating on the roadside, CFDDs producing logs or a combination of CFDD and chipper (CFDD&C) that could produce chips. Spinelli, et al. (2009) also found that the full-tree system (using CFDDCs) was also the preferred system for trees between 0.10 and 0.20

m^3 per tree. Figure 16 shows the research results of Spinelli, et al. (2009). Note that WT refers to Whole-Tree System. In the United States, the whole-tree system is the equivalent of the South African full-tree system.

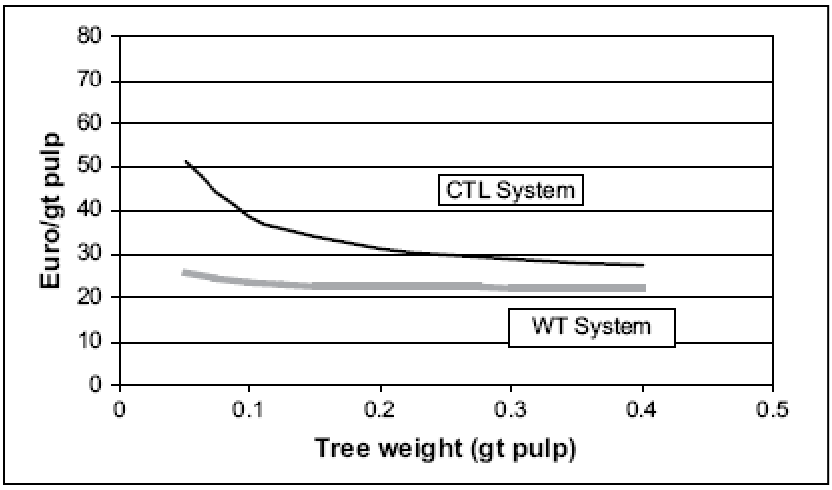


Figure 16: System cost comparison between full-tree (with CFDDC) and CTL (with harvester) systems for different tree sizes (Spinelli, et al., 2009, pg 5)

Figure 16 shows the steep CTL curve for small trees. It also shows that the system costs of the full-tree system are lower than those of the CTL system across the entire range of tree sizes. For the conditions encountered in the Spinelli, et al. (2009) research (*E. Globulus*, tree size: 0.15 m^3, two-metre logs for CTL, extraction distance: 400 m, transportation distance: 35 km, easy terrain), the full-tree system cost €20 per tonne of mill-delivered chips, whereas the CTL system resulted in a cost of between €25 and €30 per tonne for mill-delivered logs. These authors did caution that all of their data had been collected in Europe and North America. Application to southern hemisphere countries should be done with care. No indication is given in any of this research about how to rank different classes of BWBS.

Hartsough and Cooper (1999) compared a CTL harvester, forwarder and chipper system with a full-tree feller buncher, grapple skidder and CFDDC in *Eucalyptus*. They found that the CTL system was only cost competitive for larger trees with good form.

Spinelli, et al. (2009) suggested that the only way to make CTL systems cost-effective in small tree sizes would be to manage the plantations in a manner that allowed the trees to grow larger. This included using genetic improvement, fertilisation and having longer rotation lengths. Steeper areas with slopes in the region of 30 percent caused an increase in harvesting costs because productivity levels were lower. Added to this, different (more expensive) machine configurations were required to enable the system to operate effectively on the steeper slopes.

2.3.6.2 Debarking

Debarking *Eucalyptus* pulpwood trees is a complex problem and many different aspects influence the debarking method and technology used (Wingate-Hill and MacArthur, 1991). These include debarking location, tree-length or log-length processing, method of transporting, bark disposal, physical properties of the bark, BWBS, tree characteristics and labour availability.

Debarking a *Eucalyptus* tree is only one of many interconnected operations that transfer a standing tree into a product suitable for use by the customer (Wingate-Hill and MacArthur, 1991). *Eucalyptus* trees also have certain characteristics which can complicate the harvesting process. If the plantation is being coppiced after the initial planting rotation, specific technologies, systems and skills may be required for successful harvesting. The different species of *Eucalyptus* have different types of bark and bark-removal properties (Wingate-Hill and MacArthur, 1991).

Wingate-Hill and MacArthur (1991), stated that the BWBS is one of the most important properties affecting debarking ability. Hartsough and Cooper (1999) indicated that the BWBS varies with season, although they did not conduct research to quantify the claim. They expected *Eucalyptus* that grows all year round to have less variation in BWBS than deciduous species have. Wingate-Hill and MacArthur (1991) found a two-to-one variation in BWBS between winter and summer in natural stands of *Eucalyptus*. They also indicated that the sapwood moisture content was a good predictor of this bond strength, although testing sapwood moisture content is a difficult task in the forest. Wingate-Hill, Cunningham and MacArthur (1989) found that the BWBS increased significantly as days after felling increased. However, little detail is provided.

The BWBS also behaves differently as the time after felling increases. Wingate-Hill, et al. (1989) found that with species such as *E. grandis* and *E. globulus*, the BWBS tended to increase until approximately four weeks after felling, regardless of the processing machine used. From approximately four weeks to four months after felling, these trees became almost impossible to debark. After four months, the BWBS tended to become weaker once again.

Many *Eucalyptus* species have long, strongly tensioned fibres that run the length of the stem. Because it is difficult to cut these fibres transversely during debarking, the bark often comes off in long strips. These strands may wrap around the moving parts of machinery and cause blockages (Wingate-Hill and MacArthur, 1991). Kerruish (1984) categorised *Eucalyptus* species according to their debarking characteristics, as can be seen in Table 4. The table shows that different *Eucalyptus* species have different bark properties, which will affect the ability of certain machines to carry out debarking. The bark structure determines the type of debarking method to be used.

Table 4: *Eucalyptus* species categorised according to debarking characteristics
(adapted from Wingate-Hill and MacArthur, 1984, pg 112)

Category	**Bark structure**	**Species**	**Readily barked by ring-type debarker**	**Debarked by ring with difficulty**	**Hand stripping – no established mechanical process for small trees**
Type 1	Smooth surface, short fibre strands in outer and thicker bark. Bark tends to come off in platelets	*E. diversicolor* *E. maculata*	X X		
In-between 1 & 2		*E. viminalis* *E. globulus*		X X	
Type 2	Smooth surface, short fibre strands in outer bark, long in inner bark. Bark tends to come off in strips	*E. regnans* *E. grandis* *E. nitens*		? X	
Type 3	Rough surface, short fibre strands in outer and inner bark. Bark tends to come off in platelets	*E. calophylla* *E. fastigata* *E. delegatensis*	X		X X
In-between 3 & 4		*E. cloeziana*			
Type 4	Rough stringy surface, long fibre strands in outer and inner bark. Bark tends to come off in strips	*E. oblique* *E. pilularis* *E. sierberi* *E. agglomerate* *E. laevopinea* *E. muellerana*			X X X

Wingate-Hill and MacArthur (1991) concluded that the available literature did not reveal much regarding the debarking potential of *Eucalyptus* species in relation to the harvesting method, and more research would be required. Even though this literature is now dated, very little further research providing clarity on the above BWBS problem has been conducted.

Wingate-Hill and MacArthur (1991) added additional BWBS factors that compounded the general debarking problems in *Eucalyptus*:

- seasonal variation;
- between-species variation;
- within-species variation;
- compartment variation,

Spinelli, et al. (2002a) attempted to determine the effect that bark adherence had on the productivity of a harvester. They separated the trees processed in spring from those processed in winter. It was discovered that although the trees harvested in spring debarked within the first two passes, there was no productivity difference. This was due to the operators carrying out additional actions to indent the stems, making them less slippery and easier to handle. This negated any productivity benefits.

2.3.6.3 Harvester

A purpose-built *Eucalyptus* harvester head is usually heavier than harvester heads operating in similar tree sizes, but not debarking. This situation is complicated further, as the head is often too heavy to be placed on the smaller, wheeled harvesters (Spinelli, et al., 2000a). This can increase capital expenditure considerably (McEwan, 2010).

Spinelli, et al. (2002a) considered the duration of the time elements for a harvester operating in *Eucalyptus* and found that these were influenced by the terrain conditions, operational layout, tree volume, tree form, lengths of trees and the characteristics of the log assortments produced. The productivity and quality factors affecting harvesters in *Eucalyptus* are discussed below.

- *Tree size*

The affect of tree size on a harvester has been covered in the sections above.

- *BWBS and debarking*

Compression forces applied to the outside of a *Eucalyptus* log or tree are able to break the wood-bark bonds. In order for this to be effective, especially where the BWBS is high, the forces must be applied to as much of the surface area of the log or tree as is possible (Wingate-Hill and MacArthur, 1991). It is much easier when the tree is straight.

Eucalyptus processing rollers are made of hardened steel and have ridges that are angled to cut through, bruise and detach the bark and to assist the tree rotation in the head (Wingate-Hill and MacArthur, 1991). The spiralled roller ridges exert a tangential shear force between the bark and the wood. Careful matching of the feed roller ridge profile is necessary for different species and BWBSs (Hartsough and Cooper, 1999). This ensures that maximum contact is made with the tree to loosen the bark. The axis of the feed rollers is slightly angled to impart a spiral motion to the tree as it passes through the head (Hartsough and Cooper, 1999). It also allows the head to process slightly crooked trees.

In species which are difficult to debark or crooked, it might be necessary to use more than two feed rollers to increase the contact area on the tree for debarking. Then the grip can allow the head to pass over crooked or forked sections and sever large branches (McEwan, 2010). The debranching knives are designed both to debranch and to cut under the loosened bark to remove it. If there are few or no branches, the tree is often processed with the debranching knives open. This allows the tree to pass more easily through the head, especially important when processing trees with poor stem form (McEwan, 2010).

With debarking, it is normally necessary to debark and debranch before cross-cutting takes place because often more than one pass up and down is needed to remove the bark successfully. The measuring wheels struggle to measure accurately while debarking is taking place and the angles on the feed rollers also cause the tree to rotate, which makes measuring even more difficult (McEwan, 2010).

- *Tree form*

Forked and crooked trees can slow the feed speed of the tree through the head (Hartsough and Cooper, 1999). Such trees can also decrease the length of stem that can be debarked and debranched before a cross-cut has to be made. Hartsough and Cooper (1999) found the harvester was not capable of removing bark from areas close to severe crooks or forks because the feed rollers and debranching knives were not making contact at that point. Even with the harvester spending much time to remove all the bark from the tree, poor stem form can still result in debarking percentages on the tree which are unacceptable to chipping mills. In the research by Hartsough and Cooper (1999), even after considerable effort to remove all the bark from crooked and forked trees, the chip-bark content was still at 1.5 per cent, which was above the mill's limit of 1 per cent.

- *Multi-stemmed coppiced compartments*

If a harvester is used to fell multi-stemmed coppiced compartments, its productivity can be reduced due to additional handling. In research on *E. globulus* pulpwood conducted by Spinelli, et al. (2002a), it was found that if multi-stemmed coppiced trees were pre-felled with a chainsaw, productivity of the harvester increased by 13 cmin per tree. The productivity increase, measured in m^3 per PMH was not provided.

- *Debarking quality*

Hartsough and Cooper (1999) conducted research in *Eucalyptus* which examined the productivity of a harvester permitted to leave different amounts of bark on the tree. There were three categories: removing all the bark, partial bark removal and single-pass debarking (whatever bark remained after a single pass was left on the log). It took between one and nine passes to remove all the bark from the tree. Partial debarking, which attempted to remove half of the bark from the tree, took between one and five passes.

The resultant logs were then extracted to a landing where they were chipped and screened in an attempt to remove more bark utilising the screened chips from partially debarked and single-pass logs. The screening of chips in this research did not reduce bark content significantly: indeed, it appeared that none of the remaining bark had been removed. If partial debarking is going to take place infield and the mills have low bark tolerance, additional processing machines will have to be placed somewhere in the supply chain.

Wingate-Hill and MacArthur (1991) also observed that debarking performance utilising a harvester evidenced high variation between compartments and between trees within a compartment. In the best case observed, the bark was all removed with one pass of the head, but five to seven passes were sometimes necessary, and even then only 70 per cent of the bark was removed successfully. In this research, it was found that bark was often left in strips where the feed rollers did not have contact with the tree. Even though the spiral rollers attempted to turn the tree in the head, they did not always succeed, resulting in lack of roller contact with the tree and ineffective debarking. Wingate-Hill and MacArthur (1991) also discovered that the butts of some trees did not debark well. Higher BWBS at the butt-end of the tree lengths, together with the harvester head struggling to debark very close to the butt because of the distance between the felling saw and the feed rollers, resulted in the bottom 30 cm of the tree not being debarked. Attempting to debark this section often resulted in the tree falling out of the head, which reduced productivity.

2.3.6.4 Dangle-head processors (DHPs)

With *Eucalyptus,* DHPs remove the bark and branches using the same technology as a harvester does. Very little literature is available on the use of DHPs in *Eucalyptus*.

Hogg, Pulkki and Ackerman, (2009) used discrete event simulation in an attempt to provide an estimate of the DHP system performance in *Eucalyptus* harvesting on the Zululand coast of South Africa. Research was conducted on the entire system and the resultant data were used to simulate changes to the system. This research used an average tree size for the productivity determination of the entire compartment and did not consider the effect of different tree sizes on system productivity and cost. In addition, the results, while being useful for the prediction of system changes, were only applicable to the site where the research took place.

2.3.6.5 Chain-flail debrancher debarker (CFDD), Chain-flail debrancher debarker chipper (CFDDC), and Chain-flail debrancher debarker and chipper (CFDD&C)

The use of CFDDs in *Eucalyptus* is relatively new. The little information that is available is neither scientific nor detailed. CFDDs are regarded as a processing method with the potential to overcome the problems associated with small tree sizes and poor BWBS (McEwan, 2008).

- *Tree size*

The effect of tree size on a CFDD has been adequately explained in the sections above. No additional information is available at this point.

- *BWBS and debarking*

Very little research has considered the effect of BWBS on productivity. Hartsough, et al. (2000) did indicate that as BWBS became stronger, productivity was expected to decrease. However, in certain species of *Eucalyptus*, if the bark is removed too easily, it can come off in long strips. These can wrap around moving parts and eventually jam them or clog the hydraulic bark discharge. To avoid this, the feller buncher may have to fell trees a few weeks prior to processing (McEwan, 2008). Thompson and Sturos (1991) found that prolonged dry periods were noted for causing a drop in CFDD productivity because of lower BWBS. They did not, however, quantify this.

2.3.7 South African harvesting of Eucalyptus

Hogg, et al. (2009) found few benchmarks within South Africa regarding the productivity levels of mechanised harvesting systems in *Eucalyptus*. They also found that accepted, standardised operating practices for the existing mechanised systems were lacking, which meant that contractors and companies were determining best practice and productivity standards as their operations progressed. There is also no documentation referring to productivity levels in different tree sizes and stand conditions, which means that there is no productivity history with regard to the various operations. Hogg, et al. (2009) attributed this lack of background on productivity to the recent implementation of mechanised harvesting systems in *Eucalyptus* and the paucity of research on these systems.

2.3.8 Other debarking technologies

Although this section mixes debarkers with harvesting systems, other technologies can also be used to process *Eucalyptus* trees or logs. Only technologies with the ability to work within a compartment or on a roadside landing were considered for review.

2.3.8.1 Trough debarkers

Logs pass through a chamber with rotors that create a lateral, turbulent circular motion (Bren and Weidemann, 2006). Bark is removed by the logs coming into contact with each other and the rotors (Wingate-Hill and MacArthur, 1991). The logs rotate on their own axes as well as all the logs in the unit rotating together. Trough debarkers are good at debarking small, crooked logs. The logs are carried longitudinally along the debarker until they are discharged and the loose bark is collected in an outfeed chute for disposal or further processing. Trough debarkers are available in different lengths and some are even modular, with different units joined together to create a longer debarker. This would enable a continuous debarking process as opposed to having to batch process logs. More modules can be added to obtain the correct debarking quality (Wingate-Hill and MacArthur, 1991).

Bren and Weidemann (2006) tested the Savico trough debarker using various *Eucalyptus* species in Western Australia. This debarker was operated in batch fashion and showed much promise. Using ‘fresh’ wood – wood that was debarking easily – the debarker was able to obtain production rates of over 100 tonnes per machine hour. However, as time increased after felling, the debarking efficiency and productivity dropped. With one-week-old timber, only 81 per cent of the bark was removed and with two-week-old timber, only 72 per cent of bark was removed.

The debarker is only in proof-of-concept phase and needs refinement before commercialisation. It is designed to operate as a fixed type of industrial debarker and moving it to and around the plantation requires further research and modifications. At present, this debarker also requires a high kW generator (200 kW) as a power source in the plantation. Material handling, both into the debarker and after the logs have been debarked, poses additional challenges.

2.3.8.2 Pull-though debrancher

The pull-through debrancher (also known as a static delimber) is able to debranch more than one tree at a time (Hartsough, et al., 2002) and debranching is the only function this machine performs. Hydraulically operated debranching knives close around the tree bundle and the trees are then pulled through the knives. It has to be fed by an additional machine (for example, an excavator), which increases the resource requirements of the system. It can be used to debranch trees before they enter a CFDD, CFDDC or even before processing by a DHP. If used to feed CFDDs and CFDDCs, more than one debrancher would be required to keep up with the productivity of the debarking machines. It is only capable of removing approximately 70 per cent of the branches, depending on the branchiness of the trees (Hartsough, et al., 2002). If this machine is able to improve the productivity of the debarking machine sufficiently, it could result in a lower system cost overall.

2.3.8.3 Mobile chain-flail debrancher

The mobile chain-flail debrancher is mounted on a FEL and could possibly be used to remove the branches of species with excessively large, dense or strong branches, prior to further processing (Mooney, et al., 2000). It also has limited debarking capabilities. The machine operates on a similar principle to the CFDDs mentioned above, with chains mounted onto a hydraulically powered rotating drum. The FEL drives over the tree lengths with the flails removing the branches. Quality concerns demand that further debarking, and possibly debranching, takes place.

This machine would only be used as an attempt to increase the productivity of the primary processing machine, such as a DHP or CFDD. As with the pull-through debrancher, the entire processing cost would have to be examined to determine whether the use of an additional machine is justified. There are other semi-mechanised chain flails where short logs are hand-fed through a single set of chain flails. The unit is usually pulled and powered by an agricultural tractor. It is not suitable for higher production operations as it has intensive labour requirements and wide-ranging safety risks.

2.3.8.4 Double-grip harvesters

Double-grip harvesters have different attachments in order to fell and process trees. They are not suited to small *Eucalyptus* pulpwood applications where debarking is required. They are of greater value in stands where the average tree size is greater than 0.5 to 0.8 m^3 per tree (Glöde, 1999). There are very few double-grip harvesters operating today as the technology of single-grip harvesters is superior in terms of productivity and cost.

2.3.8.5 Ring debarkers

These machines, which operate in the compartment, on the roadside or at the depot, have not been considered because of their semi-mechanised operation. They have knives and scrapers mounted on rotors that rotate around the tree or log, cut into the bark and then scrape the bark off in small pieces. They are generally an option for smaller volumes of timber on isolated landholdings (for example, small landowners who have limited volumes of trees to fell per year). They can also only be operated where sufficient labour is available.

Other debarking options – such as water-hydraulic debarkers, which utilise water under high pressure, Rosser-head debarkers and drum debarkers – have not been investigated because of their non-use in the plantation. A mobile drum debarker was tested in Canada (Fortin, 1988), but was never commercialised.

2.4 Summary of main conclusions

A review of available literature has indicated that much research has been conducted on mechanised full-tree and CTL systems in the forests of northern hemisphere countries. The literature shows many advantages and disadvantages to utilisation of specific systems and describes factors affecting the operation and productivity of these systems. Most research indicates that the direct costs of CTL harvesting are greater than full-tree operations with roadside processing.

All the research pointed to tree size as the most important factor affecting system and machine productivity. It would appear that single-stem handling machines and systems are most sensitive to small tree sizes. Examples of such machines include harvesters and roadside DHPs. Costs increase rapidly for small trees. Multi-stem systems and machines were shown to be less sensitive to tree size. Examples of these machines include CFDDs and chippers. The literature shows that systems with single tree processing machines can be more expensive than multi-stem systems in tree sizes up to 0.30 m^3.

When compared with traditional northern hemisphere harvesting, it seems that minimal research has been conducted on the effects of tree size in mechanised harvesting of *Eucalyptus*. The influence of tree size on productivity is still poorly understood. The little research that has been done focuses mainly on harvesters and CFDDCs. No published information was found on the productivity of DHPs operating on the roadside. Neither had much research been undertaken on CFDDs and CFDDs operating with stand-alone chippers and accommodating different tree sizes.

The literature indicated that the additional debarking element when harvesting *Eucalyptus* compounded the problem of tree size, especially with single-tree handling machines and systems. Inevitably, costs increase, but using multi-stem full-tree systems has been recognised as an option for reducing harvesting costs in small trees. Spinelli, et al. (2009) produced the most recent and comprehensive research on the effect of tree size on mechanised CTL and full-tree multi-stem harvesting. They indicated that the heaviest cost gains for utilisation of a full-tree multi-stem system in *Eucalyptus* rather than a CTL system are for trees less than 0.20 m^3 per tree.

Researchers have found the bundle-processing method has made it difficult to determine the effect of tree size on the productivity of multi-stem processing machines. No research has been able to explain the effect of bundle size on the variation of cycle times. All current productivity determinations have been based on the average tree size occurring within a compartment or trial area and not on the actual tree sizes entering the machine. If a method were developed to determine individual tree sizes, more valuable data would be available to create a model that simulates a wider variety of tree sizes more accurately.

3 Research design and methodology

This chapter includes the aims of the research, key concepts and variables related to the research design, research sites, productivity data collection and analysis, cost data analysis and shortcomings and sources of error.

3.1 The aims of the research and the research hypotheses

To conduct successful research requires explicit aims and clearly defined hypothesis statements.

3.1.1 Aims of the research

This research encompassed the following aims:

- to investigate the productivity relationship between tree size and bundle size for various processing machines;
- to build a productivity prediction model that could relate the productivity of the processing machines to tree size and bundle size;
- to determine the costs per m^3 for different tree and bundle sizes per system in which the processing machines operated;
- to verify whether full-tree multi-stem systems have much lower costs than CTL and full-tree single-stem processing systems in very small tree sizes.

3.1.2 Hypotheses

The null and alternative hypotheses are outlined below.

3.1.2.1 Null hypotheses

- Prediction models are not able to relate the productivity of chain-flail debrancher debarker, chain-flail debrancher debarker chipper, chain-flail debrancher debarker and chipper, dangle-head processor and harvester processing machines to tree size and bundle size.
- Full-tree multi-stem systems do not have lower costs than cut-to-length and full-tree single-stem processing systems in very small tree sizes.

3.1.2.2 Alternative hypotheses

- Prediction models are able to relate the productivity of chain-flail debrancher debarker, chain-flail debrancher debarker chipper, chain-flail debrancher debarker and chipper, dangle-head processor and harvester processing machines to tree size and bundle size.
- Full-tree multi-stem systems do have lower costs than cut-to-length and full-tree single-stem processing systems in very small tree sizes.

3.2 Key concepts and variables related to the harvesting systems researched

Five different mechanised harvesting systems were researched, with the focus on the processing equipment. Four of the systems were full-tree systems and one was CTL. Three of the full-tree systems had multi-stem processing machines and one had a single-stem processing machine (DHP).

The systems have been named according to the processing technologies as follows:

1. **CFDD (Chile):** feller buncher – grapple skidder – CFDD – three-wheeled loader – slasher loader;
2. **CFDDC (Western Australia):** feller buncher – grapple skidder – CFDDC;
3. **CFDD&C (Western Australia):** feller buncher – grapple skidder – CFDD – chipper;
4. **DHP (Zululand, South Africa):** feller buncher – grapple skidder – DHP – slasher loader;
5. **Harvester (Zululand, South Africa):** harvester – forwarder.

The above systems did not all generate the same products. The CFDD, DHP and harvester systems all produced debarked logs, while the CFDDC and CFDD&C produced bark-free chips. However, different prices would be paid for the two products at the mill gate, which still makes comparisons possible. Also, not all processing machines carried out the same processing activities. Examples are the harvester, which felled and processed the trees into logs, whereas the DHP only debarked, debranched and topped trees. Therefore, the productivity of each processing machine needed to be determined, and then placed into systems costings in order to make accurate comparisons.

From the literature examined in Section 2, it was predicted that tree size would play a large role in processing machine and system productivity. In the context of this research, tree size refers to the utilisable volume of the tree in cubic meters (m^3). The volume is determined using the total tree height, diameter at breast height (DBH) over bark and the topping diameter of the tree. To make measurements, productivity and cost comparisons easier, tree size was categorised into various size classes. This is expanded upon in the sections below. The productivity of the multi-stem processing machines was hypothesised to be dependent on bundle size (the number of tree lengths fed through the machine per work cycle), while bundle size could also be dependent on the average tree size in the bundle. Other variables that were predicted to play a role in machine productivity were BWBS and tree form (straightness of the tree and the number and size of branches). This has also been described in more detail in the sections below.

The species selected for the research consisted of *E. globulus*, *E. grandis* and *E. grandis x camaldulensis.* These are some of the most important species for global pulpwood production. Different species had to be researched because of the different geographic locations: *E. globulus* was researched as part of the CFDD, CFDDC and CFDD&C systems in Western Australia and Chile and the *E. grandis*-based species were researched as part of the DHP and harvester systems in South Africa. As mentioned in the literature review, these species had very similar debarking characteristics and could therefore be compared in research. Through the determination of BWBS before debarking, it was possible to ensure that different systems were compared objectively.

3.3 Background to the selection of research sites, data collection methods and other machine productivity influencing factors

All harvesting systems consisted of a number of machines that carried out various functions to enable logs or chips to be transported to a mill. Depending on the type of harvesting system, each machine could be more, or less, dependent on another and was affected by the performance of the machine that worked before or after it. To understand the operation of a harvesting system fully, the dynamics of each machine in the system needs to be understood. In full-tree systems, such as the CFDD, CFDDC, CFDD&C and DHP, the machines' form of dependency on the others is due to their higher productivity levels and the need to optimise storage and processing space. The harvester was less sensitive to the operation of the forwarder in a CTL system as it was the first machine in the system and was able to build up higher stock levels infield for the forwarder.

Time-and-motion research has been, and still is, used to describe, understand and improve forestry operations accurately (Spinelli and Visser, 2008). This research investigated the time taken for specific processing activities and the quantity produced during the same period for these activities (Steinlin, 1955).

In this research, only the processing machine within each harvesting system was investigated, even though the processing machines could theoretically be influenced by other machines within the system. This was possible as only the productivity per productive machine hour (PMH) of the processing machines was researched, and not the machine utilisation levels. All processing technologies always operated at full efficiency and did not slow production because of a machine of lower productivity working before or after them: they either functioned at full production or they did not operate. It was therefore possible to isolate the productivity of the processing machines. Further to this, as highlighted in the literature review, the lack of knowledge only existed for the processing technologies. The productivity and operation of other machines in the systems had been researched and information recorded. Therefore, the focus fell on the processing machines only.

The **input variables** for each type of processing machine researched consisted of **tree size** (in m^3), **number of trees processed per bundle** (for the CFDD, CFDDC and CFDD&C), **BWBS and tree form**. These variables were chosen for their potential effects on processing machine productivity, as identified in the literature review. These variables are further described in Section 3.4.3.1.

The **output variables** consisted of **debarking quality, machine productivity per PMH and system costs per m^3 produced**. Debarking quality needed to be considered, as the machines could potentially operate at very high productivity levels, but the product might not meet the customer's bark-quality requirements. Processing machine productivity per PMH showed the production rate of the machine per unit of time. However, it was not possible to make direct comparisons between productivity per PMH or the processing machine costs per m^3, as each of the machines carried out a different number of processing functions. It was therefore necessary to examine the entire costing of each system under review in order to select which was most cost-effective.

Machine costs within each system were determined by identifying all machines used in the system and then collecting all input costs and assumptions. The productivity figures determined from the research for each processing technology were then used in the system's costings to obtain a cost per m^3. The description of debarking quality and machine productivity was included in Chapter 2 and system costs appear at the end of this chapter.

3.4 Research sites

Owing to the very high operating costs of the machinery, it was not possible to get all the systems or processing machines working on one site and the researcher had to find sites where the machines were operating. Research was ultimately conducted on ten different processing machines that harvested 11,632 trees on ten different sites in three countries on three different continents. An overview is first provided of the general areas where the research was conducted, followed by the detailed compartment information in the subsections below. The description of the productivity variables studies and the actual data collection is included in Section 3.5.

The only place in the world where the CFDD was operating in *Eucalyptus* to produce debarked tree lengths for logs was in Chile. There were other CFDDs in use in *Eucalyptus*, but these systems were set up to feed the debarked and debranched trees into mobile disc chippers. One week was spent in Chile investigating the CFDD system and related productivity.

Both the CFDDC and CFDD&C were researched across various sites in Western Australia. Western Australia was chosen for the research owing its large concentration of CFDDC and CFDD&C systems operating in *Eucalyptus*, on sites similar to those found in South Africa and Chile. One week was spent on the four CFDDC sites and one week on the three CFDD&C sites. Each technology was researched at various sites: even though it would have been possible to spend the entire week at one site, different sites added variation to the data, especially regarding tree size.

The DHP and harvester were researched in the Zululand area of South Africa. The DHP and harvester processing heads were mounted on 20-tonne construction excavators as carriers. This was the predominant carrier used in *Eucalyptus* pulpwood harvesting in South Africa, Australia and Chile, as well as in most other parts of South America. Within the full-tree systems, the working routines of like machines were similar. This included the feller bunchers, grapple skidders, CFDDs and CFDDCs. This is discussed further below.

The terrain conditions at each site were determined using the South African National Terrain Classification System (Erasmus, 1994), which considers the trafficability of a compartment for ground-based machines. Table 5 indicates how the terrain is evaluated. The exact conditions encountered in each compartment are included in the subsections below.

Table 5: Terrain classification classes
(Erasmus, 1994, p3)

Ground conditions	Ground roughness	Slope
1. Very good	1. Smooth	1. Level (0-10%)
2. Good	2. Slightly uneven	2. Gentle (11-20%)
3. Moderate	3. Uneven	3. Moderate (21-30%)
4. Poor	4. Rough	4. Steep 1 (31-35%)
5. Very poor	5. Very rough	5. Steep 2 (36-40%)
		6. Steep 3 (41-50%)
		7. Very steep (>50%)

Slope was measured with a clinometer at various points across the research sites and averaged. Ground conditions were not monitored in the research as this had little influence on the processing machines researched. Ground conditions considered topsoil clay percentage and the diagnostic topsoil type (Erasmus, 1994). Vehicle trafficability was determined for ground conditions in dry, moist and wet states. Ground roughness was based on the presence of obstacles (stones and boulders) and depressions, their frequency and size (Erasmus, 1994). The terrain conditions for each of the research sites are included in the subsections below.

Bark had to be removed completely at all research sites. All mills that took possession of the debarked logs or chipped had bark tolerances of less than one per cent of the clean fibre delivered (N. Hechem, personal communication [conversation], 3 April 2008; D. Sawers, personal communication [conversation], 7 July 2008; A. van Rooyen, personal communication [conversation], 2 October 2008).

3.4.1 Chain-flail debrancher debarker (CFDD) (Chile) research site, operation and system information

The research site was located close to the town of Concepcion in Chile. The compartment was level, with few obstacles. The relevant compartment information is indicated in Table 6.

Table 6: CFDD compartment information in Chile

Dates (all 2008)	**21 to 26 April 2008**
Harvesting contractor/company	Mecharv
Grower company	CMPC – Forestal Mininco
Farm	Totoras
Compartment number	3
Species	*E. globulus*
Plant year	199805
Fell age (yrs)	9 yrs, 11 m
Average tree volume	0.190 m^3
Ground conditions	Not determined
Ground roughness	1 - Smooth
Slope	1 - Level

There was visual variability in tree size, which appeared to be related to soil quality, across the compartment. Parts of the compartment evidenced very good growth, while other parts had smaller trees. This particular area of Chile was under drought conditions, which resulted in the smaller (stressed) trees dying back. The ground roughness for all research sites was classified as smooth, as no obstacles were found. Tree form was relatively good for *E. globulus*. These variations were captured and analysed.

A topless, full-tree harvesting system was used. After felling, the trees were topped with chainsaws. Only the trees that were accessible to the chainsaw operators were topped. Table 7 shows the detailed activities that were measured during the operation of the CFDD.

Table 7: CFDD operation

Pre-processing	The CFDD operated within the compartment on a roadside landing. A feller buncher felled trees and grapple skidders extracted them to the CFDD. The grapple skidder presented the bundles to the CFDD in two lines, one slightly to the left of the infeed and one slightly to the right.
Feeding	The infeed rollers gripped the trees and pulled them into the machine. The CFDD operator picked up the large trees as far down the stem as he could, lifted the bunch and pushed it into the machine. The CFDD operator fed the machine from one bunch of timber while the skidder placed the next bunch beside it. In this way, the skidder did not disturb the feeding element. Trees were fed into one side of the feed chute and spread out for maximum contact with the flails. As the trees moved through, the next batch of trees was placed on the other side of the infeed and spread. The trees were often placed over the tops of previous trees. This allowed the flails to beat the tops against a solid surface to facilitate debarking.
Debarking/ debranching	The CFDD had an integral knuckle-boom loader for feeding trees and removing residue from the infeed area and the hydraulic bark pusher. The CFDD fed trees through a chamber that consisted of feed rollers and three sets of chain flails mounted on rotating drums. The flails

	on the rotating drum beat the bark and branches from the tree. This debris fell to the bottom of the chamber where it was expelled by a hydraulic pusher. The first two flails rotated in the direction of tree movement and were mostly run at maximum speed. The last flail was rotated in the opposite direction. It functioned as a sweep to prevent loose material from being swept out of the outfeed. Various rollers inside the chamber assisted with keeping the trees moving.
Outfeed	A pair of outfeed rollers pulled the trees out of the chamber to the waiting three-wheeled loader. A working rack of debarked stems was placed at the outfeed of the debarker as a bearer. The trees were able to slide along this surface, which helped prevent soil contamination. These bearer stems were moved from landing to landing as the system progressed through the compartment. As the debarked trees exited the CFDD, the three-wheeled loader gripped the butt ends and pulled the trees. As the three-wheeled loader moved forward, the trees rested on a plate above its drive wheels. The trees were placed in a 'V' formation on a bearer log in front of the CFDD's outfeed. This enabled the slasher to process one pile while the other was being rebuilt. The three-wheeled loaders scattered slash across their work area to prevent soil contamination and to protect the soil surface. The debarked trees were then slashed to length and stacked along the roadside.
Other	Chain life depended upon the BWBS of the trees, which flail drum they were on and their position on the drum. Standard practice was to use the chains for 18 hours, then rotate them and use them for a further 9 hours. The operator could tell the condition of the flails from the appearance of the debarked stem. The CFDD sourced its power from one engine, with each flail drum having its own hydraulic motor (hydrostatic drive).

Figures 17 and 18 show trees being fed into and out of the CFDD. The Bell loader carried the logs to the slasher.

Figure 17: Trees being fed into the CFDD, and Figure 18: The Bell loader removing trees

The other elements of the system were as follows:

- **Felling – feller buncher**

  Trees were felled, accumulated and placed in optimal bunches for the grapple skidder by means of a wheeled feller buncher,.
- **Topping – chainsaw**

  Two chainsaw operators topped the larger trees in the compartment while the trees lay bunched. Very big branches were also removed. The tops of trees that were hidden by other trees were not topped.
- **Extraction – grapple skidder**

  Bunches were collected, extracted and deposited at the infeed of the CFDD by means of a grapple skidder. The skidder also removed slash from the hydraulic bark pusher and stockpiled it for a separate processing operation for energy production. When the research commenced, two skidders were being used. One skidder was removed during the research to test how well the system would function with only one skidder.
- **Debarking and debranching – CFDD**

  A detailed description of the operation can be found in Table 7 above.
- **Tree handling – three-wheeled loaders**

  Two three-wheeled loaders were used to pull the debarked trees from the outfeed of the CFDD to the slashing area. However, there was often only one loader working, as the other would be used to help with other functions of the operation.
- **Slashing and stacking**

  A tracked excavator loader, operating with a slasher, crosscut the debarked and debranched trees into logs of seven metres and stacked them. A separate loader (the same type of machine as the slashing excavator) loaded the rigid trucks with drawbar trailers, which were piggy-backed onto the rigid truck. The loader would remove the trailer from the truck for loading.
- **Log transport**

  A six-axle rigid truck with a two-axle drawbar trailer was used to transport the seven-metre logs to the pulp mill. When travelling empty, the stanchions of the trailer and truck were lowered and the trailer was placed on the drawbar truck. The loading and transporting of seven-metre lengths enabled higher productivity. Compared with costs incurred when shorter log lengths were used in other similar operations, the operating costs of both the slashing and loading machines were lower because of the increased productivity with the seven-metre lengths

The equipment used in the CFDD system is shown in the matrix in Figure 19 on the following page. The matrix provides a visual indication of how the processing equipment interacts with the rest of the equipment in the system.

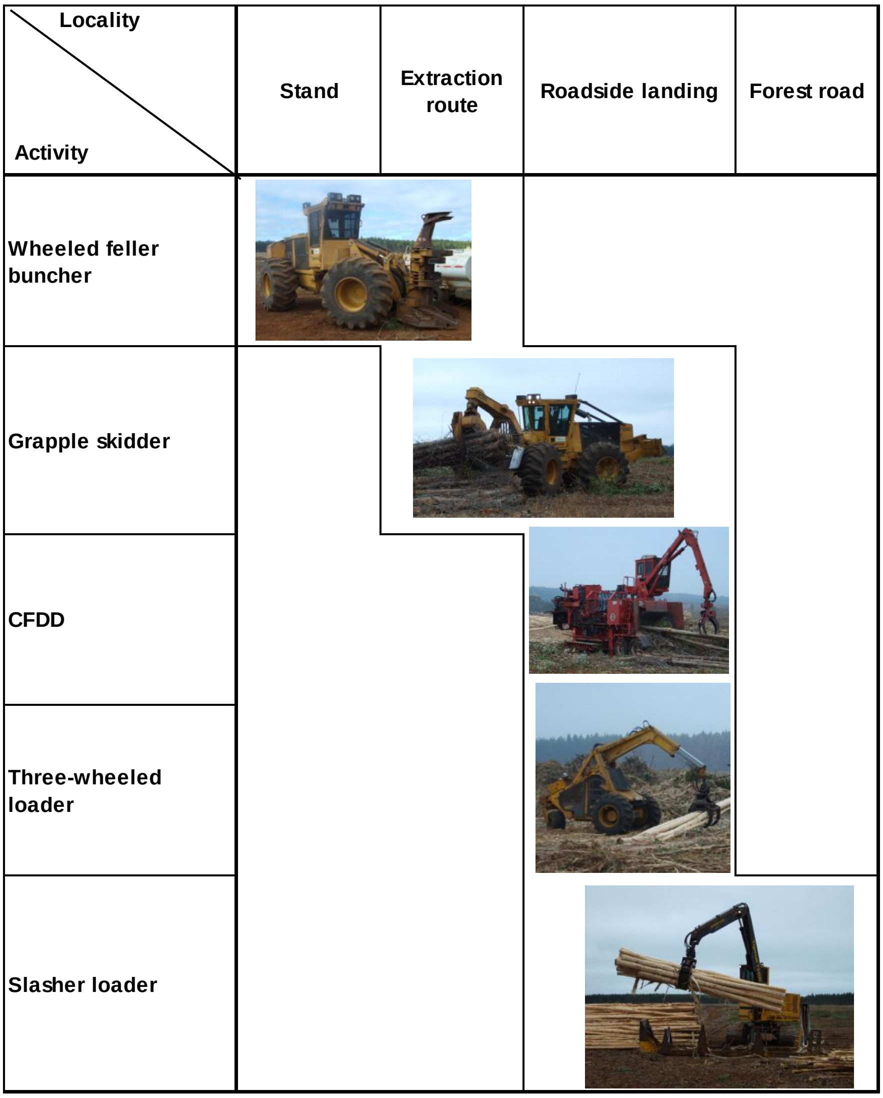


Figure 19: CFDD system matrix

The details of the machines used in the CFDD system are indicated in Table 8 on the following page. This provides a more detailed indication of the machines used during the research.

Table 8: Machine information for CFDD system

Activity	Machine type and detail	Machine make and model
Felling	Feller buncher: • wheeled drive-to-tree • continuous disc saw • accumulator	One Tigercat 724E
Extraction	Grapple skidder: • single arch • bunching grapple	One or two Tigercat 620Cs
Debarking and debranching	CFDD: three flail drums	One Morbark 2455
Tree handling	Three-wheeled loader: telescopic boom	Two Bell 220 (Super) Teleloggers
Slashing and stacking	Slasher loader: • tracked • swing-to-tree • bar-and-chain slasher	One Tigercat 240B

3.4.2 Chain-flail debarker debrancher chipper (CFDDC) (Western Australia) research site, operation and system information

The operations in Western Australia were chosen because of the similarity of the site conditions, tree sizes and tree characteristics to those in South Africa and Chile. Numerous CFDDC systems were also working within close proximity to each other, which catered for a wider variety of tree sizes and characteristics, as well as making research logistics easier. All chips produced were transported from the compartments by means of chip trucks, with the chips eventually being exported by ship, mostly to Japan (Sawers, personal communication [conversation], 7 July 2008). Four different research sites were selected, as per Table 9.

Table 9: CFDDC research sites in Western Australia

Dates (all 2008)	26 & 27June	30 June & 01 July	30 June & 02 July	26 June & 03 July
Harvesting contractor/company	Softwood Logging	WAPRES 1	WAPRES 2	Dohnt LV & Co
Grower company	GSP	ITC	ITC	ITC
Farm	Oriole	Willow Springs	Willow Springs	Coopers
Compartment number	10	13	12	CH12
Species	*E. glob*	*E. glob*	*E. glob*	*E. glob*
Plant year	1997	1997	1997	1997
Fell age (yrs)	11	11	11	11
Average tree volume	0.105 m^3	0.335 m^3	0.272 m^3	0.344 m^3
Ground conditions	Not determined	Not determined	Not determined	Not determined
Ground roughness	1 - Smooth	1 - Smooth	1 - Smooth	1 - Smooth
Slope	1 - Level	1 - Level	1 - Level	1 - Level

The systems were operated by the organisations indicated below.

- **Softwood Logging**

  One research site with one operation close to the town of Albany and a separate contractor (Southern Haulage) transporting the chips.
- **WAPRES**

  Two research sites close to the town of Bunbury, but the same operation being conducted on both sites. A separate contractor (Brooks) transported the chips. WAPRES are also plantation owners, but have their own harvesting operations that harvest procured timber.
- **Dohnt LV & Co.**

  One research site and one operation close to the town of Albany, with a separate contractor (Southern Haulage) transporting the chips.

The various compartments were all level, some with gentle slopes in certain areas. The compartments were obstacle-free, and therefore had a ground-roughness class of smooth. The soils were mostly sandy, which necessitated good road access. All compartments were planted with *E. globulus*. The average tree size across the research sites varied substantially. This was due to site-quality factors, as opposed to tree age. The compartments were all harvested in winter, which is the rainy season in Western Australia.

Full-tree harvesting systems were used throughout. Table 10 shows the detailed activities that were measured during the operation of the CFDDC. A large part of the basic operation of the CFDD operation is the same as documented in the section on the Chile CFDD.

Table 10: CFDDC operation

Pre-processing	Trees were felled with a feller buncher and brought to the CFDDC by means of grapple skidders. The grapple skidder presented the bundles to the CFDDCs in two lines, one slightly to the left of the infeed and one slightly to the right. This operation used an integrated machine that had both flailing and chipping functions. The remainder of the grapple-skidder operation was the same as that at the CFDD.
Feeding	An integral knuckle-boom loader was used for feeding trees in and removing residue from the infeed area and the hydraulic bark pusher. Feeding the trees through the CFDDC was also the same as described for the CFDD, with the exception that the trees were also chipped.
Debarking/ debranching/ chipping	Trees were fed through a chamber that consisted of feed rollers and sets of chain flails mounted on rotating drums. The number of flails, the flailing action and operation were the same as the CFDD. This debris also fell to the bottom of the chamber, from where it was expelled by a hydraulic pusher. With the Peterson 5000, a pair of dual-feed rollers inside the CFDDC pulled the trees from the flail chamber and pushed them against the chipper disc.
Chip chute/ truck loading	The chips and waste material were then discharged (blown) through the two chutes. Chips were fed directly into chip trucks and the waste chips deposited on the ground next to the chipper from where the grapple skidder removed them. The acceptable chips were blown into the chip truck and the waste material deposited on the ground. It was not possible to view the tree after it had been debarked; therefore, the operator had to judge debarking quality by observing the material exiting the waste and chip chutes. Experienced operators were able to maintain a consistently good chip quality by doing this. The chip loading and transport operations were integral to the operation of the CFDDCs. All chip trucks consisted of truck tractors, with semi-trailers pulling drawbar trailers. These Australian road-train trucks were approximately 27 m long, with a gross combination mass of 75 tonnes and a TARE weight of 25 tonnes, resulting in a payload of approximately 50 tonnes. The figures differed according to configuration and design of the road train. The trucks parked along the road and were filled up from the front. If possible, the truck faced downhill so that moving forward was more energy-efficient and created less component wear. The truck moved slowly forward as a section of each bin was filled. The chip chute was also able to direct the chips into whichever part of the bin was desired. This was controlled from the cab of the CFDDC and chipping did not need to stop when one bin (trailer) was full.
Other	The Peterson Pacific CFDDC sourced its power from one engine and each flail drum had its own hydraulic motor (hydrostatic drive).

A general overview of the other components of the systems follows.

- **Felling – feller bunchers**

  With the exception of WAPRES, the operations used tracked, swing-to-tree, non-levelling feller bunchers with shear felling attachments. WAPRES used a wheeled, drive-to-tree feller buncher, with a shear felling attachment. Only one feller buncher was used per operation. Trees were felled, accumulated and placed into optimal bunches for the grapple skidders.

- **Debranching – chainsaws**

  This was only observed at the WAPRES operation, where it was carried out when there were excessively large branches. At this operation, chainsaws were sourced and the team members themselves carried out the debranching.

- **Extraction – grapple skidders**

  With the exception of at WAPRES, two grapple skidders with bunching grapples were used (see 'Slash removal – front-end loader' below). Bunches were collected, extracted and deposited at the infeed of the CFDDC. The skidder (or front-end loader) would also remove slash from the hydraulic bark pusher and the chipper waste chute, and either stockpile it for burning or return it to the compartment.

- **Debarking, debranching and chipping – CFDDC**

  A detailed description of the operation can be found in Table 10 above.

- **Slash removal – front-end loader**

  WAPRES made use of a front-end loader (FEL), as shown in Figure 20, with a log/slash grab attachment. This was used to remove slash from the infeed area and the hydraulic bark pusher and stockpile it nearby. It also assisted the grapple skidder to bring trees to the CFDDC if extraction distances were very far or when the grapple skidder had a breakdown. The front-end loader would usually work closer to the landing than the grapple skidder.

Figure 20: Front-end loader for slash removal and tree extraction

- **Chip transport – chip trucks**

  The chips were then transported on chip trucks, as per Figures 21a and 21b. These figures show examples of the chip trucks. The most common truck configuration was a three-axle truck tractor, with a three-axle semi trailer pulling a five-axle drawbar trailer.

Figure 21 a and b: Chip transport trucks

The equipment used in the CFDDC system is shown in the matrix in Figure 22. The matrix provides a visual indication of how the processing equipment interacts with the rest of the equipment in the system.

Locality / Activity	Stand	Extraction route	Roadside landing	Forest road
Wheeled or tracked feller buncher				
Grapple skidder (and front-end loader - WAPRES)				
CFDDC				

Figure 22: CFDDC system matrix

The details of the machines used in the CFDDC system are indicated in Table 11 below.

Table 11: Machine information for CFDDC system

Activity	Machine type and detail	Machine make and model
Felling	Feller buncher (WAPRES): • wheeled drive-to-tree • shear felling attachment • accumulator Feller buncher (Dohnts, Softwood Logging): • tracked non-levelling • shear felling attachment • accumulator	Softwood Logging: one Caterpillar 521 WAPRES: one Tigercat 726 Dohnts: one Tigercat 822C
Extraction	Grapple skidder: • dual arch • bunching grapple	Softwood Logging: two Caterpillar 545Js WAPRES: one Tigercat 630C Dohnts: two Tigercat 630Cs
Slash removal (and tree extraction)	Front-end loader: log/slash grab	WAPRES: one Volvo L90E
Debarking, debranching and chipping	CFDDC: • three flail drums • disc chipper	Softwood Logging: one Peterson 5000H WAPRES: one Peterson 5000G Dohnts: one Peterson 5000G

3.4.3 Chain-flail debrancher debarker & chipper (CFDD&C) (Western Australia) research site, operation and system information

The research site and conditions were the same as the CFDDCs. The chips that were produced were also transported from the compartments by means of chip trucks.

As seen in Table 12, the research consisted of three harvesting operations on separate geographical sites (Millinup, Dondydowns and Snowball) close to the town of Albany. They were all being operated by Edenborn Pty Ltd. Edenborn also ran the chip transport operation under the name of Auschip.

Table 12: CFDD&C research sites in Western Australia

Dates (all 2008)	23 & 24 June	23 & 25 June	04 July
Harvesting contractor/company	Edenborn 1	Edenborn 2	Edenborn 3
Grower company	ITC	GSP	GSP
Farm	Millinup	Dondydowns	Snowball
Compartment number	13	1	
Species	*E. glob.*	*E. glob*	*E. glob*
Plant year	1997	1997	1997
Fell age (yrs)	11	11	11
Average tree volume	0.236 m^3	0.179 m^3	0.254 m^3
Ground conditions	Not determined	Not determined	Not determined
Ground roughness	1 - Smooth	1 - Smooth	1 - Smooth
Slope	1 - Level	1 - Level	1 - Level

The various compartments were level and obstacle-free. The soils were sandy which necessitated good road access. The compartments were planted with *Eucalyptus globulus*. The tree-size variation was large. The compartments were all harvested in winter, which as indicated, is the rainy season in Western Australia.

Table 13 shows the detailed activities that were measured during the operation of the CFDD&C.

Table 13: CFDD&C operation

Pre-processing	The CFDD operated within the compartment on a roadside landing. The trees were felled and extracted in the same way as the CFDD and CFDDC.
Feeding	Feeding the trees through the CFDD was the same as for the CFDD and CFDDC systems. It had an integral knuckle-boom loader for feeding trees and removing residue from the infeed area and the hydraulic bark pusher.
Debarking/ debranching	A CFDD was used to remove bark and branches. The operation of the CFDD part of the operation was similar to that documented in the Chile CFDD section, with similar flail speeds. However, the Precision Husky CFDD had four flail drums. The first three flails rotated in the direction of the tree movement and the fourth rotated in the opposite direction, functioning as a sweep.
Chipping	The processed tree lengths were then fed directly into the chipper. The disc chipper was able to chip multiple tree lengths simultaneously. It had a crane for feeding trees and removing residue ejected from the outfeed of the CFDD. A pair of outfeed rollers pushed the trees out of the CFDD towards the chipper. The two machines were aligned approximately three metres apart and the debarked and debranched trees moved straight through into the disc chipper via a set of infeed rollers. These ensured that the trees were pulled into the chipper at constant feed speed. The tree was then chipped.
Chip chute/ truck loading	The chips were fed via the chip chute into the chip truck which was parked on the road. Waste material was fed through the waste chute onto the ground from where it was removed by a grapple skidder. The chip-loading method was the same as with the CFDDC, as were

	the chip-truck configurations used.

As per the CFDDC, full-tree harvesting systems were used throughout. A general overview of the components of the systems follows.

- **Felling – feller bunchers**
  All of the operations used tracked, swing-to-tree, non-levelling feller bunchers with shear felling attachments. Only one feller buncher was used per operation. Trees were felled, accumulated and placed in optimal bunches for the grapple skidders.
- **Extraction – grapple skidders**
  Two grapple skidders with bunching grapples were used at all operations. Bunches were collected, extracted and deposited at the infeed of the CFDD. The skidder also removed slash from the hydraulic bark pusher and from the chipper waste chute. The slash was either stockpiled for burning or returned to the compartment, depending on grower company requirements.
- **Debarking and debranching – CFDD**
  A detailed description of the operation can be found in Table 13 above.
- **Chipping – disc chipper**
  A detailed description of the operation can be found in Table 13 above. Figure 23 shows the CFDD feeding into the chipper and the chips being fed via the chip chute into the chip truck. Note the grapple skidder removing residue from the waste chute.

Figure 23: CFDD, chipper and chip truck

- **Chip transport – chip trucks**

  The chips were then transported from the site on chip trucks, as per Figures 21a and b in the CFDDC section.

The equipment used in the CFDD&C system is shown in the matrix in Figure 24. The matrix provides a visual indication of how the processing equipment interacts with the rest of the equipment in the system.

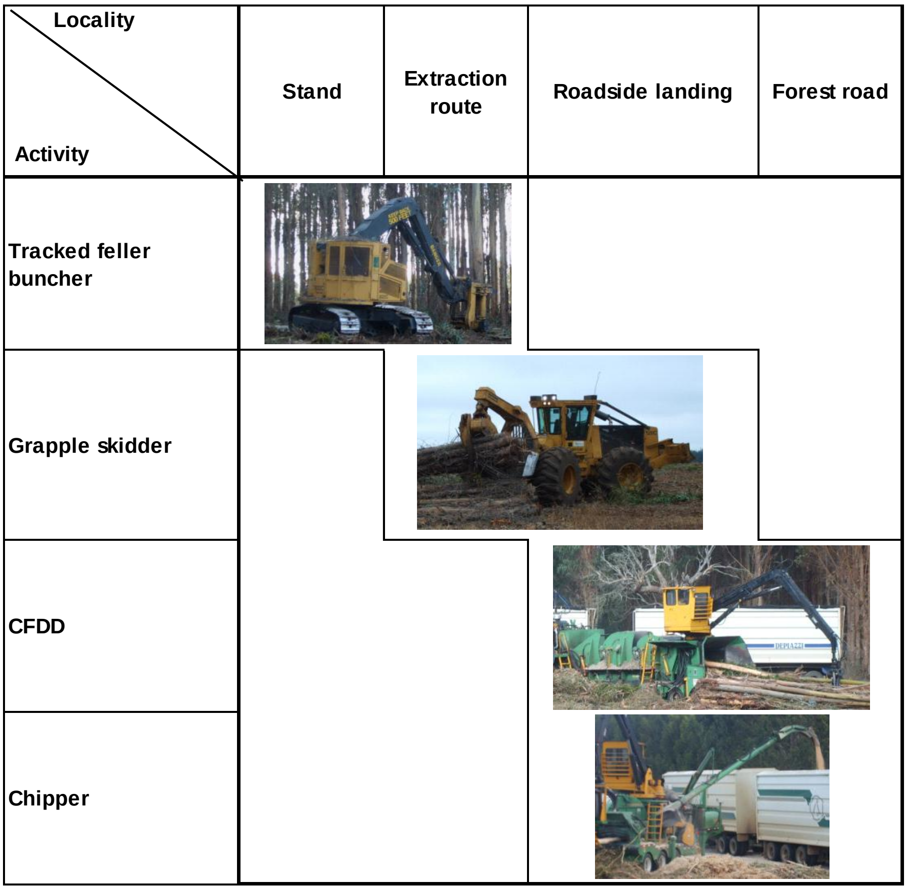


Figure 24: CFDD&C system matrix

The details of the machines used in the CFDD&C system are indicated in Table 14 on the following page.

Table 14: Machine information for CFDD&C system

Activity	Machine type and detail	Machine make and model
Felling	Feller buncher: • tracked non-levelling • shear felling attachment • accumulator	Edenborn all sites: one Tigercat 845C per site
Extraction	Grapple skidder: • dual arch • bunching grapple	Edenborn all sites: two Tigercat 630Cs per site
Debarking/ debranching	CFDD: four flail drums	Edenborn all sites: one Precision Husky FD-2300-4 per site
Chipping	Chipper: disc chipper	Edenborn all sites: one Precision Husky WTC-2366 per site

3.4.4 Dangle-head processor (DHP) (Zululand, South Africa) research site, operation and system information

The operations in Zululand were chosen because of the similarity of the site conditions, tree sizes and tree characteristics to Western Australia and Chile. The system in Zululand had been operating since 2005 and was the only one of its kind in South Africa. There were other DHP systems operating in *Eucalyptus* around the world, but the logistics of getting to this site was quicker and more cost-effective.

The compartments in which the system worked varied regarding tree size. This made it possible to use fewer compartments and still have sufficient variation. The species harvested was *Eucalyptus grandis.* Logs of 5.2 m were produced and transported by log truck to the Mondi pulp mill at Richards Bay.

The contractor owning and operating the systems was Iningi Investments and the plantations belonged to Mondi Business Paper. The plantation formed part of the Umfolozi area and the specific farm (Mill Site) was located next to the Mondi pulp mill in Richards Bay. Table 15 provides more information on the research site.

Table 15: DHP research site in Zululand, South Africa

Dates (2008)	**01 to 06 Sep**
Harvesting contractor	Iningi Investments
Grower company	Mondi
Farm	Mill Site
Compartment number	G004B
Species	*E. grandis*
Plant year	2002
Fell age (yrs)	6.1
Average tree volume	0.156 m^3
Ground conditions	Not determined
Ground roughness	1 - Smooth
Slope	1 - Level

The various compartments were all level and obstacle-free. The soils were mostly sandy, which necessitated good road access. The average tree size was 0.156 m^3 per tree, but this was variable as pure *E. grandis* is not ideally suited to Zululand conditions. The compartment was harvested at the beginning of spring (September) and a full-tree harvesting system was used.

Table 16 shows the detailed activities that were measured during the operation of the DHP.

Table 16: DHP operation

Pre-processing	The harvester heads were mounted on tracked 20-tonne construction excavators. Trees were processed one at a time and three DHPs were used in the system. Felling took place by means of a feller buncher and full-tree extraction utilised a grapple skidder. The skidder placed bunches of full trees in a row parallel to the road, but approximately one-and-a-half tree lengths from the road. The three processors worked a variable distance from each other, but always observed a safe distance of at least 50 m.
Grab and position	Each processor was positioned just ahead and to the side of each bundle. This enabled easy grabbing of the trees, unhindered slewing during processing and space for the bark, branches and tree tops to be deposited. The DHP grabbed the tree by the butt end from the top of the stack.
Debarking/ debranching	The tree would be passed up and down through the head until debarked by the feed rollers' placing pressure on the bark to loosen it. The spiralled and offset angles of and the ridges on the feed rollers spun the tree through the head, ensuring that these rollers made contact with a different part of the tree with each pass. This increased the chance of the bark being removed. If some remained after this action, the debranching knives slid underneath the bark and removed it. The tighter the wood-bark bond, the more passes were required to remove the bark. Naturally, this had an effect on productivity. If the bark came off very easily, only one pass from the butt to the top of the tree was necessary.
Topping and placing	As it passed through the processing head for the last time, the DHP pushed the debarked tree towards the road by means of its top and then topped it.

Other	The debarked tree lengths were then slashed into 5.2 m lengths and loaded directly onto the log-transport trucks. The skidder also removed slash where the DHPs were operating and returned it to the compartment in the form of small piles, spread throughout the compartment. The skidder also occasionally indexed the butts of the debarked and debranched trees to make slashing of tree lengths into logs more accurate.

A general overview of the other components of the systems follows.

- **Felling – feller bunchers**
  The DHP system used a wheeled, drive-to-tree feller buncher with an accumulating, continuous disc saw. Only one feller buncher was used per operation. Trees were felled, accumulated and placed in optimal bunches for the grapple skidders.
- **Extraction – grapple skidders**
  One grapple skidder with a bunching grapple was used for full-tree extraction. Bunches were collected, extracted and deposited in front of where the DHPs were operating.
- **Debarking, debranching and topping – DHP**
  A detailed description of the operation can be found in Table 16 above. An example of one of the DHPs is shown in Figure 25.

Figure 25: The DHP in operation

- **Slashing and loading**
  A tracked, construction excavator-loader, operating with a slasher (as per Figure 26), crosscut the debarked and debranched trees into 5.2 metre logs and either loaded them directly onto the log trucks or stacked them if no trucks were available.

- **Log transport**

  As per Figure 27, a three-axle rigid truck with a four-axle drawbar trailer was used to transport the 5.2 metre logs to the pulp mill.

Figure 26: Debarked tree slashing, and Figure 27: Log transport truck

The equipment used in the DHP system is shown in the matrix in Figure 28. The matrix provides a visual indication of how the processing equipment interacts with the rest of the equipment in the system.

Locality / Activity	Stand	Extraction route	Roadside landing	Forest road
Wheeled feller buncher				
Grapple skidder				
DHP				
Slasher loader				

Figure 28: DHP system matrix

The details of the machines used in the DHP system are indicated in Table 17 below.

Table 17: Machine information for DHP system

Activity	Machine type and detail	Machine make and model
Felling	Feller buncher: • wheeled drive-to-tree • continuoaus disc saw • Accumulator	One Tigercat 720D
Extraction	Grapple skidder: • dual arch • bunching grapple	One Tigercat 630C
Debarking, debranching and topping	Construction excavator carrier: • tracked Dangle-head processor: • two feed rollers • four debranching knives (two moveable and two fixed)	Two Volvo EC210Cs One Hitachi Zaxis 200 All with SP 591LX harvester heads
Slashing and log-truck loading (occasional log stacking)	Slasher loader: • tracked • swing-to-tree • bar-and-chain slasher	One Volvo EC210C with slasher

3.4.5 Harvester (Zululand, South Africa) research site and system information

The research site selected for the harvester system was adjacent to the site where the DHP system was operating, but in a different compartment. The compartments were too small to allow both the DHP and harvester to operate together. The research sites in South Africa were virtually identical to the DHP site and those in Western Australia and Chile. The compartment in which the system operated evidenced highly variable tree size. This was compounded by its being a coppice compartment, although the stem form was good. As with the DHP compartments, this natural variation made it possible to carry out the research in one compartment only. The species harvested was a *Eucalyptus grandis x camaldulensis* clone, producing logs of 5.2 m, which were transported by log truck to the Mondi pulp mill in Richards Bay. The contractor owning and operating the systems was Iningi Investments and the plantations belonged to Mondi Business Paper. As per the DHP system, the plantation formed part of the Umfolozi area and the specific farm (Mill Site) was located next to the pulp mill in Richards Bay. Table 18 provides more information on the research site.

Table 18: Harvester research site in Zululand, South Africa

Dates (2008)	**01 to 06 Sep**
Harvesting contractor	Iningi Investments
Grower company	Mondi
Farm	Mill Site
Compartment number	G001B
Species	*E. grandis x camaldulensis*
Plant year	2001
Fell age (yrs)	6.8
Average tree volume	0.139 m^3
Ground conditions	Not determined
Ground roughness	1 – Smooth
Slope	1 – Level

The terrain and sandy conditions were the same as described for the DHP system. The average tree size was 0.139 m^3 per tree, but this was variable because of the *E. grandis x camaldulensis* coppice, as well as the site's varying from one side of the compartment to the other. The compartment was harvested in the beginning of spring (September). A CTL harvesting system was used. Because the harvester processes immediately after felling, it was not possible to manipulate BWBS as was done in the other research.

Table 19 shows the detailed activities that were measured during the operation of the harvester.

Table 19: Harvester operation

Pre-processing	The harvester worked on a five-row felling system. It straddled the stumps of the third row. If there was no tree mortality, the harvester would be able to reach 10 standing trees without moving the carrier. Some minor movements did take place, however, to enable optimal slewing and ensure the operator had good sight of the trees.
Grab and fell	One tree was felled and processed at a time.
Debarking/ debranching	After the tree had been felled, it was fed up and down through the head by means of feed rollers. This continued until an acceptable debarking quality was achieved. Debarking took place in the same way as discussed in the DHP system.
Topping/	The operator then zeroed the optimisation computer at the butt of the tree and crosscut the

crosscutting	tree into 5.2 m lengths. No bearer logs were used to raise the stack off the ground to facilitate easier forwarder loading and less slash being loaded. Log stacks were placed to the left of the extraction route, over the 4th and 5th row stumps. The forwarder would then load from these stacks and transport logs to the roadside landing. They would be placed here until they were scheduled to be transported to the mill.
Deposit residue	The slash was placed in front of the harvester, which then travelled over it as it moved forward. This was also the extraction route for the forwarder, which travelled over the slash to protect the soil.
Other	At the end of each swathe, the harvester turned and harvested in the opposite direction. When the harvester started harvesting the five rows adjacent and parallel to the row just harvested, the logs were placed on top of the existing stacks, thus creating larger log bundles to optimise forwarder productivity.

A general overview of the other system components follows:

- **Fell and process – harvester**

  As indicated above and shown in Figure 29, tracked, single-grip harvesters felled, debranched, debarked and crosscut the tree into 5.2 m lengths, creating log stacks at the stump inside the compartment.

Figure 29: The harvester in operation

- **Extraction – forwarder**

  A forwarder with a 20-tonne payload was used to load the logs inside the compartment and extract them to a roadside landing, where they were stacked for transport.
- **Roadside loading**

  A tracked construction excavator-loader loaded the logs onto the log trucks.
- **Log transport**

  As per the DHP system, a three-axle rigid truck with a four-axle drawbar trailer was used to transport the 5.2 metre logs to the pulp mill.

The equipment used in the harvester system is shown in the matrix in Figure 30. The matrix provides a visual indication of how the processing equipment interacts with the rest of the equipment in the system.

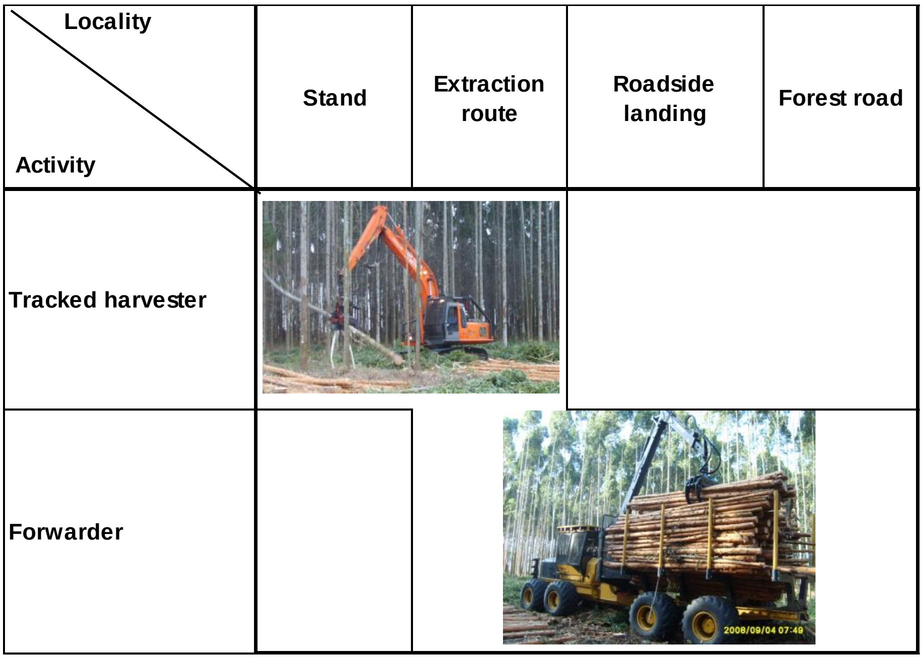


Figure 30: Harvester system matrix

The details of the machines used in the Harvester system are indicated in Table 20 on the following page.

Table 20: Machine information for the Harvester system

Activity	Machine type and detail	Machine make and model
Fell and process	Construction excavator carrier: tracked Harvester head: • two feed rollers • four debranching knives (two moveable and two fixed)	One Hitachi Zaxis 200 with an SP 591LX harvester head
Extraction	Forwarder: eight-wheel drive	One Tigercat 1075

3.5 Productivity data collection

The productivity data analysis section consists of measuring instruments, sample design and method, data collection methods and fieldwork, initial data analysis, regression analysis, identification of outliers, and regression analysis with outliers removed.

3.5.1 Measuring instruments

The measuring instruments used in the trials, as well as the reasons for their selection and a description of how they were used, are set out in Table 21.

Table 21: Measuring instruments and reasons for their use

Description of measuring instrument	Reason for use
Diameter tape	To take DBH measurements (at 1.37 m) for tree-volume calculations
Vertex hypsometer	To take eight measurements for tree-volume calculations
Diameter calliper	To measure DBHs of the trees in the sample areas to classify trees into different volume classes
30 m tape	To measure extraction distances covered by the skidders and forwarder, as well as to confirm vertex height measurements once the tree had been felled
Hatchet	To measure BWBS at various parts of the tree
Work-study stopwatch	To take time-research measurements, which were recorded in cmins. Fly-back and continuous time was used.

Description of measuring instrument	**Reason for use**
Pre-printed work-research templates	The times were recorded in pencil.
Video camera	To record the operation of the processing machines when measuring other trees or taking personal breaks. Work-research data were then collected from the videos.
Notebook using a pencil	To record measurements

3.5.2 Sample design and sampling method

The productivity of the CFDD, CFDDC, CFDD&C, DHP and harvester needed to be determined. As discussed in a previous section, it was not necessary to determine the productivity of the other machines in the systems. Productivity was determined by measuring the amount of time taken to process a tree or bundle of trees. It was necessary to record the volume, form and BWBS of each tree processed, as these were predicted to have an effect on productivity.

3.5.2.1 Individual tree-volume measurements

The trees that would be processed during the research were identified in consultation with the harvesting supervisor. A minimum of 30 trees were selected for sampling for volume calculations at each research site. It was not possible, and not desirable, to take the sample from the entire compartment. This was for two reasons:

- Mostly, harvesting had already commenced, resulting in much of the compartment's having already been felled.
- Variation of growth conditions in the compartment meant that the overall compartment-sample results might not reflect the actual research site's conditions.

Individual tree-volume measurements needed to be accurate, as this was expected to be the one of the main drivers of system productivity. A diameter tape was used for DBH measurements and readings were taken at 1.37 m above the ground (Bredenkamp, 2000). Height measurements were recorded for every tree selected, using a Vertex hypsometer. The hypsometer was calibrated each time before a measurement was taken.

The DBH and height measurements were then entered into a Microsoft Excel spreadsheet (Microsoft Corporation, 2003). The model devised by F.X. Schumacher and F.S. Hall in 1933 to determine tree volume was used for each tree sampled (Bredenkamp, 2000). The coefficients used for the volume equations for the various research sites and species are included in Table 22 (Adapted from Bredenkamp, 2000, p170).

Table 22: Coefficients used for Schumacher and Hall standing tree volume equations (adapted from Bredenkamp, 2000, p170)

Species	Technology	Coefficients				Author of original equation
		b_0	b_1	f	b_2	
E. globulus	CFDD (Chile) CFDDC (Australia) CFDD&C (Australia)	-10.2253	2.0427	0	0.8478	Bredenkamp, 1994
E. grandis (General), 50 mm top	DHP (S. Africa)	-10.8120	2.1513	0	1.0007	Coetzee, 1992
E. grandis x camaldulensis	Harvester (S. Africa)	-10.6435	1.9185	0	1.1494	Du Plessis, 1996

All volumes were calculated in metres cubed as solid volume under bark using the following formula:

$$\ln V = b_0 + b_1 \ln (dbh + f) + b_2 \ln H$$

Where ln = natural logarithm to the base *e*
V = stem volume (m^3, under-bark)
dbh = breast-height diameter (cm, over-bark)
f = correction factor
H = tree height (m)

These individual tree-volume measurements were used to model the relationship between DBH and height, using simple linear regression. The values of lower and upper tree-volume for each tree-volume class were inserted into the model for further analysis.

Stand density was not determined from the sample as it was not necessary for the research. The general planting espacement for each site was obtained from the relevant harvesting operational plans and verified infield for record purposes.

3.5.2.2 Marking of trees

Each tree that would be processed as part of the research was marked with spray-paint, a different colour being allocated to each tree-volume class. A diameter calliper, the accuracy level of which proved sufficient for the purposes of the research, was used to determine DBH instead of a diameter tape. Two measurements were taken for each tree at 90 degree angles to each other and then averaged. The resulting diameter reading was then checked against the volume-class sheet to determine between which lower and upper DBH limits it fell, thus identifying the tree-volume class it belonged to. The tree was then marked with the same colour of spray-paint as the corresponding tree-volume class.

The trees were marked on both sides to ensure that one side was always visible during the time research. With the full-tree systems, marking took place as high up the tree as possible to avoid the grapple skidder removing the bark where the marks were. Figure 31 shows an example of the tree-volume class marking that took place.

Figure 31: Tree-volume class markings

3.5.2.3 Felling and processing

With the full-tree systems (CFDD, CFDDC, CFDD&C and DHP), the trees were felled by means of a feller buncher. The trees felled at a specific time on a particular day were demarcated and drawn on a rough map. The grapple-skidder operator was not permitted to extract any of these trees without the researcher’s permission. This was to ensure that trees to be used in the time research were not accidently processed. Time from felling to processing varied from immediate processing with the harvesters to eight days with certain of the CFDD trees. Processing is always immediately after felling if a harvester has been used, but with the full-tree system processing technologies, the aim was to allow a portion of the felled trees to lie unprocessed in an attempt to increase the BWBS. Processing took place in the commercially acceptable method and this was monitored using time-and-motion work-study techniques.

3.5.2.4 Selective felling trial

When collecting data on the CFDD in Chile, selective felling and bundling of trees that were in the same tree-volume category was attempted. This would have given a very reliable indication of productivity levels that could be expected for different tree-volume classes. However, this was very time-consuming and disrupted the operations to the point where it was no longer possible to proceed. Also, space for all the different tree-volume class bundles was problematic, as the feller buncher had to manoeuvre between both standing trees and bundles of trees. With tree-volume classes that were in the minority, the feller buncher had to travel long distances to build a bundle that was of sufficient size for the grapple skidder to extract.

Selective felling was not attempted in Australia for two reasons. Firstly, it was clear from the attempt in Chile that it was not a feasible option. Secondly, apart from one, the feller bunchers in Australia were tracked machines. It was impossible for them to fell selectively between standing machines or to manoeuvre backwards and forwards to create bundles of trees of the same tree-volume class.

3.5.2.5 Testing for BWBS prior to processing

In order to determine the effect of BWBS on the productivity of the processing machines, it was first necessary to determine the BWBS of the trees before they were processed. If the time delay between felling and processing was the same for all the research, it would not have been possible to determine the effects of BWBS, as the BWBS would have been the same.

To overcome this problem, the time delay between felling and processing was manipulated. Some of the trees from the sample area were processed immediately after felling, while others were left to lie in the compartment for some time. Generally, the longer the tree is left after felling, the more difficult it is to remove the bark. This is influenced by many factors, such as the strength of the bark-wood bond while the tree is still standing, soil moisture content, atmospheric temperatures and humidity. This controlled delay enabled a much wider range of BWBS to be tested.

Owing to the length of time spent at each site, it was not always possible to manipulate BWBS to obtain a sufficiently large sample of trees for each BWBS class for each processing technology being analysed. For example, if, because of site conditions, the trees maintained a lower BWBS class throughout the research period regardless of time after felling, then it would not be possible to evaluate the poor BWBS classes. Indeed, if trees already had a high BWBS class at the time of felling, it was not possible for BWBS to improve, but only to become worse. The result would be an absence of data for the low BWBS classes in that particular sample.

3.5.3 Data collection methods and fieldwork

Each research site was physically visited to collect data. The harvesting supervisor assisted with measuring of trees with the CFDD (Chile), but with the CFDDC and CFDD&C (Australia), no assistance was available. In Zululand, South Africa, a student was present who assisted with both tree measurements and data collection for the DHP and harvester technologies.

Upon arrival at each site, time was taken to gain an understanding of the system being researched. This consisted of speaking to the supervisors and machine operators to assimilate the responsibility of their jobs, the dynamics of their machines and the operation as a whole. The actual operation was observed for approximately an hour. The operating method and the machine operators were appraised to assess work technique and competency, and the preliminary sample was recorded.

3.5.3.1 Tree-class definitions for data collection

Table 23 shows the different classes of data that were collected while observing the processing operations.

Table 23: Data collected during processing equipment observations

Tree-volume class (m^3)	BWBS class	Debarking-quality class	Tree-form class
1. < 0.050 2. 0.051 - 0.099 3. 0.1 – 0.199 4. 0.2 – 0.299 5. 0.3 – 0.499 6. >0.5 **Note: Classes 2 & 3 combined for harvester:** **3. 0.051 – 0.199**	1. Very good 2. Good 3. Medium 4. Poor 5. Very poor	1. Good 2. Medium 3. Poor (Also if a particular part of the tree is not being debarked, e.g. top or butt)	1. Good 2. Medium 3. Poor

It was relatively easy to classify each tree for the harvester and DHP. Because tree lengths were processed individually, the productivity data for each tree could be measured and correlated with the different classes. However, multi-tree (or bundle) processing by means of the CFDD, CFDDC and CFDD&C needed to be treated differently. Different numbers of trees and differently sized trees with different BWBS and form classes were being processed simultaneously. The unit of time recorded was of how long it took to process one bundle. Even though the characteristics of each tree were known, the time allocation for a specific tree could not be established because it was not possible to group trees with the same characteristics together. Therefore, some method needs to be devised to overcome this shortcoming. The method used is described under section 3.4.3.2. below. The description of tree-size classes, BWBS classes, debarking-quality classes and form classes are described below.

Bundle sizes were simply measured as the number of tree lengths being processed during one work cycle or the number of tree lengths fed through at once.

- *Tree-size class*

The trees were assigned to one of six volume classes, ranging from less than 0.05 m^3 to greater than 0.5 m^3. The harvester only had five tree-size classes, as classes 2 and 3 were combined and renamed 3. This was due to a misallocation of the upper DBH boundary of tree-size class 2, and the lower DBH boundary of class 3. Therefore, the midpoint tree-size for this new class was recalculated to be 0.0125 m^3. See Section 3.6 for more detail.

- *BWBS-class descriptions*

BWBS classes were calculated in an attempt to determine the strength of the bark-wood bond and how this affected the productivity of the different processing machines. Once the trees had been felled, a BWBS test was carried out manually with a hatchet, as can be seen in Figure 32. The bark was loosened by making a cut in the cambium down to the wood, perpendicular to the length of the tree, at the DBH height. The back of the hatchet was used to loosen the bark above the cut. A section of the loose bark, approximately 15 cm wide, was lifted by hand and pulled directly away from the tree, causing the bark to detach in a strip. Depending on the BWBS, the strip would range in length from very short to very long before it separated from the tree. The length of the strip of bark determined the BWBS class that is indicated in Table 24. These tests were carried out on various tree sizes and different positions on the tree (butt, mid-bole and top). The trees were tested again before processing and any changes were documented. Trees were processed from between a few hours and eight days after felling.

Figure 32: Example of BWBS-class testing

Table 24 provides a description of how each BWBS class was derived.

Table 24: BWBS class description

BWBS class	Description
1. Very good	The bark comes off in a very long strip that can reach into the canopy before it severs (>10 m)
2. Good	The bark comes off in long strips of half of the height of the tree (approximately from 4 to 10 m)
3. Medium	The bark comes off in medium lengths of between one and four metres
4. Poor	The bark comes off in short lengths of up to one metre
5. Very poor	The bark will not come off by hand; it needs to be chiselled off by means of the hatchet

- *Tree-form class descriptions*

Tree-form class calculations were derived from a combination of branchiness factors and actual stem form. The classes used were based on those described by Spinelli, et al. (2002b), as shown in Table 25.

Table 25: Tree-form class description
(Spinelli, et al., 2002b, p.72)

Form class	Branch density	Maximum branch diameter	Stem formation
F1	Light	< 30mm	Straight
F2	Dense	< 30mm	Straight
F3	Light	>30mm	Light sweep
F4	Dense	>30mm	Marked sweep
F5			Malformed

Spinelli, et al. (2002b) had the maximum branch diameter as 30 mm. This branch size was considered too small, as all the processing machines were capable of removing branches with a larger diameter. A maximum branch diameter of 50 mm was used, as infield measurements of branches remaining after processing indicated that this was the diameter at which branches became difficult to remove. The class, therefore, gave an indication of the number of branches, size of branches and stem sweep or severe malformation.

For this research, using five different form classes was not practical, as it became difficult to distinguish between the form classes as the trees were being processed. Thus, these five form classes were consolidated into three, as per Table 26.

Table 26: Form class description for the research
(adapted from Spinelli et al, 2002b, p.72)

Form class	Branch density	Maximum branch diameter	Stem formation
F1 – good	Light and dense	< 50mm	Straight
F2 – medium	Light and dense	> 50mm	Light to marked sweep
F3 – poor	Light and dense	Any diameter	Malformed

- *Debarking-quality class description*

Debarking-quality classes were calculated by estimating the amount of residual bark left on the tree after debarking. This was a subjective estimate as it was not possible to remove bark samples, weigh them and then correlate the results with accurate percentages. Table 27 provides a description of how each debarking-quality class was derived.

Table 27: Debarking quality class description

Debarking-quality class	**Description** (residual bark content = bark as a percentage of total volume)
1. Good	All bark is removed from the stem: residual bark content of less than 0.5 % achieved
2. Medium	Strips of residual bark remain: residual bark content of less than 1 % achieved
3. Poor	Sections of the tree have not had bark removed: residual bark content of more than 1 %

Figures 33 and 34 show good and poor debarking quality.

Figure 33: Good debarking quality, and Figure 34: Poor debarking quality

Debarking quality is not a variable-affecting productivity; it is an output or reflection of the operating method and other factors influencing debarking. The reason for considering debarking quality was to ensure that the productivity determined from the work-research measurements could be achieved with acceptable debarking quality. When logs or chips are delivered to a mill, the average bark content of the load should not be higher than the mill specification. All of the mills which consumed timber or chips from the research sites had bark tolerances, measured as volume of bark per volume of chips, with a maximum of one per cent. In the research, the debarking quality was measured at individual tree level, but was averaged thereafter to see whether the overall debarking specification would be met. The measuring of debarking quality was subjective, as it was not possible to correlate the bark remaining on individual trees with a percentage of a truck load of chips or even of a chip pile.

3.5.3.2 Data capturing and data editing

The effects of tree volume, bundle size, BWBS, form and debarking quality on time and, therefore, productivity were determined for all the research sites. Time-and-motion research was conducted on all of the operations. Statistical analysis was then carried out on the relationship between time and quantity produced. The time data were collected at the element level. Cycle times were broken down into time elements representative of the technology and operating method being used (Spinelli and Visser, 2008). This was done in order to isolate parts of the cycle that might be susceptible to influence by external factors (such as tree size) in an attempt to improve the accuracy of the models developed. The specific elements used for each technology are included in the subsection 3.4.3.1 above.

For the time-and-motion research, a combination of cumulative and fly-back timing methods was used (Kanawaty, 1992). The time for each element was recorded, using an electronic stopwatch, and cumulative elapsed time was recorded at the end of each research session, both by direct observation. Video recordings were also taken while measuring trees, marking trees or testing BWBS. However, the colour markings on each tree were very difficult to discern from the video images in the multi-tree processing operations, making use of video data not possible. Timing error was noted and was found to be well within acceptable work-study norms (Katawaty, 1992). The time was manually recorded on pre-printed work-research data sheets.

All the operators had been working with their machines for at least six months and were experienced and sufficiently skilled. The operators were assumed to be equally proficient. The researcher used his experience to determine whether operators could be classified as 'average workers', as defined by the International Labour Office (ILO) in Geneva, Switzerland (Kanawaty, 1992). Operators were instructed to work at their normal pace.

Traditionally, forest-engineering research has focused on productive and non-productive delays (Spinelli and Visser, 2008). Recently, delays encountered during research have been split into mechanical, operator and other delays (Spinelli and Visser, 2008). Any delays caused by the research itself were excluded (e.g. stopping the machines to take notes). For the purpose of this research, the delays were split into the three categories mentioned above and as defined by Spinelli and Visser (2008). All delays that fell into these categories were included, regardless of the delay length. Spinelli and Visser (2008) found that most delaying events with regard to harvesters lasted fewer than 15 minutes (94 per cent). Therefore, if all delays of under 15 minutes were ignored, the final results would be skewed. For this reason, all delays were recorded, regardless of their length. Other time-delay factors that affected machine utilisation included chain replacement, waiting for trees, refuelling and mechanical interruptions, usually for preventative maintenance.

The capturing of data for the multi-stem processing technologies preparing bundles differed slightly from the method used for the single-tree processors. As trees were fed through the CFDD or CFDDC, the tree characteristics were visually observed and noted:

- bundle size,
- individual tree size, according to the spray-paint colour on the stem,
- form, as trees were fed into the machine,
- debarking quality, as the trees exited the machine.

Simultaneously, the time taken to process the bundle was recorded. The same information was recorded for the DHP and harvester, except that all measurements were carried out at the individual tree level, as single trees were processed at a time.

- *Data transfer*

The data for each different machine was then transferred into separate Microsoft Excel workbooks (Microsoft, 2003). Each workbook contained all the information from infield data collection as follows:

- the section of the compartment from which the trees came;
- the date the trees were felled;
- the date the trees were processed;
- the cycle number;
- the cycle elements;
- the total cycle time (including averaged relevant delays);
- delay times;

- delay category;
- reason for the delay;
- total number of trees in the cycle;
- individual tree-size class;
- individual tree-BWBS class at the time of felling;
- individual tree-BWBS at the time of processing;
- individual tree-form class;
- individual debarking-quality class;
- other general research conditions, such as climatic and terrain factors.

At the start of the CFDD research, an attempt was made to record feed-roller damage to the trees. Occasionally the feed rollers struggled to pull large trees in the CFDD and scraped into the butt of the tree until the operators used the crane to pull the tree further into the machine. Chain-flail damage – trees that were excessively debarked, resulting in damage to the wood fibre – was also recorded. However, it was not possible for one person to collect so much information without compromising the quality of the pertinent data. Feed-roller and chain-flail damage seldom occurred and was not considered to be of high importance for the objectives of the research.

- *Error checking*

The data were then examined for obvious errors made during recording or while transferring information to the Excel workbook. Any recording errors were either corrected or removed.

The many different tree sizes and characteristics occurring in one bundle, with only one time recorded for all these trees, posed an important challenge. The method to overcome the problem with the CFDD, CFDDC and CFDD&C was as follows:

- the individual tree sizes in each cycle were added together to get a total tree-volume per cycle;
- the individual tree sizes were taken to be the midpoint-sized tree for a particular class.

For example, tree-size class 3 consisted of trees between 0.1 and 0.199 m^3 per tree. All the midpoint-size classes used are shown in Table 28.

Table 28: Midpoint tree volume per tree size class

Tree-volume class (m^3)	Midpoint-volume class (m^3)
1. < 0.050	0.025
2. 0.051 - 0.099	0.075
3. 0.1 – 0.199	0.15
4. 0.2 – 0.299	0.25
5. 0.3 – 0.499	0.4
6. >0.5	0.55
Note: Classes 2 & 3 combined into new 3:	
3. 0.051 – 0.199	**0.125**

In the example described for tree size class 3, the midpoint was calculated as being 0.15 m^3 per tree. Therefore, the total volume per cycle was the sum of the midpoint tree sizes for each tree according to its size class. The total volume for the cycle was then divided by the number of trees in that cycle to obtain an average tree size for the cycle. The BWBS, form and debarking-quality classes of the individual trees in each cycle were then averaged to create an average BWBS, form and debarking-quality class per cycle. The total cycle time was also divided by the number of trees in the cycle to obtain an average processing time per tree. By carrying out the analysis in this way, it was possible to take into account the specific characteristics of each tree in the bundle being processed and determine what effect that had on the overall productivity.

The data in the Excel workbooks were then sorted into a format whereby summary statistics could be carried out. The data for all the processing technologies were placed into one Excel workbook from the individual machine workbooks. The information that was transferred from each machine was at the cycle level and included the name of the processing machine, the cycle number for a specific technology, the number of trees per cycle (bundle size), cycle time, average tree-volume class, average BWBS class, average form class, average debarking-quality class, total bundle volume and actual average tree volume in each bundle. These data were then imported into a STATISTICA software package for more detailed statistical analysis.

3.5.3.3 Productive-cycle elements per processing technology

The work-research elements identified for the various processing technologies are presented below. The CFDD, CFDDC and CFDD&C have been combined as the same elements are used. All time measurements were recorded in centi-minutes.

- *Work research elements for the CFDD, CFDDC and CFDD&C*

The productive-cycle elements recorded for the CFDD, CFDDC and CFDD&C were:

- **Feed trees** – the cycle commenced when the grab touched the trees lying at the infeed of the processing machine. The butts were lifted and fed into the infeed rollers. Big trees were lifted to aid feeding.
- **Debranch and debark** – as the butts of the trees passed through the infeed rollers, the debranching and debarking element commenced. When the top of the tree passed through the infeed rollers, the debranching and debarking element terminated. However, as is normally the case, if more trees were fed into the machine while the previous trees were still passing through the infeed rollers, a new debarking cycle commenced. This enabled rapid debarking elements.
- **Remove residue** – the grab was used to move residue from the infeed area and hydraulic pusher. Normally, this occurred while debarking took place, but if there was excessive residue, it took place without any trees being debarked.

- *Work research elements for the DHP*

The productive cycle elements that were recorded for the DHP are outlined below.

- **Move to tree** – After dropping the top of the previous tree, the boom extended to the next tree at the top of the bunch. The element ended when the head, with open debranching knives, touched the next tree on the bunch that would be processed.
- **Grab tree** – The debranching knives closed and the tree was lifted from the bunch and slewed into position.
- **Debark/debranch** – The feed rollers started to feed the tree backwards and forwards through the head. This continued until the bark had been removed according to the mill specifications.
- **Top tree** – The crosscut saw was activated and the top of the tree was removed. The head was slewed to where the top was to be deposited. The debranching knives and feed rollers opened and released the top onto the residue pile.
- **Change position** – The excavator moved backwards and forwards on the landing to position itself better to process or to move to a new bundle of trees that needed to be processed. The initial and final movements of the tracks indicated the start and the finish of this element.

- *Work research elements for the harvester*

The productive cycle elements that were recorded for the harvester are described below.

- **Move to tree** – After dropping the top and other residue from the previous tree, the boom extended to the next tree. The cycle ended when the head, with open debranching knives and feed rollers, touched the next standing tree.
- **Fell tree** – The debranching knives and feed rollers closed around the tree. The felling cut was made and the tree fell towards the ground.
- **Debark/debranch** – The cycle commenced when the feed rollers started to move. They fed the tree backwards and forwards through the head. This continued until the bark had been removed according to the mill specifications.
- **Crosscut** –The crosscut saw was activated to zero the computer when the head was positioned at the butt of the tree. The tree was fed through the head and crosscut until the entire tree had been crosscut into logs. Occasionally, especially with larger trees, the harvester would start crosscutting before the top half of the tree had been debarked. This would result in subelements of debarking/debranching and cross-cutting.
- **Top tree** – The crosscut saw was activated and the top of the tree removed. The head was slewed to where the top and other residue was deposited. The debranching knives and feed rollers opened and released the top onto the residue pile.
- **Change position** – The harvester moved forward to position itself better to fell and process the next set of trees. When the harvester reached the end of a rack, it turned to start harvesting in the opposite direction. The initial and final movements of the tracks indicated the beginning and the end of this element.

3.6 Data analysis

Time-research data collected from the research sites were examined using descriptive statistics, which investigated relationships between average tree volume, bundle size, BWBS, form, debarking quality and hourly machine production. The statistical summary was carried out in Microsoft Excel, with more detailed analysis in STATISTICA. The sample size (number of observations) required for each processing machine was determined using the equation from the ILO as set out below (Kanawaty, 1992).

$$n = \left(\frac{40\sqrt{n' \sum x^2 - \left(\sum x\right)^2}}{\sum x} \right)^2$$

Where:

n = the sample size required for a 95 per cent confidence level with an error margin of five per cent.

n' = the number of observations in the preliminary study.

$\sum$ = sum of values.

x = observation value.

Fifty preliminary observations were timed for each processing machine. The formula outlined above was applied to the results. The sample size in terms of the number of observations and the number of trees processed by each processing machine researched can be seen in Table XX. The multi-stem handling processors had much higher numbers of trees processed as many trees were handled at the same time. The research data sample size exceeded the minimum required for the 95 per cent level of confidence for all the processing machines.

Table XX: Sample size per processing machine

Processing machine	No. observations	No. trees processed
CFDD	875	3793
CFDDC	1786	2903
CFDD&C	1609	3939
DHP	547	547
Harvester	430	450

3.6.1 *Initial data analysis*

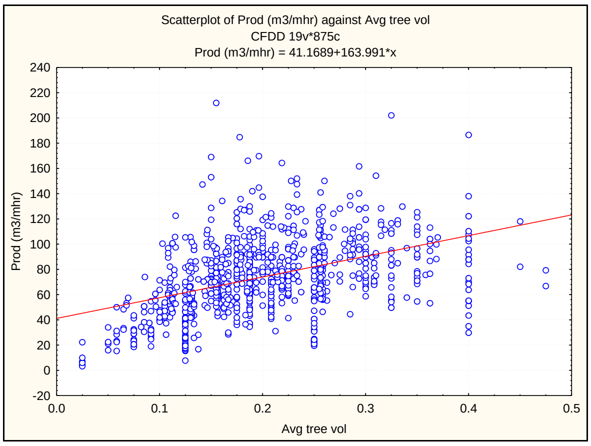
For the summary statistics in Excel, the productivity was determined in cubic metres per PMH at the cycle level. The mean, standard deviation, variance and sample size were determined for each combination and the results were tabulated and described. Combinations with sample sizes of less than 10 were highlighted in yellow and sample sizes of between 10 and 19 were highlighted in red. This was done to draw attention to small sample sizes which could potentially influence the results. Results from smaller samples should be interpreted more cautiously. In a small sample, for example, an outlier can easily distort the results.

Debarking quality was also examined for each of these combinations to try to explain some of the results that did not follow the general trend of the data.

A separate model was developed for each processing technology. The specific variables per cycle included processing machine, cycle time, tree-volume class, BWBS class, form class, debarking-quality class, average actual tree-volume per bundle, the bundle volume, the bundle size (number of trees) and productivity (m^3/PMH). Sorting the data was not important as the models developed were based on the actual tree sizes and not the tree-size classes.

3.6.1.1 Scatterplot investigation of productivity relationships

Once the dataset of each technology had been imported into STATISTICA, scatterplots were used to investigate the form and strength of relationship between the dependant variable (productivity) and independent variables. The scatterplots were used to investigate whether the various variables were relevant in explaining productivity. Scatterplots of bundle size versus productivity and average tree volume versus productivity were compiled. The results for each technology are shown in the various figures below. Figures 38 and 39 represent the CFDD and show that productivity increased for increasing average tree volume and also for increasing bundle size. The productivity increased from approximately 50 m^3 per PMH in small trees of 0.075 m^3 to 100 m^3 per PMH in large trees of 0.40 m^3, while the productivity increased from approximately 45 m^3 per PMH when the bundle consisted of one tree, to 100 m^3 per PMH when eight trees per bundle were processed.



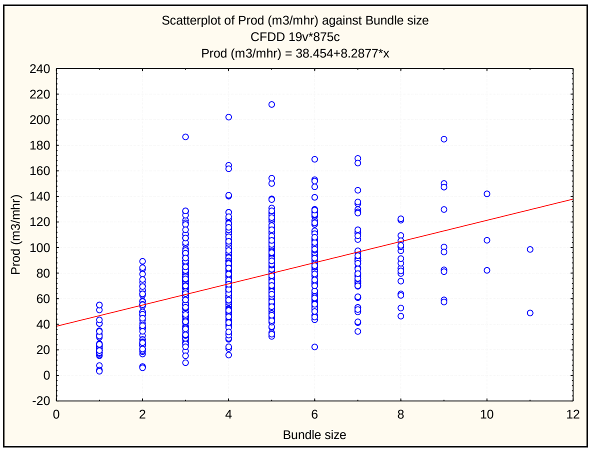
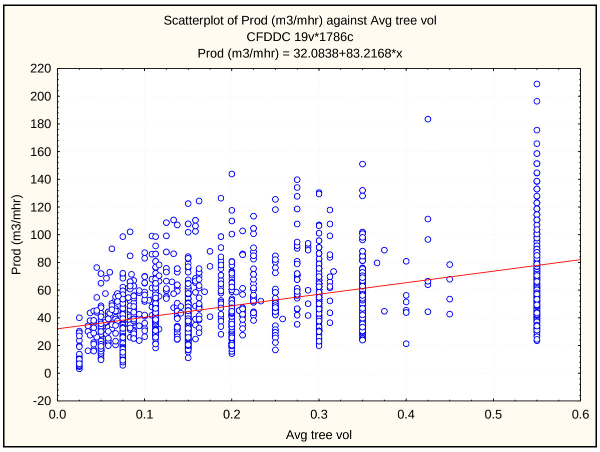


Figure 35: CFDD scatterplot of average tree volume versus productivity, and Figure 36: CFDD scatterplot of bundle size versus productivity

Figures 40 and 41 represent the CFDDC and show that there was a slight upward trend in productivity for increasing average tree volume. The productivity increased from 40 m^3 per PMH in small trees of 0.075 m^3 to 80 m^3 per PMH in large trees of 0.55 m^3. However, it should also be noted that the data is very variable with huge ranges in productivity for any specific average tree volume. There was no increase in productivity as the bundle size increased. This was unexpected and could possibly be due to the operators' processing fewer trees in a bundle, but feeding bundles into the machine more frequently.



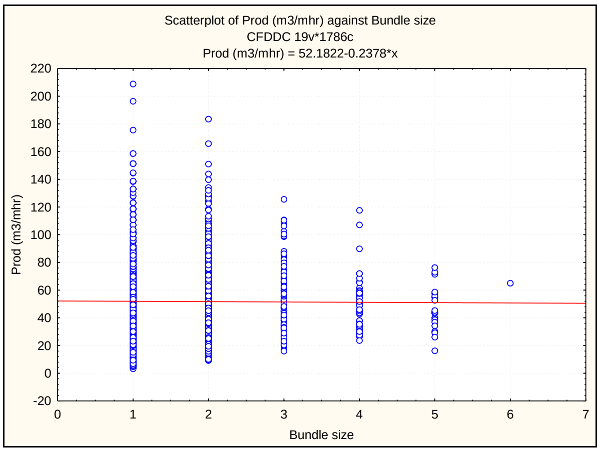
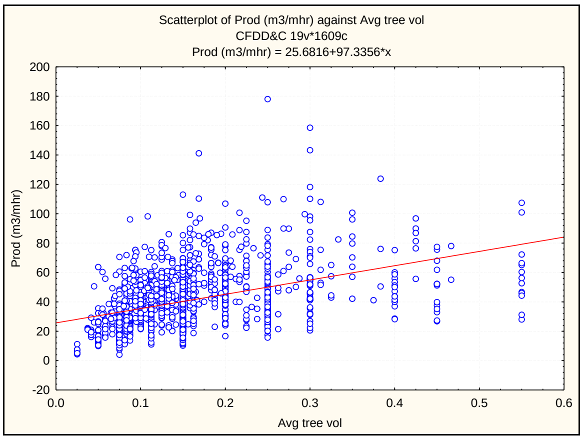


Figure 37: CFDDC scatterplot of average tree volume, and Figure 38: CFDDC scatterplot of bundle size

Figures 42 and 43 represent the CFDD&C and show that there were productivity increases as the bundle size and tree volume increased. The productivity increased from approximately 30 m^3 per PMH in small trees of 0.075 m^3 to 80 m^3 per PMH in large trees of 0.55 m^3, while the productivity increased from approximately 30 m^3 per PMH when the bundle consisted of one tree, to 60 m^3 per PMH when five trees per bundle were processed.



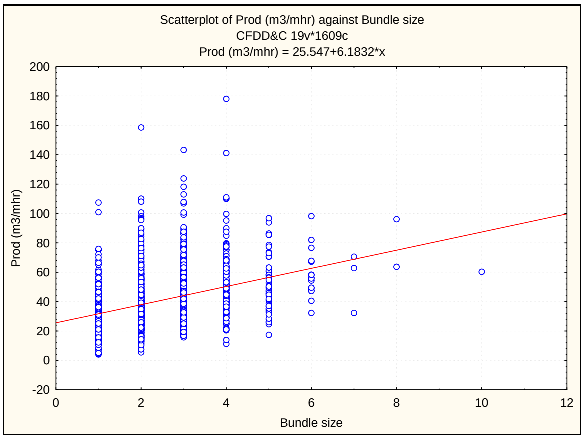
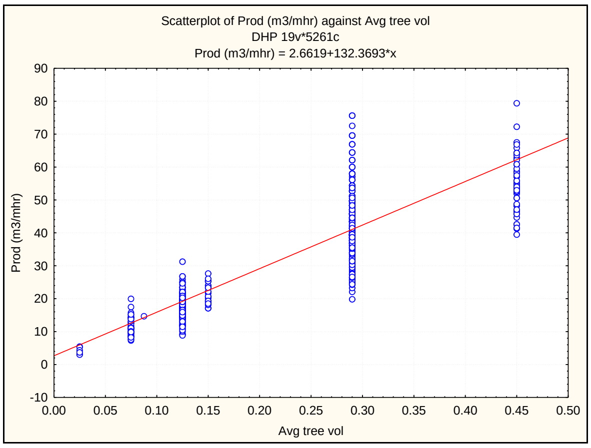


Figure 39: CFDD&C scatterplot of average tree volume, and Figure 40: CFDD&C scatterplot of bundle size

Figures 44 and 45 represent the DHP and harvester and show that there were productivity increases as tree volume increased. The DHP and harvester process single stems and there is therefore no graph for bundle size versus productivity. The productivity increased from approximately 12 m^3 per PMH in small trees of 0.075 m^3 to 64 m^3 per PMH in large trees of 0.45 m^3 with the DHP, and the productivity increased from approximately 3.5 m^3 per PMH in small trees of 0.025 m^3 to 25 m^3 per PMH in large trees of 0.45 m^3 with the harvester.



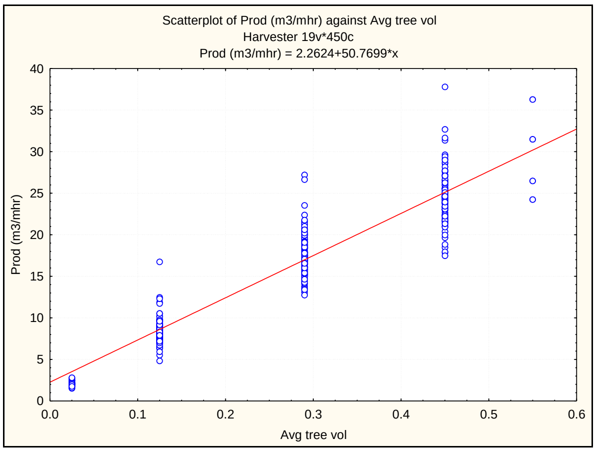


Figure 41: **DHP scatterplot of average tree volume, and Figure 42: Harvester scatterplot of average tree volume**

From Figures 38 to 45, one can conclude that there is a relationship between average tree volume and productivity, and also bundle size and productivity. These variables can therefore be included in a regression model explaining productivity.

Bundle size and tree volume were then plotted against each other. This only applied to the CFDD, CFDDC and CFDD&C, as the DHP and harvester did not process bundles. Figures 46a-c show two-dimensional scatterplots of the resultant relationships. All three graphs show a decrease in average tree size as the bundle size increased. This was expected as the operator made bigger bundles of smaller trees.

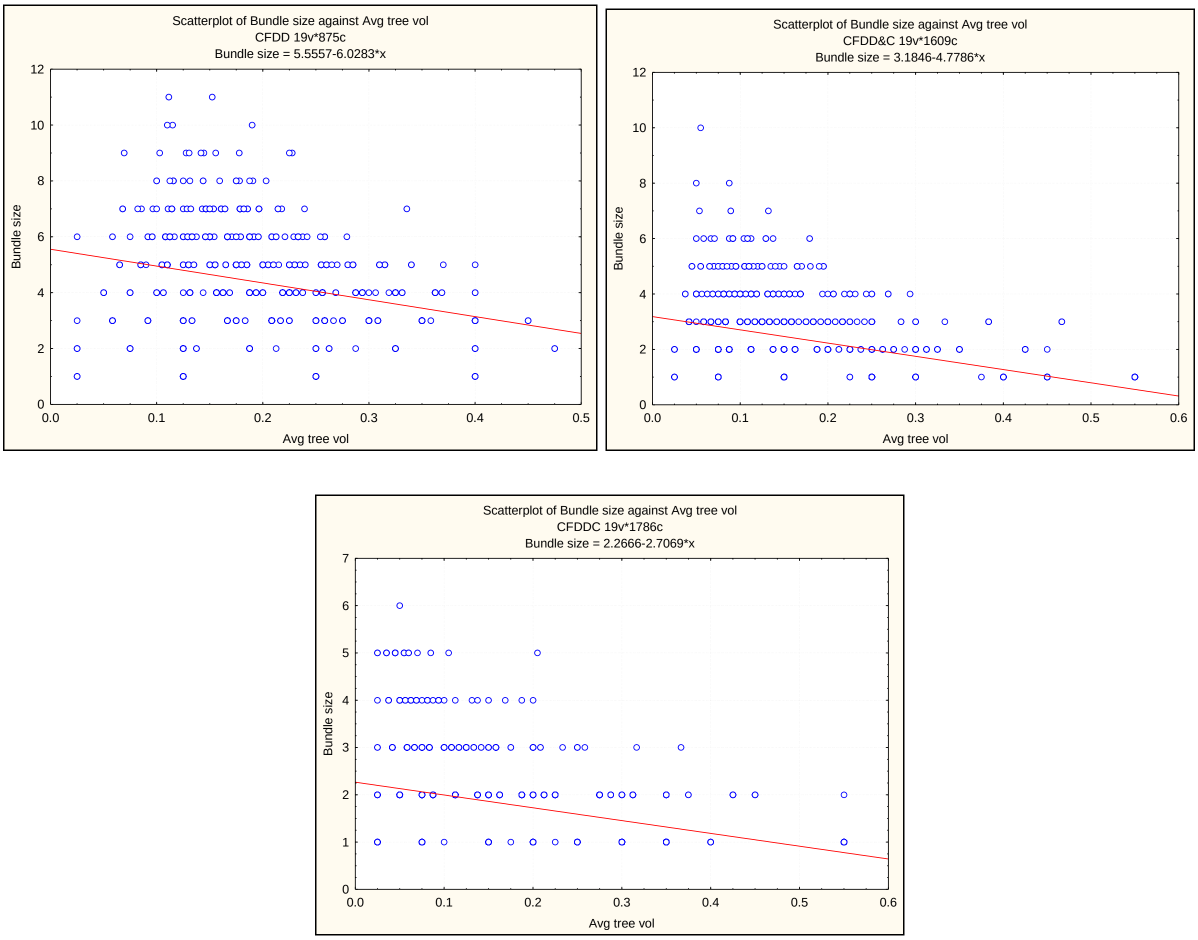


Figure 43a: CFDD, Figure 46b: CFDDC and Figure 46c: CFDD&C - all scatterplots of average tree volume against bundle size

3.6.1.2 Examination of the distribution of productivity variables

Histograms were created in STATISTICA to examine the distribution of the relevant variables. The histograms for each of these variables for each technology can be found in Annexure A. For the CFDD, all three variables were distributed approximately normally. The most frequently occurring productivity level for the CFDD was between 60 and 80 m^3 per PMH. The most frequent tree volume for the CFDD was between 0.1 and 0.2 m^3 per tree, followed by between 0.2 and 0.3 m^3 per tree. The most frequently occurring bundle size for the CFDD was four trees per cycle.

For the CFDDC, productivity was slightly skewed towards the right, with higher frequencies for the lower productivity levels. The most frequent productivity for the CFDDC was between 20 and 60 m^3 per PMH and there was a long tail towards the higher productivity levels. The most frequent tree size was between 0.1 and 0.2 m^3. However, the sizes between 0 and 0.1 m^3; 0.2 and 0.3 m^3; and 0.5 and 0.6 m^3 were also often observed. This last value reflects the very big tree sizes that were encountered on two of the research sites. With the CFDDC, the most common bundle sizes consisted of only one tree per cycle, with a long tail towards the right (positively skewed). This reflected the bigger trees found on many of the sites and an operating method where fewer trees were fed into the machine, but the bundles were fed more frequently.

With the CFDD&C, the most common productivity level was between 20 and 60 m^3 per PMH, but with a longer tail towards the higher productivity levels. The most frequent tree size was between 0.1 and 0.2 m^3 and the most frequent bundle size was two trees per cycle, followed by three trees per cycle. With the DHP, the most frequent productivity was between 10 and 20 m^3 per PMH. However, there was a slightly lower second peak of between 40 and 50 m^3 per PMH (bimodal). The most frequent average tree volume was between 0.2 and 0.3 m^3. With the harvester, the most frequent productivity was between 15 and 20 m^3 per PMH. A second peak occurred between 5 and 10 m^3 per PMH. The most frequent tree volume was between 0.2 and 0.3 m^3.

3.6.2 Regression analysis

Regression models that described the effect of tree and bundle sizes on productivity were then developed to find and describe significant relationships. The model developed needed to show the processing-technology productivity in relation to tree size, as well as bundle size, for the CFDD, CFDDC and CFDD&C. Bundle size and tree volume were used as independent variables and were related to machine productivity as m^3 per PMH. In order to ensure that the model was valid and accurate, the assumptions in the model were validated and the input-output transformations for the model were compared to the real system information used to build the model.

3.6.2.1 Regression model construction

The scatterplots, which were used to explore relationships (whether there is a relationship and also the form of the relationship), suggested that relationships between independent variables and productivity might be quadratic rather than linear for some processing technologies. Therefore, square effects were included. It is not unreasonable to suspect that average tree volume and bundle size might have an interactive effect on productivity (see *Section 3.4.4 – Initial data analysis*) and, because of this, the interaction term was also included in the model-building process. Thus, the various models that were constructed for each processing technology examined the productivity variables, the square effects of each variable and the interaction between the variables. These models were constructed in sequence and were as follows:

- **main effects model (MEM):** average tree volume and bundle size;
- **main effects and interaction model (MEIM):** average tree volume and bundle size and the interaction between these two;
- **main effects and square effects model (MESEM):** average tree volume and average tree volume squared, as well as bundle size and bundle size squared;
- **main effects, square effects and interaction model (MESEIM):** average tree volume and average tree volume squared; bundle size and bundle size squared; and the interaction between average tree volume and bundle size.

The coefficient of determination (R-squared value) of each model was examined. The R-squared value is an indicator of goodness of fit. It measures how well the estimated regression line fits the observed machine productivities. In order for it to be acceptable to introduce new factors into the model, the adjusted R-squared has to increase. The results of the adjusted R-squares for each successive model for each processing technology are outlined in Table 29.

Table 29: Adjusted R-squared examination per model per processing technology

Model	CFDD	CFDDC	CFDD&C	DHP	Harvester
MEM	0.5518	0.3395	0.4768	0.7275	0.8881
MEIM	0.5962	0.3751	0.5683		
MESEM	0.6014	0.3902	**0.5596**	0.7513	0.8951
MESEIM	0.6168	0.3918	0.5814		

The interaction model could not be used by the DHP and harvester technologies because no bundles were processed. In all instances, except for MESEM for the CFDD&C, the adjusted R-squared value increased. Therefore, it is acceptable to add new variables to the model. However, the MESEM for the CFDD&C decreased. In this instance, the addition of the square effects did not improve the model significantly and was therefore not included. The productivity regression equation that was constructed from the regression is shown below.

Productivity $(m^3/PMH) = \beta_0 + (\beta_1 * \text{Ave tree vol}) + (\beta_2 * (\text{Ave tree vol})^2) + (\beta_3 * \text{Bundle size}) + (\beta_4 * (\text{Bundle size})^2) + (\beta_5 * \text{Ave tree vol} * \text{Bundle size})$

3.6.2.2 Productivity coefficients of the regression model

The regression coefficients were established for each processing technology. These estimated coefficients are given in Table 30 below. These coefficients were substituted into the regression model above.

Table 30: Coefficients of the productivity model for each processing technology

Effect	CFDD	CFDDC	CFDD&C	DHP*	Harvester*
Intercept (β_0)	-28.601	-17.167	-10.419	-6.856	**0.3269**
Average tree volume (β_1)	266.053	188.718	158.233	229.563	69.2628
Bundle size (β_2)	12.251	24.654	8.759		
Average tree volume^2 (β_3)	-365.449	-152.547	-192.348	-201.501	-34.0318
Bundle size^2 (β_4)	-0.759	-3.130	-0.708		
Average tree volume x Bundle size (β_5)	35.407	23.341	47.509		

* Bundle size is not applicable

The coefficients follow a similar trend for each processing technology, with the intercept having a small negative value. Average tree-volume and bundle size have positive values, indicating that as tree and bundle size increased, productivity also increased. The coefficients for average tree-volume and average tree-volume squared were very large, indicating that tree volume was a very important factor in determining productivity. Average tree-volume squared and bundle size squared have negative values, indicating that the productivity increase is non-linear for both of these variables. However, these two effects played a much smaller role in dtereming productivity as can be seen by their smaller values. The larger the value of the coefficient for the interaction between bundle size and tree volume, the more the gradient of the productivity curve for different bundle sizes will vary. Therefore, CFDD&C and CFDD have more variable gradients than the CFDDC.

The p-value's for each coefficient were also examined. The regression coefficients were all significant at the five per cent level of significance, with the exception of the harvester intercept. Because the harvester intercept co-efficient is not significant, it has not been used in the harvester-productivity equation.

The model developed above was used to determine processing technology productivity as per the conditions recorded in the research. The estimated values produced by the model and the real research values were then compared.

3.6.2.3 Validation of assumptions of normality

The assumptions of normality and homoscedasticity of the error terms in the regression analysis were examined. These assumptions were tested by analysing the residual terms resulting from the regression model.

The graphs showing the differences between the observed productivity values and the productivity values predicted by the model are shown for each technology in Figures 47a-e.

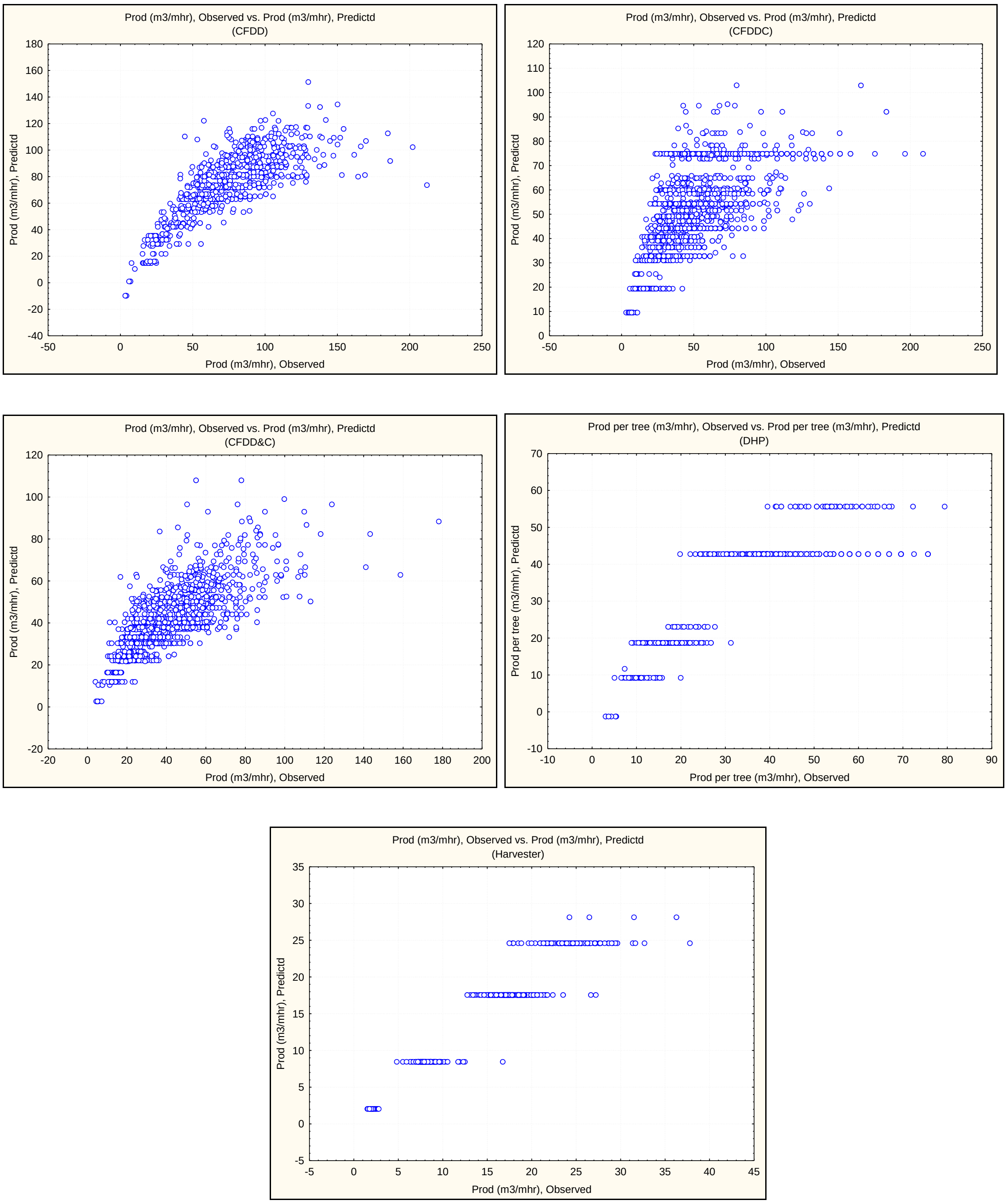
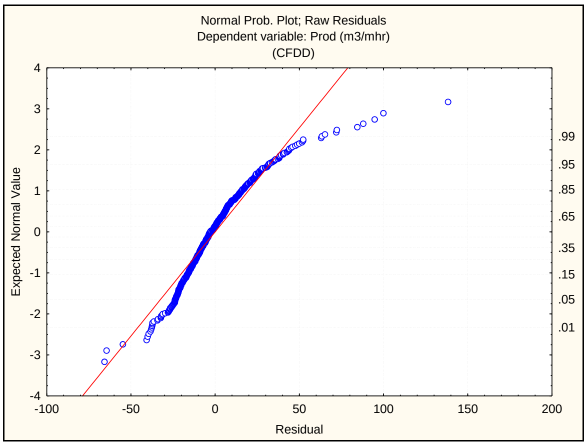
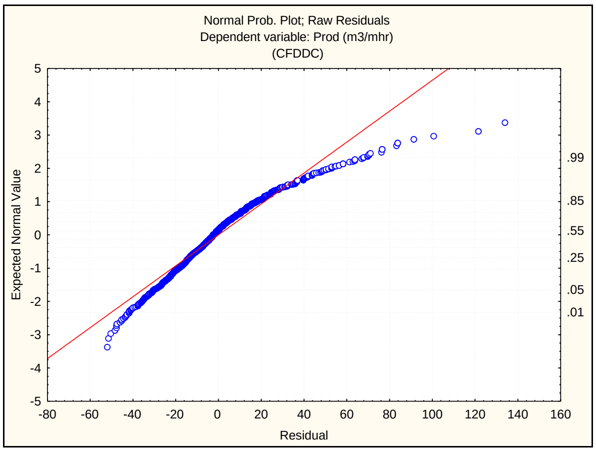


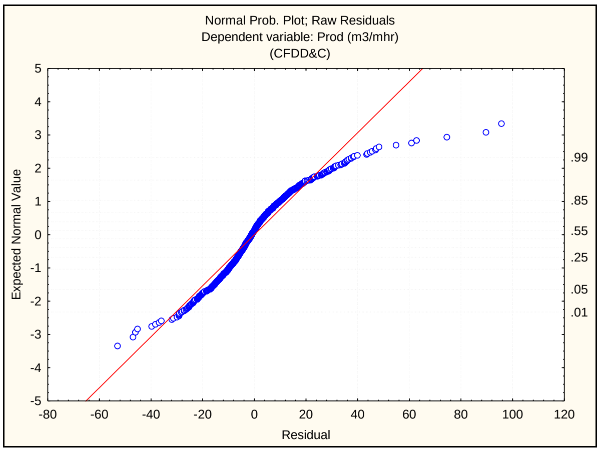
Figure 44a: CFDD, Figure 47b: CFDDC, Figure 47c: CFDD&C, Figure 47d: DHP and Figure 47e: Harvester – all observed productivity versus predicted productivity values

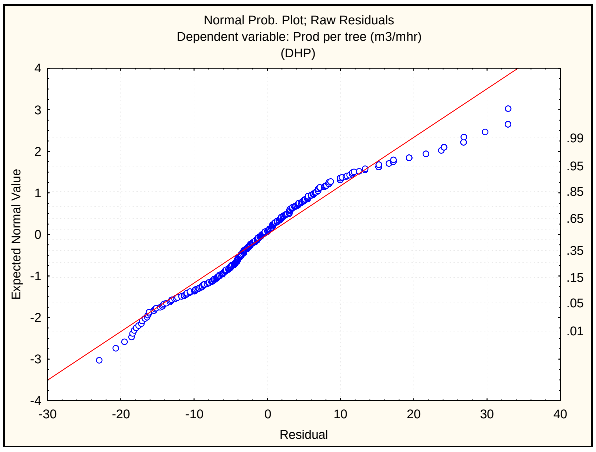
The predicted productivity versus observed productivity evaluates how well the model fits the data. The model is able to predict more accurately at lower productivity levels. With the bundle-fed processing machines, if a new bundle was placed at the infeed immediately after a previous bundle had been placed, it created a spike in the productivity of the previous bundle. The result is a very short cycle time in relation to the volume being fed through the processor. This creates very high productivity levels for those specific cycles, which is reflected in the graphs. At very low and very high levels of productivity, the model is generally under-predicting, with the exception of the harvester. This could be caused by outliers and has been investigated further below.

The test for normality is carried out by constructing a normal probability plot for residuals. When examining the plot, the most emphasis should be placed on the central values and not the extremes (Montgomery, 1984). If the assumptions are valid, the fitted line in a normal probability plot would be a straight line. One could then assume that the residual term is normally distributed. The test for normality of error terms (residuals) is shown in Figures 48a-e.









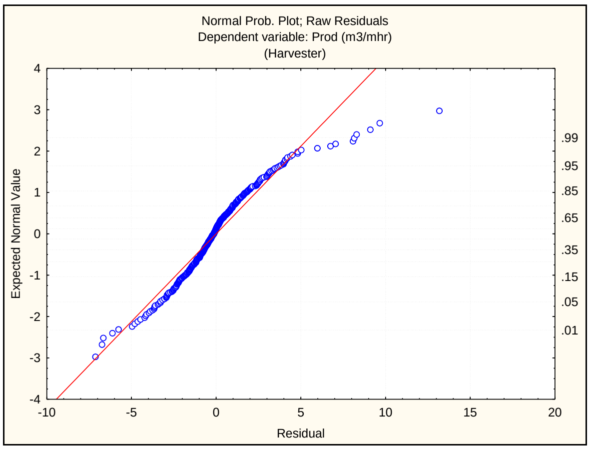
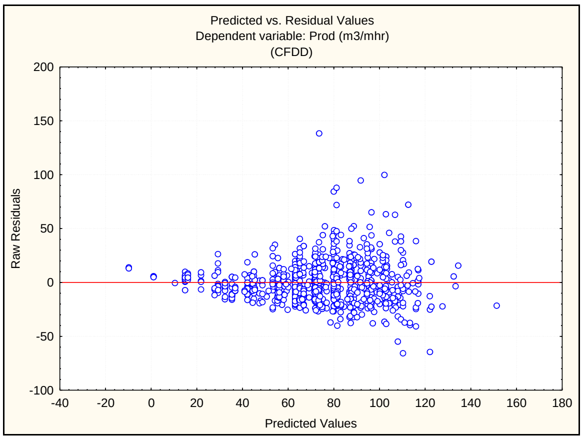
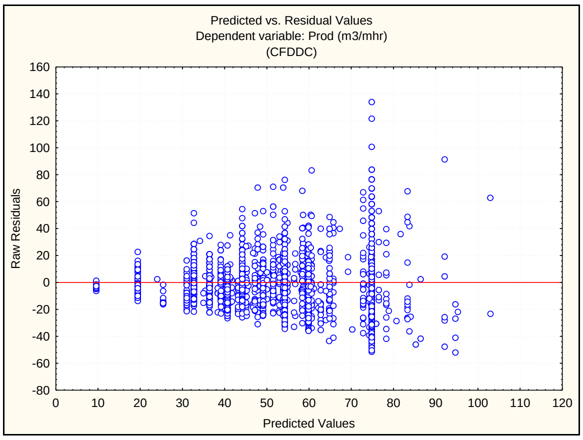


Figure 45a: CFDD, Figure 48b: CFDDC, Figure 48c: CFDD&C, Figure 48d: DHP and Figure 48e: Harvester – all normality of error terms

At the extremes of the data and at certain positions along the line, the terms were not lying along the line. Therefore, the assumptions of normality were not met, as it appeared that outliers were affecting the error terms for all the different technologies. Outliers, therefore, needed to be identified and removed.

The investigation of homoscedasticity of the error terms is shown in Figures 49a-e. The plot of residuals (error terms) versus the predicted mean values checks for homoscedasticity (Gujarati, 1999). For the assumptions to be valid, the plot should be random without clear recognisable patterns.





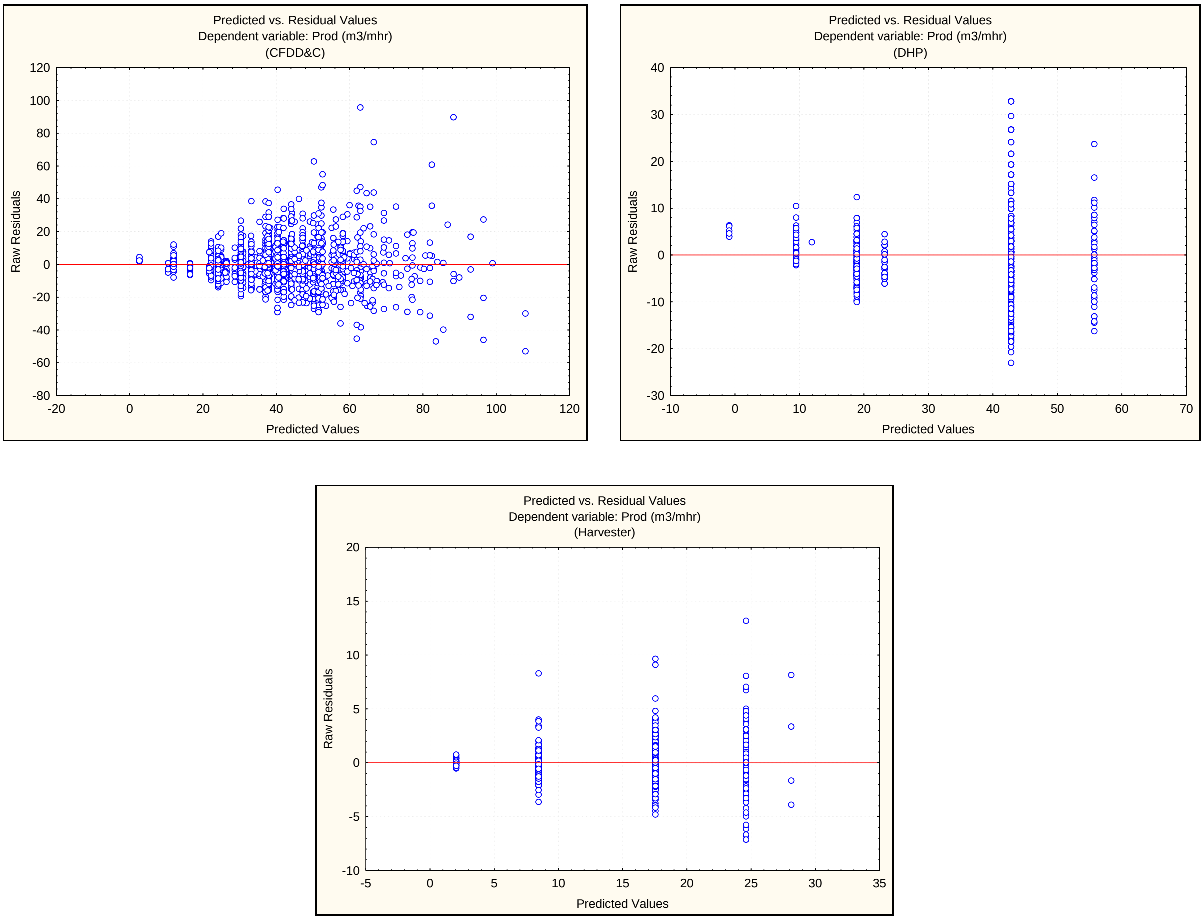


Figure 46a: CFDD, Figure 49b: CFDDC, Figure 49c: CFDD&C, Figure 49d: DHP and Figure 49e: Harvester – all homoscedasticity of error terms

The variance is not constant and, therefore, the assumption of homoscedastic variance has not been met. Once again, it appeared that outliers were responsible and needed to be identified and removed.

3.6.3 Identification of outliers

The data of each processing technology were once again handled separately. The data were sorted by tree size and productivity only. New tree-size classes were created as per Table 32.

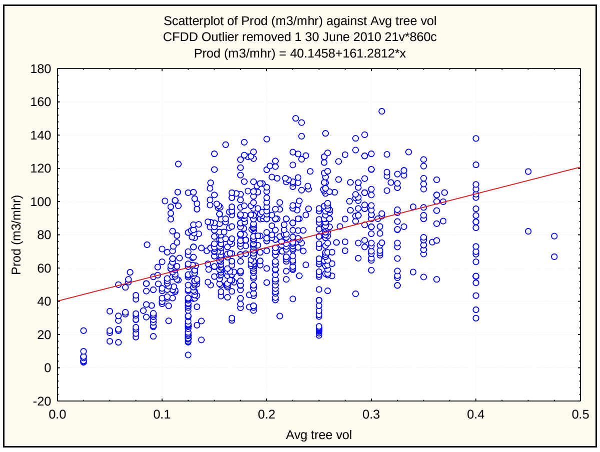
Table 31: New tree-size classes for outlier removal

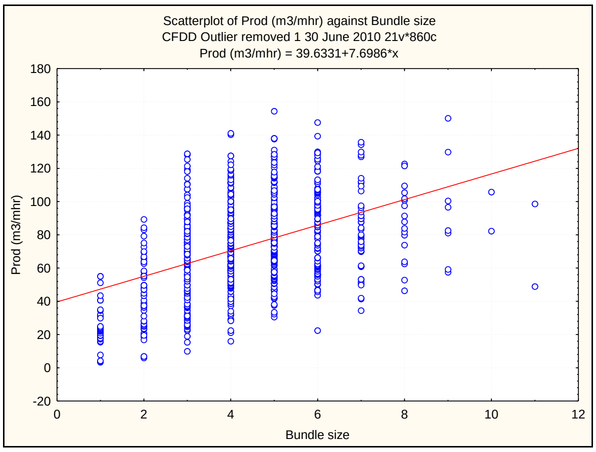
Tree-size class	Tree-size range
1	0.0 to 0.099 m^3
2	0.10 to 0.199 m^3
3	0.20 to 0.299 m^3
4	0.30 to 0.399 m^3
5	0.40 to 0.499 m^3
6	0.50 to 0.599 m^3

The existing data already had specific tree sizes, so besides sorting, no data manipulation was necessary. The first and third quartiles for productivity were determined for each tree-size class for each processing technology. The interquartile range was then determined by subtracting the first quartile value from the third quartile value. One-and-a-half times the interquartile range was added to the third quartile value and subtracted from the first quartile value. Any productivity figures above or below these values were deemed to be outliers. These were highlighted in the data and removed.

3.6.3.1 Scatterplot investigation of productivity relationships with outliers removed

Once the dataset of each technology had again been imported into STATISTICA, scatterplots were once again used to investigate the nature and strength of dependencies between independent variables and the dependant variable, as well as to investigate relationships, for model development and to predict productivity. The x-axis (bundle size and average tree volume) was independently plotted as two-dimensional scatterplots against the y-axis (the productivity per PMH). The results for each technology are shown in the various tables below. Figures 50a-h represent all the processing technologies.





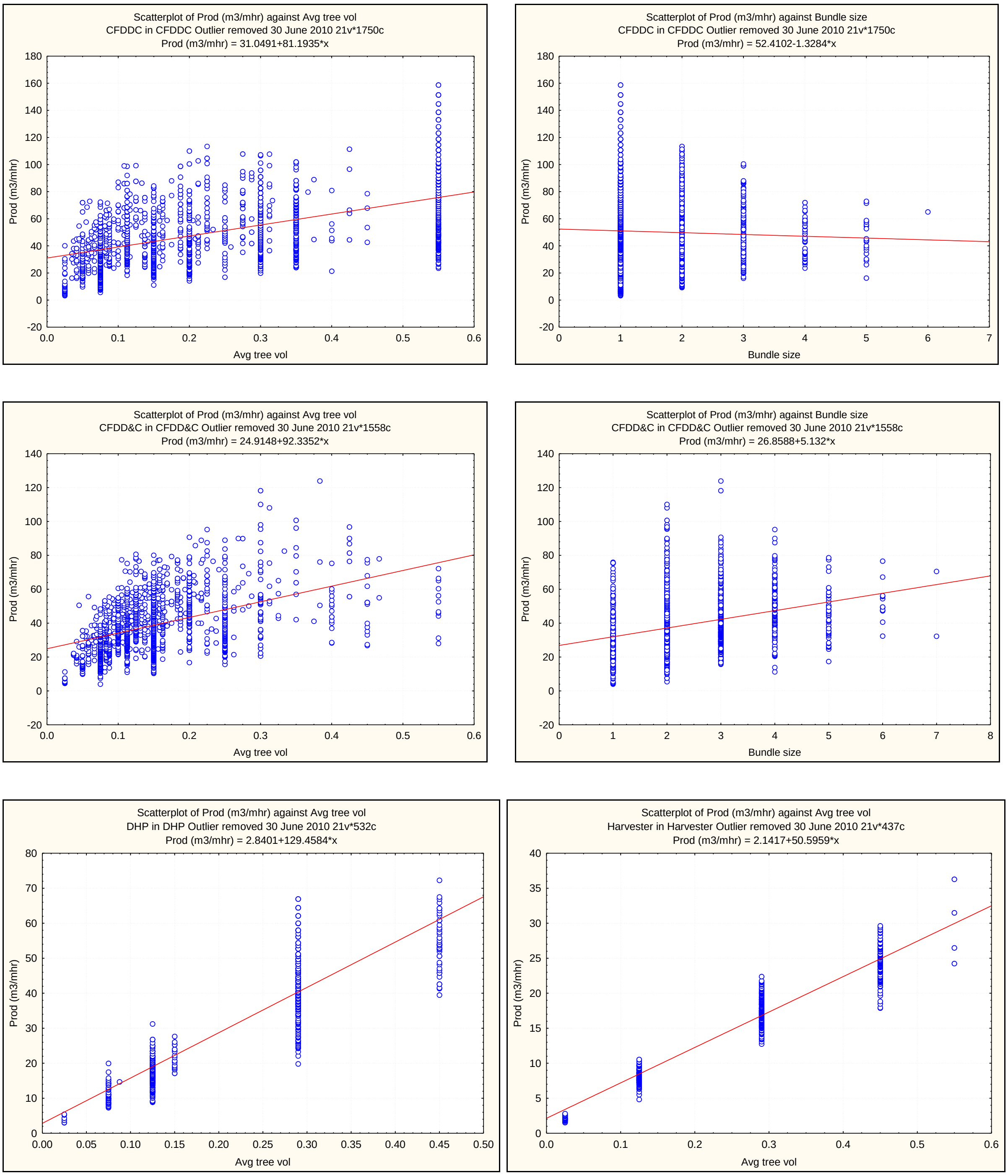


Figure 47a: CFDD scatterplot of average tree-volume, outliers removed, Figure 50b: CFDD scatterplot of bundle size, outliers removed, Figure 50c: CFDDC scatterplot of average tree-volume, outliers removed, Figure 50d: CFDDC scatterplot of bundle size, outliers removed, Figure 50e: CFDD&C scatterplot of average tree-volume, outliers removed, Figure 50f: CFDD&C scatterplot of bundle size, outliers removed, Figure 50g: DHP scatterplot of average tree-volume, outliers removed and Figure 50h: Harvester scatterplot of average tree-volume, outliers removed

The outlier removal slightly improves the fit of all the processing machines. The decrease in productivity with increasing bundle size for the CFDDC (Table 50d) could be due to the feeding method, where large trees were fed through individually, but in quick succession.

Small trees were fed through as bundles, with a longer time delay before the next bundle was processed. The small number of bunches with many trees could also be skewing the data slightly.

Once again, the tree volume and bundle size were then plotted against each other (only for CFDD, CFDDC and CFDD&C). Figures 51a-c show two-dimensional scatterplots of the resultant relationships.

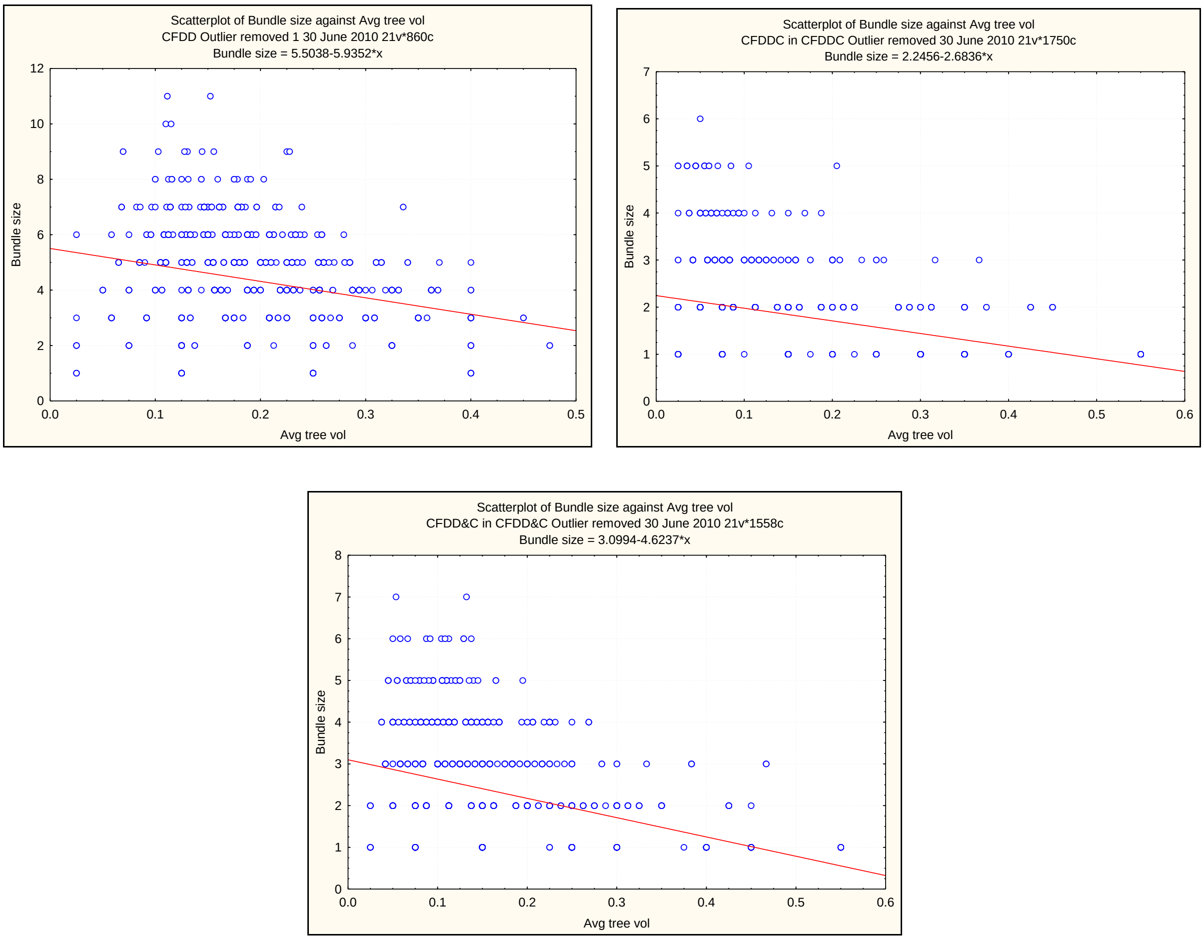


Figure 48a: CFDD, Figure 51b: CFDDC and Figure 51c: CFDD&C – all scatterplots of average tree volume against bundle size, outliers removed

As expected, all three technologies processed fewer trees per bundle as the tree size increased. It is to be noted that for a fixed average tree volume, there was a lot of variation in bundle size. Although the relationship is negative, it is not very strong.

3.6.3.2 Examination of the distribution of productivity variables with outliers removed

Histograms were then again created in STATISTICA to examine whether the distribution of the data were normal when outliers were removed. The histograms for each of these variables for each technology can be found in Annexure A. As a reference, Annexure A includes the histograms with the outliers included and removed. The histogram data distributions with outliers removed are almost exactly the same as with the outliers included. The model developed was used to determine productivity of processing technology with the outliers removed, as per the conditions recorded in the research. The estimated values produced by the model and the real research values (both with outliers removed) were then compared. Once the outliers had been removed, the assumptions were again tested, using the two methods described above (that is, determining if error terms were normally distributed and determining homoscedasticity of the error terms).

3.6.4 Regression analysis with outliers removed

Regression analysis was done on the data with the outliers removed. Models were once again constructed as per the method previously described. The sequence of model construction was the main effects model (MEM), main effects and interaction model (MEIM), main effects and square effects model (MESEM) and main effects, square effects and interaction model (MESEIM).

The results of the adjusted R-squares for each successive model for each processing technology are outlined in Table 33.

Table 32: Adjusted R-squared examination per model per processing technology with outliers removed

Model	CFDD	CFDDC	CFDD&C	DHP	Harvester
MEM	0.5883	0.3634	0.4788	0.7585	0.9152
MEIM	0.6376	0.3830	0.5697		
MESEM	0.6557	0.4065	0.5904	0.7801	0.9230
MESEIM	0.6680	**0.4062**	0.6031		

Apart from MESEIM for the CFDDC, the adjusted R-squared value increased. Therefore, it was acceptable to add new variables to the model because the adjusted R-squared value would also increase. The only exception was the MESEIM for the CFDDC, which decreased.

Therefore, the MESEIM should not be used and the addition of all of the variables did not improve the model accuracy. The adjusted R-squared values for all of the models and technologies increased over the original model results, which included outliers. This means that the removal of outliers improved the fit of the data.

Research that concentrates on the variables affecting the productivity of harvester machines found it rare for one productivity variable to describe more than 50 per cent of the variation in the data. Low variability description is common for forestry machines, because element and cycle times are affected by many factors that are difficult to record and estimate (Spinelli and Hartsough, 2001). An example of such a factor is operator concentration.

3.6.4.1 Productivity coefficients of the regression model with outliers removed

New regression coefficients were then determined for the models. The coefficients of the model for each processing technology are outlined in Table 34 below and show the significance of the coefficients.

Table 33: Coefficients of the productivity model for each processing technology with outliers removed

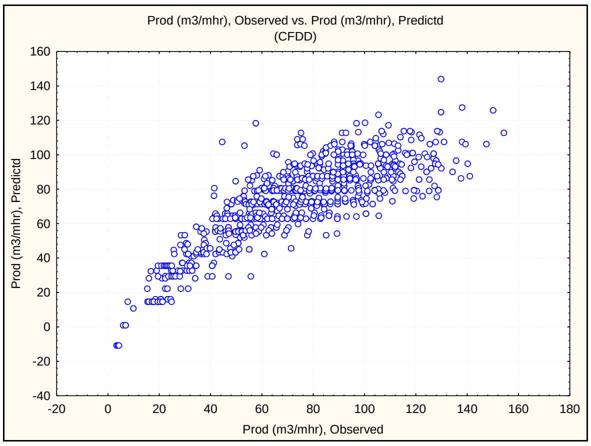
Effect	CFDD	CFDDC	CFDD&C	DHP	Harvester
Intercept (β_0)	-31.130	-19.723	-18.175	-5.555	**0.1641**
Average tree volume (β_1)	280.271	218.570	193.666	217.321	69.5225
Bundle size (β_2)	13.660	27.188	14.504		
Average tree volume^2 (β_3)	-382.485	-164.051	-235.663	-183.513	-34.9054
Bundle size^2 (β_4)	-0.910	-3.388	-1.645		
Average tree volume x Bundle size (β_5)	31.081	**-2.533**	33.512		

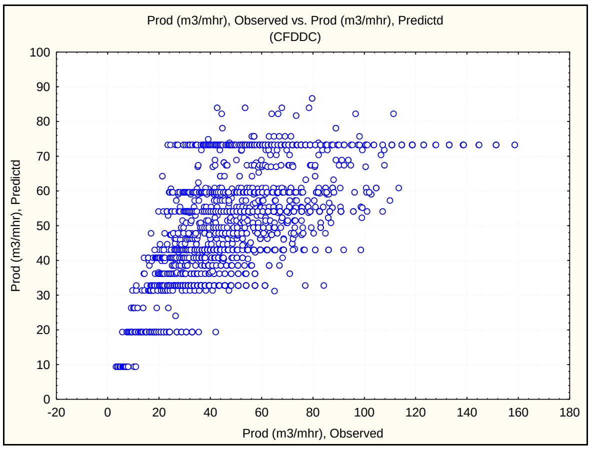
Except for the interaction between average tree volume and bundle size for the CFDDC, all coefficients were significant at the five-per-cent level of significance. This interaction will therefore not be included in the final model for the CFDDC.

The most noticeable change in the coefficients can be found in the CFDDC and CFDD&C. The β_1 coefficient (average tree volume) has increased from 189 to 219 and 158 to 194 for the CFDDC and CFDD&C respectively. Therefore, as tree size increased, there was a more pronounced increase in productivity than when the outliers were included. The β_3 (average tree volume squared) coefficient still plays a largely negative role, even though it has decreased slightly from when the outliers were included. This indicates that as the tree size becomes larger for a given bundle size, the productivity increase will be slow.

The β_2 (bundle size) coefficient for the CFDD&C also markedly increased from 8.8 to 14.5, indicating increased productivity with more trees per bundle for a given tree size. However, the effect is clearly not as large as with tree size. The β_4 (bundle size squared) coefficient for all the multi-stem processing technologies plays a much smaller role, but it is still significant. The β_5 (interaction) coefficient has decreased with the outliers removed, most notably for the CFDDC (from 23.3 to -2.5) and this coefficient is no longer significant. The insignificant coefficient for the interaction term of the CFDDC shows that the gradient of the productivity curve is not variable for different bundle sizes. There is a significant interaction effect between average tree volume and bundle size for the CDFF and CFDD&C.

The graphs showing the differences between the observed productivity values and the productivity values predicted by the model are shown for each technology in Figures 52a-e. All the data should fall on a 45 degree line. The model is able to predict more accurately at lower productivity levels.





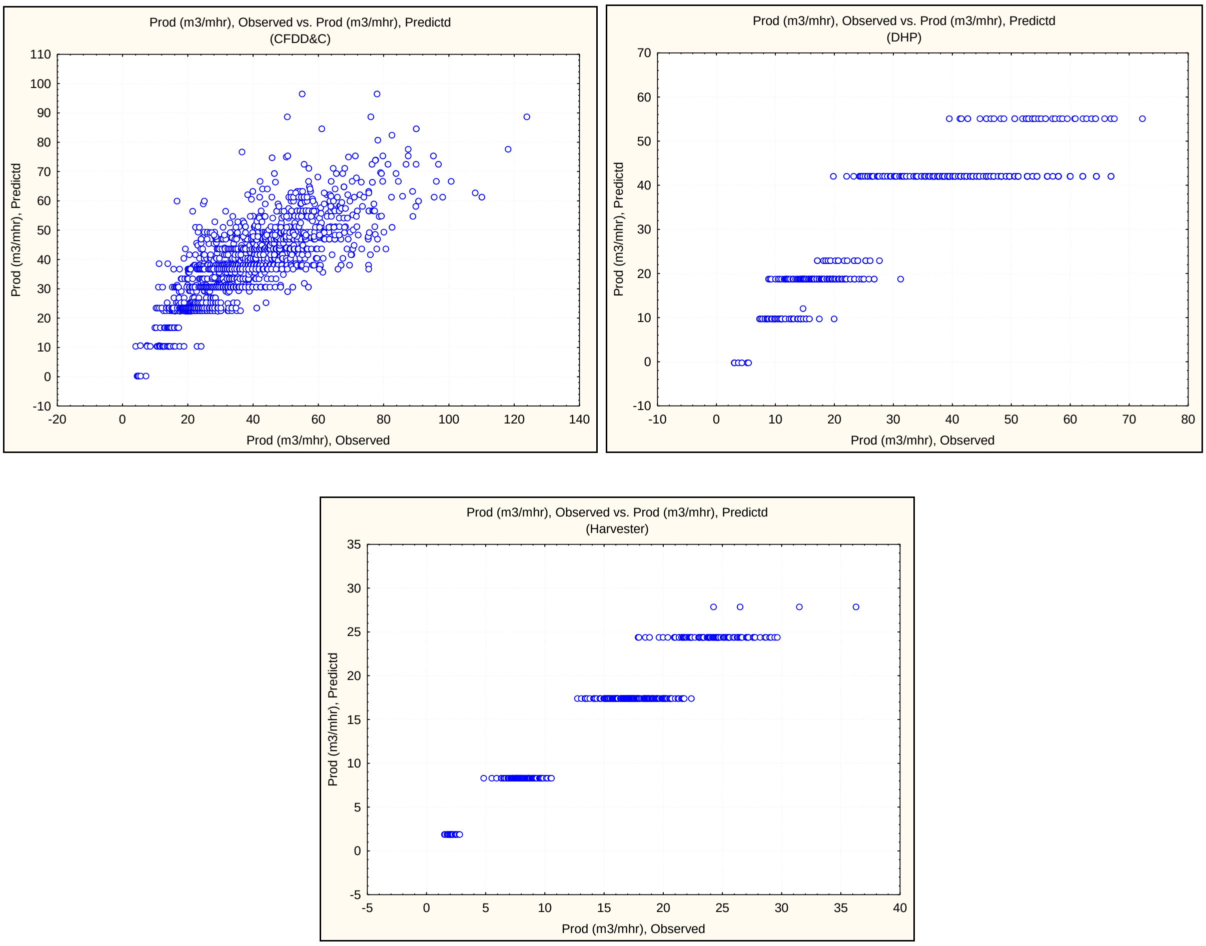
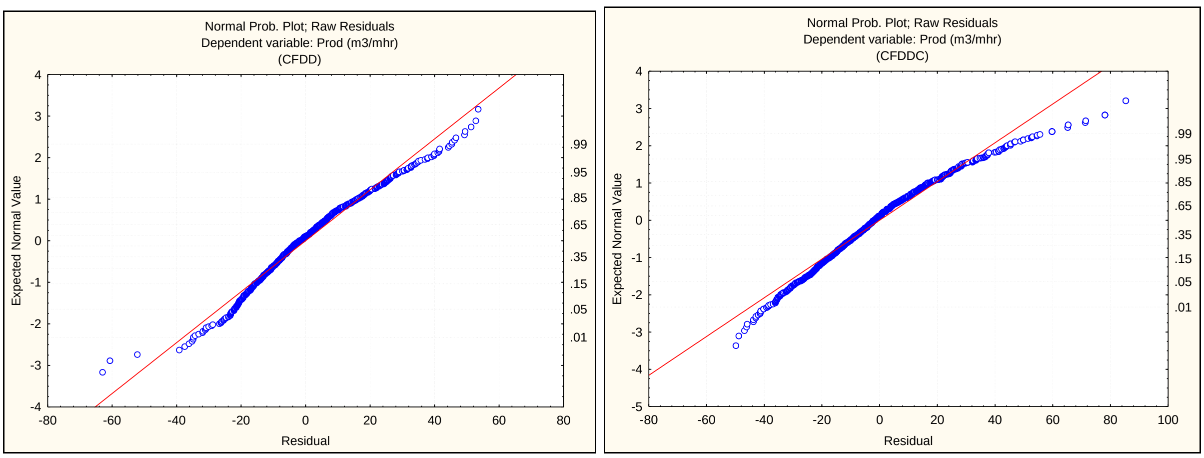


Figure 49a: CFDD, Figure 52b: CFDDC, Figure 52c: CFDD&C, Figure 52d: DHP and Figure 52e: Harvester – all observed productivity versus predicted productivity values, outliers removed

3.6.4.2 Validation of assumptions of normality with outliers removed

This test for normality of error terms is shown in Figure 53a-e.



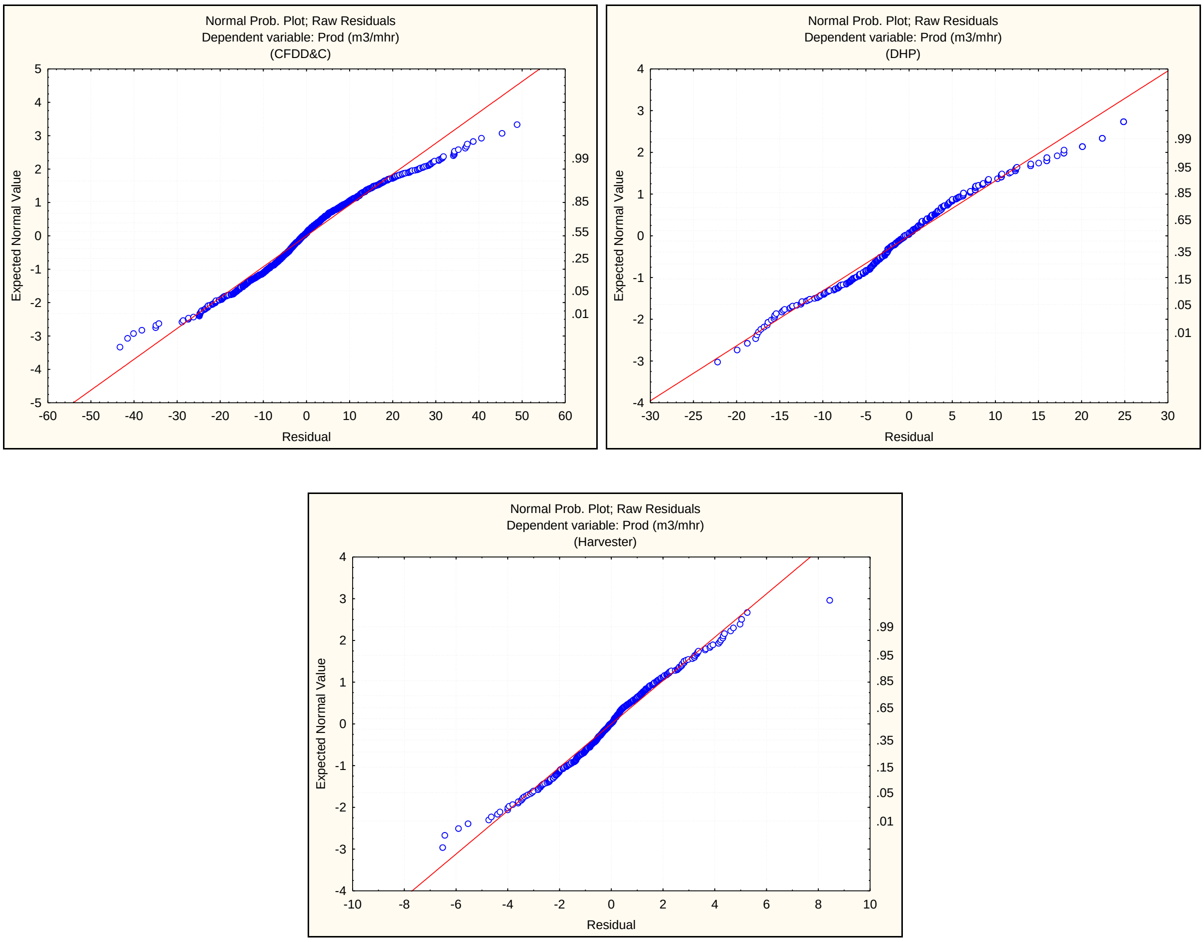
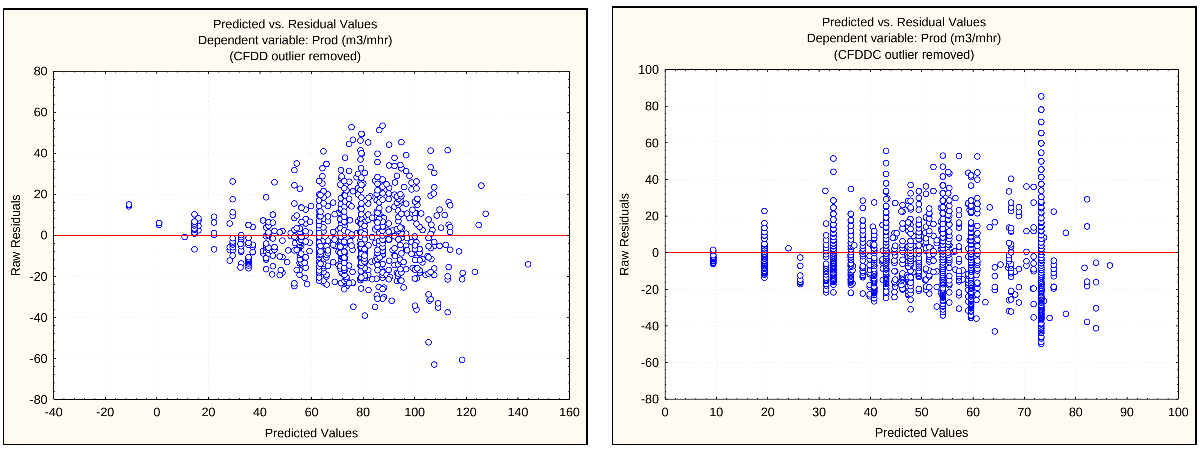


Figure 50a: CFDD, Figure 53b: CFDDC, Figure 53c: CFDD&C, Figure 53d: DHP and Figure 53e: Harvester – all normality of error terms, with outliers removed

The normal probability plot of residuals checks for the assumption of normality. With the outliers removed, the error terms now lie along the straight line. The assumption of normality was therefore found to have been met.

Homoscedasticity of the error terms was tested again, as per Figures 54a-e



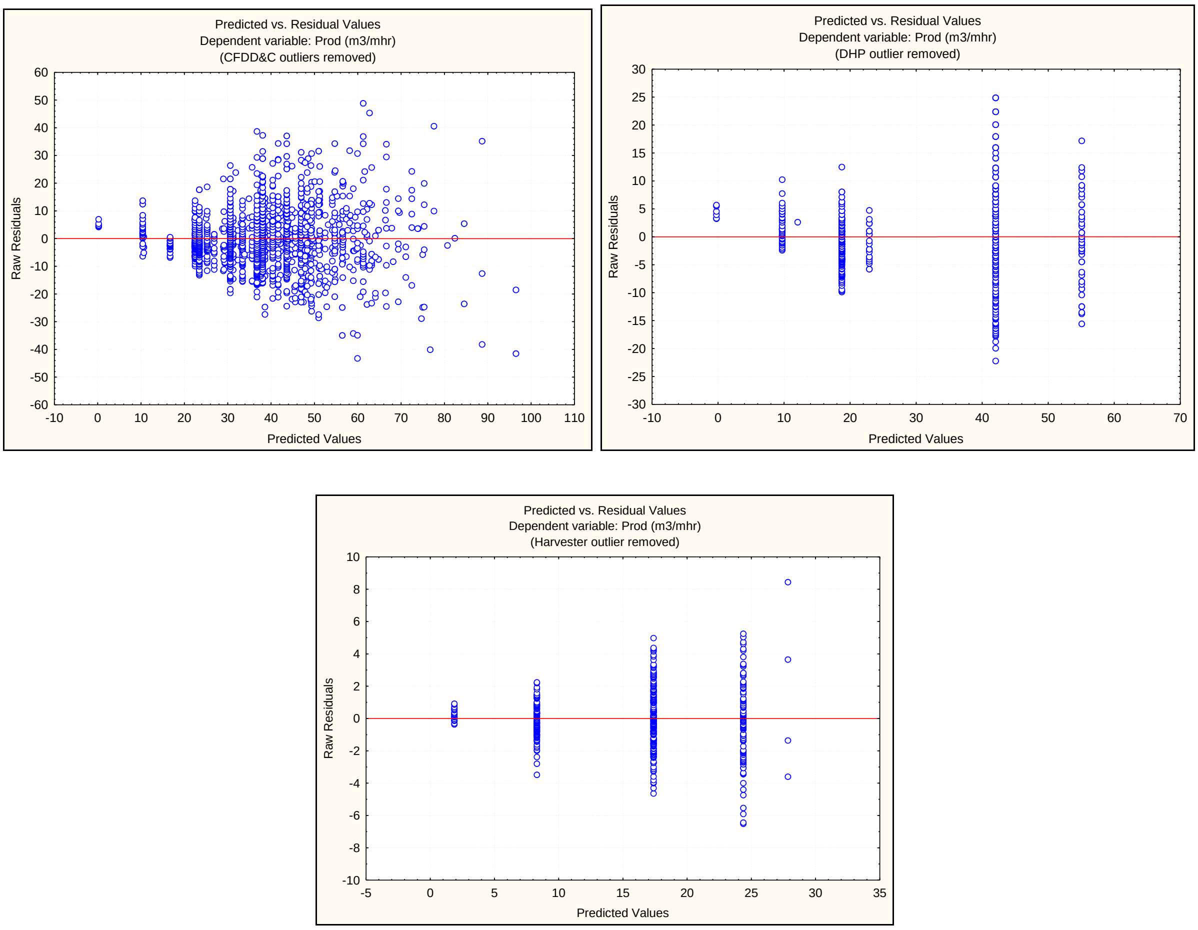


Figure 51a: CFDD, Figure 54b: CFDDC, Figure 54c: CFDD&C, Figure 54d: DHP and Figure 54e: Harvester – all homoscedasticity of error terms, with outliers removed

The plot of residuals versus the predicted values checks for homoscedasticity. There was constant variance of the residuals from the zero line for the predicted values of each processing technology. The assumption of homoscedastic variance was met. Therefore, the productivity equations developed can be used to predict the productivity of all of the various processing technologies for different tree sizes and bundle sizes.

3.7 Cost data analysis

To determine the costs of harvesting per m^3, it is necessary to divide the cost of operating the machine (usually per hour) by the production achieved during that time period (Akay and Sessions, 2004). To determine the machine rate, the following information is required:

- the ownership costs (depreciation, interest, insurance and scheduled operating time);
- operating costs (maintenance, fuel, lubricants, tyre- or track-replacement costs); and

- labour or machine-operator costs (wages, salaries, legislated costs and other labour overheads).

These factors are influenced by many variables. For example, the repair-cost factor is influenced by operators abusing equipment, difficult terrain and the inherent reliability of the machine. A further example is fuel consumption, which is influenced by load size, engine size, operator skill and operating conditions. Hence, the accuracy of the results of a machine costing depends upon the quality of the information used in the costing.

Jarck (1965) classified the accuracy of information used in machine costings into three categories: empirical data (long-term cost records), good estimates from knowledgeable sources and unknown (questionable or rule-of-thumb sources). For the purpose of the research, empirical data was used as far as possible. However, not all the sources required to substantiate this research have been empirically investigated and some information recorded offers the best estimates available from knowledgeable sources. Costing information was placed into the Forestry Solutions mechanised harvesting system costing model developed in Microsoft Excel (2003). All costings are included in Annexure C.

The input assumptions into the costing were obtained from various sources. Table 36 shows the sources of the different factors used in the cost calculations described under the results. Apart from the CFDDC, the same machines and models used during the research have been used for the costings. The Morbark 2455 was used to calculate the CFDDC costing, owing to a lack of response from the South African Peterson agents.

Table 34: Information sources for machine-cost factors

Machine-cost factor	Source
Capital cost of machine	As indicated in text
Machine life (machine hours)	As indicated in text
Residual values (% of capital employed)	Brinker, et al. (2002)
Machine utilisation	Brinker, et al. (2002)
Insurance rates	Brinker, et al. (2002)
Repair-cost factor	Brinker, et al. (2002)

Machine-cost factor	Source
Fuel consumption	Grobelaar (2000)
Oil and lubrication	Grobelaar (2000)
Operator rates (cost to company)	As indicated in text
Overhead costs	Grobelaar (2000)

3.7.1 Ownership costs

The various ownerships assumptions and costs of the machines and systems used in the harvesting system cost calculations are described below.

3.7.1.1 Capital costs of equipment

New machine prices were collected from agents in South Africa. The capital cost of the machines considered all the logistical costs of transporting the new machines to the point of use (Miyata, 1980). For this research, the point of use was Richards Bay, where the DHP and harvester worked during the research trials. Because most of the equipment across the trial sites was of the Tigercat brand, most costs were sourced from Afrequip, their South African agents (G. Olsen, Tigercat international sales manager, South Africa, personal communication [email], 27 September 2010). This ensured that fair comparisons were made between systems. Exceptions to Tigercat were:

- Morbark – CFDD (M. Custers, Ritlee Xecutech managing director, South Africa, personal communication [email], 5 October 2010);
- Precision Husky – CFDD&C (F. Breytenbach, Afrequip general manager, South Africa, personal communication [email], 27 September 2010);
- STIHL – chainsaw (H. Hutton, National sales manager of STIHL South Africa, personal communication [conversation], 7 October 2010);
- Bell – three-wheeled logger (D. Howe, Bell Equipment general manager sales: forestry and sugar, South Africa, personal communication [conversation], 25 September 2010);
- SP – harvesting and processing head (T. van Eeden, SP agent, South Africa, personal communication [conversation], 5 October 2010);

- Hitachi – harvester and processor carrier (T. van Eeden, personal communication [conversation], 5 October 2010).

The machine capital costs used in the system costings are shown in Table 37 below.

Table 35: Capital cost of machines in US$

Machine type	Machine brand and model	Capital cost (US$)
Wheeled feller buncher	Tigercat 720E	315,717
Grapple skidder	Tigercat 630D	394,798
Three-wheeled logger	Bell 220E Telelogger	80,500
Slasher loader	Tigercat T234 with slasher	381,224
Forwarder	Tigercat 1075B	571,139
CFDD	Morbark 2455	714,371
CFDDC	Morbark 2355	1,059,368
CFDD for chipper below	Precision Husky 2300-4	734,324
Chipper	Precision Husky 2366	589,848
DHP and harvester	Hitachi Zaxis 200 with SP 591	428,571

3.7.1.2 Machine life and depreciation

A machine life of 15,000 productive machine hours (PMH) was used in the cost calculations (Howe, personal communication, 2010; Olsen, personal communication, 2010), with a depreciation period of five years, which was based on the annual utilisation.

3.7.1.3 Residual value

A residual value of 20 per cent of the machine purchase price was used in all costings (Brinker, et al., 2002).

3.7.1.4 Interest rate

The interest rate was eight per cent, which was the current prime interest rate in South Africa at the time of the costing.

3.7.1.5 Insurance

Insurance rates per machine were obtained from Brinker, et al. (2002) and are included in Table 38 below. The insurance rate varies per machine due to the different risk profiles of the various machines.

Table 36: Insurance (percentage of purchase price) costs for the various machines used

(Brinker, et al., 2002)

Machine	Percentage of purchase price
Grapple skidder	5%
Feller buncher	4.5%
Harvester, DHP and forwarder	4%
CFDD & CFDDC & chipper	2%
Three-wheeled logger	2%
Slasher loader	1.5%

3.7.1.6 Scheduled machine hours (SMH)

All machines were scheduled to work two shifts of eight hours each per day. The SMH per day was therefore 16 hours. Systems were scheduled to work six days per week. An additional 13 days was removed from the balance of the days available in the year to make provision for public holidays and other possible non-productive time (for example, weather or mill-related delays). Therefore, the machines were scheduled to work for 300 days per year, or 4,800 SMH.

3.7.2 Operating costs

The various operating assumptions and costs of the machines and systems are described below.

3.7.2.1 Machine utilisation

A machine-utilisation rate of 65 per cent was used (Brinker, et al., 2002). This describes the percentage of SMH that the various machines will actually be working. Even though delays were measured during the field research, these values were not used to determine machine utilisation. To determine machine utilisation levels accurately, the research needed to be carried out over a longer period. For example, the CFDD-based systems process from one landing for some time before moving and setting up at a new landing. If the time taken to carry out the move and setup is incorrectly proportioned to productive time, then an incorrect machine-utilisation figure will be used, which will affect system costs. Therefore, published figures for machine utilisation were used. A machine utilisation of 65 per cent would result in 3,120 PMH being used out of the available 4,800 SMHs. The equivalent would be 5.2 PMH per eight hour shift. However, the systems would have to be balanced and this could change the final utilisation figure.

3.7.2.2 Repair-and-maintenance factor

The repair-and-maintenance cost factor has also been taken from Brinker, et al. (2002). Table 39 below shows the factors used per machine. It is calculated as a percentage of the capital cost of the machine, divided over the economic life of the machine. The repair-and-maintenance cost used in the costings included the total cost of purchasing and running a full workshop and doing daily infield maintenance on the machines. Tyre-and-track replacement is also included. However, the repair-and-maintenance figure does not distinguish between labour cost, back-up vehicle cost and the cost of spare parts, tyres and tracks.

Table 37: Repair-and-maintenance cost factors

Machine	Percentage
Feller buncher	100%
Grapple skidder	90%
Forwarder	100%
Slasher stacker	90%
CFDD, CFDDC, Chipper	100%
Three-wheel loader	100%

3.7.2.3 Parts not included in the repair-and-maintenance factor

Table 40 gives all the additional consumable parts that were not included in the repair-cost factor, but needed to be included in the machine cost calculations. The costing considers how many of each part are required, the economic life of each part, as well as the cost of each part.

Table 38: Additional parts important for the costings

Machine	Part	Cost each	Number required	Life (PMH)	Source
Feller buncher	Cutting teeth	$9,300.00	1 (set)	2,500	Olsen, personal communication, 2010
CFDD	Chains	$8.00	78 per flail	30 (Precision 40 hrs)	Nantz, personal communication, 27 Sept, 2010
CFDDC	Knives	$24.40	12	50	Nantz, personal communication, 2010
Slasher	Bar and sprocket	$714.00	1	350	Olsen, personal communication, 2010
Slasher	Chain	$195.00	1	70	Olsen, personal communication, 2010
Harvester/ processor	Bar and sprocket	$400.00	1	200	Olsen, personal communication, 2010
Harvester/ processor	Chain	$145.00	1	50	Olsen, personal communication, 2010

3.7.2.4 Fuel consumption

The diesel price per litre was R8.19 (US$1.17), which was the current price at the pump in South Africa. Fuel cost is measured as litres consumed per PMH. The fuel (diesel) consumption figures described by Grobelaar (2000) have been used in the cost calculculations. They are based on a factor (0.268) multiplied by the nominal power (kW) of the machine and an engine-load factor. The 0.268 multiplied by the nominal power determines the fuel consumption at full engine speed. The load factor is used to reduce this factor to a level more representative of the operating conditions. A load factor of 40 per cent (an amount which is often used in contract agreements) was used with the feller buncher, grapple skidder and forwarder, as they were deemed to be executing above-average work. The load factors for the other machines ranged from 50 to 60 per cent and reflect the heavier work loads of these machines in relation to their engine sizes. Grobelaar (2000, p.293) described it as “heavy work in hard jobs”. A load factor of 20 per cent was used with the chipper, as this is a high-capacity machine that has a very low volume of trees fed through per hour in relation to its potential. The load factor of 20 per cent is described by Grobelaar (2000, p.293) as “average work load”. The figures used are outlined in Table 41 below.

Table 39: Diesel consumption rates per machine

Machine	kW	Factor	Load factor	Fuel cons/ PMH
Tigercat 720E	142	0.268	0.4	15.2
Tigercat 630D	194	0.268	0.4	20.8
Bell 220E Telelogger	49	0.268	0.5	6.6
Tigercat T234 with slasher	129	0.268	0.5	17.3
Tigercat 1075B	205	0.268	0.4	22.0
Morbark 2455	354	0.268	0.6	56.9
Morbark 2355	783	0.268	0.5	104.9
Precision Husky 2300-4	432	0.268	0.5	57.9
Precision Husky 2366	875	0.268	0.2	46.9
Hitachi Zaxis200 with SP 591	118	0.268	0.6	19.0

3.7.2.5 Oil and lubrication costs

Table 42 shows the rates used in the cost calculation to determine the cost of lubrication for all machines as a percentage of the fuel cost. The cost is calculated as a percentage of the fuel cost per PMH. It is based on whether the machine has no hydraulics, simple hydraulics or extensive hydraulics.

Table 40: Cost of lubricants as a percentage of fuel cost
(adapted from Grobelaar, 2000, p.293)

Machine	Lubricant, % of fuel cost
Feller buncher, grapple skidder, forwarder, three-wheeled loader, slasher loader, CFDD, CFDDC, disc chipper	15%
Harvester, DHP, chainsaw	20%

3.7.3 Machine-operator wages

The operator wage rate was set at $1,700.00 per month ($9.80 per hour), which is an industry norm in South Africa (F. Oberholzer, CMO harvesting contractor owner, South Africa, personal communication [conversation], 30 September 2010). The chainsaw-operator wage for the topping function in the CFDD system was $700.00 per month ($4.03 per hour). The hourly rate reflected in the costing includes this figure, as well as an additional US$15.76 for the daily operating costs of a chainsaw (Oberholzer, personal communication, 2010). The operator costs are cost-to-company amounts and therefore include all overheads. The working days were calculated at 21.67 days per month. Owing to the machines operating six days per week and 300 days per year, additional operators would need to be available in the system, as operators need time off, would have to take annual leave and, possibly, sick leave. An allowance for this has been made in the costing by allocating 1.1 operators for each machine per shift. The operator wages reflect as a cost per PMH in the Excel costing models.

3.7.4 Overheads and other costs and assumptions

The various overhead assumptions and costs of the machines and systems are described below.

3.7.4.1 Overhead costs

A 10 per cent overhead cost (Grobelaar, 2000) has been added to the base harvesting machine costs.

3.7.4.2 Other costs and assumptions

Other general assumptions used in the Excel costing model are shown in Table 43

Table 41: Other general assumptions used in the systems costings

Log length	5.2 m
Average slope	Level to moderate
Ground roughness	Smooth
Extraction distance (all systems)	250 m
Exchange rate	US$1.00 = ZAR7.00
Machine moves with low-bed per year	4 moves @ US$1,300 per move

3.7.5 Cost data analysis conclusion

The systems were then balanced to ensure that the annual volume for each machine in the system was the same. Because each machine has a different productivity for a given tree size, the annual volume output per machine would differ. Balancing can be by increasing productivity or the SMHs. Alternatively, more machines can be added to the system (Stokes & Hartsough, 1993). Balanced systems incur the lowest cost, as long as there is sufficient machine capacity to overcome temporary system imbalances. There also has to be enough buffer stock between machines to allow them to continue for a period after the machine before or after them has stopped unexpectedly. The results of the Excel based machine and system costings are included in the results section, and copies of costings are included in Annexure C.

3.8 Shortcomings and sources of error

The CFDD operator did not pay sufficient attention to using the tools at his disposal to increase productivity and improve debarking quality. The operator tended to feed the same number of trees through per cycle for a given average tree size, regardless of the debarking quality. It is uncertain why the operator behaved like this. By changing the number of flails on each drum, flail speeds, feed speeds and number of trees per cycle, an optimal productivity for a given set of operating conditions could be achieved. However, this is not thought to have affected the research results.

When measuring the trees infield for the harvester, a sample was taken to determine the tree volumes within the compartment. These volumes were used to determine the DBH cut-off points for tree size class. A mistake was made in determining the upper cut-off DBH for the class 2 tree size and, therefore, also the lower cut-off point in the class 3 tree size. This resulted in an incorrect marking of trees infield. The mistake was only discovered after the trees had been processed. This made it necessary to combine tree-size classes 2 and 3 into one class, which was renamed class 3. This created class had a new midpoint tree size of 0.125 m^3.

4 Results and discussion

The results-and-discussion section has been structured to provide an overview of descriptive statistics results for all the processing machines. Following this, the results for each processing machine have been presented separately. Then the statistical results are presented and these culminate in the productivity models. Productivity data is then entered into the Excel based costing models to determine the United States dollar ($) costs per cubic metre (m^3) of timber harvested. This is followed by a discussion of the results as evidenced by both processing machine and tree size.

4.1 Processing machine productivity: results and discussion

The sample size and average tree size were presented in Section 3 (Research design and methodology). The mean cycle times for all the processing machines are set out in Table 44 below.

Table 42: Mean cycle times for processing machines

CFDD, CFDDC and CFDD&C	Mean cycle time (minutes)	Average trees per bundle
CFDD	0.68	4.33
CFDDC	0.52	1.63
CFDD&C	0.39	2.45
DHP	0.44	1
Harvester	1.00	1

Table 44 shows that the CFDD tended to have a much higher cycle time (0.68 min/cycle) than the CFDDC (0.52 min/cycle) and CFDD&C (0.39 min/cycle). This can be attributed to more trees being fed through simultaneously, with a longer delay until the next bundle was fed through. Other differences between these machines are due to the differences in the average tree size best accommodated by each processing technology. The cycle time for the DHP was very low (0.44 min/cycle) in relation to the harvester (1.00 min/cycle), due to no felling, cross-cutting or topping elements taking place, as well as a shorter debarking cycle. This low cycle time reflected a good BWBS (indicated below) and good form. To investigate the importance of this, a summary of the average BWBS and form factors has been provided in Section 4.1.2 and 4.1.3 to determine whether these aspects had any effect on the productivity levels achieved.

4.1.1 Effect of tree-size class on productivity

The productivity figures described for all processing machines included all data for a specific tree-size class, regardless of BWBS, form or quality produced. Productivity was expected to increase as tree-size class increased, as long as the tree size remained within the physical limits of the machine. A brief overview of the productivity results is given below, with a more detailed discussion in the sections covering the individual processing machines.

Figure 55 shows the different productivity levels of the different processing machines per tree-size class, as per the summary of statistical results.

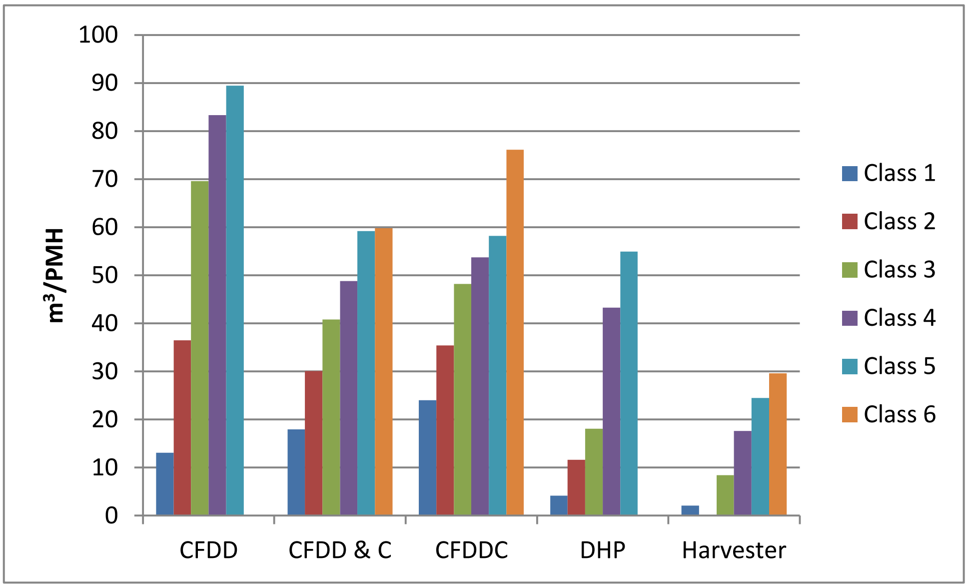


Figure 52: Processing technology productivity per tree-size class

Figure 55 shows that the CFDD had the highest overall productivity levels across all tree size classes, especially in the larger tree-size classes. It had the lowest productivity of all the multi-stem processors in tree-size class 1. The CFDD&C and CFDDC productivity was very similar across all tree-size classes. However, the CFDDC productivity was slightly higher in the smaller tree-size classes. Tree-size class 5 of the CFFDC was slightly lower than that of the CFDD&C, but then the CFDDC had a much higher productivity in tree-size class 6. The DHP had much higher productivity than the harvester for all tree-size classes: this is most noticeably with the large tree-size classes. These general trends are discussed in more detail in the sections that follow.

4.1.2 Effect of only BWBS class on productivity

From the analysis run in Microsoft Excel (2003), to determine whether any results could be obtained by examining the productivity achieved for each BWBS class (ignoring tree-size class), the results did not add any value to the research as tree-size class was the main factor affecting productivity. Each BWBS class was principally influenced by the dominant tree-size class in that BWBS class. Figure 56 provides the average BWBS class occurring for each processing technology. The CFDD generally had the highest BWBS class (3.8) to process and the DHP the lowest (2.6). The BWBS values were sufficiently close together to ignore their effect on productivity. However, if the DHP and harvester were to work in trees with very high BWBS classes, it was expected that the productivity levels would be closer together. This is discussed in greater detail later in this chapter. An opportunity exists for more detailed research on the effects of BWBS on productivity to be undertaken. Annexure B provides the results of some of the summarised statistics for BWBS.

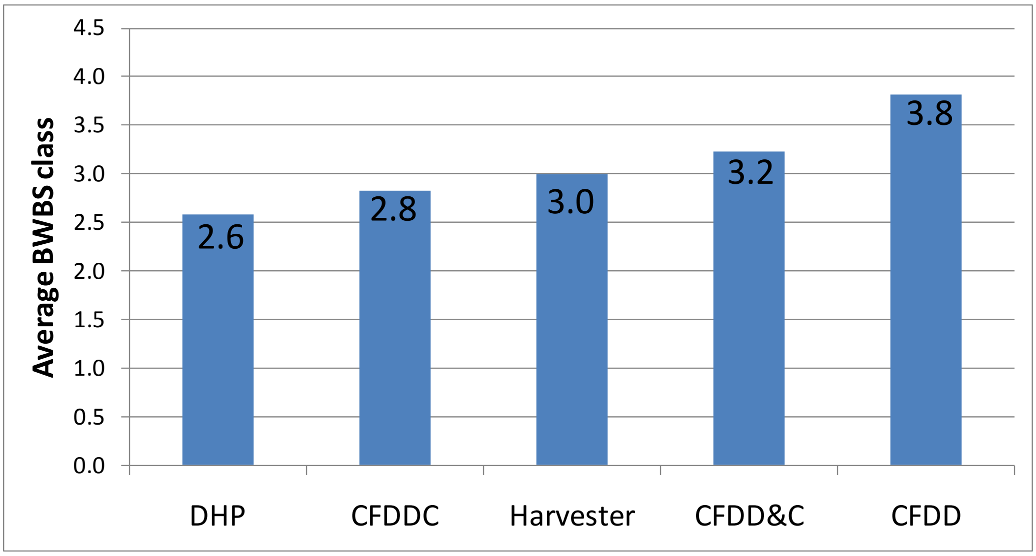


Figure 53: Average BWBS class for each processing technology

4.1.3 Effect of form class on productivity

Figure 57 gives the average form class for each processing technology. These form values were calculated by summing the form class values for each machine and dividing the result by the number of trees processed. Almost all data for the various processing technologies were found in form class 1. The harvester processed the trees with the lowest average form class (1.0) and the CFDDC the trees with the highest (1.3). The other processing technologies processed trees with an average form class of 1.1. This lack of variation made it impossible to monitor the effect of form class on productivity. For the effects of form on productivity to be known, further research would have to take place.

Annexure B provides the results of some of the summarised statistics for form class.

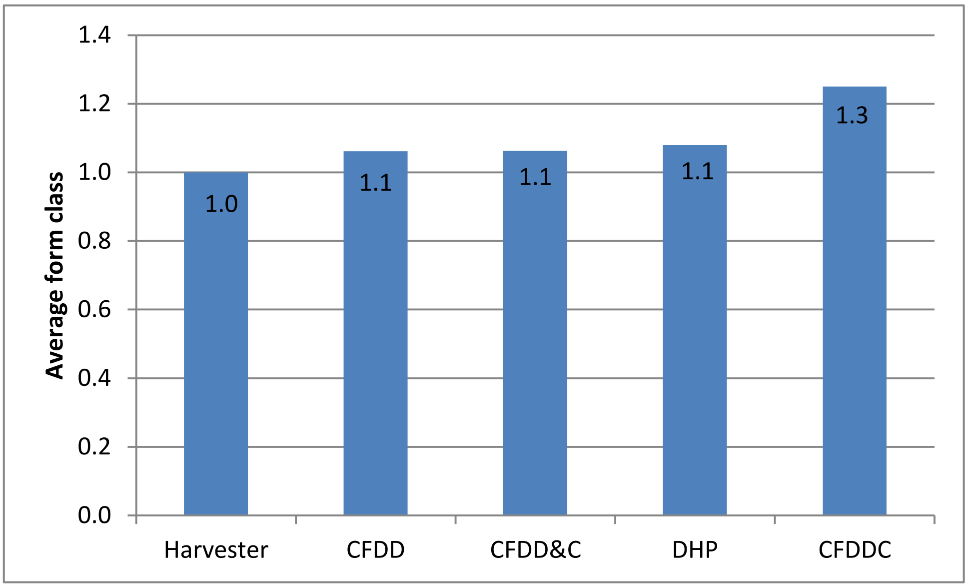


Figure 54: Average form class for each processing technology

4.1.4 Debarking quality

Poor debarking quality occurs due to the various processing machine's being unable to remove all bark from the tree. This could be due to a number of factors:

- the operator not processing the tree for long enough;
- too many trees being processed in multi-stem machines simultaneously;
- trees with differing BWBS being fed through the multi-stem machine simultaneously;
- small trees being propelled through the multi-stem machines together with larger trees. Under these circumstances, the feed rollers could not gain sufficient grip on and control over the small trees to ensure proper debarking.

Annexure B provides the results of some of the summarised statistics for the debarking-quality class.

4.1.5 Productivity-model results

The productivity models developed in STATISTICA were used to determine machine productivity. The productivity-model results for processing technology are discussed in the sections below.

4.1.5.1 Productivity-model result risks when considering bundle size

For each technology, a table was set up in Microsoft Excel (2003) that illustrated productivity for the different tree-size classes and bundle-size combinations (between 1 and 10 trees per bundle). Every combination of the above values was entered into the equation. Some coefficients were not relevant or proved insignificant and were excluded, for example:

- bundle size with the DHP and harvester;
- bundle size and tree-size interaction with the CFDDC model;
- an intercept for the harvester mode.

As per the data-analysis section, the model was accurately able to predict productivity within the range of tree-sizes encountered during the research. The productivity tables developed in the sections below, on the other hand, was able to predict productivity levels for all tree- and bundle-size combinations, whether they were practically possible or not. Therefore, the model was trying to make productivity predictions in some cases for tree- and bundle-size combinations that had not been encountered in the research and are not even possible. For example, it is not possible to put 10 trees, each measuring 0.55 m^3, through a machine at one time. It is also very unlikely that only one tree of 0.025 m^3 would be fed through the machine at a time. In situations such as these, it is quite likely that the model would produce unrealistic productivity results. Interpretation is therefore required to determine where the model is producing realistic values and where not.

To identify the unrealistic productivity outputs, it was necessary to overlay the occurrence of actual combinations of tree- and bundle sizes encountered in the research over the results offered by the productivity-model matrix. The sections on the individual processing technologies discussed below also provide an indication as to the extent to which each model is limited.

The average bundle size encountered during the research for each tree-size class had to be used in the productivity equations to make final predictions for productivity and tree-size. It was not possible to use a modelled bundle-size result as it was not possible to determine which bundle size was preferable. Figure 58 shows the average bundle sizes found in each tree-size class for each of the machines that processed bundles.

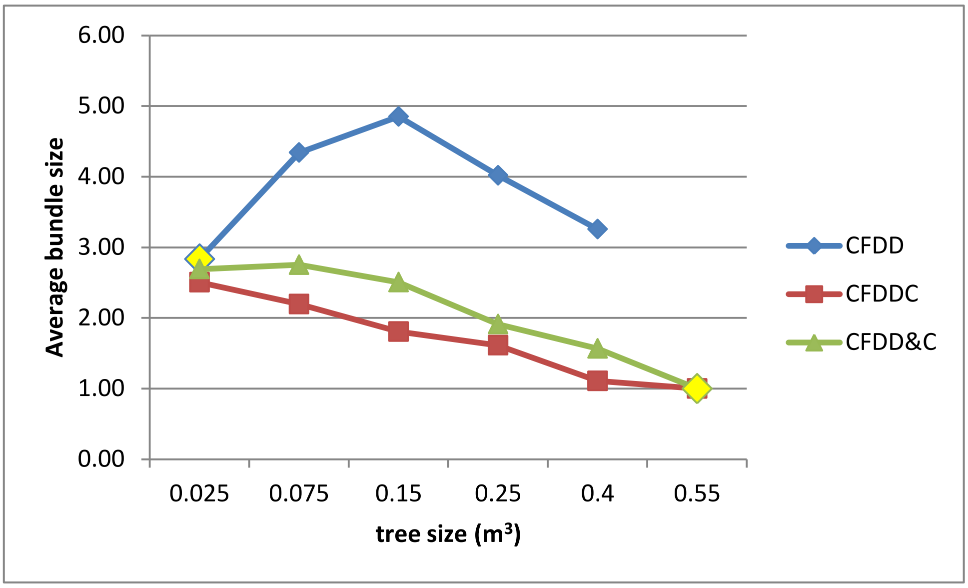


Figure 55: Average bundle size per tree-size class value per processing technology

In Figure 58, small sample sizes are identified by the yellow (n = 10 to 19) and red (n < 10) tabs. Bundle sizes processed by the CFDD were larger than those of the CFDDC and CFDD&C. With regard to the CFDD, bundle sizes for the 0.025 m^3 tree-sizes are small, but increase in size up to the 0.15 m^3 trees. This was not expected and is due to a small sample size in this tree-size class. Even though the 0.075 m^3 tree size of the CFDD is not highlighted as having a small sample size, only 44 bundles were processed as opposed to tree-size classes 3 to 5, which all have sample sizes greater than 119. It is unlikely in that 0.075 m^3 trees would have fewer trees per bundle than the 0.15 m^3 trees. In general, the CFDD&C had marginally (between 0 and 0.8 more trees per bundle) larger bundle sizes than the CFDDC. The CFDD&C had a small sample size in the 0.55 m^3 class (class 6). However, the trend of the data does not seem to indicate this as being problematic. The process that was followed for each processing technology is discussed in the sections outlining individual results.

The results of the summarised statistics that show the productivity results for the processing technologies are discussed below. In all of the figures in the sections below, a red data point indicates that the sample size was less than 10 and the yellow data point shows that the sample size was between 10 and 19. An enlarged data point indicates that more than 50 per cent of that tree-size and BWBS-class combination had quality classes of 2 and 3. It is important to remember that quality-class 2 still falls within mill specifications (half to one per cent), but class 3 does not meet the specifications (more than one per cent). Thereafter, the detailed statistical results are presented.

4.1.5.2 Chain-flail debrancher debarker (CFDD): productivity results

The productivity results of the CFDD are discussed below.

4.1.5.2.1 CFDD productivity per tree-size class

Table 45 provides the summary of statistical results for the CFDD. The productivity figure offers all data for a specific tree-size class, regardless of BWBS, form or debarking quality produced.

Table 43: Summary of statistical results: CFDD

Tree-size class	Mean	Std dev	n	n % of sample	Variance
1	13.07	9.90	12	1.37	98.02
2	36.49	13.68	44	5.03	187.12
3	69.57	28.37	411	46.97	805.06
4	83.33	27.66	289	33.03	765.20
5	89.46	26.96	119	13.60	727.10
6				0	

Tree-size class 1 of the CFDD had a small sample size of 12. Most of the trees of the CFDD were found in tree-size class 3 (47 per cent), followed by class 4 (33 per cent). The standard deviation for the CFDD varies from 9.9 to 28. The lower standard deviations occurred in the smaller tree-size classes and the higher standard deviations in the larger tree classes. The productivity results are explained further with Figure 59, which shows the productivity of the CFDD when considering tree-size class only.

Figure 56: CFDD productivity per tree-size class

As indicated in the research design and methodology section, no tree-size class 6 trees were found in the research. As with the tree-size and BWBS combinations above, this is based upon examination of the Microsoft Excel (2003) worksheet data and no modelling has taken place. Tree-size class 1, indicated in yellow, has a sample size of less than 20 and should be interpreted with caution. It is, however, following the productivity trend demonstrated by the remainder of the graph. There is a rapid increase in productivity over the first three tree-size classes, then productivity increase starts to taper off from class 4. There is a very large difference in productivity from tree-size class 1 (13 m^3 per PMH) to tree-size class 5 (89 m^3 per PMH).

The CFDD struggled with large trees. Often the operator would feed the bundle into the machine and then have his attention diverted elsewhere (for example, to the residue pile). He would not notice that the infeed rollers were not able to pull the trees in. Only once this was noticed would the operator then pull the tree into the machine, using the crane. It is expected that relatively minor design changes would be able to rectify these large-tree infeed problems with the CFDD. These machines are relatively new in *Eucalyptus* and it does not appear that the problem of a slippery bole (for example, when the infeed rollers have removed some of the bark), has yet been mastered.

Additional points that could affect the productivity results of the CFDD are outlined below.

- For bigger trees to be pulled into the CFDD easily, the trees needed to be at the same level as the infeed rollers. At the same time, the tree had to be lifted by the crane so that the larger butt-end half of the tree was parallel to the ground. The straighter the path of the trees through the machine, the easier the infeed. If the trees entered at an angle off the horizontal, the infeed rollers struggled to pull the bigger trees in.

- If the trees were not spread out during the infeed, debarking quality reduced, with the smaller trees being poorly debarked.
- If too many trees were fed through the CFDD at once, some of the bark tended to be ejected at the out-feed.

4.1.5.2.2 Modelled productivity results: CFDD

Table 46 provides the modelled productivity for different tree- and bundle-size combinations.

Table 44: CFDD modelled productivity data for tree- and bundle-size combinations

Trees per bundle	Tree-size in m^3					
	0.025	0.075	0.15	0.25	0.4	0.55
1	-10.8	2.8	19.7	35.6	45.0	37.2
2	0.9	16.1	35.3	54.3	68.3	65.2
3	10.8	27.5	49.1	71.1	89.9	91.4
4	18.8	37.1	61.0	86.2	109.6	115.8
5	25.1	44.9	71.2	99.4	127.5	138.3
6	29.5	50.9	79.5	110.9	143.6	159.1
7	32.1	55.1	86.0	120.5	157.8	178.0
8	32.9	57.4	90.6	128.2	170.3	195.1
9	31.9	57.9	93.5	134.2	180.9	210.4
10	29.0	56.6	94.5	138.3	189.7	223.9

In Table 46, the tree sizes indicate the tree-size classes used in the data collection and all tree-size combinations were modelled, regardless of whether or not they were practically possible. The table clearly shows that some of the productivity figures cannot be achieved in reality. For example, tree-size 0.025 m^3 and bundle-size 1 have a negative productivity figure of -10.8 m^3 per PMH and tree-size 0.55 m3 and bundle-size 10 have an impossibly high figure of 223.9 m^3 per PMH.

To identify where the model has predicted productivity correctly, all tree- and bundle-size combinations that occurred during the research have been highlighted in green in Table 46. This helps to explain the unrealistic data for the large tree- and bundle-size combinations, but does not explain the small tree- and bundle-size combinations. To understand the data better, the productivity result for the average bundle size encountered within each tree-size class has been reflected in red print.

In Table 46, the bundle size for each tree class has been rounded up or down to the nearest class. For example, the actual bundle size for tree-size class 1 (0.075 m^3 tree) was 2.83 trees, but this has been rounded up to 3 trees per bundle. The result of this process gives an indication of the productivity for each average bundle size per tree-size class actually encountered in the research. The productivity result for tree-size 0.025 m^3 trees is low. The reason for this is the very small sample size in this tree-size class (n = 12). The table also seems to indicate that there would be a reduction in productivity with large trees of 0.55 m^3. However, there is no actual data to verify this premise.

Figure 60 was then produced from the productivity model, which used the exact average bundle size (not rounded off) for each tree-size class.

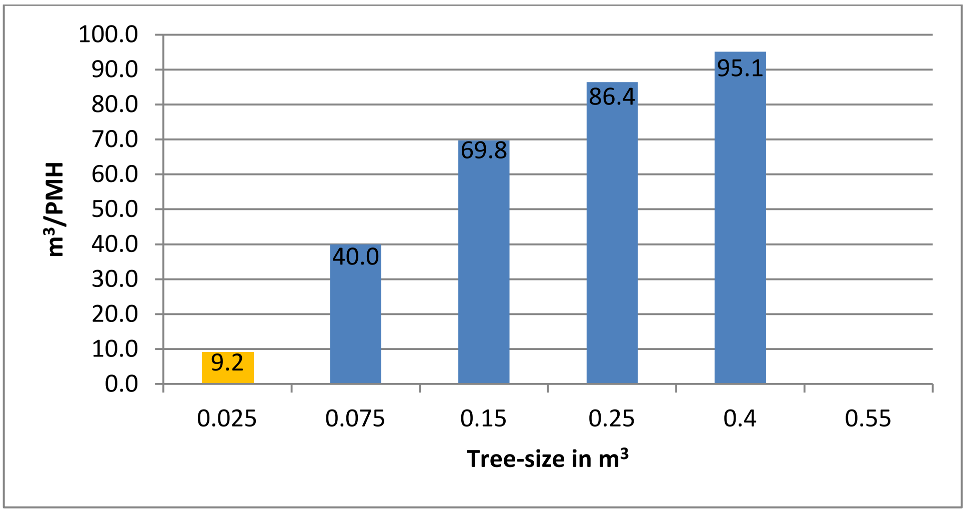


Figure 57: CFDD modelled productivity using actual bundle sizes per class

Figure 60 shows that no 0.55 m^3 trees were encountered during the research. The CFDD was capable of very high productivity levels, although the productivity began to taper off at a tree size of 0.25 m^3. This suggests that approximately 0.4 m^3 was the maximum tree size that the machine could process comfortably. Because of the small sample size for trees of 0.025 m^3, and the lack of data for trees of 0.55 m^3, only the four intermediate tree sizes were used in the system-costing section. The model worked well in these four tree sizes.

4.1.5.3 Chain-flail debrancher debarker chipper (CFDDC): productivity results

The productivity results of the CFDDC are discussed below.

4.1.5.3.1 CFDDC productivity per tree-size class

Table 47 provides the summary of statistical results. The productivity figure shows all data for a specific tree-size class, regardless of BWBS, form or debarking quality produced.

Table 45: Summary of statistical results: CFDDC

Tree-size class	Mean	Std dev	n	n % of sample	Variance
1	23.99	15.57	106	5.94	242.57
2	35.42	16.39	296	16.57	268.60
3	48.19	20.21	495	27.72	408.50
4	53.70	26.46	220	12.32	700.00
5	58.21	21.49	397	22.23	461.90
6	76.12	33.44	272	15.23	1118.10

Table 47 shows that the largest tree-size class was class 3 (28 per cent), but this was closely followed by tree-size class 5 (22 per cent). Increasing variation occurred as the tree-size class became larger (243 in class 1 to 700 in class 4). The standard deviation for the CFDDC varied from 16 to 33. As indicated, the lower standard deviations occurred in the smaller tree-size classes and the higher standard deviations in the larger tree-size classes due to their increased variability in cycle times.

Figure 61 shows CFDDC productivity per tree-size class.

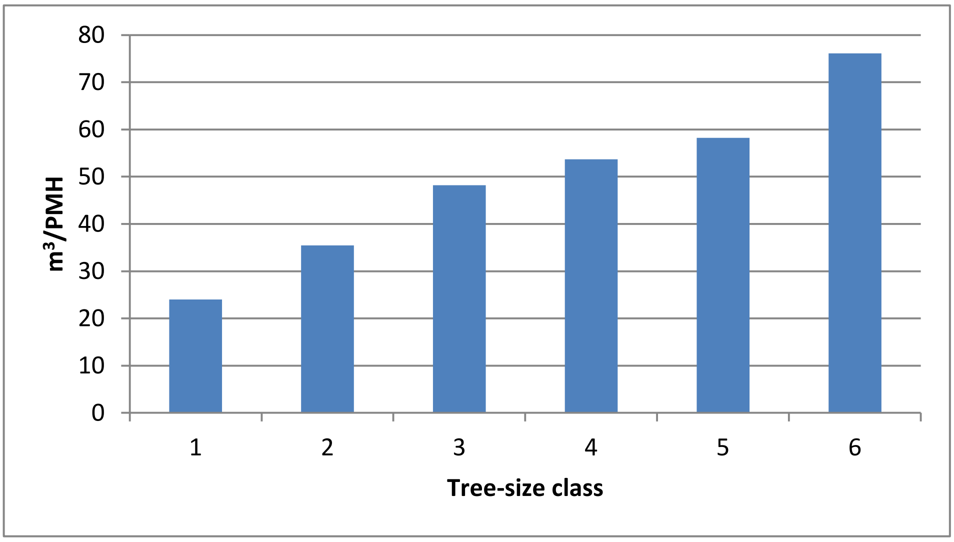


Figure 58: CFDDC productivity per tree-size class

Figure 61 shows that the CFDDC had large sample sizes for each tree-size class. It evidenced relatively high productivity even in tree-size class 1 (24 m^3 per PMH), with a steady productivity increase to tree class 5 (58 m^3 per PMH). Tree-size class 6 for the CFDDC did not seem to follow the trend of productivity increase with tree-size class increase. There appears to be a spike in productivity with these very large trees. It could be that the CFDDC used in the research was able to handle large trees very well: indeed, the researcher observed that the CFDDC was able to feed large trees in easily, while the CFDD and CFDD&C were not able to pull such trees in effectively. The operators of the CFDDCs had also been working on these machines for some time and that, combined with a longer development period in *Eucalyptus,* could have resulted in the higher productivity in both the small and large tree-size classes.

Additional points that could affect the productivity results of the CFDDC are outlined below.

- As with the CFDD, the straighter the path of the trees through the machine, the easier the infeed.
- If too many trees were fed through the CFDDC at a time, the trees could potentially not debark properly and the chips could have high bark content.
- Even though the Australian operators saw merit in leaving the bigger branches and tops infield (to improve the productivity of the skidder and CFDDC, and to reduce the amount of slash being handled at the landing), the lack of chainsaw operators prevented this from happening.

4.1.5.3.2 Modelled productivity results: CFDDC

Table 48 provides the modelled productivity for different tree- and bundle-size combinations.

Table 46: CFDDC modelled productivity data for tree- and bundle-size combinations

Trees per bundle	Tree-size in m^3					
	0.025	0.075	0.15	0.25	0.4	0.55
1	9.4	19.5	33.2	48.5	65.3	74.7
2	26.5	36.6	50.2	65.5	82.3	91.7
3	36.7	46.8	60.4	75.7	92.5	101.9
4	40.2	50.3	63.9	79.2	96.0	105.4
5	36.9	47.0	60.6	75.9	92.7	102.1
6	26.8	36.9	50.5	65.8	82.6	92.0
7	9.9	20.1	33.7	49.0	65.8	75.2
8	-13.7	-3.6	10.0	25.3	42.1	51.5
9	-44.1	-34.0	-20.4	-5.1	11.7	21.1
10	-81.3	-71.2	-57.5	-42.3	-25.5	-16.1

Table 48 shows the same procedure has been followed as with the CFDD. The table shows that the model was not able to predict the productivity accurately when very large bundle sizes were involved, even with small tree sizes. This makes sense, as very few large bundle sizes were encountered during the research, as may be seen from the data highlighted by the green shading.

The results in red print in Table 48 for tree-sizes 0.025 m^3 and 0.075 m^3 per tree showed very similar productivities. This is due to the rounding of the bundles sizes and would not occur when using actual bundle sizes for each tree size.

Figure 62 was then produced from the productivity model, using the exact average bundle size (not rounded off) for each tree-size class.

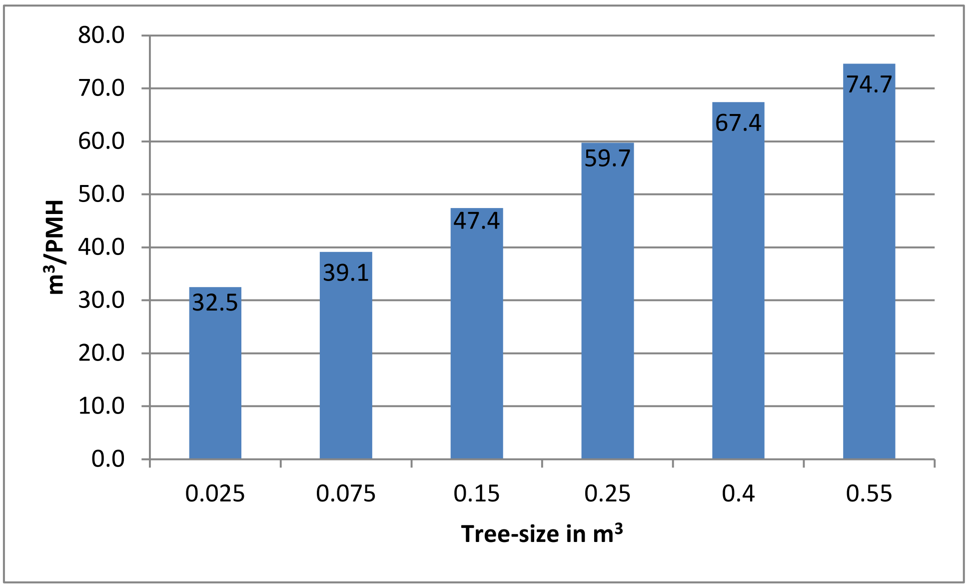


Figure 59: CFDDC modelled productivity using actual bundle sizes per class

The difference in the productivity of tree-sizes 0.025 and 0.075 m^3 are now evident, where Table 48 did not show this difference. The CFDDC showed a steady increase in productivity from small to large tree sizes (32.5 to 74.7 m^3/PMH). This indicates that the CFDDC could process very small trees productively and that the maximum machine capacity for processing larger trees had not yet been met. It would be possible to carry out system costings on all of the tree-size categories, as the model predictions are all good.

4.1.5.4 Chain-flail debrancher debarker and chipper (CFDD&C): productivity results

The productivity results of the CFDD&C are discussed below.

4.1.5.4.1 CFDD&C productivity per tree-size class

Table 49 provides a summary of statistical results for the CFDD&C. The productivity figure outlines all data for a specific tree-size class, regardless of BWBS, form or debarking quality produced.

Table 47: Summary of statistical results: CFDD&C

Tree-size class	Mean	Std dev	n	n % of sample	Variance
1	17.97	10.48	53	3.29	109.83
2	30.07	14.04	302	18.77	197.10
3	40.80	16.21	877	54.51	262.80
4	48.79	20.95	258	16.03	438.90
5	59.21	25.34	106	6.59	642.00
6	59.80	23.61	13	0.81	557.30

Table 49 shows that tree-size class 6 of the CFDD&C had a small sample size of 13. The largest class was class 3 at 55 per cent of the sample. The remaining classes were lower. The standard deviation for the CFDD&C ranged from 10.5 to 25. The lower standard deviations occurred in the smaller tree-size classes and the higher standard deviations in the larger tree-size classes. Figure 63 shows CFDD&C productivity per tree-size class.

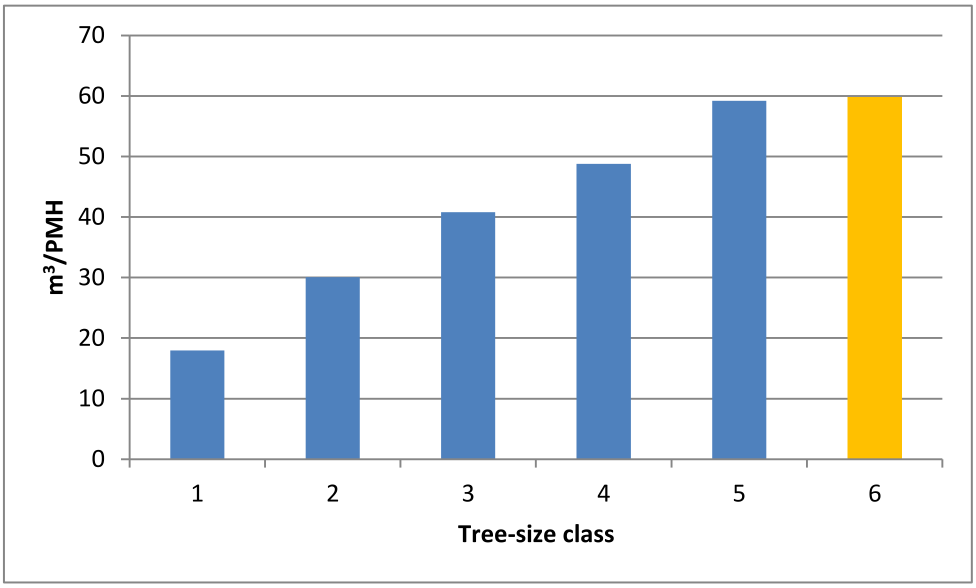


Figure 60: CFDD&C productivity per tree-size class

The productivity of the CFDD&C increased steadily from tree-size class 1 (18 m^3 per PMH) to tree-size class 5 (59.8 m^3 per PMH). The productivity for class 6 (60 m^3 per PMH) is almost the same as for class 5. This was not expected and is due to the small sample size of fewer than 20 trees (as indicated by the yellow bar in Figure 63). The CFDD&C was not tested at the upper extremes of the tree sizes, but there were large sample sizes for tree-size class 5 and below.

As with the CFDD, the CFDD&C struggled to feed large trees into the machine. The operator would feed the bundle into the machine and then divert his attention elsewhere (for example, to the residue pile or chip truck) and not notice that the infeed rollers were not able to pull the trees in. Only once this was noticed would the operator pull the tree into the machine, using the crane. It is expected that, like the CFDD, relatively minor design changes could rectify these large-tree infeed problems with the CFDD&C system. These machines were also relatively new in *Eucalyptus* at the time of the research and it appears that they had not quite mastered the problem of a slippery bole when the infeed rollers had removed some of the bark.

Additional points that could affect the productivity results of the CFDD&Care outlined below.

- The four flails of the CFDD may not have been necessary as the bark was detaching fairly easily. However, should BWBS become very poor, the four flails may become especially important to maintain high productivity.
- Occasionally, trees wedged themselves against the entrance of the chipper and the chipper crane dislodged them and fed them in.
- Unless there was a tree wedged or slash had to be moved away from the outfeed of the CFDD or the waste chute of the chipper, the chipper operator was largely idle.

4.1.5.4.2 Modelled productivity results: CFDD&C

Table 50 provides the modelled productivity for different tree- and bundle-size combinations.

Table 48: CFDD&C modelled productivity data for tree and bundle size combinations

Trees per bundle	Tree-size in m^3 0.025	0.075	0.15	0.25	0.4	0.55
1	0.2	10.4	23.5	36.7	47.8	48.3
2	10.6	22.5	38.1	54.7	70.8	76.3
3	17.7	31.3	49.4	69.4	90.5	101.1
4	21.6	36.8	57.4	80.7	106.9	122.5
5	22.1	39.0	62.1	88.8	120.0	140.6
6	19.4	37.9	63.5	93.6	129.8	155.4
7	13.3	33.5	61.7	95.1	136.3	167.0
8	4.0	25.9	56.5	93.3	139.6	175.3
9	-8.6	14.9	48.1	88.2	139.5	180.2
10	-24.6	0.7	36.4	79.8	136.2	181.9

With Table 50. the same procedure was followed as with the CFDD. The model was not able to predict the productivity when very large bundle sizes were involved – even when the bundles were made up of small trees – as these had not been encountered in the research. When investigating the figures in red print, it becomes evident that the productivity of tree-size 0.55 m^3 (class 6) was very low (48.3 m^3 per PMH). This is due to a very small sample size (n = 13).

Figure 64 was then produced from the productivity model, which used the exact average bundle size (not rounded off) for each tree-size class.

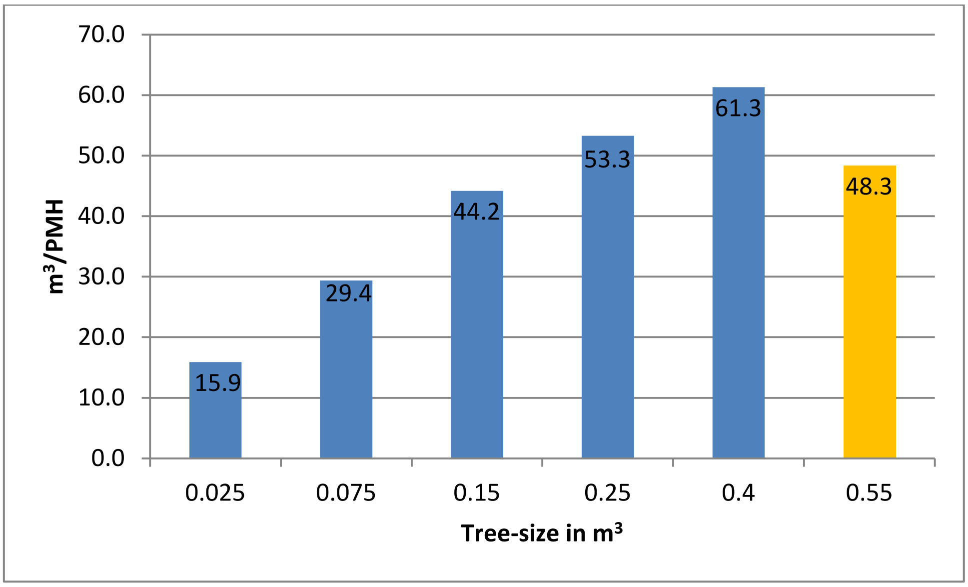


Figure 61: CFDD&C modelled productivity using actual bundle sizes per class

In Figure 64, the CFDD&C showed a steady increase in productivity from the smaller to the larger tree sizes. The productivity for tree-size 0.025 m^3 was low at 15.9 m^3 per PMH. The productivity steadily increased from tree-size 0.025 m^3 to 0.4 m^3 (61.3 m^3 per PMH). It does appear that the maximum machine capacity for processing larger trees had not yet been met, but the lack of data for 0.55 m^3 trees makes this difficult to confirm. Apart from 0.55 m^3 trees, it would be possible to carry out system costings on all other tree sizes.

4.1.5.5 Dangle-head processor (DHP): productivity results

Because the DHP was a single-tree processing technology, bundle size was not applicable.

4.1.5.5.1 DHP productivity per tree-size class

Table 51 provides the summary of statistical results. The productivity figure covers all data for a specific tree-size class, regardless of BWBS, form or debarking quality produced.

Table 49: Summary of statistical results: DHP

Tree-size class	Mean	Std dev	n	n % of sample	Variance
1	4.13667	1.053691779	6	1.109057	1.110266
2	11.62016	2.79422673	46	8.502773	7.8
3	18.10968	4.168914468	159	29.39002	17.4
4	43.26392	10.38421083	285	52.68022	107.8
5	54.89744	8.630957948	45	8.31793	74.5
6				0	

In Table 51, tree-size class 1 for the DHP had a small sample size of six trees. The DHP mostly processed trees in tree-size class 4 (53 per cent), with class 3 next at 29 per cent. The standard deviation for the DHP varied from 1 to 10. The lower standard deviations occurred in the smaller tree-size classes and the higher standard deviations in the larger tree-size classes.

Figure 65 shows the productivity per tree size of the DHP.

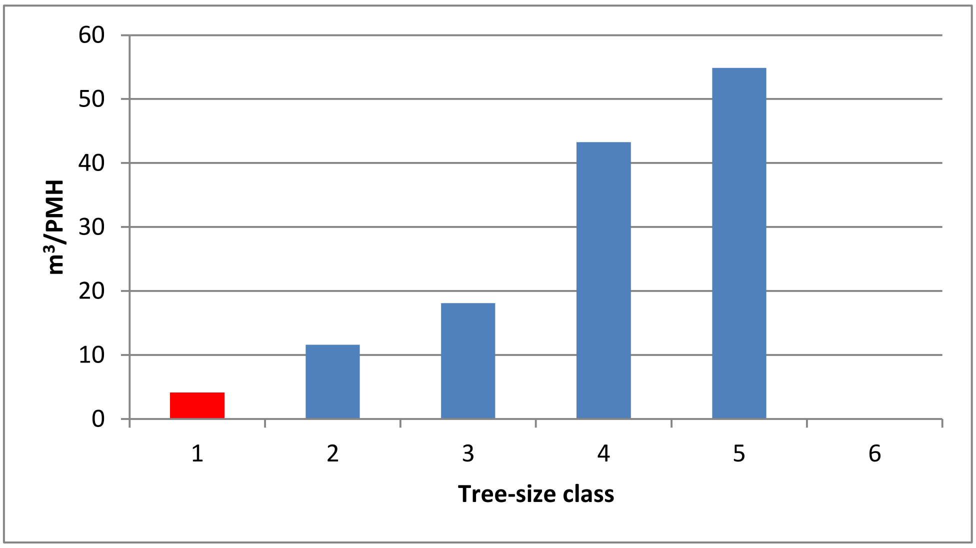


Figure 62: DHP productivity per tree-size class

Figure 65 shows that productivity remained relatively low for tree-size classes 1 to 3 (4 to 18 m^3 per PMH). Productivity then increased rapidly for classes 4 and 5 (43 and 55 m^3 per PMH). There were no class 6 trees found in the research. It is more than likely this exponential increase in productivity is due to the DHP being a single-tree processing technology, dominated by the debarking element in the work cycle. Because the debarking element consumed such a large proportion of the work cycle, increases in tree size caused large increases in productivity.

Tree-size class 1 was very small (fewer than 10 trees), but still seemed to follow the trend of the graph in Figure 65. It appears that the productivity at class 6 was starting to taper off, but only the presence of class 6 trees would have been able to confirm this. The DHP did not work in any BWBS class 5 trees, and in very few BWBS class 4 trees. It is highly likely that the productivity curve would have been significantly lower had the DHP worked predominantly in BWBS classes 4 and 5.

Additional points that could affect the productivity results of the DHPare outlined below.

- Only one grapple skidder was required because it was able to place more inventory in front of the DHPs than the CFDDs or CFDDCs. The DHPs took some time to work through the stockpile, as they only processed one tree at a time. Had the DHP run out of timber, it could easily have moved along the processing area to where other trees had been placed by the grapple skidder.

- Should the grapple skidder have had an extended breakdown, the DHPs were fully functional as harvesters. They could then have started felling and processing trees along the edge of the compartment.
- Even though sufficient labour was available to top trees and remove large branches, it was not used. This is mainly due to the shorter period between tree felling and debarking. The feller buncher did not work with large buffer stocks between it and the DHP. Had it done so, the BWBS would have become strong and the productivity of the DHPs would have dropped.

4.1.5.5.2 Modelled productivity results: DHP

Because the DHP only processed single trees at a time, bundle sizes were not investigated. Figure 66 shows the results of the modelled productivity.

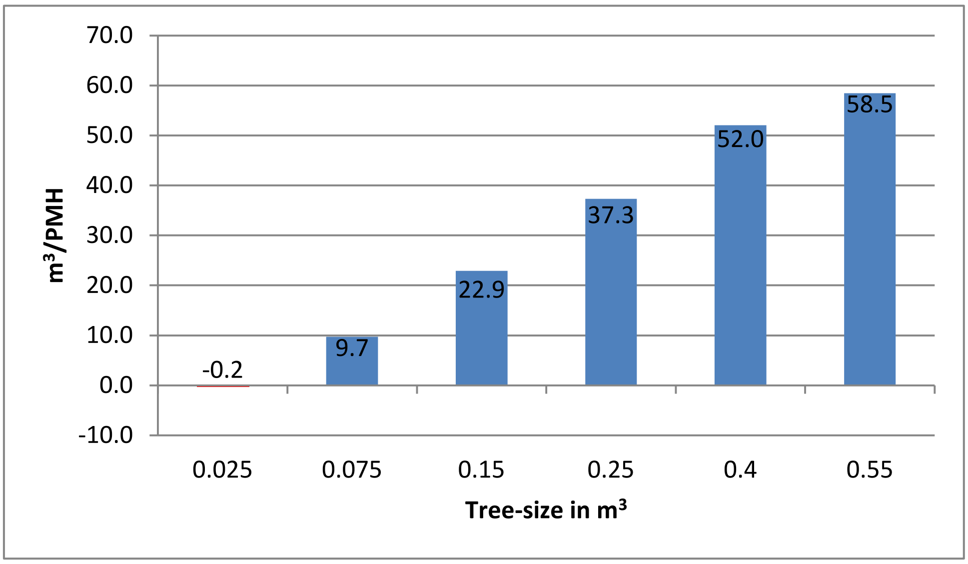


Figure 63: DHP modelled productivity per tree size

Figure 66 shows that the negative productivity value of -0.2 m^3 per PMH for tree-size 0.025 m^3 is due to the very small sample size (n = 6). The productivity predictions for the remainder of the tree sizes are good. There were large productivity increases from tree-size 0.075 m^3 (9.7 m^3 per PMH) to 0.4 m^3 (52.0 m^3 per PMH). Productivity appeared to be tapering off at tree-size 0.55 m^3, which could indicate that the physical limitations of the machines were being reached. Only tree-size 0.025 m^3 would have to be excluded from the system's costings.

4.1.5.6 Harvester (CTL): productivity results

The productivity results of the Harvester are discussed below.

4.1.5.6.1 Harvester productivity per tree-size class

Table 52 provides the summary of statistical results. The productivity figure contains all data for a specific tree-size class, regardless of BWBS, form or debarking quality produced.

Table 50: Summary of statistical results: harvester

Tree-size class	Mean	Std dev	n	n % of sample	Variance
1	2.11853	0.362244	21	4.666667	0.131221
2				0	
3	8.395013	1.49414	112	24.88889	2.2
4	17.61269	2.134215	201	44.66667	4.6
5	24.48229	3.067869	112	24.88889	9.4
6	29.62448	5.374509	4	0.888889	28.9

Table 52 shows that tree-size class 6 for the harvester had a small sample size of four trees. The harvester had tree-size class 4 as the dominant class (45 per cent), followed by both classes 3 and 5 (at 25 per cent) (again note that class 3 consisted of both tree-size classes 2 and 3). The standard deviation for the harvester varied from 0.4 to 5. The lower standard deviations occurred in the smaller tree-size classes and the higher standard deviations in the larger tree-size classes.

An additional point that could have affected the productivity results of the harvester was that the harvester operator’s view was more restricted with the construction-type excavators than it would have been with purpose-built forestry excavators.

4.1.5.6.2 Modelled productivity results: harvester

As per the DHP, the harvester only processed single trees at a time, and therefore bundle sizes were not investigated. Figure 67 shows the results of the modelled productivity.

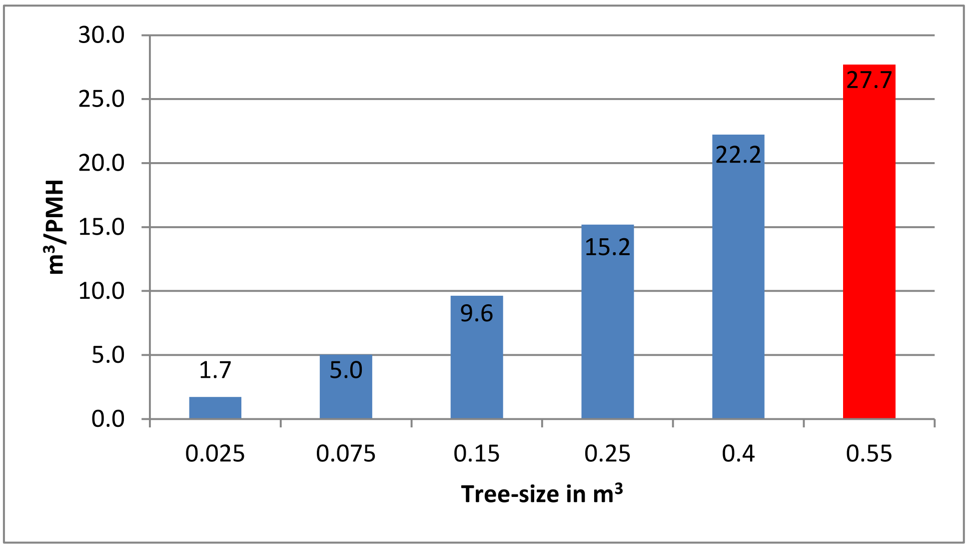


Figure 64: Harvester modelled productivity per tree size

Tree-size 0.025 m^3 is not highlighted in Figure 67 as having a small sample size, but it's sample size was relatively small (n = 21), which could possibly be influencing the model at the very small tree sizes. However, as indicated in the literature review, harvesters do have very low productivity when processing very small trees. Tree-size 0.55 m^3 also had a very small sample size (n = 4), although the productivity graph does appear to be following the correct trend. However, when investigating the performance of the harvester at this tree size, there was a tapering off of productivity. Therefore, the modelled productivity figure for tree-size 0.55 m^3 should be used with care. Tree-size 0.025 m^3 and 0.55 m^3 should not be used in the system costings.

4.1.5.7 Productivity summary of results of processing equipment

The standard deviation was always lower in the smaller tree-size categories and increased with tree size. The high standard deviations found for the processing equipment are typical for research carried out on this type of forestry equipment because of high variability within the cycle time and bundle size (Spinelli, et al., 2002a).

The single-tree processing technologies of the DHP and harvester had the lowest standard deviations. As tree size increased and many trees were processed at once, so the standard deviation increased. This is to be expected as the harvester and DHP have certain cycle elements that are fixed, regardless of tree size. However, as tree size increased with these two machines, the debarking/debranching element consumed a progressively larger percentage of the total cycle time, thus increasing the variation in cycle time and therefore increasing the standard deviation.

With the CFDD, CFDDC and CFDD&C, the standard deviations were higher as there was only one dominant work element (debarking/debranching). This is a naturally variable element because of the complexity of removing the bark and the speed of the trees through the machine. Smaller trees being fed through showed less variation as there tended to be a more consistent feed of trees into the machine. As tree size increased, feeding of new trees into the machine while the previously introduced trees were still being processed could occur at any time, making the cycle length variable. Also, because few big trees were fed through per cycle, the effect of new trees being fed while the other tree/s was/were still being processed was compounded. Further research will be required into the influence of the individual cycle elements to determine whether it is necessary to try to reduce this variation. Figure 68 shows the productivity results in m^3 per PMH for all of the processing technologies.

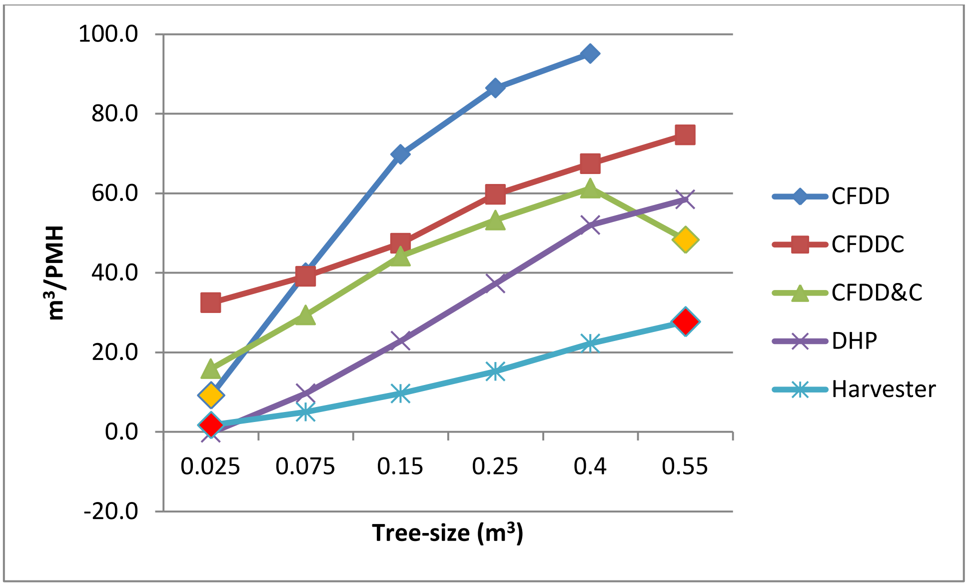
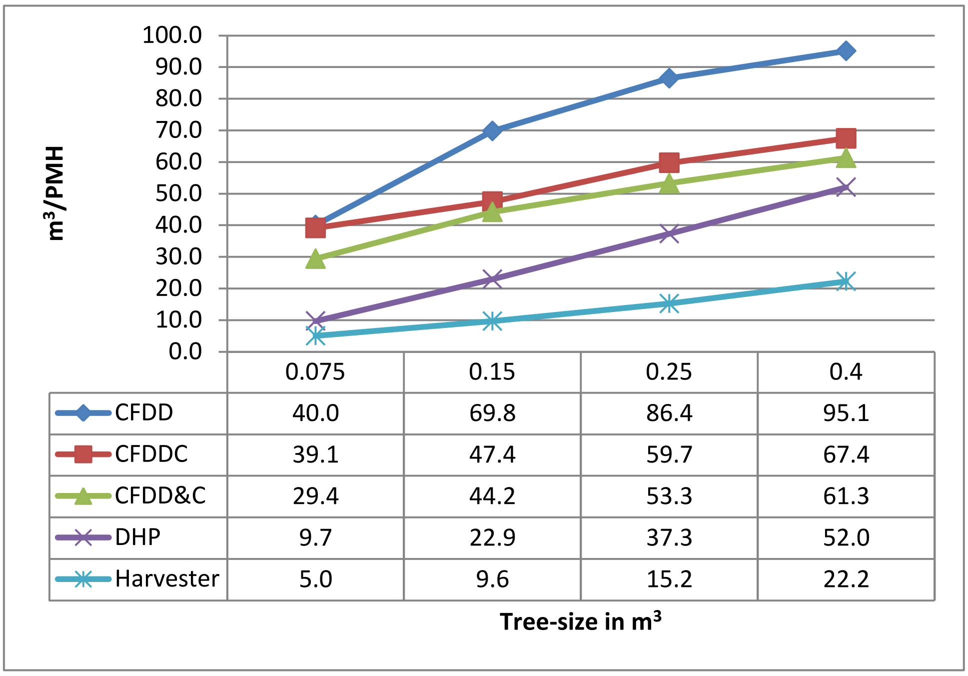


Figure 65: Processor modelled productivity based on tree size

In Figure 68, the enlarged yellow and red tab points signify small sample sizes of less than 10 and 20 respectively. As indicated in the sections above, the 0.025 m^3 and 0.55 m^3 of the CFDD; the 0.55 m^3 of the CFDD&C; the 0.025 m^3 of the DHP; and the 0.025 m^3 and 0.55 m^3 of the harvester would not be used in the costing because small sample sizes resulted in incorrect productivity results. Owing to so many of the very small (0.025 m^3) and very large (0.55m^3) tree sizes not being suitable, it was decided to carry out all further evaluations on tree sizes 0.075 m^3, 0.15 m^3, 0.25 m^3 and 0.4 m^3. This was not deemed problematic, as it is unlikely for *Eucalyptus* pulpwood operations to function in such small or large trees.

Figure 69 on the following page shows the same modelled processor productivity as Figure 68, but excludes the smallest and largest tree sizes. This was the information that would be used in the Excel based machine and systems costings.



	0.075	0.15	0.25	0.4
CFDD	40.0	69.8	86.4	95.1
CFDDC	39.1	47.4	59.7	67.4
CFDD&C	29.4	44.2	53.3	61.3
DHP	9.7	22.9	37.3	52.0
Harvester	5.0	9.6	15.2	22.2

Figure 66: Modelled processor productivity excluding large and small tree sizes

Considering Figure 69, additional points that could affect the productivity results are outlined below.

- Excluding the 0.075 m^3 tree size (very similar to the CFDDC at approximately 40 m^3 per PMH), CFDD had the highest overall productivity, increasing more quickly than for any of the other processing equipment, but flattening off at 0.4 m3 per PMH.

- The CFDDC productivity remained slightly higher than the CFDD&C throughout the range of tree sizes.

- The DHP productivity started low (9.7 m^3 pr PMH), but followed a steep gradient to 52.0 m^3 per PMH in 0.4 m^3 trees. It is interesting that the DHP productivity for 0.4 m^3 trees differed from the CFDD&C and CFDDC by only 10 m^3 per PMH and 15 m^3 per PMH respectively. It is predicted that the gap would become much wider with a very high BWBS class. This requires further research.

- In relation to the other processing equipment, the harvester productivity for the 0.075 m^3 tree size was very low (5.0 m^3 per PMH) and had the flattest of all the productivity gradients, only reaching 22.2 m^3 per PMH in 0.4 m^3 trees.

To conclude the section on productivity results, even though the productivity models were able to include bundle size as an input variable, the average bundle size per tree-size class encountered during the research had to be used. The predictions based on tree size were very good where the sample size was large enough. Owing to small sample sizes in the research data, tree-size classes 1 and 6 were not used for cost calculations.

4.2 Cost of systems: results and discussion

The cost results presented in Section 4.2 are all based on balanced systems for each processing technology for each tree size evaluated. The cost results of the individual machines and the systems in which they operated are presented first, followed by cost comparisons. Even though the costs per PMH are indicated, this financial figure only becomes valuable when combined with the productivity achieved and is usually the most important result for forest managers. The systems selected were the same as those used in the trials, but these are highlighted again when the results of each processing technology are discussed below. The productivity information obtained in the research for the processing equipment was used in the system costings. Forestry Solutions work-study data (Forestry Solutions, 2010) were used for the remainder of the machines in the system.

An important consideration when comparing the costs is that comparisons are being made between two different products – logs and chips. This will be discussed further under the summary discussion of the results.

4.2.1 CFDD system cost results

The system cost results for the CFDD are described below.

4.2.1.1 CFDD system cost results: productivity figures used

The productivity figures obtained from Section 4.1 and used in the system costing per machine and per tree size can be found in Table 53.

Table 51: Productive rates of the CFDD system equipment per tree-size class

Machine or activity	0.075m^3/tree (m3/PMH)	0.15m^3/tree (m3/PMH)	0.25m^3/tree (m3/PMH)	0.40m^3/tree (m3/PMH)
Feller buncher	34.2	56.3	76.1	98.1
Grapple skidder	31.6	46.8	55.6	69.2
CFDD	40	69.8	86.4	95.1
Logger	24	36	50	64.8
Slash	48	75	93.8	120

4.2.1.2 CFDD system cost results: balancing

Figure 70 shows the number of machines required to balance the system, as well as the annual volume required, for each tree size. Two feller bunchers were required for all tree sizes except 0.40 m^3, which required two. Two grapple skidders, one CFDD, two loggers and one slasher were required for all the tree sizes. Annual system production increased from 130,000 m^3 to 300,000 m^3 as tree size increased. This is due to all the machines in the system becoming more productive in larger trees.

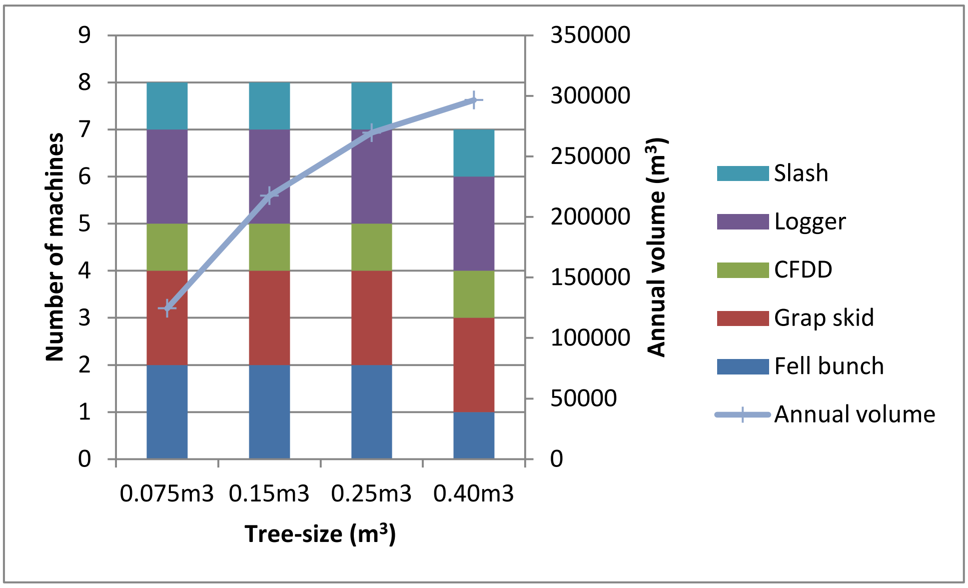


Figure 67: CFDD machine and volume requirements per system and tree size

The system balancing in Figure 70 took place around the CFDD as it was the most productive machine. Only one CFDD was required for each tree size. Theoretically, slightly more than one feller buncher was required for felling with the first three tree sizes, which, practically, meant two were used. The lowest cost was obtained by fully utilising the CFDD, which still made it cost-effective to include two feller bunchers. This is clearly shown in Figure 71, which shows machine utilisation.

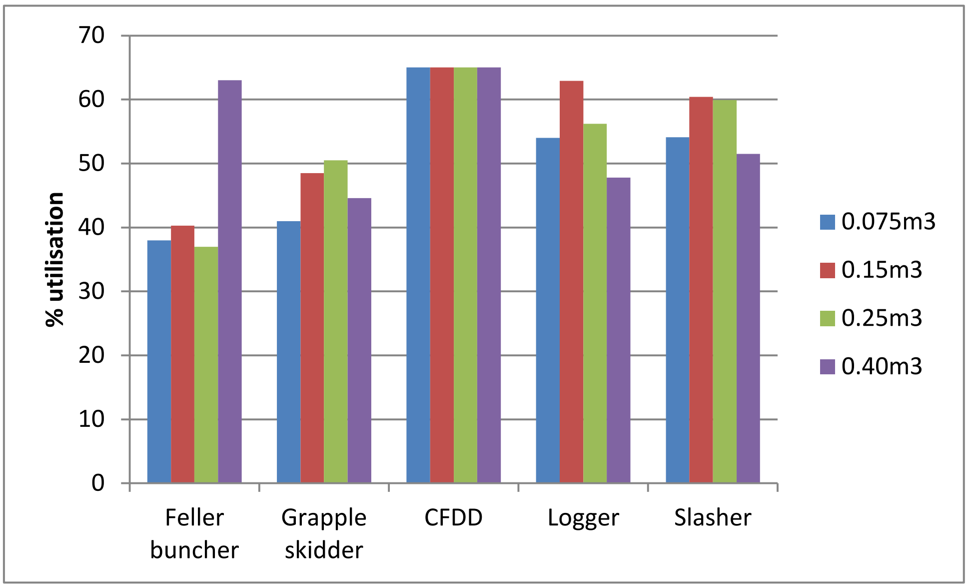


Figure 68: Machine utilisation per CFDD system per tree size

Figure 71 shows that the utilisation of the feller buncher for the first three tree sizes was just under 40 per cent. In practice, the feller buncher might have an increased SMH to try to avoid purchasing a second machine. The feller buncher might also be carefully managed in an attempt to achieve a higher utilisation percentage within the planned SMH. For 0.4 m^3 trees, only one feller buncher was required, which increased its utilisation to over 60 per cent.

The grapple skidders also experienced low utilisation through the tree sizes. All systems that included the flail method of debarking used a minimum of two grapple skidders. This is due to the hot nature of the system. Little stock could be kept at the infeed of the CFDD or CFDDC. If the grapple skidder broke down and there were only one in the system, the CFDD or CFDDC would have to stop working almost immediately. For the same reason, two Bell three-wheeled loggers were also required in the system, regardless of their individual utilisations. The CFDD or CFDDC would be able to work for slightly longer than if a grapple skidder had broken down, but there would soon be a mass of debarked tree lengths congesting the landing and stopping the entire system.

There was a steep increase in the volume required both to balance the system and to keep the machines sufficiently utilised as the tree size increased. For 0.075 m^3 trees, 125,000 m^3 was required, but this increased to nearly 300,000 m^3 for 0.4 m^3 trees.

4.2.1.3 CFDD system cost results: costs per PMH

Table 54 shows the results of the machine costs per PMH for the CFDD.

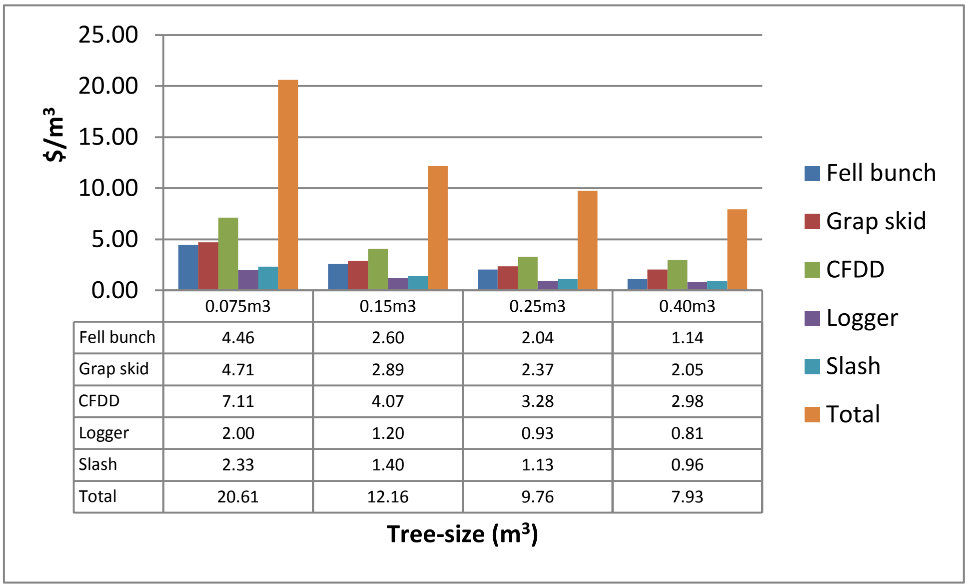
Table 52: CFDD system machine costs per PMH

	Ownership cost ($/PMH)	Machine operating cost (US$/PMH)	Operator costs ($/PMH)	Overhead costs ($/PMH)	Total cost ($/PMH)	Total cost ($/yr)
Feller buncher	44.26	48.07	46.02	13.83	152.18	277,578
Grapple skidder	52.24	54.31	28.87	13.54	148.96	293,483
CFDD (0.075m^3)	52.81	188.25	16.75	25.78	283.60	884,820
Logger	7.16	16.25	20.15	4.36	47.92	124,289
Slasher	33.14	48.27	20.13	10.15	111.69	289,974
Feller buncher	41.77	47.91	43.45	13.31	146.45	282,958
Grapple skidder	44.20	53.91	24.44	12.25	134.80	313,821
CFDD (0.15m^3)	52.81	188.25	16.75	25.78	283.60	884,820
Logger	6.15	15.97	17.30	3.94	43.36	130,983
Slasher	29.65	48.06	18.02	9.57	105.30	305,482
Feller buncher	45.45	48.15	47.27	14.09	154.95	275,190
Grapple skidder	42.45	53.82	23.47	11.97	131.71	319,285
CFDD (0.25m^3)	52.81	188.25	16.75	25.78	283.60	884,820
Logger	6.89	16.18	19.39	4.25	46.70	125,861
Slasher	29.93	48.08	18.18	9.62	105.80	304,138
Feller buncher	26.69	46.94	27.76	10.14	111.53	337,267
Grapple skidder	48.04	54.10	26.55	12.87	141.56	303,269
CFDD (0.40m^3)	52.81	188.25	16.75	25.78	283.60	884,820
Logger	8.09	16.51	22.78	4.74	52.13	119,597
Slasher	34.81	48.37	21.15	10.43	114.77	283,608

Table 54 shows that because only one feller buncher was used for the 0.40 m^3 trees, it was better utilised than with the other tree sizes where two feller bunchers were required. This translates into a lower cost per PMH for this tree size ($112 versus $150 per PMH), as the ownership and operator costs were more diluted. The grapple-skidder costs varied between $130 and $150 per PMH because of utilisation levels as two grapple skidders were used with each tree size. The CFDD costs per PMH stayed constant at $284 because utilisation was constant per tree size. This is considerably higher than the other machines in the systems and is mainly due to higher machine-operating costs. The Bell three-wheel loggers and slasher had a relatively stable cost of around $50 and $110 per PMH respectively, again owing to the relatively stable utilisation levels of these two machines.

4.2.1.4 CFDD system cost results: costs per m^3

System and machine costs per m^3 for each tree size are indicated in Figure 72 below.



	0.075m3	0.15m3	0.25m3	0.40m3
Fell bunch	4.46	2.60	2.04	1.14
Grap skid	4.71	2.89	2.37	2.05
CFDD	7.11	4.07	3.28	2.98
Logger	2.00	1.20	0.93	0.81
Slash	2.33	1.40	1.13	0.96
Total	20.61	12.16	9.76	7.93

Figure 69: CFDD system cost results per m^3 for different tree sizes

Figure 72 indicates that the total cost per m^3 was $20.61 for 0.075 m^3 trees. There was then a sharp drop to 0.15 m^3 trees, where the cost was $12.16 per m^3. The cost decrease slowed after this, with 0.25 m^3 trees costing $9.74 per m^3 and 0.40 trees, $7.93 per m^3. As indicated previously, the small sample size of 0.075 m^3 trees resulted in unusually low tree numbers per bundle, which resulted in productivity being lower than expected. If this gap in the data were researched further, it is likely that higher productivity would result in the 0.075 m^3 tree class, which would result in lower costs per m^3.As can be seen in Figure 72, the machine with the highest cost per m^3 across all the tree sizes was the CFDD. This is most pronounced with the 0.075 m^3 tree size ($7.11/m^3). The feller buncher costs per m^3 for 0.40 m^3 trees were four times less than that of 0.075 m^3 trees ($1.14 versus $4.46). The grapple skidder costs per m^3 for 0.40 m^3 trees were less than half those of the 0.075 m^3 trees ($2.05 versus $4.71). After the CFDD, the feller buncher and grapple skidder cost the most per m^3.

The two poorly utilised feller bunchers (the exception was the 0.40 m^3 trees, which only had one feller buncher) and grapple skidders per system contributed to this cost, but within the system, the overall cost per m^3 was optimised. All feller bunchers and skidders, with the exception of the one feller buncher in 0.40 m^3 trees, had utilisation percentages below 50 per cent.

4.2.2 CFDDC system cost results

The system cost results for the CFDDC are described below.

4.2.2.1 CFDDC system cost results: productivity figures used

The productivity values used in the system costing per machine and per tree size can be found in Table 55. These values were obtained from Section 4.1. The feller buncher and grapple skidder productivity figures are the same as those in the CFDD system (Table 53).

Table 53: Productive rates of the CFDDC system equipment per tree-size class

Machine or activity	0.075m^3/tree (m3/PMH)	0.15m^3/tree (m3/PMH)	0.25m^3/tree (m3/PMH)	0.40m^3/tree (m3/PMH)
Feller buncher	34.2	56.3	76.1	98.1
Grapple skidder	31.6	46.8	55.6	69.2
CFDDC	39.1	47.4	59.7	67.4

4.2.2.2 CFDDC system cost results: System balancing

Figure 73 shows the number of machines needed to balance the system, as well as the annual volume required, for each tree size. One feller buncher was required for all tree sizes except 0.075 m^3, which required two. Two grapple skidders and one CFDDC were required for the different tree sizes. Annual system production increased from 150,000 m^3 to 210,000 m^3 as tree size increased. This is due to all the machines in the system becoming more productive in larger trees.

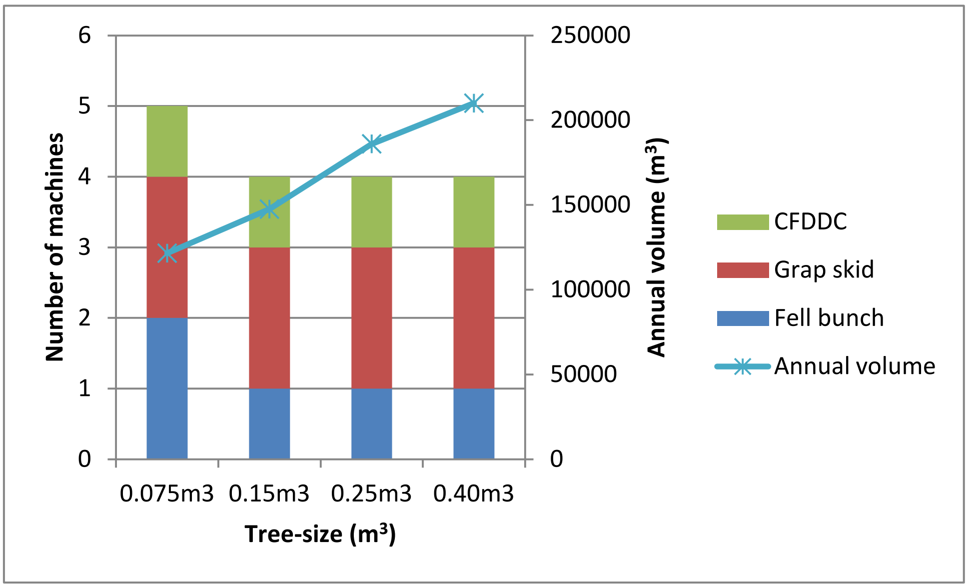


Figure 70: CFDDC machine and volume requirements per system and tree size

As can be seen in Figure 74, the systems were balanced around the CFDDC as it was the most productive machine and the largest potential bottleneck in the system.

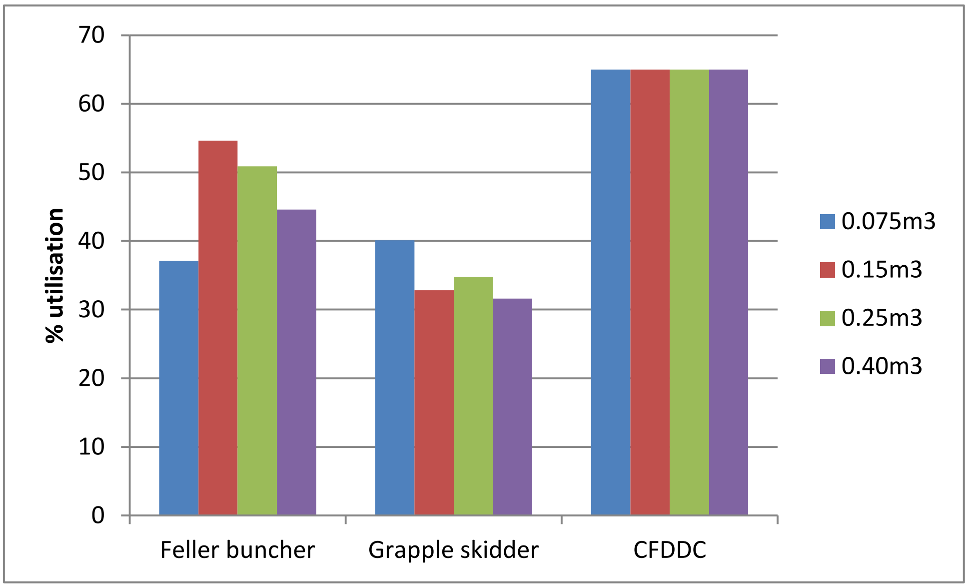


Figure 71: Machine utilisation per CFDDC system per tree size

Figure 74 shows that the utilisation of the CFDDC remained a constant 65 per cent for all the tree sizes. Apart from tree-size 0.075 m^3, which required two feller bunchers, all the tree sizes had the same system requirements for machines. For tree-size 0.075 m^3, a scenario was run whereby the utilisation of the CFDDC was reduced so that only one feller buncher would be required. This resulted in higher system costs than if two feller bunchers had been included, but the CFDDC was fully utilised. The effect of using two feller bunchers for this tree size is illustrated by the low utilisation of the two machines, merely 37 per cent. Again, two grapple skidders were forced into the system for the same reasons provided in the CFDD system balancing. This resulted in low utilisation of the two skidders, less than 40 per cent, for all tree sizes.

The volume requirements increased from 120,000 m^3 per year for 0.075 m^3 trees to 210,000 for 0.40 m^3 trees.

4.2.2.3 CFDDC system cost results: costs per PMH

Table 56 shows the results of the machine costs per PMH for the CFDDC.

Table 54: CFDDC system machine costs per PMH

	Ownership cost ($/PMH)	Machine operating cost (US$/PMH)	Operator costs ($/PMH)	Overhead costs ($/PMH)	Total cost ($/PMH)	Total cost ($/yr)
Feller buncher	45.33	48.14	29.35	12.28	135.10	240,581
Grapple skidder	53.51	54.38	29.58	13.75	151.22	290,807
CFDDC (0.075m^3)	78.32	281.69	18.13	37.81	415.96	1,297,781
Feller buncher	30.79	47.20	19.94	9.79	107.72	282,402
Grapple skidder	65.29	54.97	36.10	15.64	172.00	271,076
CFDDC (0.15m^3)	78.32	281.69	18.13	37.81	415.96	1,297,781
Feller buncher	33.02	47.35	21.38	10.17	111.92	273,598
Grapple skidder	61.52	54.78	34.01	15.03	165.35	276,571
CFDDC (0.25m^3)	78.32	281.69	18.13	37.81	415.96	1,297,781
Feller buncher	37.70	47.65	24.42	10.98	120.75	258,482
Grapple skidder	67.79	55.10	37.48	16.04	176.41	267,774
CFDDC (0.40m^3)	78.32	281.69	18.13	37.81	415.96	1,297,781

Table 56 shows that the feller-buncher costs per PMH for tree size 0.075 m^3 were higher than those of the larger tree sizes. This was due to lower utilisation levels because two machines were used ($135 per PMH versus less than $121 for the rest). The feller bunchers were not working sufficient hours to dilute the higher ownership and operator costs per PMH.

The grapple-skidder cost per PMH slowly increased as the tree size increased ($151 for 0.075 m^3 trees to $176 for 0.40 m^3 trees). This was due to the grapple skidders becoming more productive in larger trees, which reduced the utilisation rate. The CFDDC costs per PMH stayed constant, regardless of tree size, as the utilisation rate was constant at 65 per cent. Compared to the other machines in the system, the CFDDC cost per PMH was high, more than double that of the grapple skidder and feller buncher. This is mainly due to the high machine operating costs.

4.2.2.4 CFDDC system cost results: costs per m^3

In the CFDD system above, the costs refer to dollars per m^3 of logs produced at the roadside. With the CFDDC system, the costs refer to dollars per m^3 of chips produced at the roadside. System and machine costs per m3 for each tree size are indicated in Figure 75 below. The total cost per m^3 decreased from $19.43 for 0.075 m^3 trees to $9.96 for 0.40 m^3 trees.

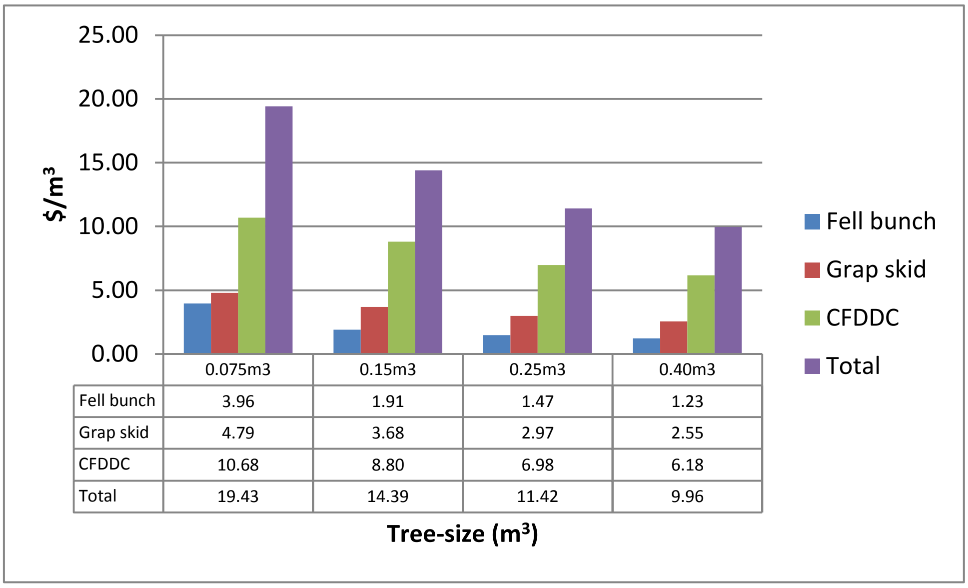


Figure 72: CFDDC system cost results per m^3 for different tree sizes

As per Figure 75, the CFDDC had the highest individual machine cost per m^3 across all the tree sizes by some margin. The cost for the CFDDC reduced by approximately $4.50 between 0.075 m^3 and 0.40 m^3 tree sizes. The feller-buncher cost for the 0.075 m^3 trees was considerably higher than for the other tree sizes. This is due to low utilisation of two feller bunchers compared with high utilisation of only one feller buncher with each of the other tree sizes. Again, two grapple skidders were used in each system. Therefore, the cost reduction with increasing tree size was only a result of higher productivity in larger trees.

4.2.3 CFDD&C system cost results

The system cost results for the CFDD&C are described below.

4.2.3.1 CFDDC&C system cost results: productivity figures used

The productivity figures used in the system costing per machine and per tree size can be found in Table 57. These values were obtained from Section 4.1.

Table 55: Productive rates of the CFDD&C system equipment per tree-size class

Machine or activity	0.075m³/tree (m3/PMH)	0.15m³/tree (m3/PMH)	0.25m³/tree (m3/PMH)	0.40m³/tree (m3/PMH)
Feller buncher	34.2	56.3	76.1	98.1
Grapple skidder	31.6	46.8	55.6	69.2
CFDD	29.4	44.2	53.3	61.3
Chipper	29.4	44.2	53.3	61.3

4.2.3.2 CFDD&C system cost results: balancing

Figure 76 shows the number of machines needed to balance the system, as well as the annual volume required for each tree size. One feller buncher, two grapple skidders, one CFDD and one chipper were required for the different tree sizes.

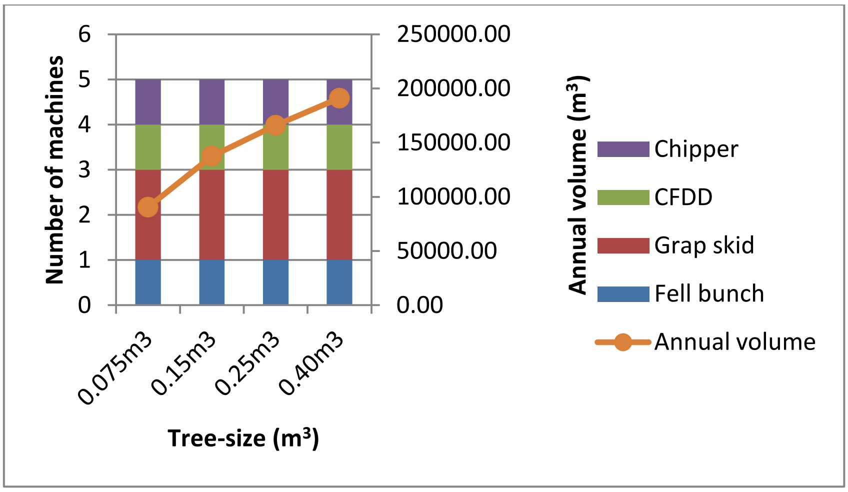


Figure 73: CFDD&C machine and volume requirements per system and tree size

Figure 76 shows that the number of machines stayed constant across the entire tree-size range, with five machines required per system. As indicated in the section on balancing the CFDD system, two skidders were forced into the system, but only one of all the other machines was required per system. This is due to the productivity rates of all these machines being higher than that of the CFDD&C. The volume required per system ranged from approximately 90,000 m^3 for the 0.075 m^3 trees to 191,000 m^3 for the 0.40 m^3 trees.

Figure 77 shows machine utilisation within each system.

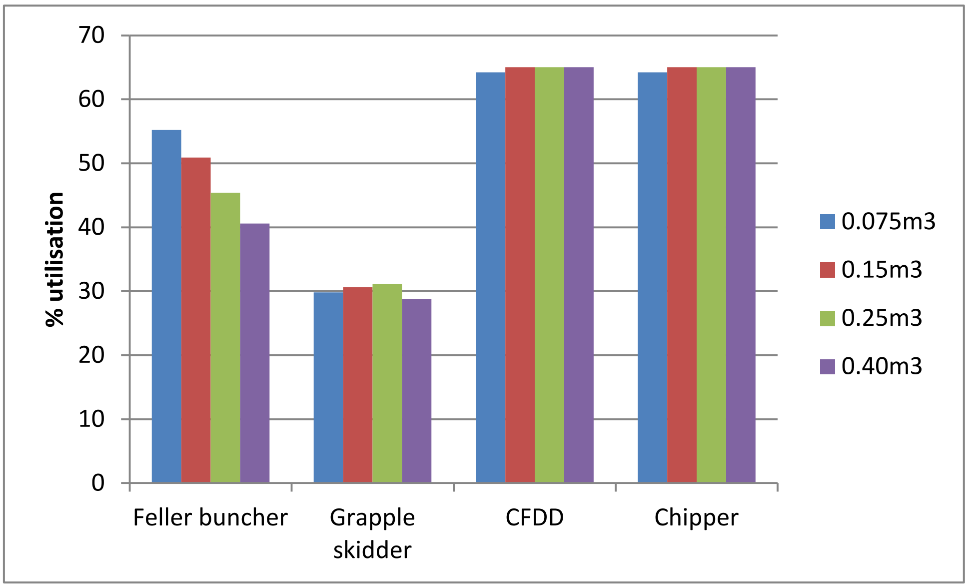


Figure 74: Machine utilisation per CFDD&C system per tree size

Figure 77 illustrated that the system was balanced around the CFDD and chipper as they were the most expensive machines to operate per PMH, as can be seen in the system-cost section below. Because the CFDD fed straight into the chipper, they had exactly the same utilisation. Utilisation for the CFDD and chipper was 65 per cent for all the tree sizes, apart from tree size 0.075 m^3, where the utilisation for both machines was 64.2 per cent. This is slightly lower because the annual volume used for all the different processing-technology systems and the various tree sizes within them have been rounded down to the nearest 500 m^3. This rounded figure is easier to work with and is a more realistic reflection of volume that would be allocated in practice. The feller buncher was better utilised in the 0.075 m^3 trees (55 per cent), but the utilisation dropped as the tree size increased, ending at 41 per cent for the 0.40 m^3 trees. This indicates that, relative to the other machines in the system, the feller buncher was more productive as the tree size became larger. Grapple-skidder utilisation stays fairly constant at approximately 30 per cent for all the tree sizes. In theory, only one grapple skidder should be required for all the tree sizes, but, as mentioned earlier, the system risks associated with grapple-skidder downtime are too high.

4.2.3.3 CFDD&C system cost results: costs per PMH

Table 58 shows the system machine costs per PMH for each tree size.

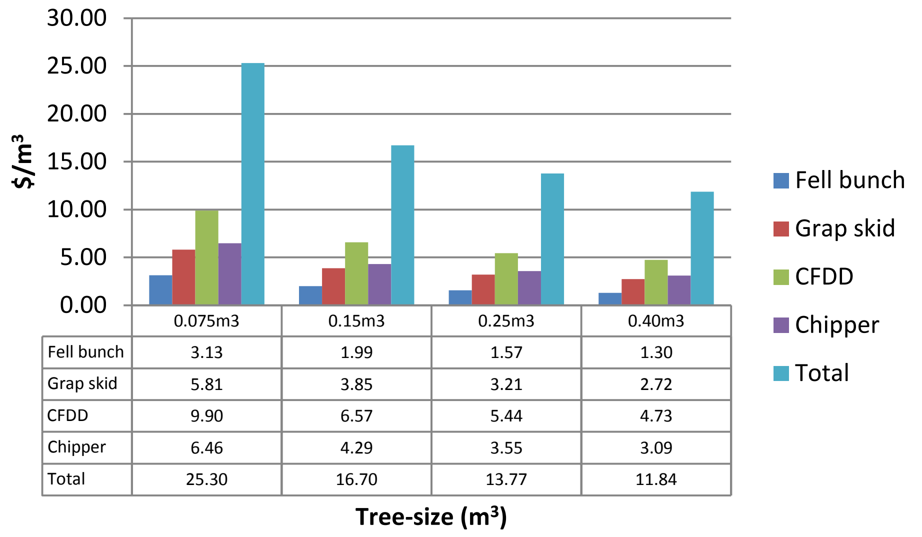
Table 56: CFDD&C system machine costs per PMH

	Ownership cost ($/PMH)	Machine operating cost (US$/PMH)	Operator costs ($/PMH)	Overhead costs ($/PMH)	Total cost ($/PMH)	Total cost ($/yr)
Feller buncher	30.49	47.18	19.74	9.74	107.16	283,681
Grapple skidder	71.86	55.31	39.73	16.69	183.59	262,890
CFDD (0.075m^3)	54.96	190.95	18.36	26.43	290.70	895,815
Chipper	44.15	109.97	18.36	17.25	189.73	584,668
Feller buncher	33.04	47.35	21.40	10.18	111.97	273,505
Grapple skidder	70.04	55.21	38.72	16.40	180.37	265,006
CFDD (0.15m^3)	54.29	190.93	18.13	26.33	289.68	903,809
Chipper	43.61	109.95	18.13	17.17	188.86	589,242
Feller buncher	37.00	47.60	23.96	10.86	119.42	260,509
Grapple skidder	68.93	55.16	38.11	16.22	178.42	266,348
CFDD (0.25m^3)	54.29	190.93	18.13	26.33	289.68	903,809
Chipper	43.61	109.95	18.13	17.17	188.86	589,242
Feller buncher	41.84	47.89	26.84	11.62	127.79	248,868
Grapple skidder	74.57	55.44	41.22	17.12	188.35	259,940
CFDD (0.40m^3)	54.29	190.93	18.13	26.33	289.68	903,809
Chipper	43.61	109.95	18.13	17.17	188.86	589,242

Table 58 shows that the constant utilisation percentage of the CFDD and chipper kept the costs per PMH constant for each tree-size. The CFDD, the machine with the highest cost in all the systems (approximately $190 per PMH), had a total cost of $290 per PMH, while the chipper cost was $189 per PMH. This is mainly due to high operating costs of the CFDD. Operating cost per PMH was also the highest cost component per PMH for the chipper. These two machines had high fuel consumption rates and the costs of chains were high for the CFDD. With the feller buncher, the total cost per PMH increased with tree size as utilisation increased. Decreasing tree size (hence, utilisation) resulted in fewer machine hours per annum into which the fixed and operator costs could be divided. The total costs per PMH for the grapple skidder stayed fairly constant across all the tree sizes, fluctuating from $178 to $188 per PMH. This is due to the utilisation of the grapple skidders remaining fairly constant.

4.2.3.4 CFDD&C system cost results: costs per m^3

The CFDD&C cost results per m^3 reflect the cost of chips at the roadside. System and machine costs per m^3 for each tree size are indicated in Figure 78 below. Included in Figure 78 is a table which reflects the exact values of the individual graph columns.



	0.075m3	0.15m3	0.25m3	0.40m3
Fell bunch	3.13	1.99	1.57	1.30
Grap skid	5.81	3.85	3.21	2.72
CFDD	9.90	6.57	5.44	4.73
Chipper	6.46	4.29	3.55	3.09
Total	25.30	16.70	13.77	11.84

Figure 75: CFDD&C system cost results per m^3 for different tree sizes

Figures 78 shows that at $25.30, the system cost per m^3 was very high in 0.075 m^3 trees. There was a large cost reduction per m^3 to $16.70 in 0.15 m^3 trees. Thereafter, the cost reduction per m^3 slowed, reaching $13.77 in 0.25 m^3 trees and $11.84 in 0.40 m^3 trees.The CFDD had the highest cost per m^3 component of the system across all the tree sizes. CFDD costs per m^3 ranged from $9.90 in 0.075 m^3 trees to $4.73 in 0.40 m^3 trees. This is followed by the chipper, whose costs per m^3 ranged from $6.46 in 0.075 m^3 trees to $3.09 in 0.40 m^3

trees. When comparing the CFDD&C system with other infield chipping systems, the costs of the CFDD and chipper would need to be combined. There was one feller buncher and two grapple skidders in all the systems. Machine productivity in different tree sizes was responsible for the cost differences.

4.2.4 DHP system cost results

The system cost results for the DHP are described below.

4.2.4.1 DHP system cost results: productivity figures

The productivity figures used in the system costing per machine and per tree size can be found in Table 59. These values were obtained from Section 4.1.

Table 57: Productive rates of the DHP system equipment per tree-size class

Machine or activity	0.075m^3/tree (m3/PMH)	0.15m^3/tree (m3/PMH)	0.25m^3/tree (m3/PMH)	0.40m^3/tree (m3/PMH)
Feller buncher	34.2	56.3	76.1	98.1
Grapple skidder	31.6	46.8	55.6	69.2
DHP	9.7	22.9	37.3	52
Slash	48	75	93.8	120

4.2.4.2 DHP system cost results: balancing

Figure 79 shows the number of machines needed to balance the system, as well as the annual volume required, for each tree size.

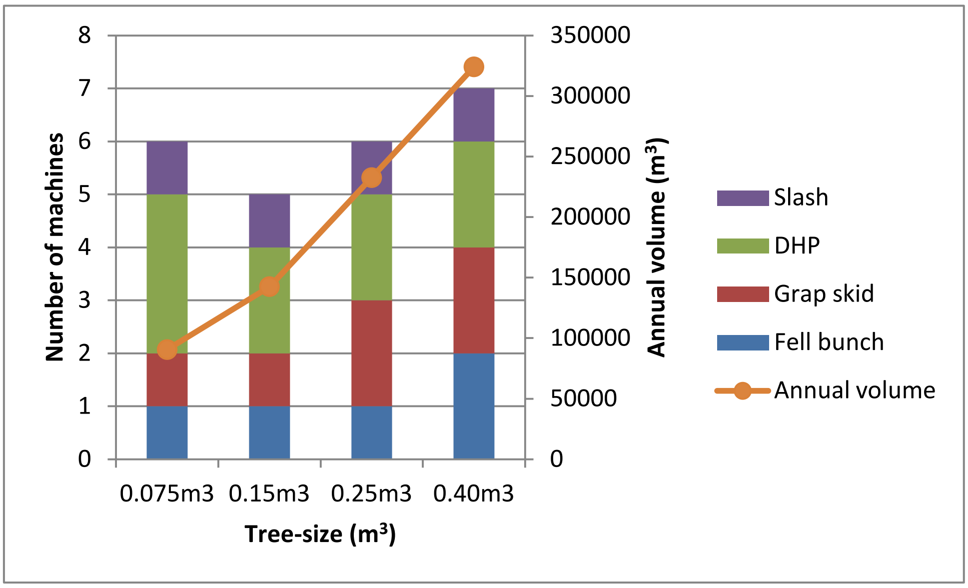


Figure 76: DHP machine and volume requirements per system and tree size

Figure 79 shows that the DHP system had varying machine numbers for different tree sizes, ranging from five machines for 0.15 m^3 trees to six for 0.075 and 0.25 m^3 trees and seven for the 0.40 m^3 trees. Three DHPs were utilised for the 0.075 m^3 trees, but thereafter only two were needed. It was unnecessary to force two grapple skidders into the DHP systems, as a single skidder was able to build up a bank of stock in front of the DHPs. In the case of a grapple-skidder breakdown, this stock would be available to be processed. Also, in the case of an extended grapple-skidder breakdown, the DHPs could move into the compartment to start felling and processing trees into logs if the trees were close to a road. Should the trees be far from a road, the DHPs could produce debarked tree lengths, which the grapple skidder would extract once the breakdown had been overcome. However, two skidders were used for the 0.25 and 0.40 m^3 tree sizes, because of the high production per hour of the two DHPs, necessitating additional extraction capacity. Apart from 0.40 m^3 trees, one feller buncher was required for the other tree sizes. Indeed, the DHPs were so productive at the 0.40 m^3 tree size that two feller bunchers were required. Only one slasher was required for all tree sizes, as this machine's productivity was higher than that of all the other machines. The volume required per annum per system increased greatly from 91,000 m^3 for 0.075 m^3 trees to 324,000 m^3 for 0.40 m^3 trees.

Figure 80 shows machine utilisation per DHP system per tree size.

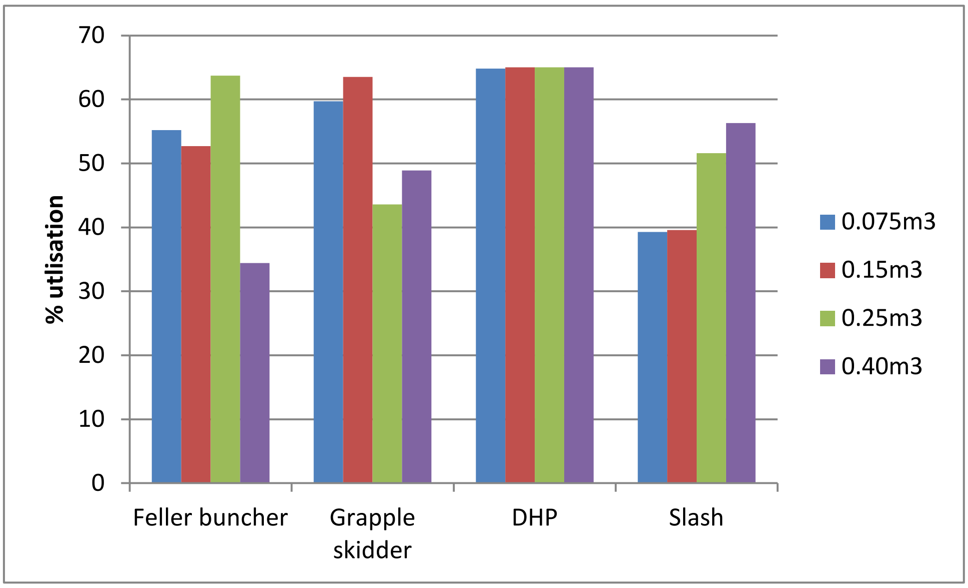


Figure 77: Machine utilisation per DHP system per tree size

Figure 80 shows that the systems have all been balanced around the DHPs. These machines had utilisation rates of 65 per cent (the 0.075 m^3 tree size is 64.8 per cent owing to rounding down to the nearest 500 m^3). Feller-buncher utilisation was above 50 per cent for tree sizes 0.075 to 0.25 m^3. Because two feller bunchers were required for the 0.40 m^3 trees, the utilisation dropped to 34 per cent to reflect the shared volume. Grapple-skidder utilisation was high in 0.075 and 0.15 m^3 trees, at 60 per cent and 64 per cent respectively. However, the utilisation dropped for 0.25 and 0.40 m^3 trees (44% and 49% respectively) as two skidders were used. The slasher utilisation increased as the tree size became larger, ranging from 39 per cent for 0.075 m^3 trees to 56 per cent for 0.40 m^3 trees. This is due to increased annual volumes of bigger trees, which required greater use of the slasher.

4.2.4.3 DHP system cost results: costs per PMH

Table 60 shows the system costs per PMH for each machine for various tree sizes.

Table 58: DHP system machine costs per PMH

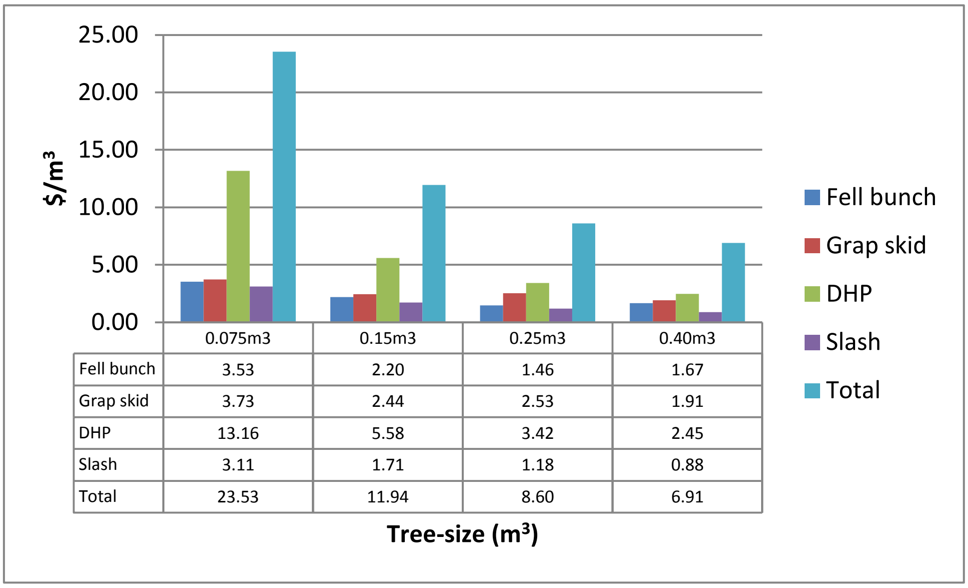
	Ownership cost ($/PMH)	Machine operating cost ($/PMH)	Operator costs ($/PMH)	Overhead costs ($/PMH)	Total cost ($/PMH)	Total cost ($/yr)
Feller buncher	30.49	47.18	32.10	10.98	120.75	319,669
Grapple skidder	34.68	52.67	19.85	10.72	117.93	337,915
DHP (0.075 m^3)	34.54	64.68	16.81	11.60	127.63	396,922
Slasher	51.26	56.57	27.71	13.55	149.09	281,281
Feller buncher	31.88	47.27	33.58	11.27	124.01	313,895
Grapple skidder	32.61	52.57	18.66	10.38	114.21	348,125
DHP (0.15 m^3)	34.43	64.67	16.75	11.59	127.44	397,613
Slasher	38.68	50.39	27.50	11.66	128.23	243,763
Feller buncher	26.40	46.92	27.79	11.11	111.22	340,079
Grapple skidder	47.51	53.35	27.20	12.81	140.86	294,609
DHP (0.25 m^3)	34.43	64.67	16.75	11.59	127.44	397,613
Slasher	29.66	49.75	21.09	10.05	110.56	274,063
Feller buncher	48.88	48.37	51.46	14.87	163.58	270,132
Grapple skidder	42.33	53.08	24.24	11.96	131.61	308,918
DHP (0.40 m^3)	34.43	64.67	16.75	11.59	127.44	397,613
Slasher	27.23	49.58	19.36	9.62	105.79	285,668

Table 60 shows that the total cost per PMH of feller bunchers was higher for the large, 0.40 m^3 trees ($164 compared with approximately $120 for the other tree sizes), as two feller bunchers were required for this tree size. As indicated above, these two feller bunchers had low utilisation levels, which increased the ownership and operator component per PMH. Similarly, the grapple skidders evidenced higher total costs per PMH for the 0.25 and 0.40 m^3 trees ($141 and $132 per PMH respectively) compared with the costs for 0.075 and 0.15 m^3 trees ($118 and $114 per PMH respectively). Two skidders were required in each of these systems compared with only one needed for the two smaller tree sizes. Once again, it is the ownership and operator components which contributed to this increase.

The total cost per PMH of the DHP was the same for most tree sizes owing to the same utilisation levels. There was, however, a minor variance in the 0.075 m^3 trees because of the marginally lower utilisation. The total cost per PMH for the slasher reduced as tree size increased, decreasing from $149 per PMH for 0.075 m^3 trees to $106 for 0.40 m^3 trees. The machine was used for more hours per year with larger trees, which diluted the ownership and operator costs.

4.2.4.4 DHP system cost results: costs per m^3

The DHP system produced logs stacked on the roadside. System and machine costs per m^3 for each tree size are indicated in Figure 81 below.



	0.075m3	0.15m3	0.25m3	0.40m3
Fell bunch	3.53	2.20	1.46	1.67
Grap skid	3.73	2.44	2.53	1.91
DHP	13.16	5.58	3.42	2.45
Slash	3.11	1.71	1.18	0.88
Total	23.53	11.94	8.60	6.91

Figure 78: DHP system cost results per m^3 for different tree sizes

Figure 81 shows that the cost per m^3 in 0.075 m^3 trees was very high in relation to the other tree sizes. The costs per m^3 reduced from $23.53 in 0.075 m^3 trees to $11.94 in 0.15 m^3 trees. The cost per m^3 reduction from 0.15 m^3 trees to 0.25 m^3 was still high, decreasing to $8.60 per m^3. Thereafter, the cost reduction to 0.40 m^3 ($6.91) was not as pronounced, but this is still a very low system cost per m^3 with regard to the smaller tree sizes.In the DHP system, the DHP had the highest cost per m^3 for the range of tree sizes. This was most pronounced in the 0.075 m^3 trees, where the DHP cost alone was $13.16 per m^3. As the tree size increased, the cost-per-m^3 differential between the DHP and the other machines in the system narrowed. With 0.40 m^3 trees, the DHP was only marginally more expensive per m^3 than the feller buncher and grapple skidder ($2.44 versus $1.67 and $1.91 respectively). The feller-buncher cost per m^3 in 0.40 m^3 trees was higher than in 0.25 m^3 trees ($1.67 versus $1.46). Although the feller-buncher cost in 0.40 m^3 trees was expected to be lower, two feller bunchers were required for these large trees, which resulted in lower machine utilisation and, therefore, slightly higher costs. Even though the feller-buncher costs per m^3 in this tree size were slightly higher, the overall system cost had reduced. Similarly, the grapple-skidder costs per m^3 in the 0.25 m^3 and 0.40 m^3 trees were not as low as expected. This is due to two grapple skidders having been utilised with these two tree sizes as opposed to only one for the smaller tree sizes.

4.2.5 Harvester system cost results

The system cost results for the harvester are described below.

4.2.5.1 Harvester system cost results: productivity figures

The productivity figures used in the system costing per machine and per tree size can be found in Table 61. These values were obtained from Section 4.1.

Table 59: Productive rates of the Harvester system equipment per tree-size class

Machine or activity	0.075m³/tree (m3/PMH)	0.15m³/tree (m3/PMH)	0.25m³/tree (m3/PMH)	0.40m³/tree (m3/PMH)
Harvester	5	9.6	15.2	22.2
Forwarder	25.2	35.7	40.5	51.8

4.2.5.2 Harvester system cost results: balancing

Figure 82 shows the number of machines needed to balance the system, as well as the annual volume required, for each tree size.

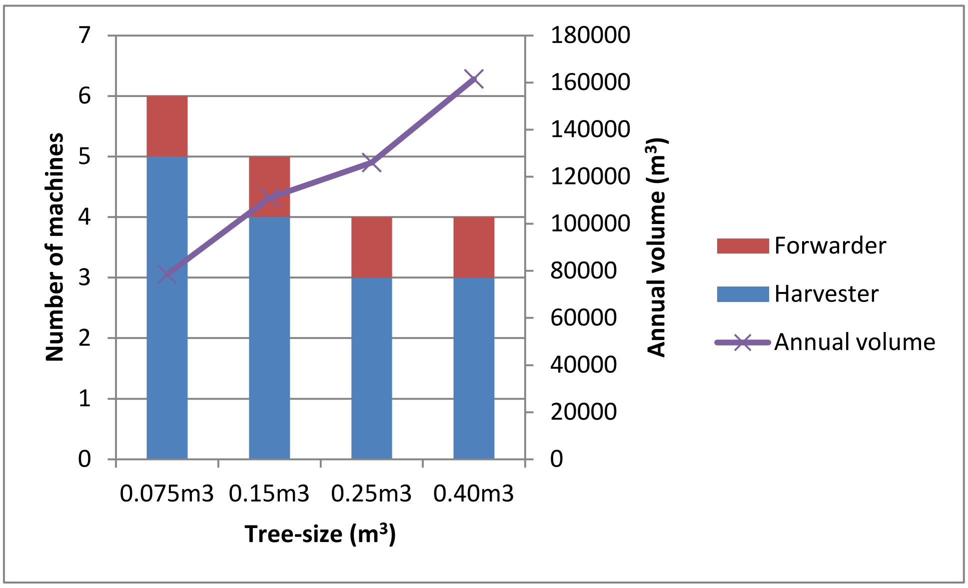


Figure 79: Harvester machine and volume requirements per system and tree size

The number of harvesters decreased from six for the 0.075 m^3 trees to five for the 0.15 m^3 trees and to four for the 0.25 m^3 and 0.40 m^3 trees. Only one forwarder was required for each system, so the number of harvesters decreased with each tree-size reduction. The annual volume requirements increased from 78,500 m^3 in 0.075 m^3 trees to 162,000 m^3 in 0.40 m^3 trees.

Figure 83 shows the utilisation levels of the various machines in each system for each tree size.

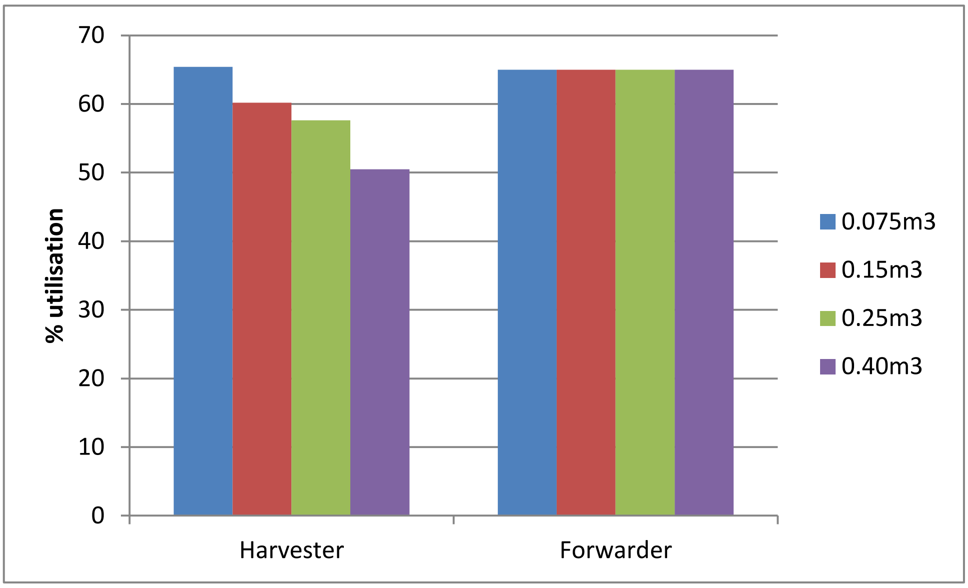


Figure 80: Machine utilisation per harvester system per tree size

All previous processing-technology systems were balanced around the processing equipment. Figure 83 shows that with the harvester system, the lowest cost per m^3 was obtained by balancing the systems around the forwarder. The forwarder utilisation was 65 per cent for all the tree sizes. The harvesters showed reduced utilisation levels as the tree size increased. For the 0.075 m^3 trees, the harvester utilisation was 65.4 per cent. This is 0.4 per cent higher than the utilisation figures indicated in the assumptions. Had a third harvester been included in this tree-size scenario, utilisation levels of the harvesters would have been too low and the costs would have become very high. In reality, a forest-machine owner would not purchase an additional machine if the utilisation level was a few decimal points away from the indicated maximum utilisation level. For tree sizes greater than 0.075 m^3, the utilisation levels of the harvesters did decrease from 60 per cent for 0.15 m^3 trees to 58 per cent for 0.25 m^3 trees and to 51 per cent for 0.40 m^3 trees.

4.2.5.3 Harvester system cost results: costs per PMH

Table 62 shows the harvester machine costs per PMH.

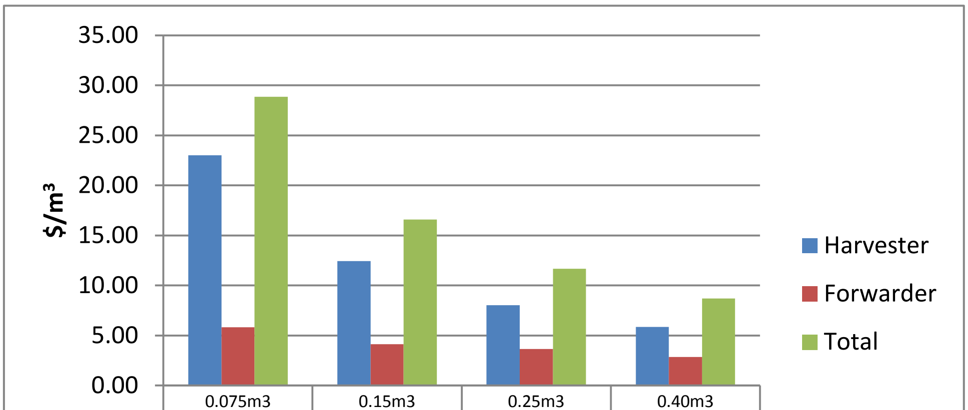
Table 60: Harvester system: machine costs per PMH

	Ownership cost ($/PMH)	Machine operating cost (US$/PMH)	Operator costs ($/PMH)	Overhead costs ($/PMH)	Total cost ($/PMH)	Total cost ($/yr)
Harvester (0.075 m3)	28.50	59.42	16.65	10.46	115.03	361,217
Forwarder	45.89	69.34	18.23	13.35	146.81	458,039
Harvester (0.15 m3)	30.97	59.57	18.08	10.86	119.48	345,367
Forwarder	45.89	69.34	18.23	13.35	146.81	458,039
Harvester (0.25 m3)	32.39	59.65	18.92	11.10	122.06	337,267
Forwarder	45.89	69.34	18.23	13.35	146.81	458,039
Harvester (0.40 m3)	36.91	59.91	21.55	11.84	130.20	315,810
Forwarder	45.89	69.34	18.23	13.35	146.81	458,039

Table 62 shows that as the harvester worked in larger trees, its utilisation dropped slightly owing to system balancing and, therefore, the cost per PMH increased. This was due to the ownership and operators' costs not being diluted as much. The total cost per PMH increased from \$115 per PMH for 0.075 m^3 trees to \$130 for 0.40 m^3 trees. The utilisation of the forwarder stayed the same and, therefore, the total costs per PMH remained at \$147 per PMH for all the tree sizes.

4.2.5.4 Harvester system cost results: costs per m^3

The harvester system produced logs at the roadside. System and machine costs per m^3 for each tree size are indicated in Figure 84 below.



	0.075m3	0.15m3	0.25m3	0.40m3
Harvester	23.01	12.45	8.03	5.87
Forwarder	5.83	4.13	3.64	2.84
Total	28.84	16.57	11.67	8.70

Figure 81: Harvester system costs per m^3 for different tree sizes

Figure 84 shows that the total cost differences between the harvester system operating in small and large trees were very pronounced. Costs in 0.075 m^3 trees were \$28.84 per m^3. This dropped to \$16.57 per m^3 in 0.15 m^3 trees, \$11.67 per m^3 in 0.25 m^3 trees and \$8.70 per m^3 in 0.40 m^3 trees. The largest cost per m^3 reduction was between 0.075 m^3 and 0.15 m^3 trees.

The harvester was the main driver of the harvesting-system costs, as the cost difference between the harvester working in 0.075 m^3 and 0.40 m^3 trees was only \$2.99 per m^3. The difference in harvester costs over the same tree-size range was \$17.14. The harvester cost alone in the 0.075 m^3 trees was \$23.01 per m^3. It is clear that tree size had a very large effect on harvester productivity, as the reduced cost per m^3 in large trees was achieved with lower machine utilisation.

4.3 Summary discussion of results

Table 63 shows the costs per m^3 per tree size for all of the processing technology systems. The interpretation of Table 63 takes place below Figure 85.

Table 61: Processing technology systems costs per tree size

	Tree-size (m^3)			
	0.075m^3	**0.15m^3**	**0.25m^3**	**0.40m^3**
CFDD system	20.61	12.16	9.76	7.93
CFDDC system	19.43	14.39	11.42	9.96
CFDD&C system	25.30	16.70	13.77	11.84
DHP system	23.53	11.94	8.60	6.91
Harvester system	28.84	16.57	11.67	8.70

Table 63 can be viewed in conjunction with Figure 85 which gives a graphical presentation of the results.

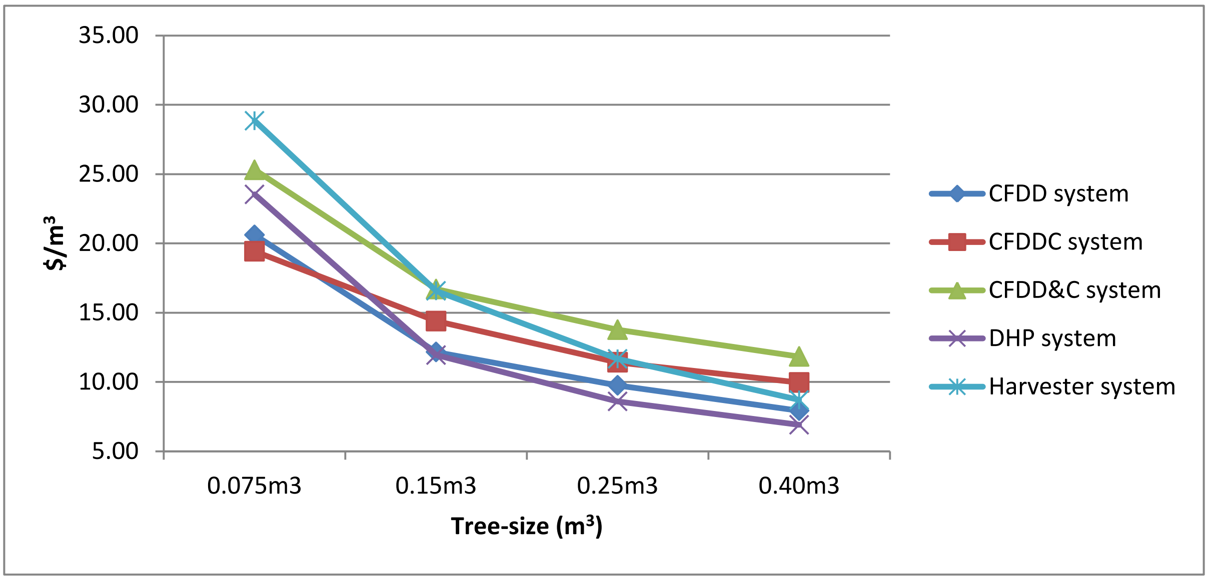


Figure 82: Processing technology systems costs per tree size

Figure 85 shows there is not one single system which is more cost-effective per m^3 across all the tree sizes. What is common for all systems is the initial high cost in 0.075 m^3 trees, ranging between \$19.43 per m^3 for the CFDDC system and \$28.84 for the harvester system, a difference of \$9.41 per m^3. The cost differences in the larger 0.40 m^3 trees are much lower, ranging from \$6.91 per m^3 for the DHP system and \$11.84 per m^3 for the CFDD&C, a difference of only \$4.93 per m^3. It is interesting to note that the cost per m^3 differences between the systems had already narrowed with the 0.15 m^3 trees: the difference between the most expensive (CFDD&C) and most cost-effective (DHP) is $4.67 per m^3. This difference is then maintained through to the largest tree size of 0.40 m^3.

4.3.1 Summary discussion of results for the various processing machine systems

A summary discussion of the results is discussed below. This section provides an overview of the system results per processing technology. Due to five systems being researched, it was necessary to separate them into sub-sections. The summary discussion of results which compares the different processing technology systems takes place per tree size in Section 4.3.2.

4.3.1.1 DHP: summary discussion of results

With regard to tree sizes of 0.15 m^3 and larger, the DHP system had the lowest cost, closely followed by the CFDD system. This was unexpected as single-tree processing technologies are often perceived to be higher cost options. An important point to note is that, on average, the DHP processed trees with a BWBS class of 2.6 and the CFDD processed trees with a BWBS class of 3.8. The DHP was more sensitive to BWBS than the CFDD. This became clear during processing, as often the DHP only required one pass to debark the tree. As the BWBS class increased, more passes were required to remove the bark. This caused the productivity per m^3 to drop very rapidly.

Poor tree form also reduced the productivity of the DHP more than it did the multi-tree processing machines. The reason is that with the DHP, the tree had to be tightly gripped and handled, as opposed to being fed through a large chamber that could accommodate crooked and forked trees, as well as trees with large branches. The form class encountered during the research was good. Therefore, the results presented for the DHP are only applicable to situations where the BWBS class is lower than 3 and the form class is good.

4.3.1.2 CFDD: summary discussion of results

The CFDD managed to produce low costs per m^3 for all the tree sizes greater than 0.075 m^3. As explained previously, the cost results for tree size 0.075 m^3 could possibly have been lower. These low costs were achieved even while processing trees with a high BWBS class of 3.8. However, because there were quality-related issues when debarking the trees of higher BWBS classes, it is likely that the productivity and, therefore, cost per m^3 would not reduce should trees with a lower BWBS be processed.

This system has further potential for cost reduction, for example, through the use of a front-end-loader with a timber grab as a substitute for one skidder and one logger. This machine could be used to extract trees if the grapple skidder broke down or was undergoing scheduled maintenance. It could also help remove debarked tree lengths from the outfeed of the CFDD, should the logger not be available. This type of front-end-loader would also be more effective at handling the residue generated by the CFDD.

Further cost-improvement opportunities exist through machine modifications and better planning, for example, of landing locations. The use of the Morbark 2455 CFDD in *Eucalyptus* was new and modifications to increase the capabilities of parts such as the infeed rollers would also enhance productivity.

Removing the tops and large branches after felling with chainsaws appeared to contribute to the increased productivity of the CFDD, as more trees could be fed through in one cycle. Grapple-skidder productivity was also improved as less residue had to be removed. This was not proven scientifically, but is an observation made after visiting other operations where the trees were not topped.

4.3.1.3 CFDDC: summary discussion of results

The CFDDC was expected to have higher costs than the systems which produced logs, as one more processing function (chipping) had to be carried out. However, because the chips were being produced by the same machine that debarked and debranched, the cost increase was reduced. Also, the complexities of handling debarked tree lengths and loading them onto trucks were removed as the chips were fed straight into chip trucks. This resulted in the CFDDC having the lowest system cost for 0.075 m^3 trees at \$19.43 per m^3. The CFDDC cost curve as tree size increased was flatter than that of the other systems though, with the cost for 0.40 m^3 trees at \$9.96 per m^3. This is still competitive, considering that no chipping had to take place at the processing plant.

4.3.1.4 CFDD&C: summary discussion of results

The CFDD&C-system cost was not competitive in any of the tree sizes analysed. It had the second highest cost for 0.075 m^3 trees (with only the harvester system being more expensive) and proved to be the highest cost system for all larger trees. The costs of two large processing machines, each with their own operators, were not diluted sufficiently by increased productivity. For this system to be competitive, the processing machines would have to have much higher productivity levels to make up for the high costs per PMH.

The Precision Husky CFDD used in the research was fairly new in *Eucalyptus* and machine modifications would improve productivity further. For example, the trees were often not drawn into the machine by the infeed rollers: the trees would be placed and the operator would swing the crane to remove residue from the hydraulic residue discharger, but the infeed rollers could not grip the trees and pull them in. This wasted time, which reduced productivity. If the infeed rollers were modified to have better grip on the butt of a *Eucalyptus* tree, the productivity would increase substantially, especially with larger trees where the problem was most pronounced.

In Western Australia, trials have been carried out where two CFDDs feed a single chipper as the chipper is not fully productive when fed by only one CFDD (Cameron, personal communication, 2010). This system required two feller bunchers and three grapple skidders in order to keep the CFDD&Cs fed with trees and would have very high annual volume requirements. Further research needs to take place into the current CFDD&C system to see whether modifications made have increased the productivity sufficiently to reduce cost.

Importantly, if the forest manager requires a system that can produce logs, chips and potentially use harvesting residue, this system is able to meet all these needs.

4.3.1.5 Harvester: summary discussion of results

The harvester system is not an option in very small trees sizes such as the 0.075 m^3 trees. It had the highest system cost for this tree size at \$28.84 per m^3, approximately \$3.00 more expensive than the next most costly machine. It was still very expensive for 0.15 m^3 trees (\$16.57), costing approximately the same as the CFDD&C system. With trees of 0.25 m^3, it started to become competitive at approximately the same cost as the CFDDC and less than the CFDD&C. However, it was still nearly \$2.00 per m^3 more than the CFDD and \$3.00 per m^3 more than the DHP.

That being said, the other advantages, such as improved terrain handling and lower environmental impact, could encourage companies to consider paying this cost premium on the harvester system. The harvester was cost-competitive with 0.40 m^3 trees. At \$8.70 per m^3, it was only \$0.77 per m^3 more expensive than the CFDD system and \$1.79 per m^3 more expensive than the DHP system. Unless residue was required at the landing, it is likely that the harvester system would be selected for 0.40 m^3 trees, owing to the advantages mentioned above, as well the system requiring a lower density road network.

The harvester observed during the research worked in trees with very good form (class 1) and good BWBS (class 3). An increase in the form and BWBS classes would reduce the productivity of the harvester. To quantify this, further research would need to be carried out.

4.3.2 Summary discussion of results per tree size

A brief overview is given below of the cost results per m^3 for different tree sizes. The results of the different processing technologies have already been described above.

4.3.2.1 Summary discussion of results for 0.075 m^3 trees

Table 64 shows the system costs in 0.075 m^3 trees.

Table 62: System costs in 0.075 m^3 trees

CFDD	CFDDC	CFDD&C	DHP	Harvester
20.61	19.43	25.30	23.53	28.84

The CFDDC system was the most cost-effective with 0.075 m^3 trees, expenditure being slightly lower than with the CFDD system. As mentioned already, the small sample size of the CFDD in this tree-size class is probably negatively affecting the cost per m^3: it could be that the CFDD system had the lowest cost in 0.075 m^3 trees. Compared with the other multi-tree processing systems (CFDDC and CFDD&C), the CFDD had a much larger reduction in productivity with trees ranging between 0.075 m^3 and 0.15 m^3 in size in relation to the 0.075 m^3 starting point of $8.45 per m^3 or 40 per cent of the 0.075 m^3 value. This is not consistent with the other CFDDC and CFDD&C results, which had reductions of $5.04 (26 per cent) and $8.60 per m^3 (34 per cent), or with the results produced by Spinelli, et al. (2009). This is further indication the CFDD would, in fact, be the lowest cost system for 0.075 m^3 trees. The harvester was the most expensive system in this tree size.

4.3.2.2 Summary discussion of results for 0.15 m^3 trees

Table 65 shows the system costs in 0.15 m^3 trees.

Table 63: System costs in 0.15 m^3 trees

CFDD	CFDDC	CFDD&C	DHP	Harvester
12.16	14.39	16.70	11.94	16.57

The highest cost reductions per m^3 between 0.075 m^3 and 0.15 m^3 trees were found with the harvester and DHP systems. The reduction in the harvester system was \$12.27 per m^3 and that of the DHP system, \$11.59 per m^3. The system costs per tree size were much closer to each other for the 0.15 m^3 tree size than the 0.075 m^3, and were the closest together of all the tree sizes. The harvester and CFDD&C systems had similarly high costs at \$16.70 and \$16.57 per m^3 respectively, while the CFDD and DHP systems had correspondingly low costs at \$12.16 and \$11.94 per m^3 respectively. The CFDDC may be found approximately midway between these two groups, at \$14.39 per m^3.

4.3.2.3 Summary discussion of results for 0.25 m^3 trees

Table 66 shows the system costs for 0.25 m^3 trees.

Table 64: System costs in 0.25 m^3 trees

CFDD	CFDDC	CFDD&C	DHP	Harvester
9.76	11.42	13.77	8.60	11.67

The DHP system had the lowest cost at \$8.60 per m^3. This is \$1.16 lower than the CFDD system, at \$9.76 per m^3. The CFDD&C was more than \$2.00 per m^3 higher than any of the other systems. The CFDDC and harvester systems were in-between, with costs of \$11.42 and \$11.67 per m^3 respectively.

4.3.2.4 Summary discussion of results for 0.40 m^3 trees

Table 67 shows the system costs in 0.40 m^3 trees.

Table 65: System costs in 0.40 m^3 trees

CFDD	CFDDC	CFDD&C	DHP	Harvester
7.93	9.96	11.84	6.91	8.70

With 0.40 m^3 trees, the DHP remained the lowest cost system at \$1.02 per m^3 lower than the CFDD system. The CFDD&C was still not competitive, but the harvester costs were much closer to those of both the DHP and CFDD, making it a contender for system selection, as mentioned above.

4.3.2.5 Summary discussion of results for annual volume requirements per tree size

Figure 86 gives an indication of the annual volume requirements for each processing system per tree size.

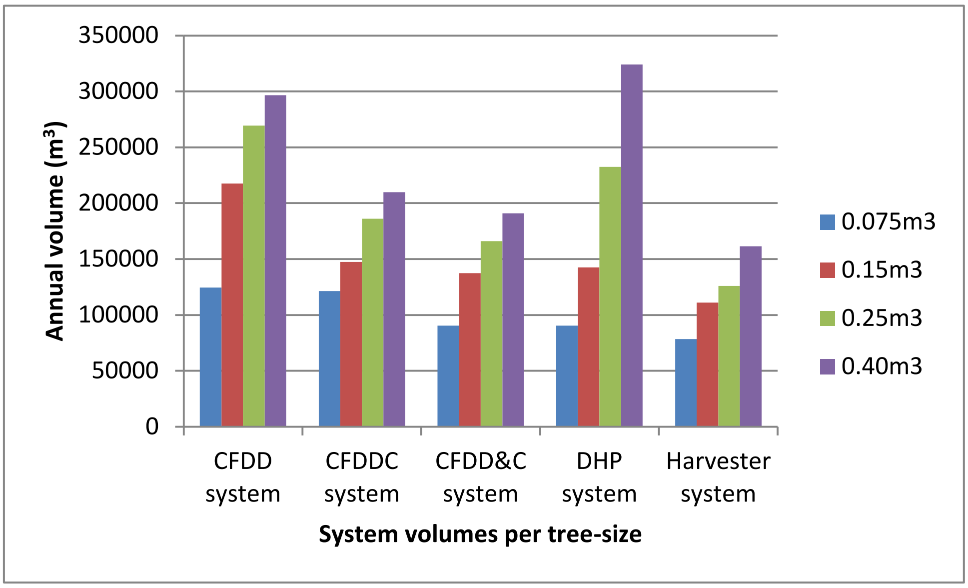


Figure 83: Annual system volume requirements per tree size

All of the systems had increased volume requirements in large tree sizes as they were more productive with large trees. The largest volume requirements occurred with the CFDD when processing trees of 0.15 m^3 or larger; the CFDDC in 0.40 m^3 trees; and the DHP in trees larger than 0.25 m^3. It is possible that the contractor or company might not have sufficient volume for these systems if processing specific tree sizes or if there is insufficient volume on the terrain that these full-tree systems need to operate efficiently. The harvester was the least sensitive to annual volume across all the tree sizes, followed by the CFDD&C and then the CFDDC.

4.3.3 Results conclusion

Trees with longer debarking elements as a percentage of the total cycle time have much higher productivity standard deviations. This mostly applies to the CFDD, CFDDC and CFDD&C, but also to the DHP and, lastly, the harvester. Any variable which affects the debarking element when it is the element that consumes the most time in the cycle will result in high variations.

When the harvester operated in small trees, the debarking element was relatively low compared with the total cycle time. As tree size became larger and the BWBS strength higher, the debarking element consumed an increasingly higher proportion of the total cycle time. This means there was higher variation in cycle times (and, therefore, productivity). For example, if BWBS is low with the DHP, the machine picks up the tree, feeds it through the head once and then places it down. However, if the BWBS is high, the machine needs to run the tree through the head many times before placing it. Therefore, there is a rapid drop in productivity if the DHP is compared with the harvester, where the cycle time is still being buffered by many other elements. As BWBS increased, the DHP and harvester productivity per m^3 moved closer together.

The research results showed that the productivity equations developed for the different processing technologies were able to predict the actual harvesting productivity within the range of researched tree sizes.

Tree and bundle size played important roles in productivity determination of the various machines. Tree size was expected to play a dominant role, as this is what the literature had indicated. Bundle size was also of importance, as not feeding sufficient trees through per cycle resulted in suboptimal productivity.

With the CFDD and CFDD&C, it was still possible for an experienced operator to determine the correct number of trees per cycle by looking at the debarking quality of the debarked trees. The models provide assistance in determining the optimal number of trees of a particular size that should be fed through the multi-stem processors at one time. Knowing the correct bundle size is of specific importance to an inexperienced CFDD operator. This knowledge is also invaluable to a CFDDC operator, who has to speculate even more in an effort to determine whether optimal productivity is being achieved at the correct quality. It should be noted that the models are not able to provide an optimal bundle size for each tree-size class.

It is clear that the full-tree systems with chain-flail technology, hence able to handle multiple stems throughout the system, are much less sensitive to tree-size than systems with DHP and harvester-head technology (CTL). This mass handling of trees, stems and logs compensates for situations where small tree sizes are encountered. The cost graphs for the various processing technologies demonstrate this. There is a large cost increase with the harvester system in very small tree sizes of 0.075 and 0.15 m^3 trees. This is due to the harvester only being able to fell and process one tree at a time.

For the type of conditions encountered in the research and when logs are required, the results show that all trees of approximately 0.075 m^3 should be harvested utilising the CFDD system. If cost per m^3 is the primary consideration, 0.15 m^3, 0.25 m^3 and 0.40 m^3 trees should be harvested with a DHP system.

When harvesting trees of 0.40 m^3, the harvester system might be better. Even though this is not the system with the lowest cost, other benefits, such as reduced environmental impact and lower road-density requirements, make it an attractive option.

Should the BWBS increase above class 3 or the form factor reach class 2 or higher, the CFDD system should be selected for all the tree sizes. The DHP operated in trees with good BWBS and very good form classes and it is predicted that the harvester and DHP would have a significant reduction in productivity (with concomitant cost increases), should the BWBS or form classes increase. If forest-management policy dictates that harvester systems should be used, the only way to reduce costs would be to manage according to a regime which allowed trees to grow to a larger individual size. The administrators of a particular company would have to determine what cost premium they would be prepared to pay for the additional, non-direct cost benefits that a harvester system can offer.

If producing chips, the most cost-effective system over all the tree sizes researched is the CFDDC system. It had the lowest cost of all the systems in 0.075 m3 trees (although as discussed, it is predicted that the CFDD is actually more economical).

If making a decision whether to chip trees in the forest or at a processing facility, it is clear that the cost difference between the chipping systems and log-production systems could make chip production in the forest worthwhile.

5 Conclusions and recommendations

This final chapter concludes the research. The main findings are summarised and briefly discussed. The results are related to the findings of the literature review. The significance of the results to the forestry industry is indicated and recommendations for the practical application of the results in future are offered.

5.1 Summary and discussion of main findings

There is currently a global increase in *Eucalyptus* pulpwood plantations. Harvesting systems traditionally utilised in the northern hemisphere are being used in *Eucalyptus* pulpwood plantations worldwide. However, the small tree size and complexity of debarking *Eucalyptus* have provided harvesting with productivity and cost challenges not previously experienced in northern-hemisphere conditions.

Cut-to-length (CTL) and full-tree systems have been the two main mechanised harvesting methods available to forestry managers. CTL systems process trees into logs at the stump inside the compartment; with full-tree systems, the tree is felled and then extracted to a landing where it is processed – its top and branches remain intact. An advantage of full-tree systems is their ability to handle multiple stems, which could assist in overcoming current problems with the small, pulpwood tree sizes.

Much research has been invested in these two harvesting methods in northern-hemisphere species and conditions. The literature identified tree size as being the major driver of processing-machine productivity for all tree species. With single-stem processing machines, the relationship between tree size and productivity is direct. However, with multi-stem processing machines, the number of trees processed at one time (bundle size) influences productivity.

There is little research available on mechanised processing-machine productivity and costs in *Eucalyptus*. This investigation therefore aimed to quantify the effect that tree and bundle size has on the productivity of different processing machines in *Eucalyptus* plantation pulpwood. This was done through regression analysis, whereby productivity models that included tree size and bundle size were constructed.

The research also aimed to determine whether or not the multi-stem systems were more cost-effective in smaller tree sizes. Because the processing machines carried out different processing functions, it was not possible to make machine or system decisions based on productivity alone. The research therefore costed out different harvesting systems associated with each processing machine for different tree sizes.

The research investigated five mechanised harvesting options that forestry managers could use in *Eucalyptus* pulpwood plantations. These systems consisted of one CTL system, one full-tree system with single-stem processing and three full-tree systems with multi-stem processing. All the full-tree systems used feller bunchers to fell trees and grapple skidders to extract them. The CTL system, researched in South Africa, used a harvester to process the trees into logs and to extract them. The full-tree system with single-stem processing, also researched in South Africa, used a dangle-head processor (DHP) to process trees into logs. The first full-tree system with multi-stem processing used a chain-flail debrancher/debarker (CFDD) to produce debarked and debranched tree lengths, which were slashed into logs. This system was researched in Chile. The remaining full-tree, multi-stem systems were researched in Western Australia. They both produced chips. The first used a chain-flail debrancher/debarker/chipper (CFDDC) and the second, a CFDD feeding into a stand-alone disc chipper (CFDD&C).

The productivity of the processing machines was measured on site, using time-and-motion study methods. The tree-size class, BWBS class and form class for each tree were identified before processing. For the multi-stem processing machines, the number of trees per bundle was measured while the bundle was being fed into the machine. Debarking quality was measured once processing had taken place. The productivity data, measured as m^3 per productive machine hour (PMH), was then statistically analysed using regression techniques. Productivity equations were formulated, considering tree size and bundle size, as well as the quadratic functions of these two variables and the interaction between them. Bundle size was only applicable to the multi-stem processing machines. The productivity equations successfully predicted processing-machine productivity, using tree size and bundle size as input variables.

The first hypothesis underpinning this study offered a null and an alternative premise. Because productivity was effectively predicted, the null hypothesis was rejected and the alternative hypothesis recognised as valid:

> Prediction models **are able** to relate productivity of chain-flail debrancher/ debarkers, chain-flail debrancher / debarker / chippers, chain-flail debrancher/ debarker and chippers, dangle-head processors and harvester-processing machines to tree size and bundle size.

The second hypothesis upon which this study is based led to an investigation of whether or not full-tree, multi-stem systems had lower costs than CTL and full-tree, single-stem processing systems in very small tree sizes.

The question of bundle size is complex. Inserting an increasing number of trees per bundle into the equation for a given tree size resulted in a productivity curve. It was not known exactly which bundle size should be used to predict processing-machine productivity for a given tree size, because in many cases the productivity curve continued to increase. Therefore, the actual bundle size observed during the research for each tree size class was used in the productivity prediction equation. As indicated in section 5.4 (Recommendations for the future) below, bundle size needs to be researched further.

The models provided the following productivity information:

- Apart from the 0.075 m^3 tree size, the CFDD had the highest overall productivity. When processing 0.075m^3 tree sizes, this machine reflected a similar productivity level to the CFDDC: approximately 40 m^3 per PMH. The CFDD productivity per PMH increased more rapidly than that of the other processing machines – indeed, it proved capable of very high productivity levels, although the productivity began to taper off at a tree size of 0.25 m^3. The CFDD processed 0.40 m^3 trees at 95 m^3 per PMH.
- The CFDDC, which can productively process small trees, showed a steady increase in productivity as tree sizes increased, ranging between 39.1 m^3 and 67.4 m^3 per PMH.
- Productivity levels in the CFDD&C also increased consistently from smaller (0.075 m^3) to larger (0.40 m^3) tree sizes: from 29.4 m^3 to 61.3 m^3 per PMH. The CFDDC productivity remained slightly higher than the CFDD&C throughout the range of tree sizes.
- DHP productivity started low (9.7 m^3 per PMH for 0.075 m^3 trees), but increased sharply to 52.0 m^3 per PMH with 0.40 m^3 trees.
- In relation to the other processing equipment, the harvester productivity for the 0.075 m^3 tree size was very low (5.0 m^3 per PMH) and had the flattest of all the productivity gradients, only reaching 22.2 m^3 per PMH in 0.40 m^3 trees.

The costs of the five systems were then calculated for different tree sizes. Costs regarding the machines (for example: ownership, operating and operator costs, overheads) were sourced for all the systems and inserted into costing models. Productivity information for other machines in the system was obtained. The results of the system costings were then summarised. Multi-stem systems were predicted to have lower costs in very small tree sizes.

The two lowest cost systems for the 0.075 m^3 tree-size class were the CFDD and CFDDC multi-stem systems. However, the costs of the DHP single-stem processing system in this tree-size class were lower than those of the CFDD&C.

Therefore, the null hypothesis was accepted for the second hypothesis:

> Full-tree, multi-stem systems **do not** have lower costs than CTL and full-tree, single-stem processing systems in very small tree sizes.

Only if systems producing logs were taken into consideration would the null hypothesis be rejected, as the CFDD system had lower system costs for small trees than both the DHP and harvester systems.

No single system was more cost-effective than the others across all tree sizes. The key results are provided below:

- In 0.075 m^3 trees, the CFDDC system proved the most cost-effective, with costings slightly lower than those of the CFDD system. Indeed, all systems evidenced high costs in the 0.075 m^3 trees, ranging between $19.43 per m^3 for the CFDDC system to $28.84 for the harvester system, with a cost difference of $9.41 per m^3 (48 per cent).
- In 0.15 m^3 trees, the DHP system had the lowest costs at $11.94 per m^3, with the CFDD following very closely at $12.16 per m^3. The harvester and CFDD&C systems were the most expensive at $16.57 and $16.70 per m^3 respectively, 40 per cent more expensive than the DHP system.
- In 0.25 m^3 trees, the DHP system had the lowest cost at $8.60 per m^3. This was followed by the CFDD system at $9.76 per m^3. The CFDD&C was the most expensive system at $13.77 per m^3, 60 per cent more expensive than the DHP system.
- In 0.40 m^3 trees, the cost differences between systems were lower, ranging from $6.91 per m^3 for the DHP system to $11.84 per m^3 for the CFDD&C, a difference of only $4.93 per m^3, but still 71 per cent higher for the CFDD&C. The costs pertaining to the CFDD system were second lowest, following the DHP, at $7.93 per m^3.

The cost-per-m^3 differences between the systems had already narrowed by the 0.15 m^3 trees, with the difference between the most expensive (CFDD&C) and most cost-effective (DHP) being $4.67 per m^3. This difference was then maintained through to the largest tree size of 0.40 m^3. The largest cost reductions occurred in the harvester and DHP systems (single-tree processing), between the 0.075 m^3 and 0.15 m^3 tree-size classes. The harvester proved to be the most expensive system for 0.075 m^3 trees, but was cheaper than the CFDD&C and CFDDC systems for the 0.40 m^3 trees.

5.2 Interpretation of results in relation to the literature review

The literature review carried out in Section 2 showed that much research information on productivity and costs of mechanised harvesting systems was available for traditional northern-hemisphere species and conditions. Many variables that could affect productivity of processing machines and systems were highlighted. Tree size was consistently accentuated as the most important variable. Productivity increased and costs decreased as tree size increased for all processing machines, until the physical limitations of the machines were reached.

However, the literature also showed that little information was available on productivity and costs of mechanised harvesting of *Eucalyptus*. The existing information only considered CTL systems with harvesters and full-tree systems with CFDDCs. There was no information that considered tree size as a productivity input variable for full-tree systems with DHPs, CFDDs or CFDD&Cs.

The research results were consistent with the general literature on the effect of tree size on productivity and cost. All processing machines showed increases in productivity with increasing tree size. All systems also showed lowering of costs per m^3 as tree size increased.

The most comprehensive research on mechanised harvesting systems for *Eucalyptus* to date was carried out by Spinelli, et al. (2009). This research investigated tree size as a productivity variable in a CTL system utilising a harvester or a forwarder, and a full-tree system, utilising the CFDDC. The cost graphs per tree size in the Spinelli, et al. (2009) research follow very similar profiles to those of the same systems researched in this study. Both sets of research results show costs per m^3 from 0.075 m^3 to 0.40 m^3.

This study confirms the findings of Spinelli., et al. (2009) that the CTL system was very expensive to operate in the small tree sizes (0.075 m^3). The cost-per-m^3 curve gradient of the CTL system is steep down to 0.15 m^3 trees and then flattens out, the latter slightly more in the Spinelli, et al. (2009) research than is evidenced in this study. Therefore, this research indicates that there are greater cost advantages with the CTL system if operating in bigger trees.

Both sets of research results show the full-tree system (with CFDDC) as having the largest cost reduction from the 0.075 m^3 to the 0.15 m^3 trees, but the drop to the 0.15 m^3 trees is not as pronounced in this study as in the Spinelli, et al. (2009) results. From 0.20 m^3 trees, the cost curve gradient for a full-tree system remains fairly flat in both sets of research results.

Because the results of CTL costs in this study show a faster decrease than in the Spinelli, et al. (2009) research, there is a cross-over point at 0.25 m^3 per tree, where the CTL costs become lower than those of the full-tree system. At the 0.40 m^3 tree size, the full-tree system is slightly more expensive than the CTL system. In the Spinelli, et al. (2009) results, there is no cross-over point. At 0.40m^3 per tree, the full-tree system is still slightly cheaper than the CTL system.

Even though the cost profiles do cross over in this investigation, the shape of the cost curves is still very similar to that of Spinelli, et al. (2009). The shapes of the cost curves for all the other processing technologies studied in this research are very similar, with high costs in the small 0.075 m^3 trees, followed by steep drops to the 0.15 m^3 trees and a flattening of the curve to the 0.40 m^3 trees. This indicates that the results are consistent with those of the most comprehensive other research carried out to date.

5.3 Significance of results in the forestry industry

This study, funded by the South African forestry industry, answers many queries regarding tree size and harvesting-system costs for different mechanised harvesting systems in *Eucalyptus* pulpwood and offers the industry solid information upon which to base system decisions. This information will enable the forestry manager to make more informed decisions regarding optimal harvesting systems, taking both tree size and cost into account. The productivity and cost information based on tree size is the first available on CFDD, CFDD&C and DHP systems operating in *Eucalyptus* plantation pulpwood.

5.4 Recommendations for the future

Because so little research on mechanised harvesting of *Eucalyptus* has been undertaken, there are many questions that still need to be addressed. Some productivity input variables for mechanised *Eucalyptus* harvesting are poorly understood.

The sample sizes in very small trees (<0.05 m^3) were too small to predict processing-machine productivity. If this tree size is commonly utilised by companies, more research should be conducted to quantify the productivity levels.

Multi-stem processing machines, like all other processing machines, are primarily dependant on tree size for productivity determination. However, for optimal productivity, the correct number of trees per bundle needs to be processed. As shown in this research, bundle size is affected by tree size, but the optimal number required could not be determined. It is suspected that other factors, such as BWBS and machine set-up, also contribute to productivity level, but no research has been conducted in this area. If this research were commissioned, the results would assist machine operators to optimise the productivity of each bundle processed.

The effect of BWBS on processing machine productivity could affect investment decisions. Some processing machines are thought to be less sensitive to changing BWBS than others because of their technological ability to remove high BWBS bark. The full range of BWBS classes for all processing technologies should be investigated, focusing on circumstances where BWBS is very strong (class 4 and 5). For example, this study showed that DHP productivity for 0.4 m^3 trees was very close to that of the CFDD&C and CFDDC. It is predicted that when the BWBS class becomes very high, this productivity gap will be much wider owing to the lower productivity of the DHP. This requires further research.

The effect of tree form (stem shape and branch size) on processing-machine productivity is also poorly understood. *Eucalyptus* that has been planted off-site, coppice stems that have been poorly managed and certain species with large branches can result in poor form. The literature has shown single-grip harvesters and DHPs to be sensitive to poor form. This is due to the strong grip that the head has to have on the tree to apply sufficient pressure to remove bark and it becomes difficult for the tree length to move through the head. Very little research has been conducted on the multi-stem processing technologies operating in *Eucalyptus*. Research needs to compare the effects of different processing machines dealing with trees of different sizes.

Because conducting research on many different machines on different continents is expensive, there is a good argument for establishing a research collaborative. Such an academic body would facilitate in-depth study without excessive travel time and costs.

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Annexure A

Histograms of actual observation distribution for productivity, bundles size and average tree volume

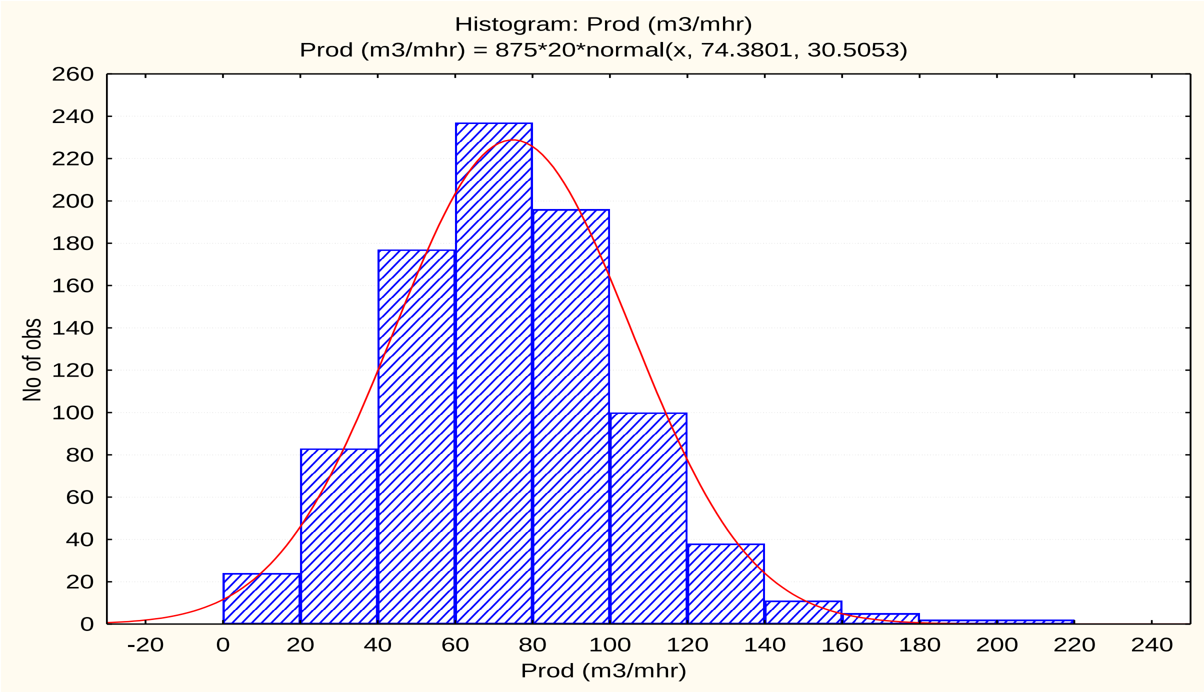

Figure 1: CFDD productivity with outliers

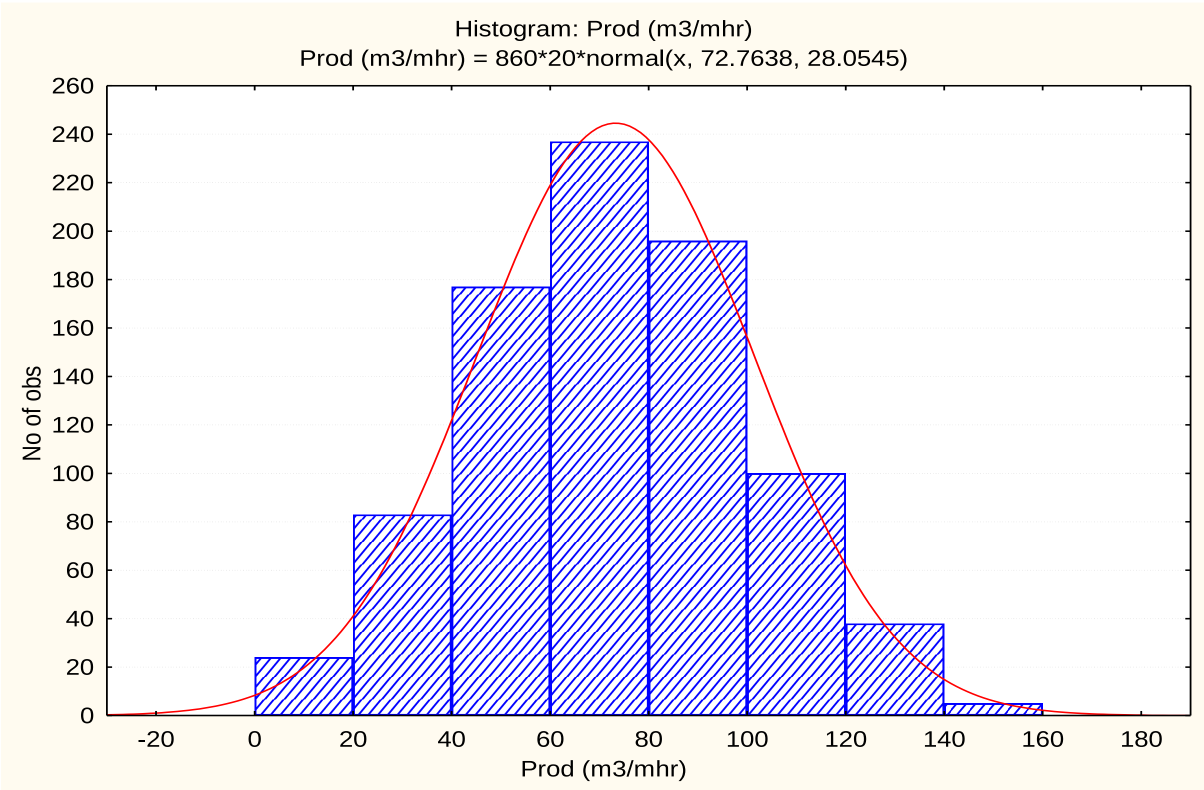

Figure 2: CFDD productivity without outliers

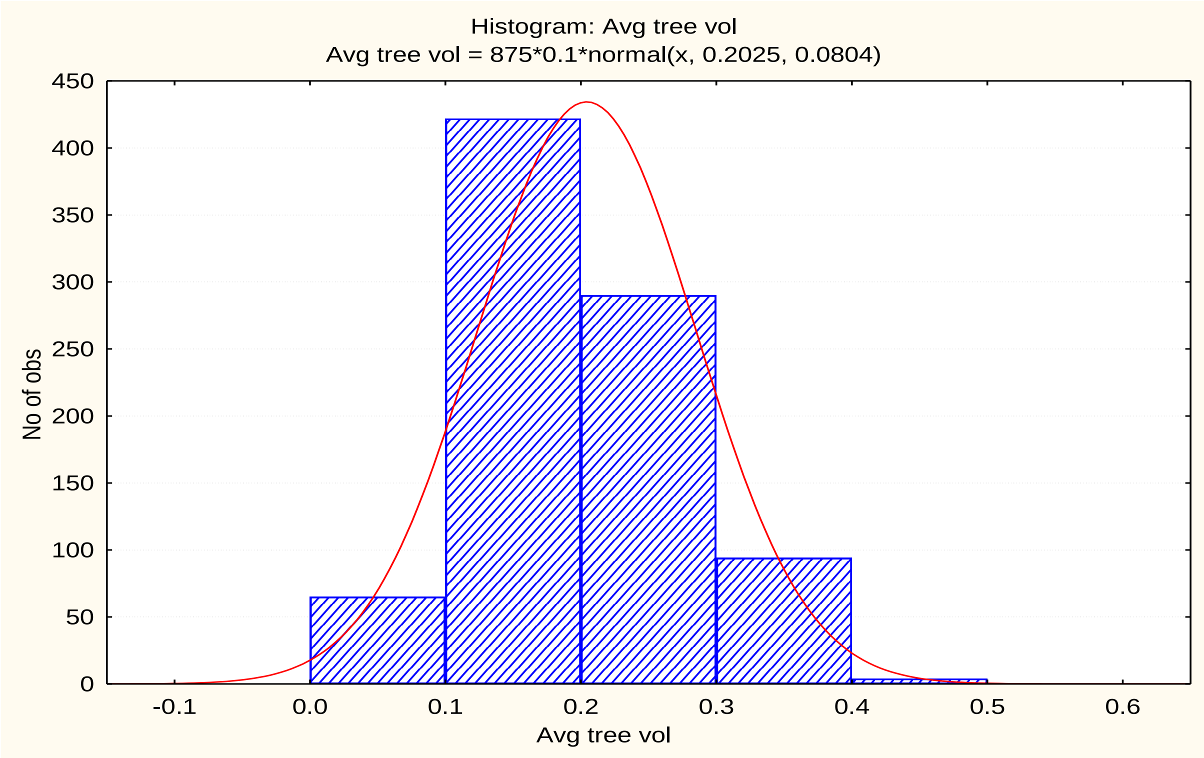

Figure 3: CFDD average tree volume with outliers

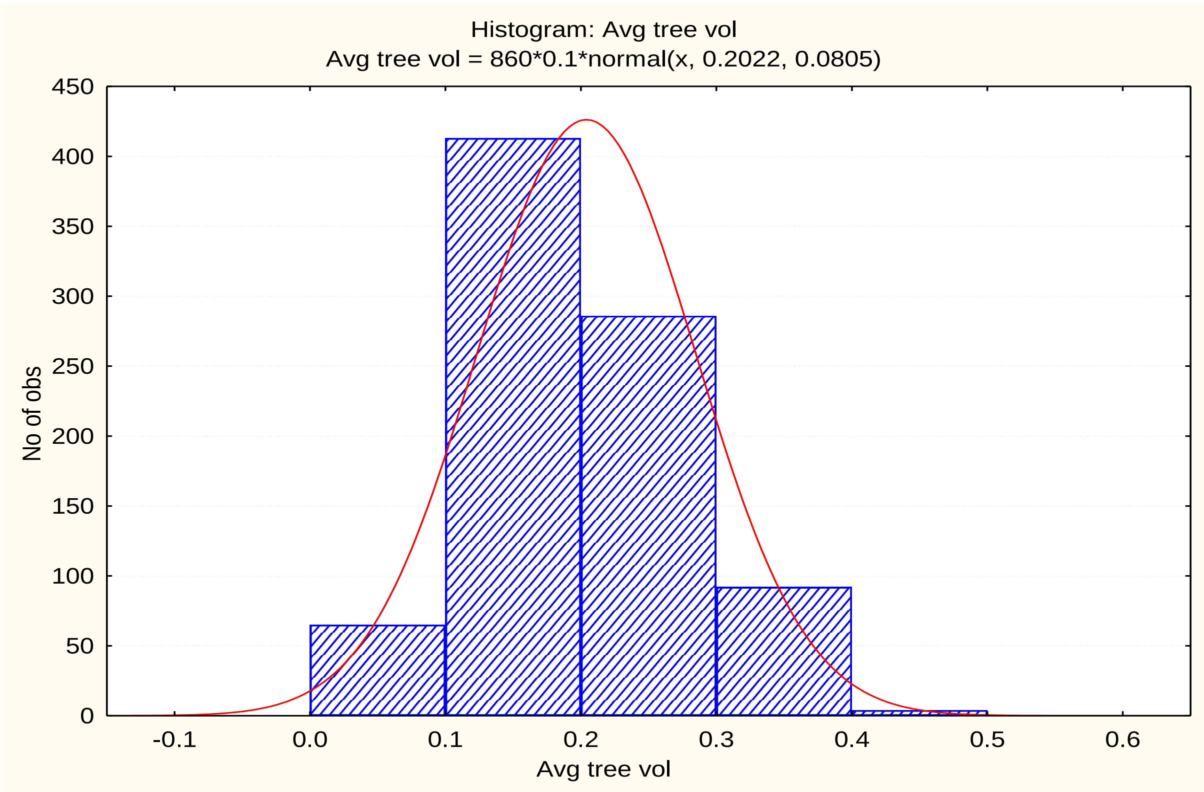

Figure 4: CFDD average tree volume without outliers

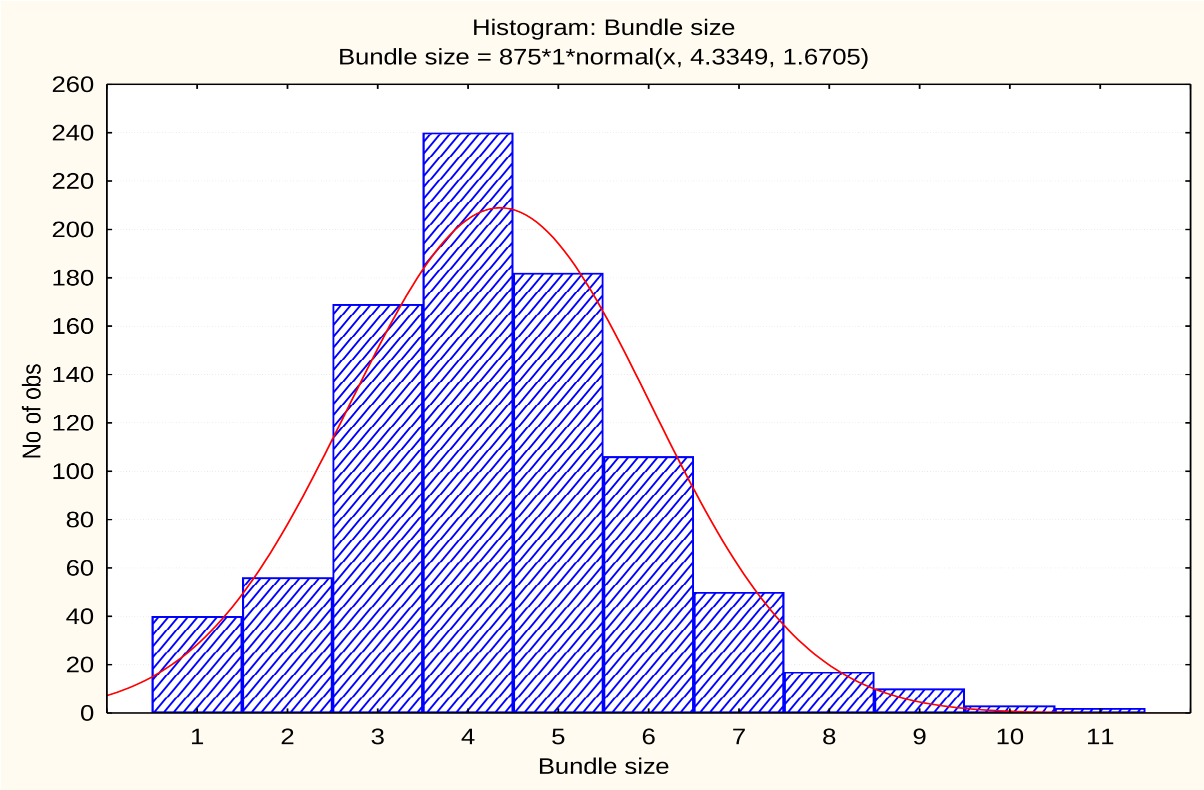

Figure 5: CFDD bundle size with outliers

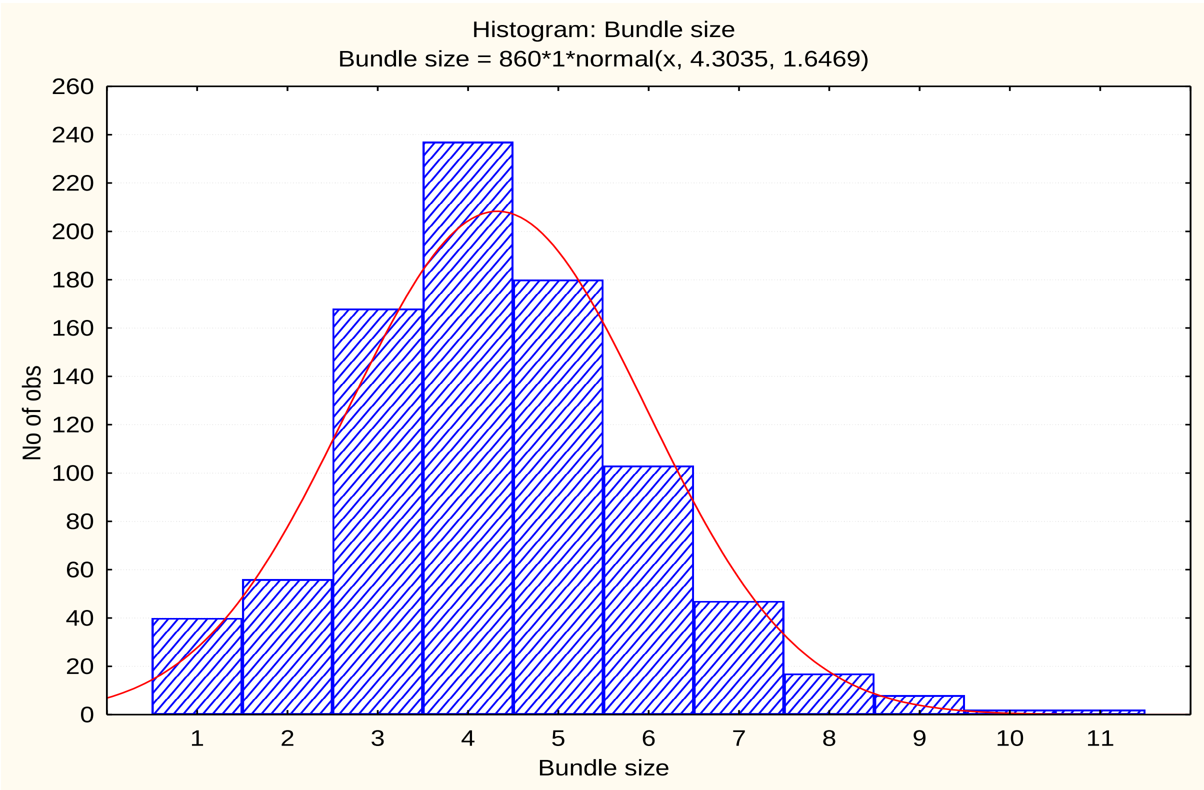

Figure 6: CFDD bundle size without outliers

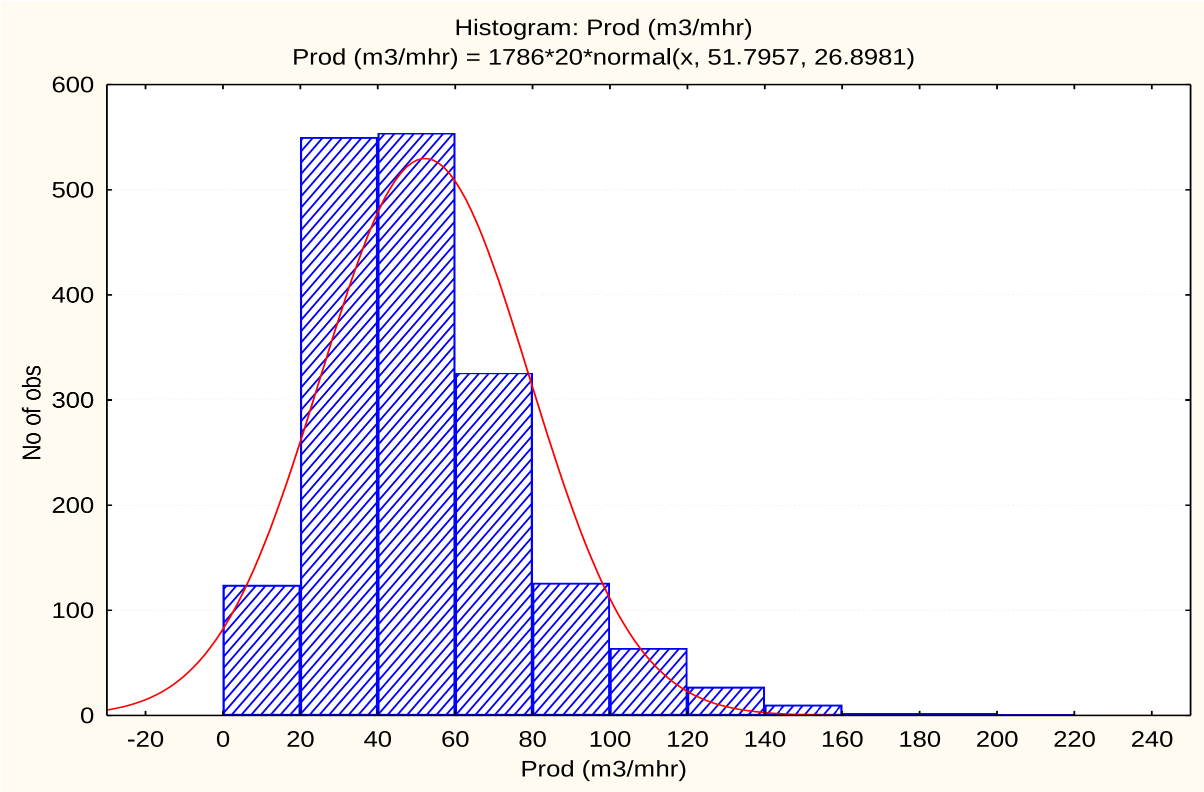

Figure 7: CFDDC productivity with outliers

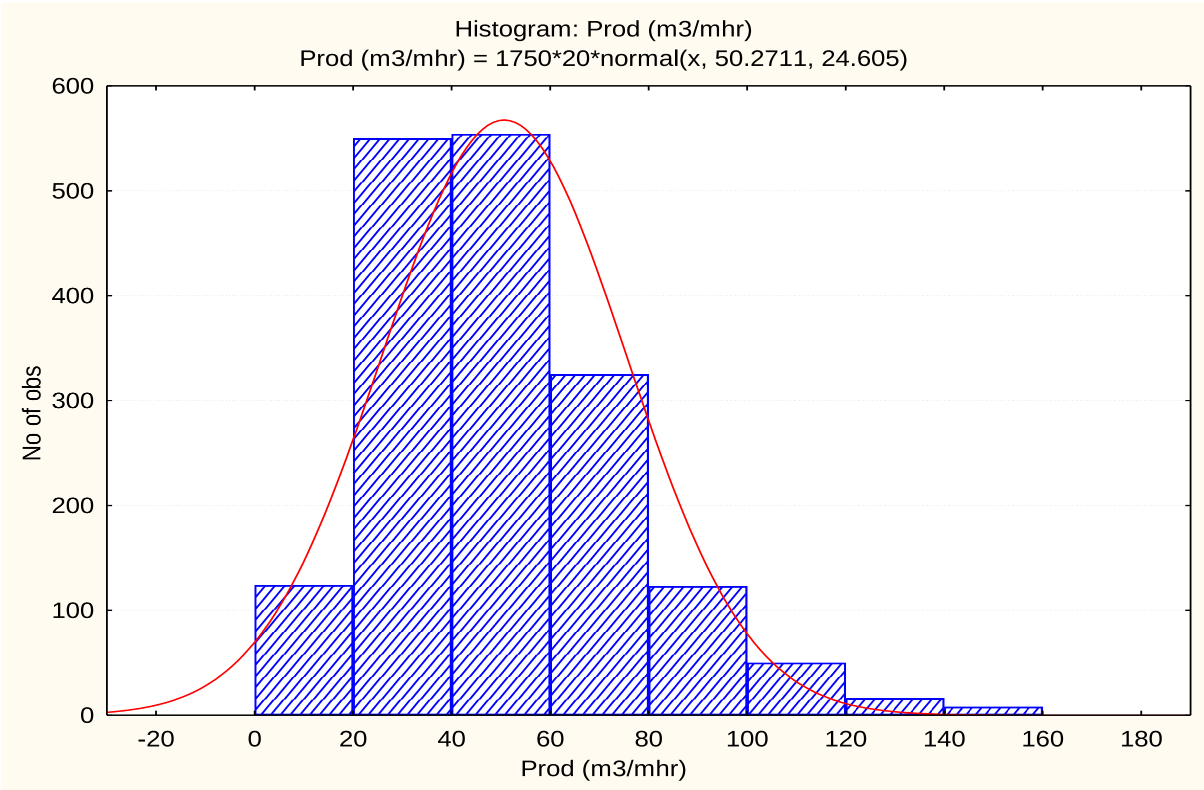

Figure 8: CFDDC productivity without outliers

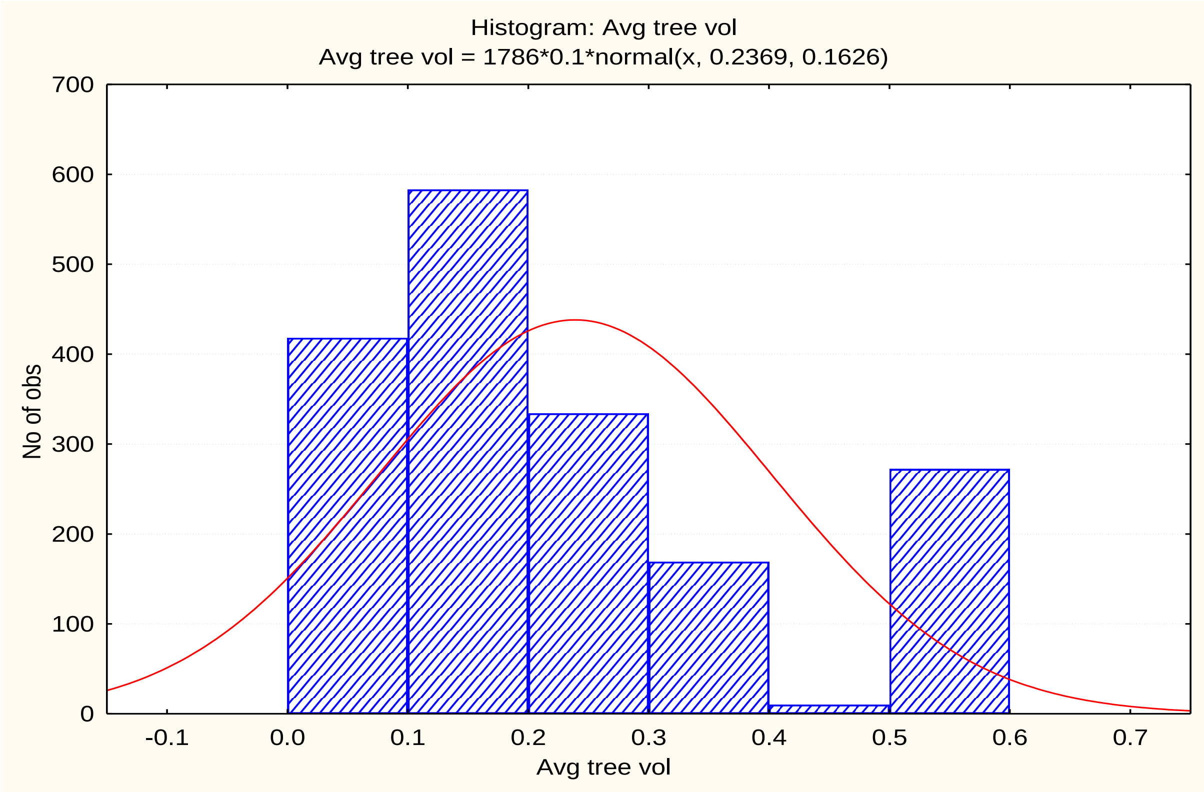

Figure 9: CFDDC average tree volume with outliers

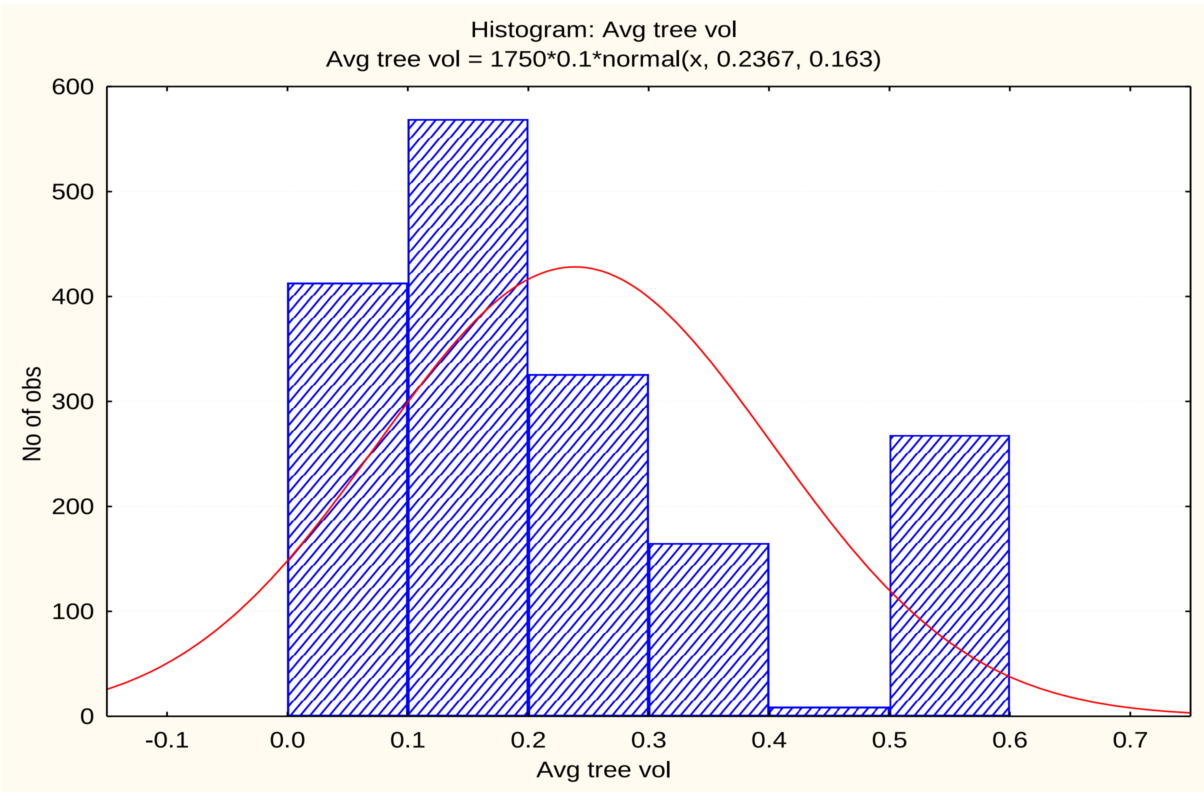

Figure 10: CFDDC average tree volume without outliers

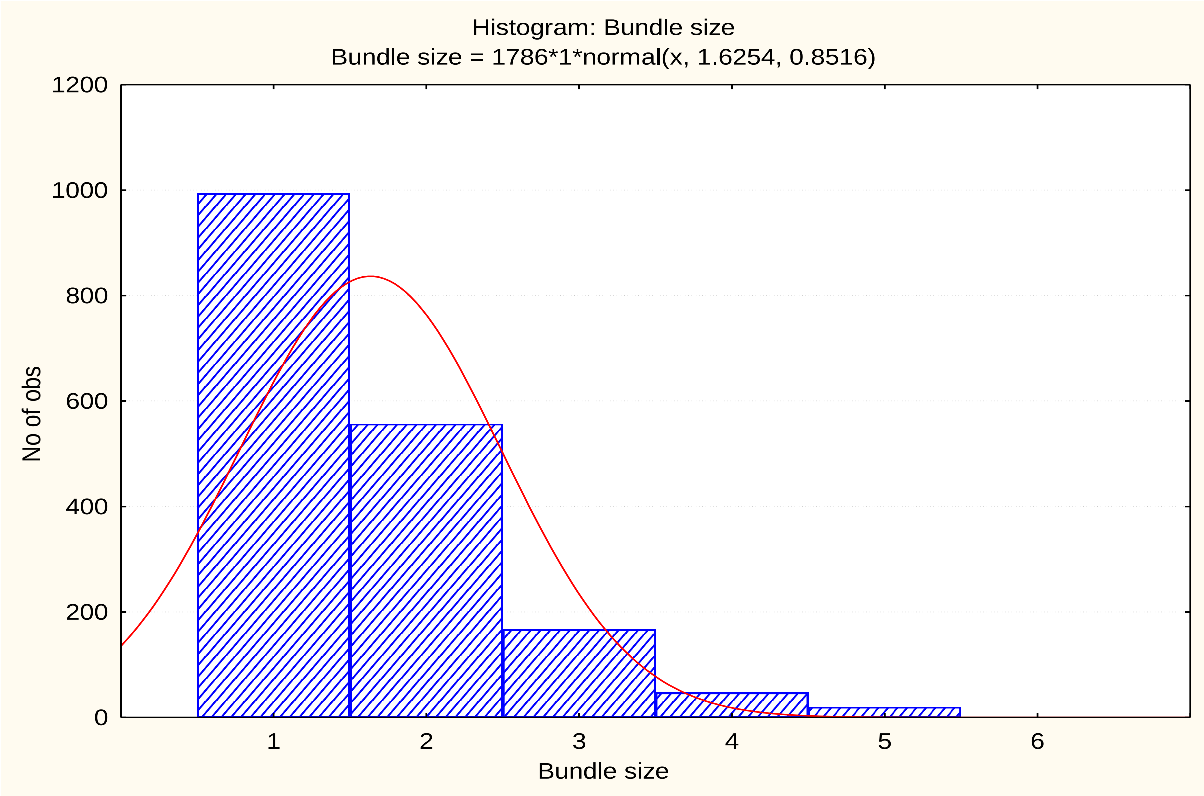

Figure 11: CFDDC bundle size with outliers

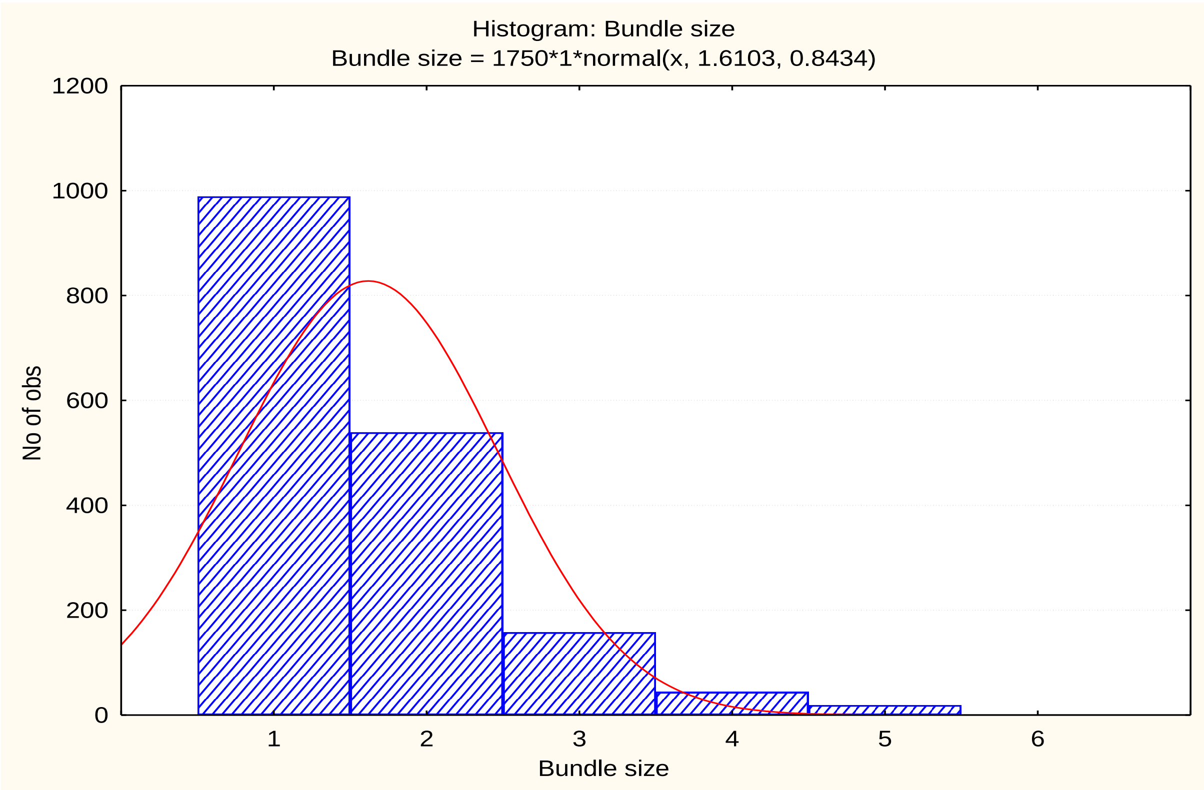

Figure 12: CFDDC bundle size without outliers

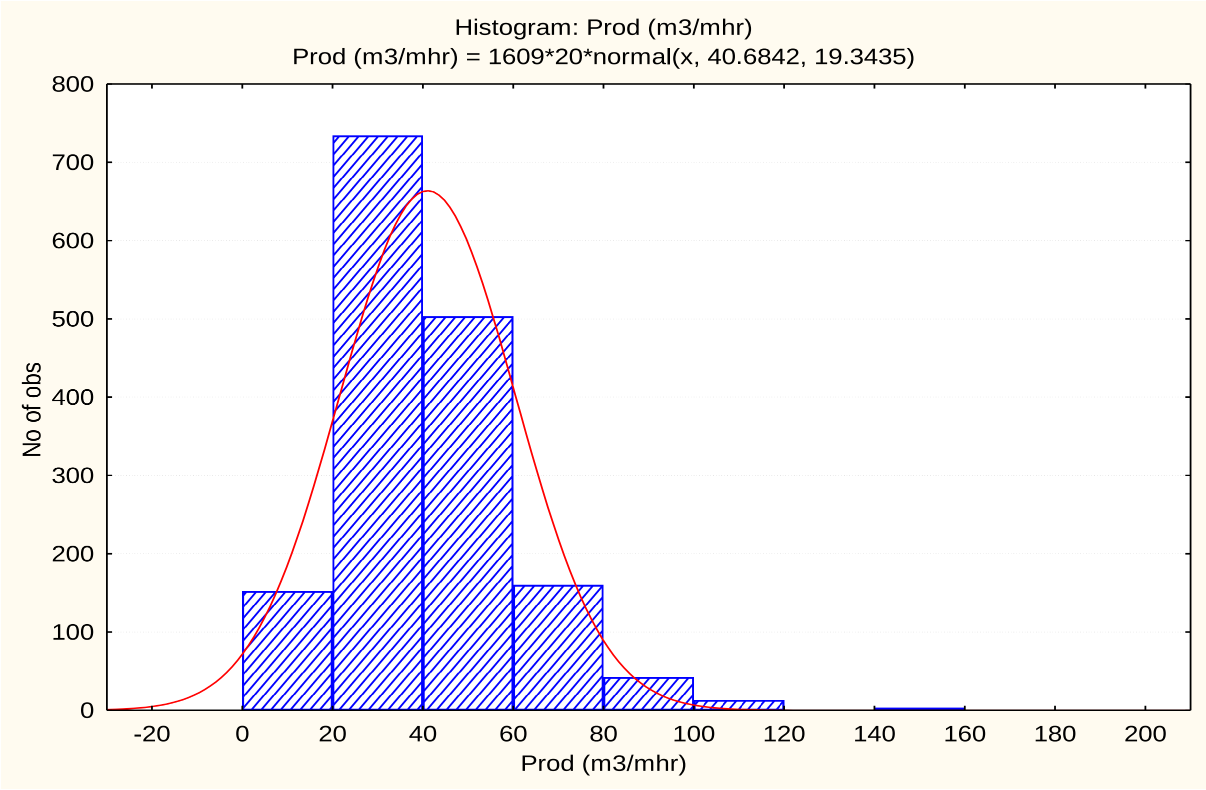

Figure 13: CFDD&C productivity with outliers

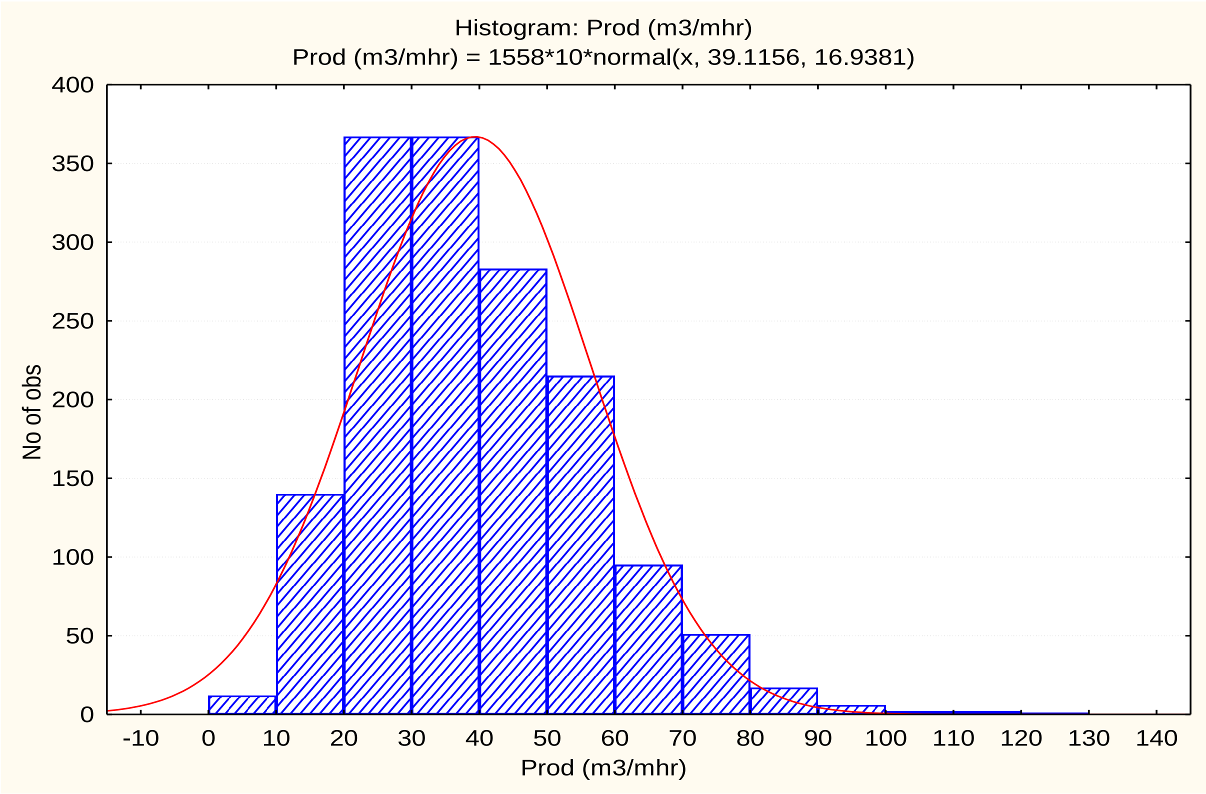

Figure 14: CFDD&C productivity without outliers

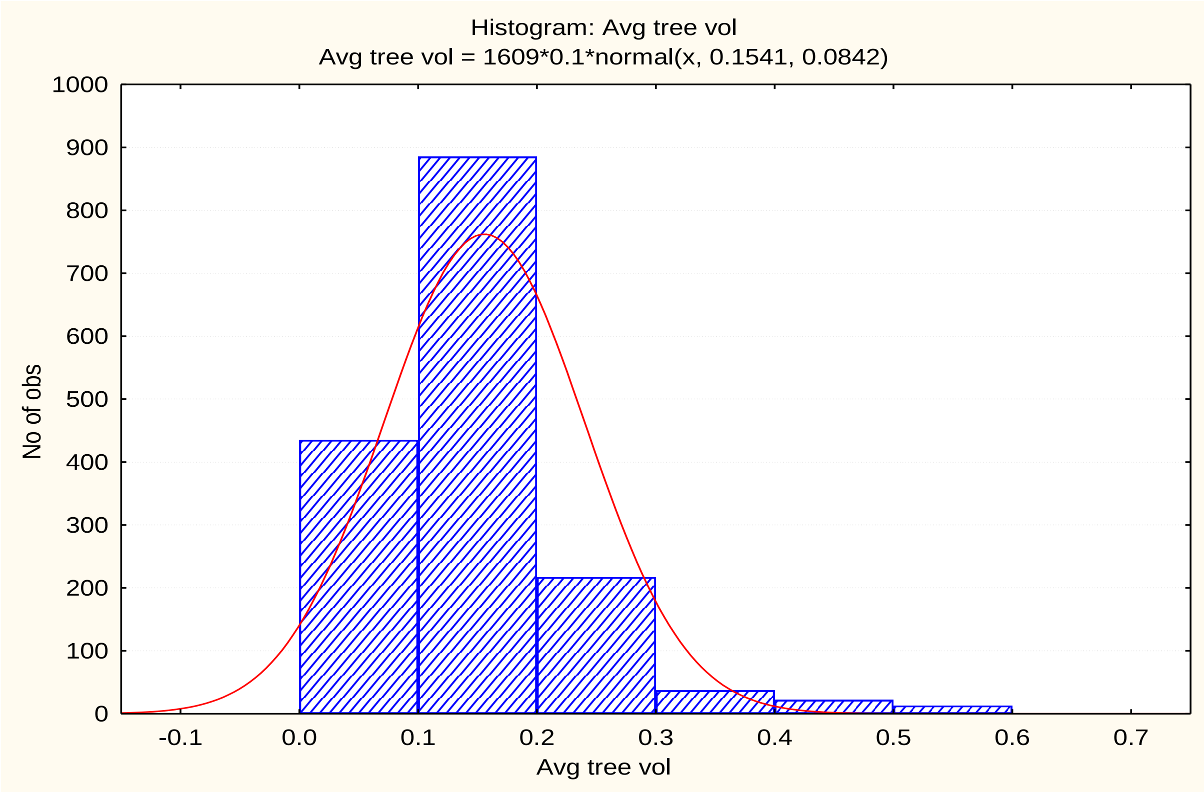

Figure 15: CFDD&C average tree volume with outliers

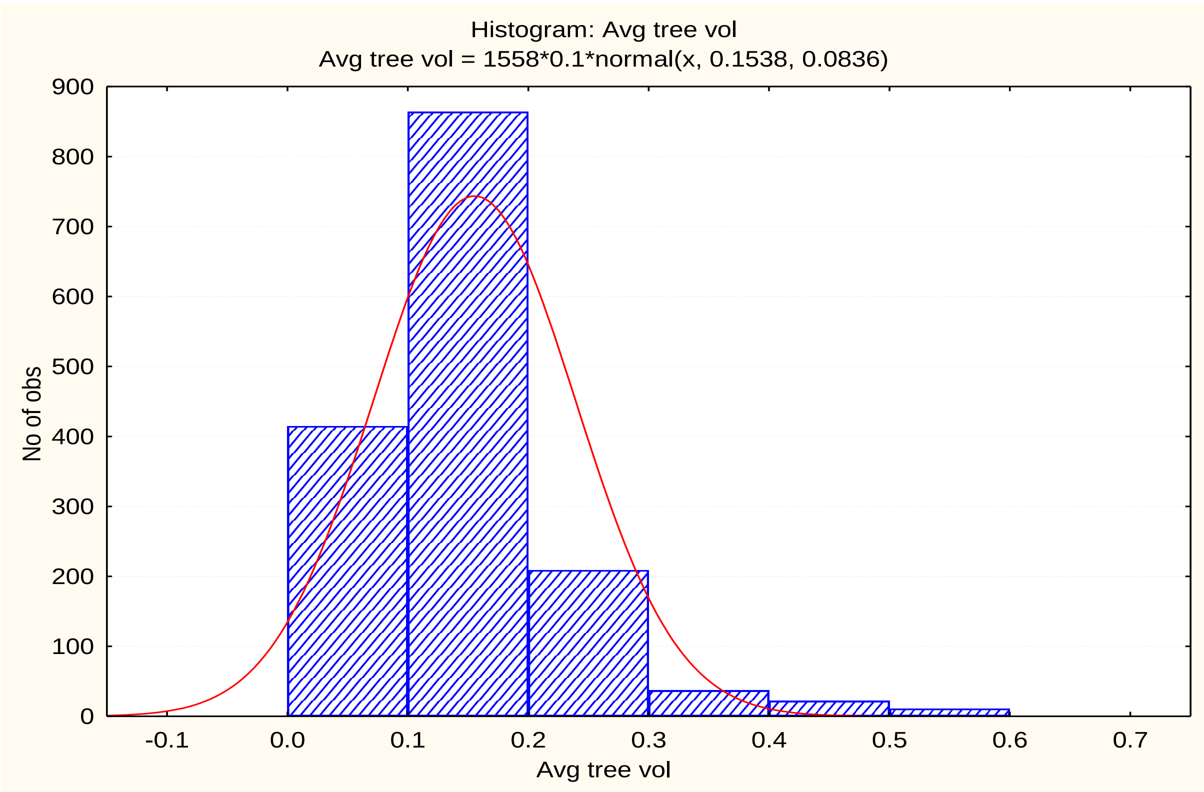

Figure 16: CFDD&C average tree volume without outliers

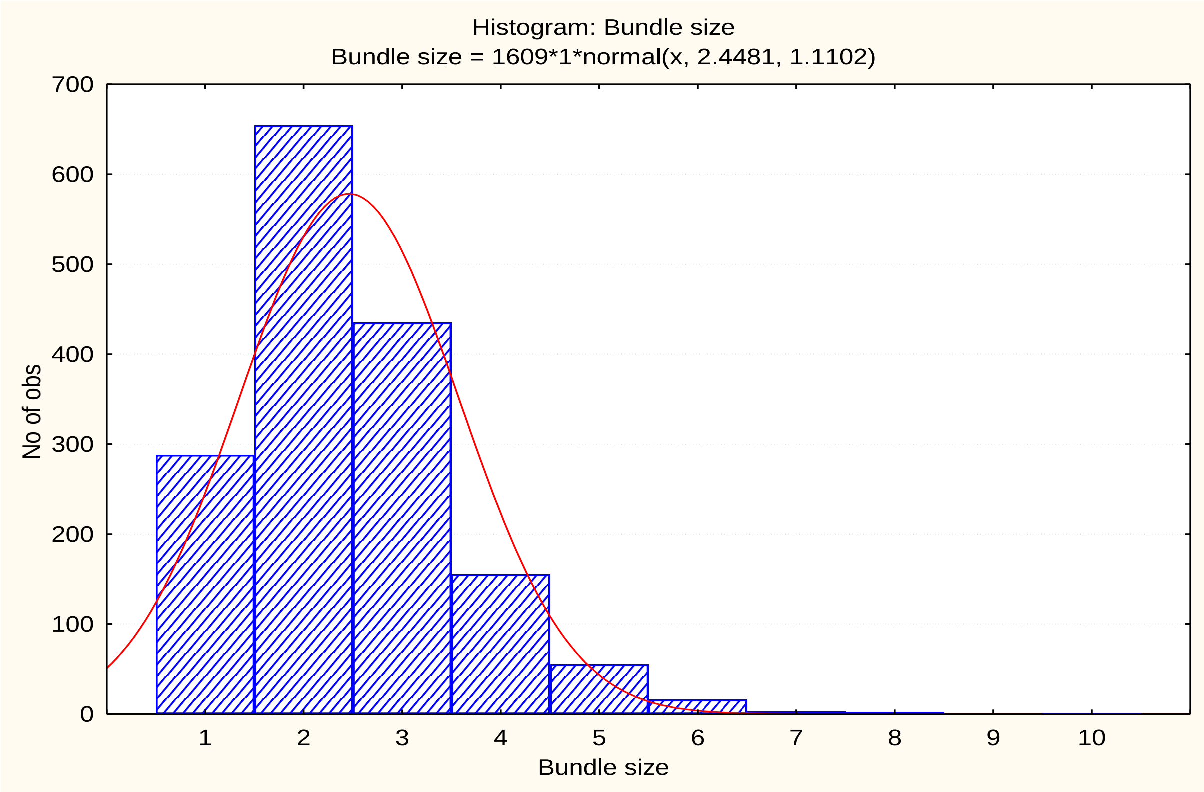

Figure 17: CFDD&C bundle size with outliers

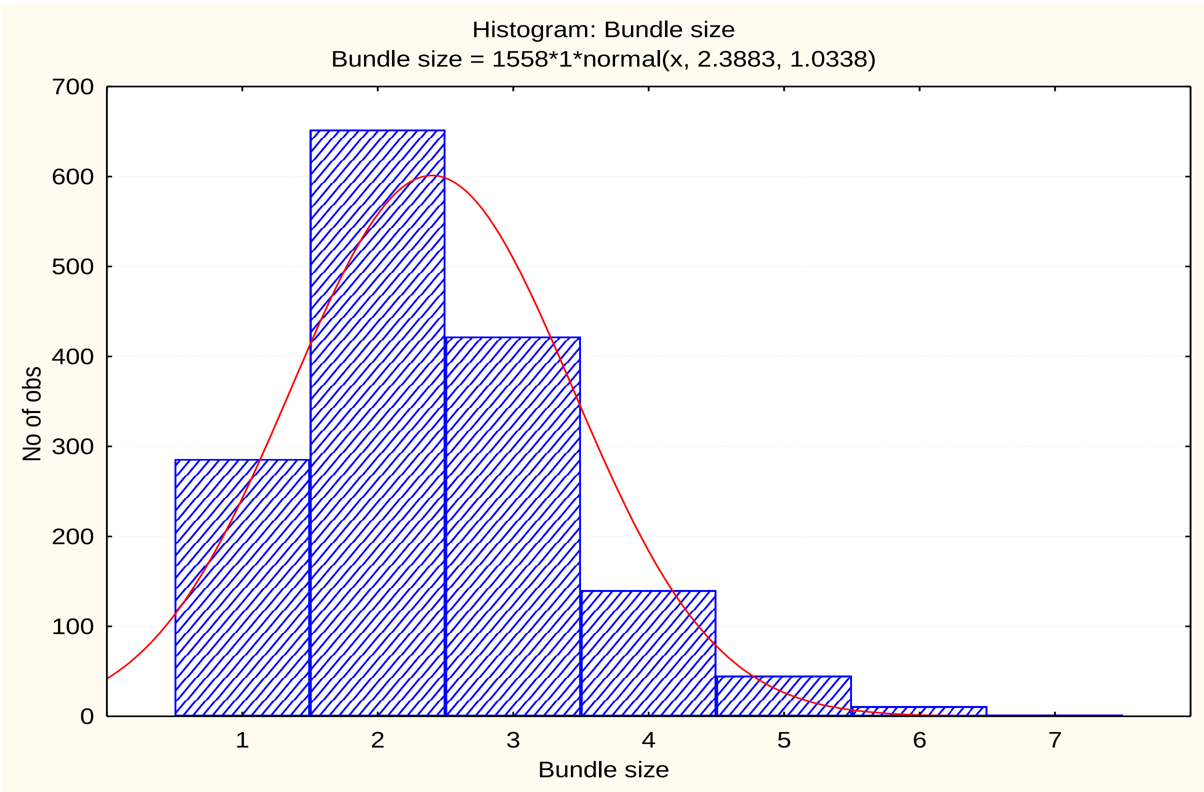

Figure 18: CFDD&C bundle size without outliers

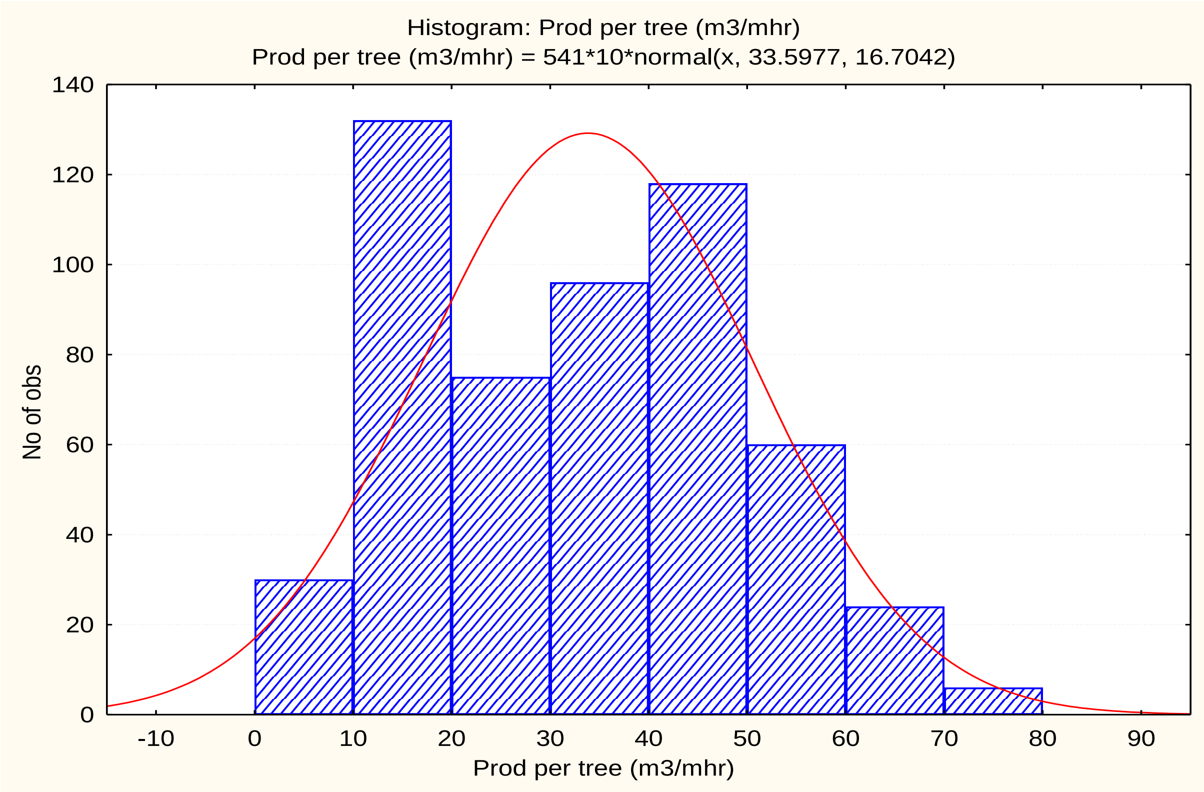

Figure 19: DHP productivity with outliers

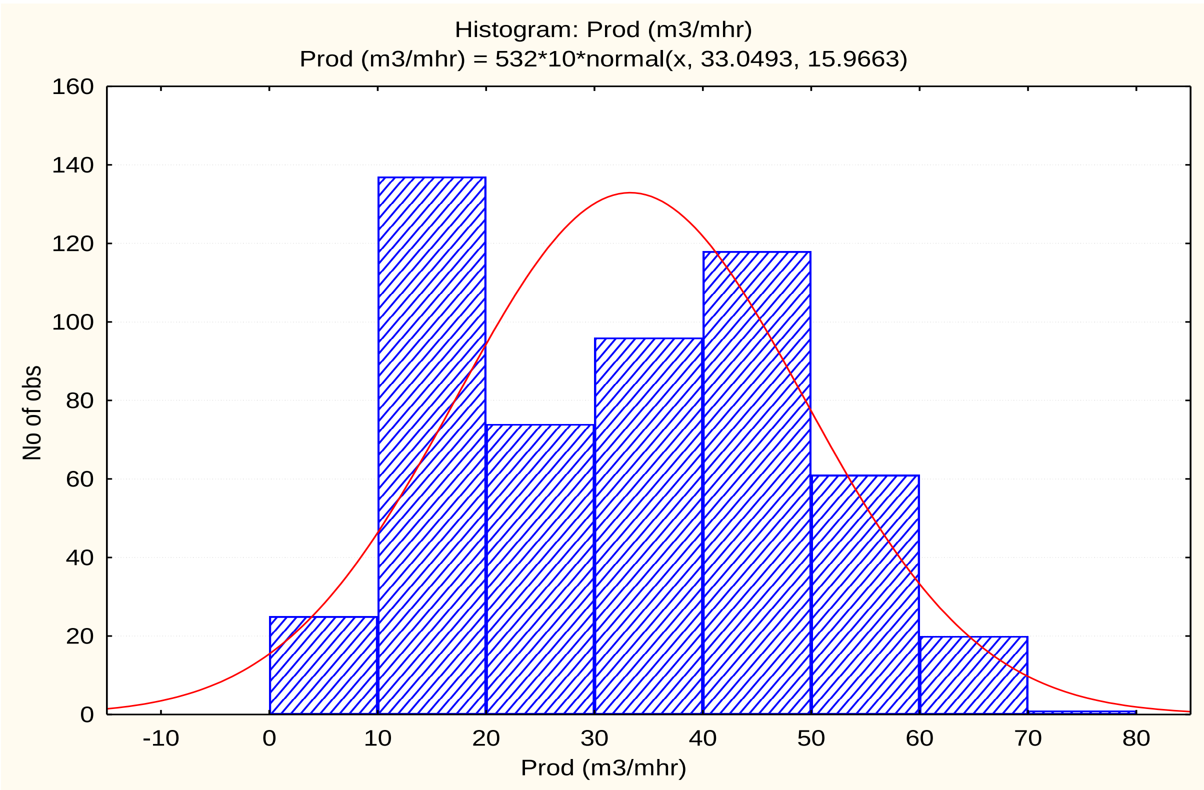

Figure 20: DHP productivity without outliers

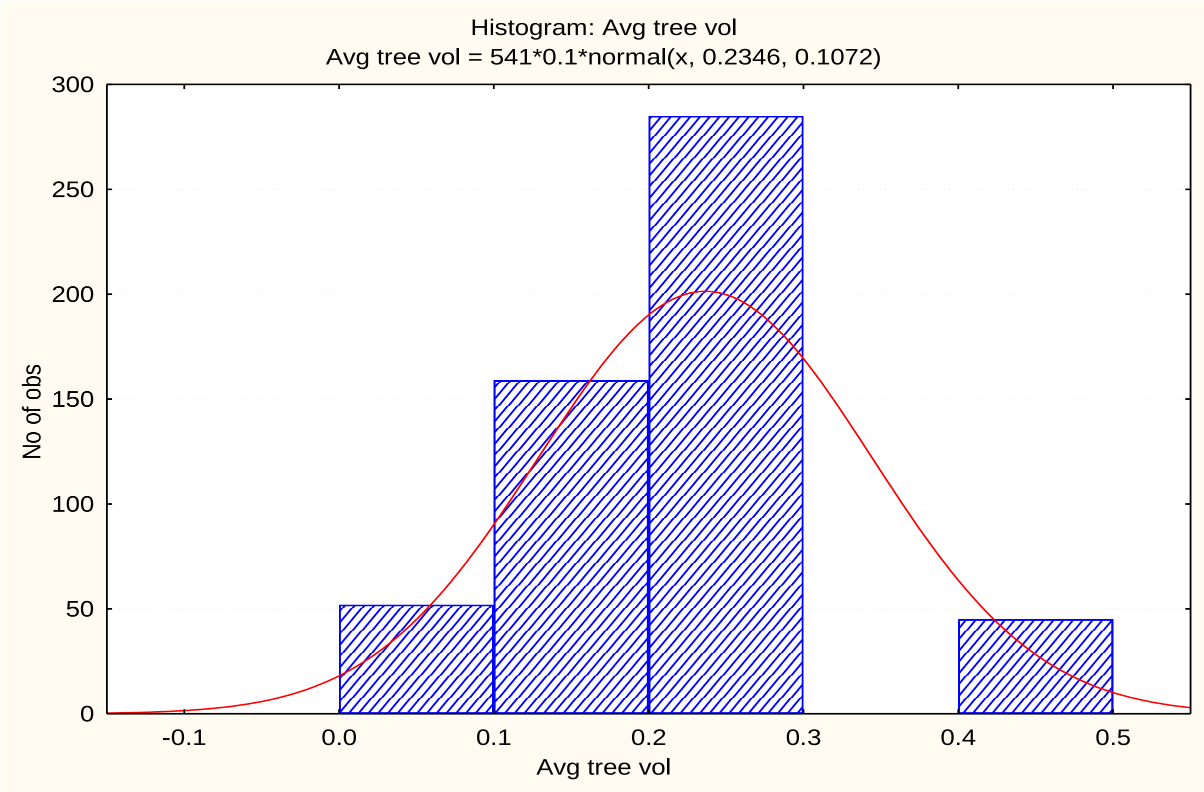

Figure 21: DHP average tree volume with outliers

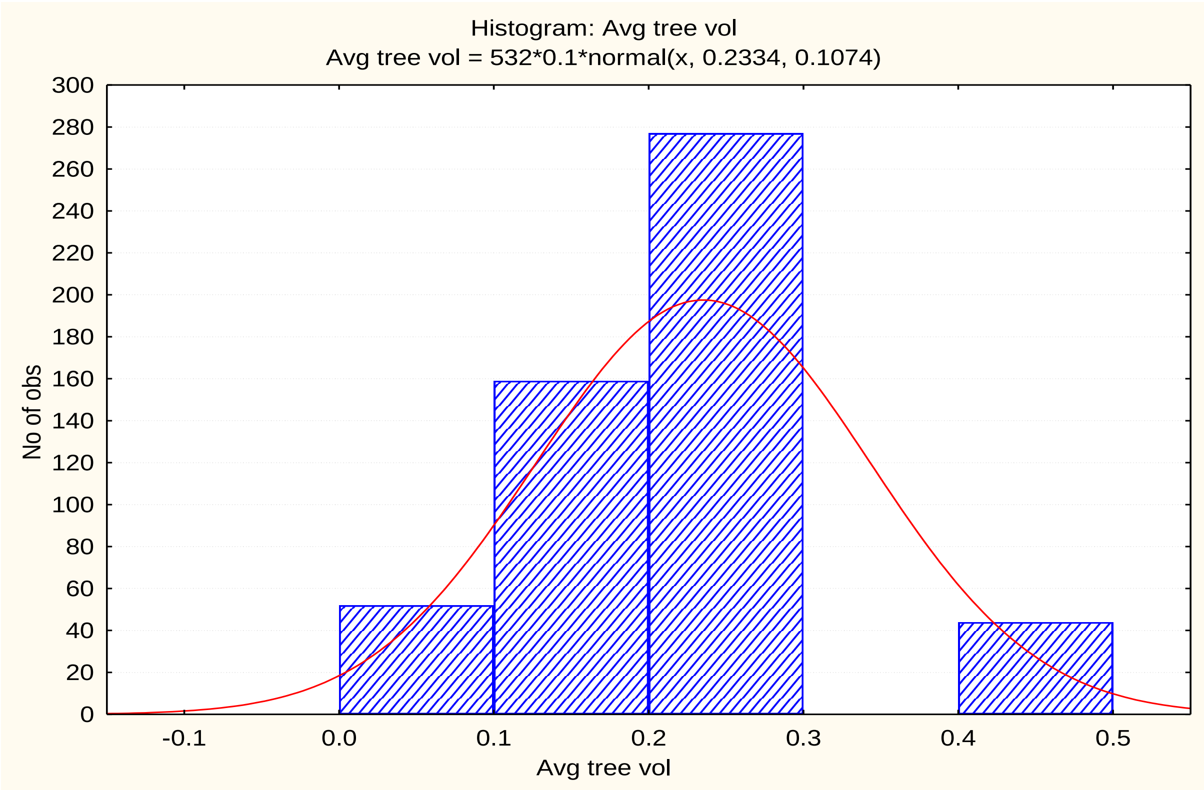

Figure 22: DHP average tree volume without outliers

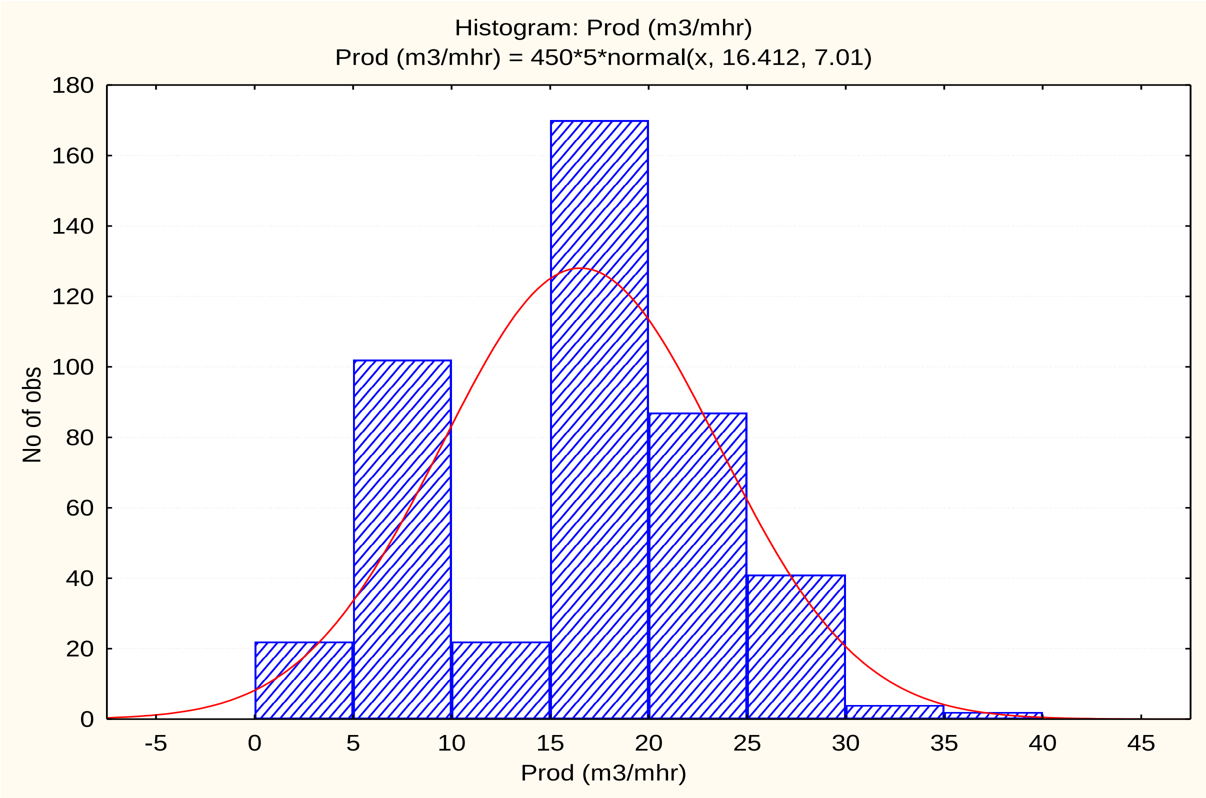

Figure 23: Harvester productivity with outliers

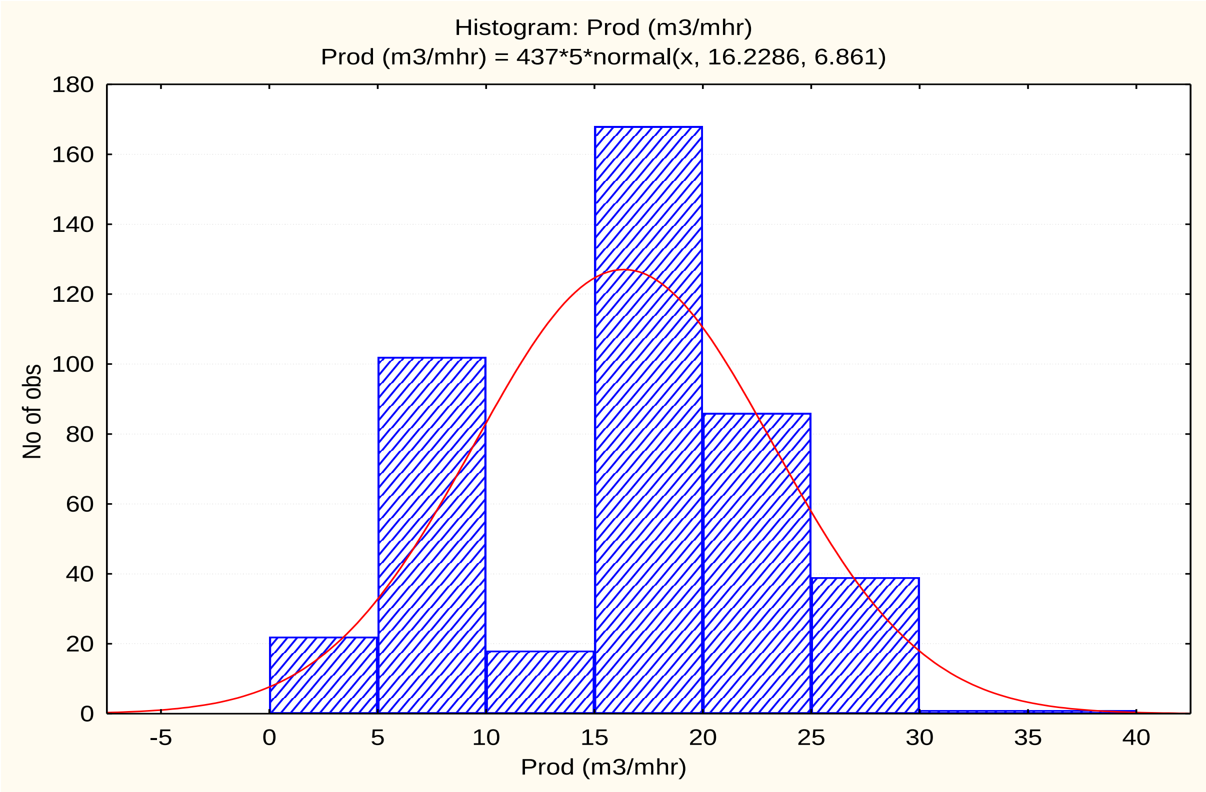

Figure 24: Harvester productivity without outliers

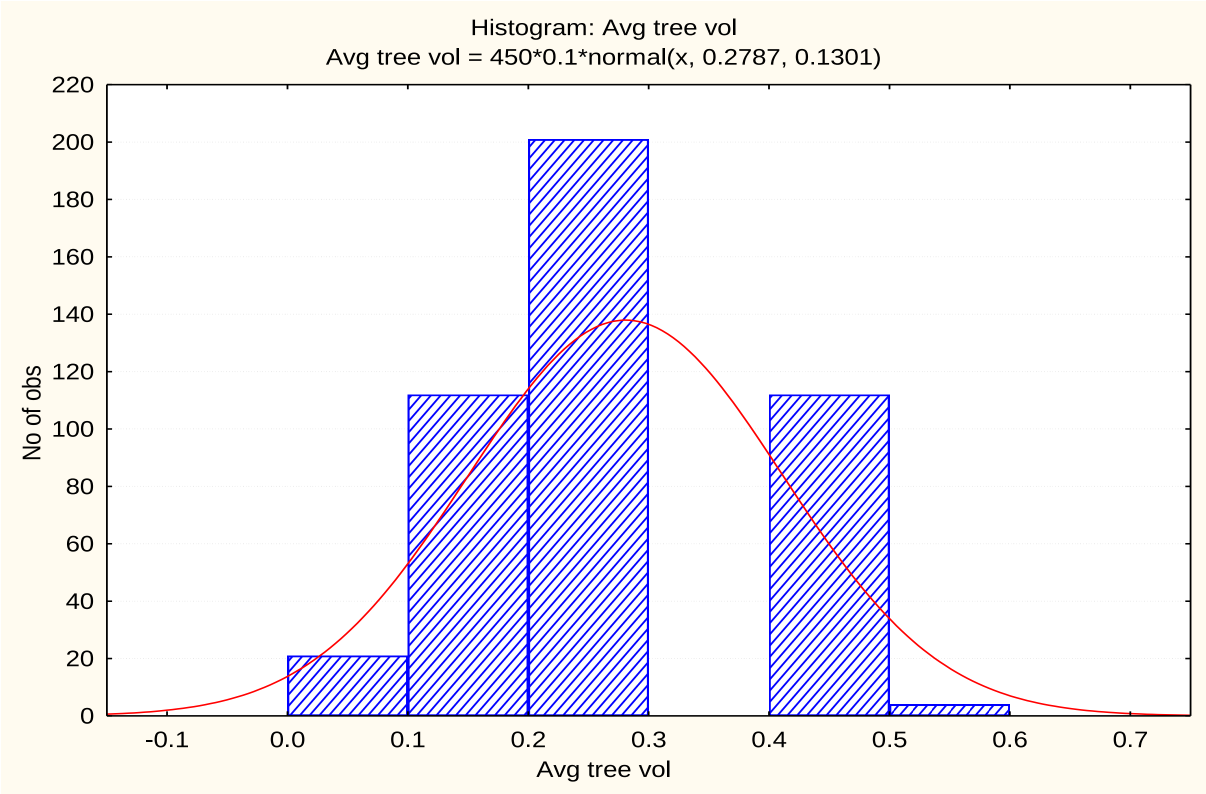

Figure 25: Harvester average tree volume with outliers

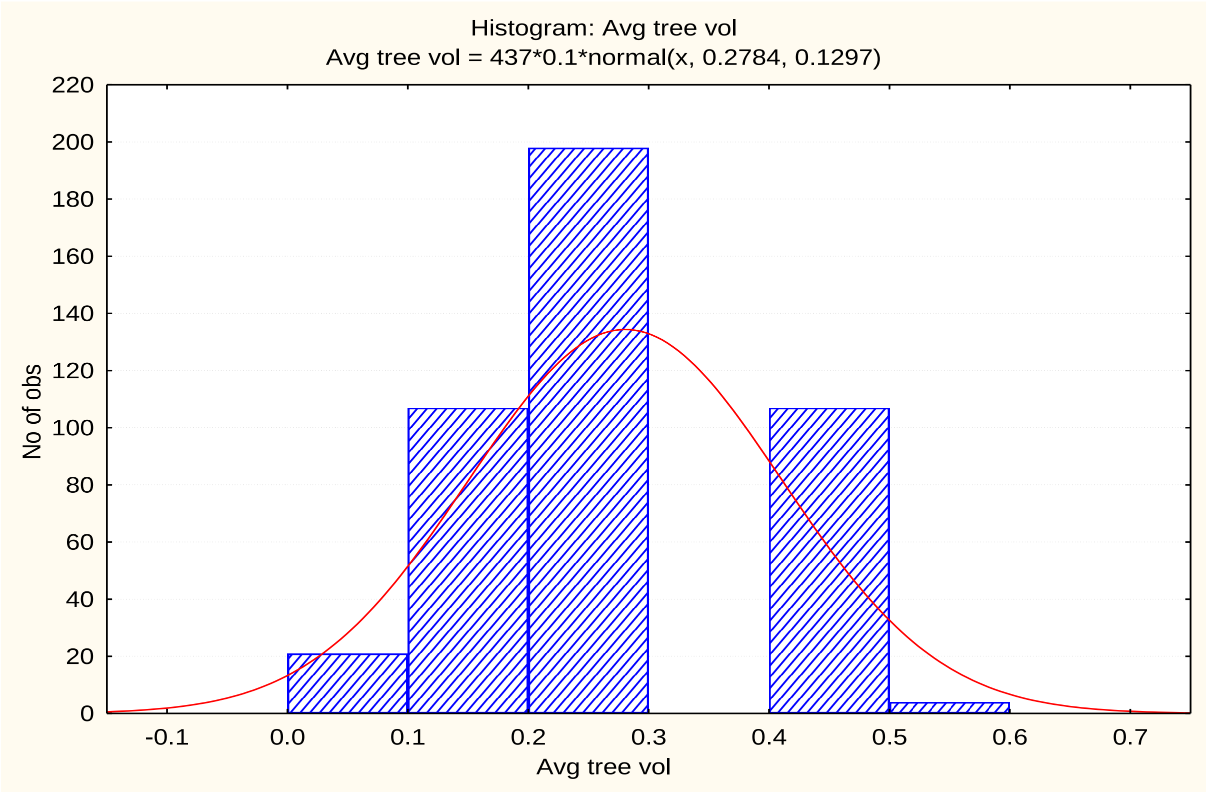

Figure 26: Harvester average tree volume without outliers

Annexure B

Additional data analysis carried out on bark-wood bond strength (BWBS), tree form and quality

1 Effect of combined tree size and BWBS class on productivity

Table 1 shows the results of the initial descriptive statistics analysis carried out in Microsoft Excel. The tables examine tree size and BWBS classes for each technology. The key can be found on the left of the table. The first number refers to the tree size class and the second to the BWBS. It is clear that there is still not sufficient information for all possible combinations of tree size and BWBS class for each processing technology. This is to be expected, as it is not possible to have all the combinations present in one compartment. The sample size would have to be very large to cater for this, which was not economically or practically possible. The green shaded boxes are where the sample sizes for each combination are greater than 20, yellow where the sample size is between 10 and 19, and red where it is below 10. This was done to try and take into account the possible effects that a small sample size might have on the general trends observed in the data. As indicated in the data analysis section, outliers in small sample sizes can easily affect the results. It is clear from Table 1 that certain combinations are missing from each processing technology, and that certain combinations have very small sample sizes. The results of the individual processing technologies are described under separate headings below.

Table 1: Summary statistics results for tree size and BWBS class for the different processing technologies.

	Machine Treatments																								
	CFDD					CFDD & C					CFDDC					DHP					Harvester				
	Mean	Std dev	n	n % of sample	Variance	Mean	Std dev	n	n % of sample	Variance	Mean	Std dev	n	n % of sample	Variance	Mean	Std dev	n	n % of sample	Variance	Mean	Std dev	n	n % of sample	Variance
11																									
12																4.220875	1.155272204	5	0.9	1.334654					
13						24.51188	12.96108	18	1.1	167.9897	27.10621	14.92618	87	4.9	222.7907	3.715643	#DIV/0!	1	0.2	#DIV/0!	2.12	0.362244	21	4.7	0.131221
14	10.11961	9.76574	9	1.0	95.36968	14.60686	7.04841	35	2.2	49.68008	9.69878	9.382414	19	1.1	88.02969										
15	21.9352	0.745785	3	0.3	0.556195																				
21																									
22																11.62016	2.79422673	46	8.5	7.807703					
23	41.5846	18.50157	3	0.3	342.3079	31.15263	15.0586	217	13.5	226.7615	37.28211	15.82924	262	14.7	250.5647										
24	35.86744	14.58382	29	3.3	212.6879	27.3007	10.59824	85	5.3	112.3227	21.10572	13.43344	34	1.9	180.4574										
25	36.71798	10.94068	12	1.4	119.6984																				
31																									
32											58.84408	#DIV/0!	1	0.1	#DIV/0!	16.90087	4.937532791	55	10.2	24.37923					
33	66.9425	21.14121	90	10.3	446.9506	41.54461	16.42166	689	42.8	269.6711	48.19756	20.23313	493	27.6	409.3796	17.38443	3.532365442	31	5.7	12.47761	8.40	1.49414	112	24.9	2.232454
34	70.33794	30.50307	262	29.9	930.4374	38.08881	15.15269	188	11.7	229.6039	31.90231	#DIV/0!	1	0.1	#DIV/0!	19.32841	3.436143269	73	13.5	11.80708					
35	70.17859	28.36117	59	6.7	804.3558																				
41																									
42											49.43648	26.85371	136	7.6	721.122	44.46633	11.59244339	201	37.2	134.3847					
43	82.31378	23.75977	107	12.2	564.5267	50.31783	21.18071	212	13.2	448.6227	60.60421	24.41172	84	4.7	595.9322	39.98517	6.07968033	67	12.4	36.96251	17.61	2.134215	201	44.7	4.554874
44	83.91349	28.57445	148	16.9	816.4993	41.76981	18.48695	46	2.9	341.7675						41.96933	4.095780113	17	3.1	16.77541					
45	83.95063	34.96309	34	3.9	1222.418																				
51																									
52											55.16397	18.7659	146	8.2	352.1589	56.84436	9.566938762	15	2.8	91.52632					
53	88.71727	24.72608	66	7.5	611.3789	60.69735	26.49826	89	5.5	702.1577	59.97788	22.77702	251	14.1	518.7928	53.90029	8.258566379	25	4.6	68.20392	24.48229	3.067869	112	24.9	9.411821
54	90.14561	30.14564	51	5.8	908.7594	51.43863	16.58568	17	1.1	275.0849						54.04243	8.277657473	5	0.9	68.51961					
55	96.19869	21.6436	2	0.2	468.4455																				
61																									
62											64.2976	27.65552	86	4.8	764.828										
63						59.80271	23.60683	13	0.8	557.2825	81.58314	34.51682	186	10.4	1191.411						29.62	5.374509	4	0.9	28.88534
64																									
65																									

Ignoring the effect of sample size within each category, the smallest variance (0.13 to 28.9) and standard deviation (0.36 to 5.37) is found with the harvester. The DHP was next with a variance ranging from 1.33 to 68.52 and standard deviation from 1.16 to 11.59. CFDD&C variance ranged from 49.68 to 702.16 and standard deviation from 7.05 to 26.50. CFDDC variance ranged from 88.03 to 1191.41 and standard deviation from 9.38 to 34.52. CFDD variance ranged from 0.56 to 1222.4 and standard deviation from 0.75 to 34.96.

Figure 1 shows the productivity information in graph format for the various processing technologies, tree size classes and BWBS classes. The information for each processing technology is discussed in detail in the sections below. Again, the colours denote different sample sizes.

Productivity is expected to increase as tree size class increases. Within each tree size class, productivity is expected to decrease as the BWBS and form class increases. However, there are certain situations where it does differ. This is explained in more detail under each individual processing technology. The highest productivity levels can clearly be found with the CFDD and the lowest with the harvester. The DHP processor has high productivity in the larger trees (from class 4). The CFDDC and CFDD&C appear to be similar but would require more detailed examination to confirm. The smallest sample sizes for all of the processing technologies were found in the smaller and larger tree sizes. However, this is explained below.

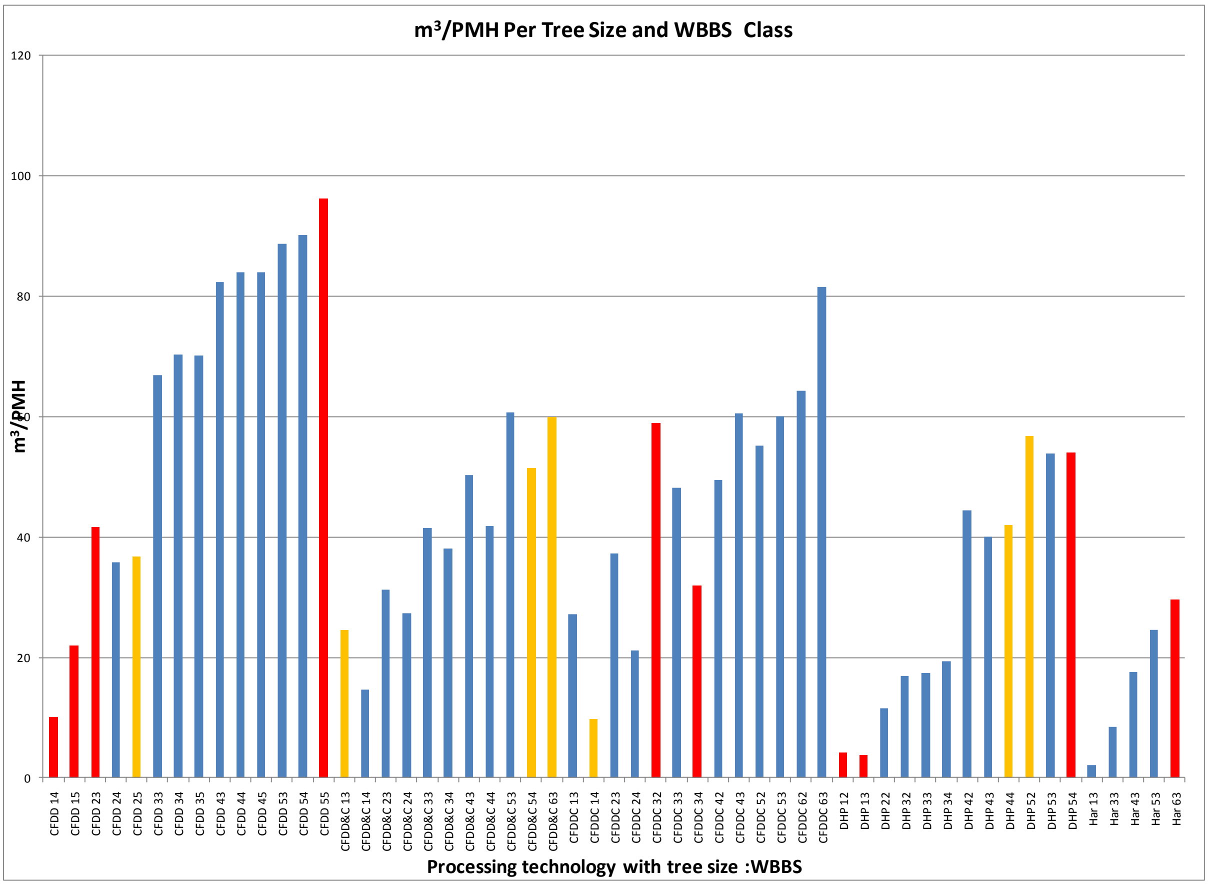

Figure 1: Productivity graph for tree size and BWBS class combinations

2 Chain Flail Delimber Debarker (CFDD) productivity results

2.1 CFDD productivity for tree size and BWBS class combinations

Figure 2 shows the effect of tree size and BWBS class on CFDD productivity.

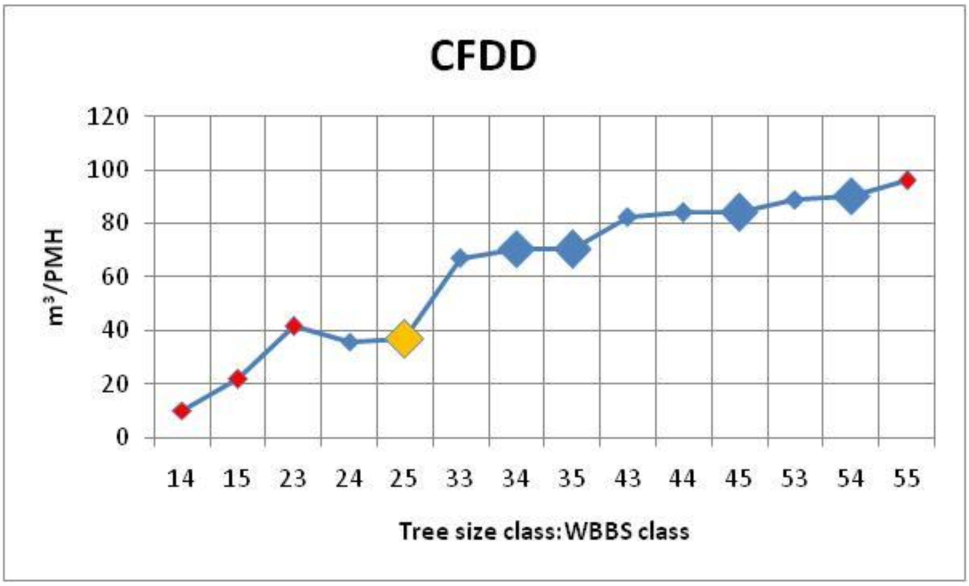

Figure 2: Effect of tree size and BWBS class on CFDD productivity.

There is a productivity increase with every increase in tree size class. However, this is only pronounced until tree size class 3. From tree size class 4, the increase in productivity is much smaller. Productivity ranges from approximately 16 m^3 per PMH for tree size class 1 (although caution must be exercised as the sample size is small), to 90 m^3 per PMH for tree size class 5. There were no trees in tree size class 6.

A drop in productivity was expected as the BWBS class increased, as the bark should theoretically be more difficult to remove. However, this did not occur. In tree size class 1 (1:4 and 1:5), the productivity increased steeply as the strippability became worse. However, the sample sizes for these two combinations are very small, with both being less than 10 cycles. Combination 2:3 also had a very small sample size. The main data set is found between combination 2:4 and 5:4. In this range, the productivity stayed stable within each tree size class, regardless of the BWBS. However, it is clear that the debarking quality is decreasing as the BWBS class increases. This is an indication that the operator is not paying enough attention to BWBS when processing. The operator is processing the same amount of trees per bundle regardless of BWBS.

2.2 CFDD debarking quality results

Figure 3 shows debarking quality per tree size and BWBS class combination.

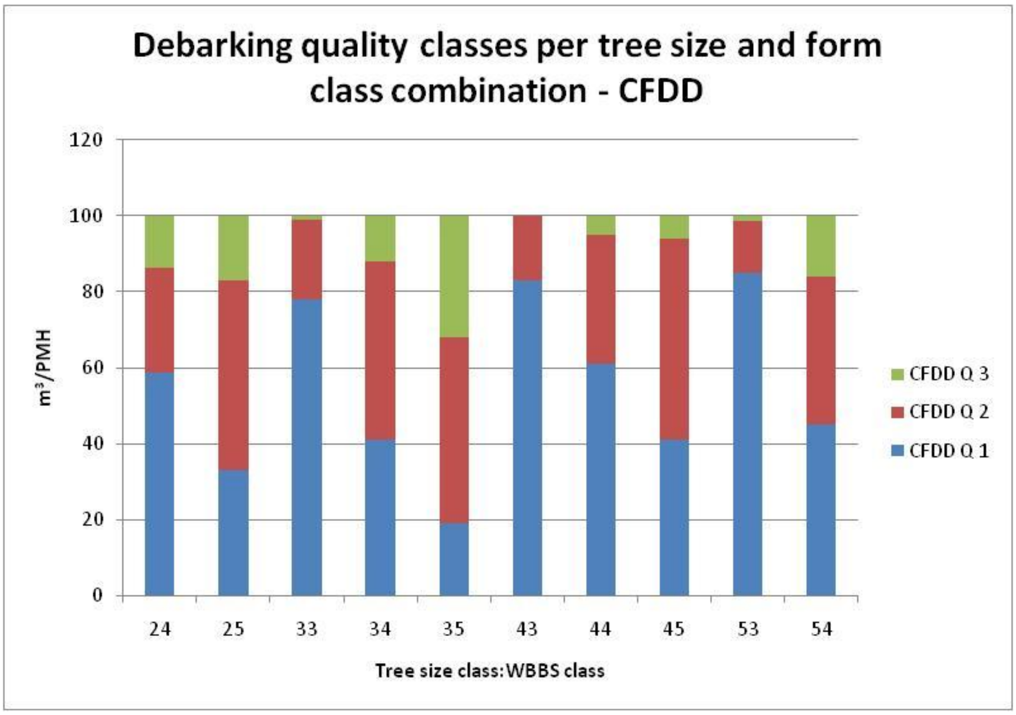

Figure 3: Debarking quality for tree size and BWBS combinations of the CFDD

The sample sizes of less than 10 were removed as it was too easy for outliers to affect the results. It is clear that the debarking quality was poor when the BWBS was class 4 and 5. The debarking quality for BWBS class 3 was good for all the tree size classes. It is therefore evident that the operators need to pay more attention to the settings on the machine (flail speeds, number of chains per flail drum and feed speeds) in order to obtain optimal debarking quality while minimising productivity losses.

3 Chain Flail Delimber Debarker Chipper (CFDDC) productivity results

3.1 CFDDC productivity for tree size and BWBS class combinations

Figure 4 shows the effect of tree size and BWBS class on CFDDC productivity.

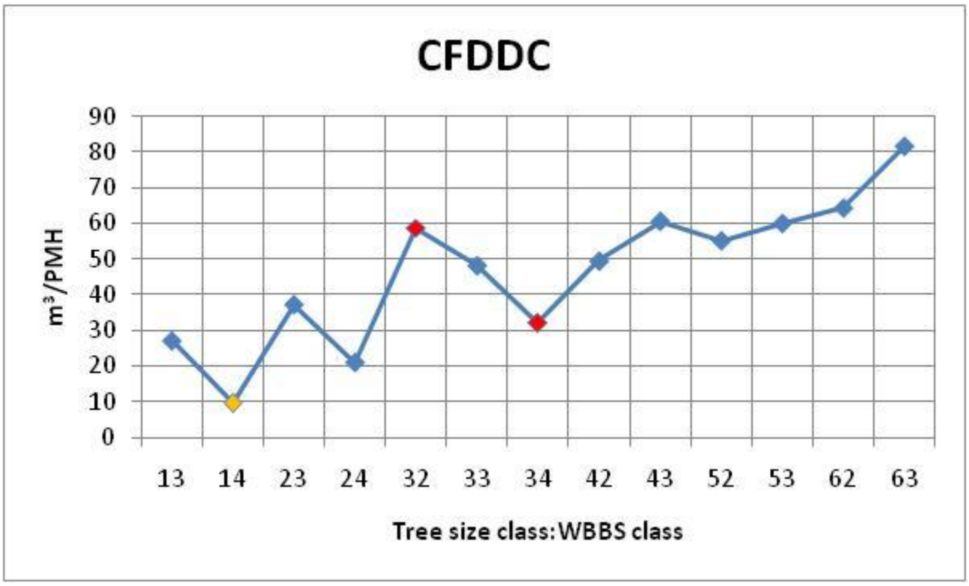

Figure 4: Effect of tree size and BWBS class on CFDDC productivity.

The full range of tree size classes was processed; however the BWBS classes ranged from 2 to 4, with most occurring in class 3 and 4. The productivity ranged from approximately 20 m^3 per PMH for trees size class 1, to 80 m^3 per PMH for tree size class 6. The trend in the CFDDC follows what would be expected from tree size class 1 to 3. Productivity increases with increasing tree size, but decreases as the BWBS increases for each tree size class. The magnitude of the decreases in these first three tree size classes is unexpected. The productivity decrease within each tree size class is dropping by between 15 and 20% for each increase in BWBS class. It appears that the operator is being conservative, as the implications of sending chips to the customer with unacceptable bark content could be serious. Therefore, as the BWBS increases, the operator is reducing machine productivity to ensure that quality is maintained. However, the trends for tree size class 1 to 3 are not maintained for tree size class 4 to 6. The overall productivity curve is still increasing but tree size class 5 is lower than tree size: BWBS class 3:4, and then there is an increase for tree size class 6 again. Also, within these three tree size classes, an increase in BWBS actually increases productivity. It cannot be explained why this is so, as the sample sizes are relatively large, with the lowest sample size for one combination being 84 cycles. It can be speculated that with a slightly higher BWBS in bigger tress, the bark might actually be more easily removed as smaller pieces, and fall to the bottom of the machine where the hydraulic bark pusher ejects it. When the bark is more easily removed, it may come off in lengths which might become entangled in-between the stems and be fed through into the chipper. The operator was not questioned on this, as this trend was only discovered during data analysis.

3.2 CFDDC debarking quality results

Debarking quality could not be monitored as the debarked stems were immediately chipped due to it being an integrated machine. However, every load was checked at the wood chip yard in Albany and Bunbury, and the bark content was acceptable for all loads.

4 Chain Flail Delimber Debarker and Chipper (CFDD&C) productivity results

4.1 CFDD&C productivity for tree size and BWBS class combinations

Figure 5 shows the effect of tree size and BWBS class on CFDD&C productivity.

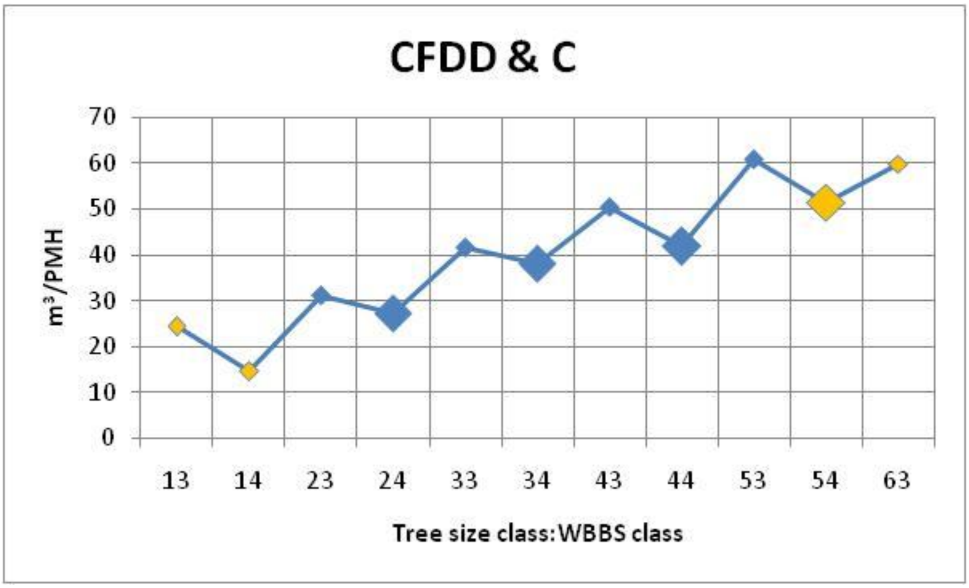

Figure 5: Effect of tree size and BWBS class on CFDD&C productivity

The complete range of tree size classes was found in the sample, but the sample size was very small for tree size class 1 and 6. All the BWBS classes are either a 3 or 4. It was still possible to determine debarking quality by observing the debarked trees as they moved from the CFDD out-feed into the chipper. The productivity ranged from approximately 20 m^3 per PMH for tree size class 1, to 60 m^3 per PMH for tree size classes 5 and 6. There is a steady increase in productivity with each tree size class increase. The productivity of tree size class 6 is approximately the same as tree size class 5. It is difficult to determine whether this is due to the CFDD having reached the upper limits of the tree size that it is able to process, or whether it is just due to the sample size being too small. As the BWBS class increases within each tree size class, the productivity is reduced. Even though the productivity does reduce with increasing BWBS class, debarking quality is still lower in the higher BWBS class for each tree size.

4.2 CFDD&C debarking quality results

Figure 6 shows the debarking quality classes per tree size and form class combination.

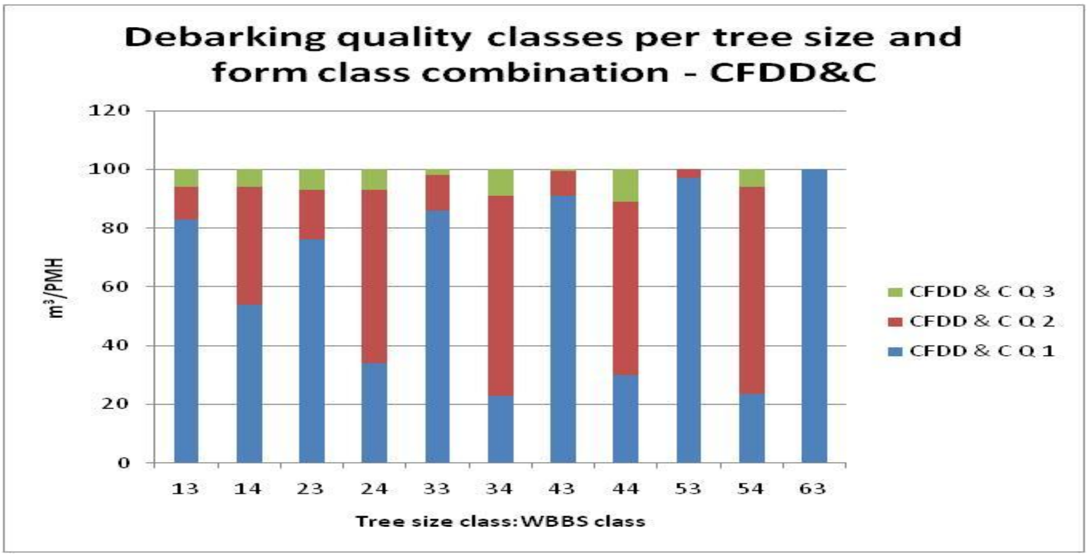

Figure 6: Debarking quality for the tree size and BWBS combinations of the CFDD&C

The debarking quality for BWBS class 3 was generally very good, regardless of tree size. The debarking quality for BWBS class 4 dropped for each tree size class, although the overall debarking quality for all combinations was still well within acceptable mill quality specifications. This was backed up by the feedback from the chip yards, which indicated that all loads were of acceptable quality.

5 Dangle Head Processor (DHP) productivity results

5.1 DHP productivity for tree size and BWBS class combinations

Figure 7 shows the effect of tree size and BWBS class on DHP productivity.

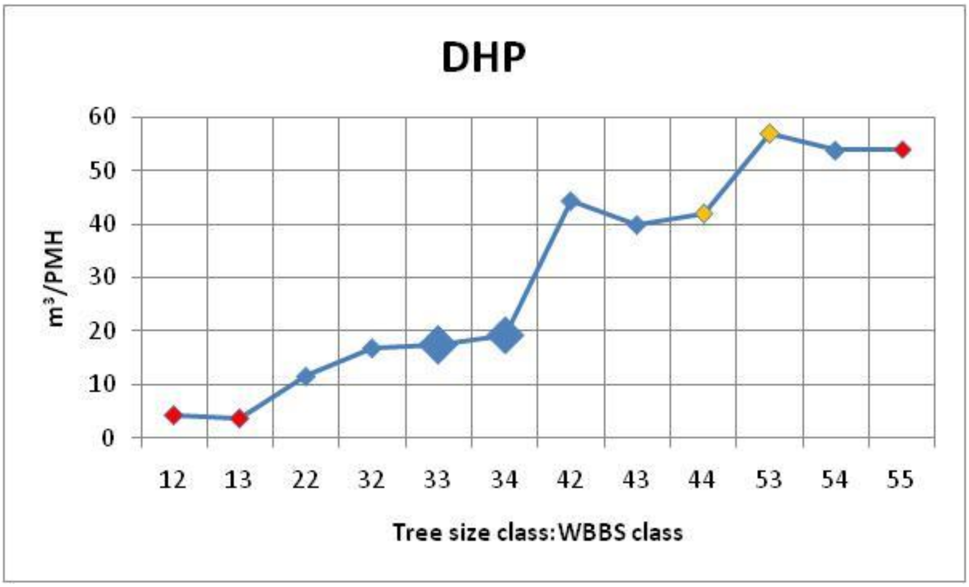

Figure 7: Effect of tree size and BWBS class on DHP productivity

All tree size classes with the exception of class 6 were found in the sample. BWBS classes 2 to 5 were found in the sample, but not for each tree size class. BWBS class 2 was only found in tree size classes 1 to 4, while the sample size of BWBS class 5 was very small and only occurred in tree size class 5. All the trees in tree size class 2 consisted of BWBS class 2. An overall increase in productivity is experienced from tree size class 1 (approximately 4 m^3 per PMH) through to tree size class 5 (approximately 55 m^3 per PMH). The sample size of tree size class 1 is small and therefore care must be taken when examining the graph. However, there is a small drop in productivity as the BWBS moves from class 2 to class 3. There is only one BWBS class for tree size class 2, so no deductions can be made regarding increases or decreases in productivity with changes in BWBS class. In tree size class 3, there is a decrease in productivity as the BWBS class increases. However, there was also a drop in debarking quality. Therefore, there may have been a decrease in productivity within this tree size class if the operator continued to debark to a higher quality. Figure 7 clearly shows this drop in debarking quality. In tree size class 4, productivity drops from BWBS class 2 to BWBS class 3, but then increases again slightly for BWBS class 4. The very small sample size for BWBS class 4 could be the reason for this. Tree size class 5 has a reduction in productivity from BWBS class 3 through to 5. BWBS class 5 is only slightly lower than BWBS class 4, but again the sample size is very small for BWBS class 5 which could be affecting the results.

5.2 DHP debarking quality results

Figure 8 below shows the debarking quality that was achieved with all the combinations that had sample sizes of 20 or more.

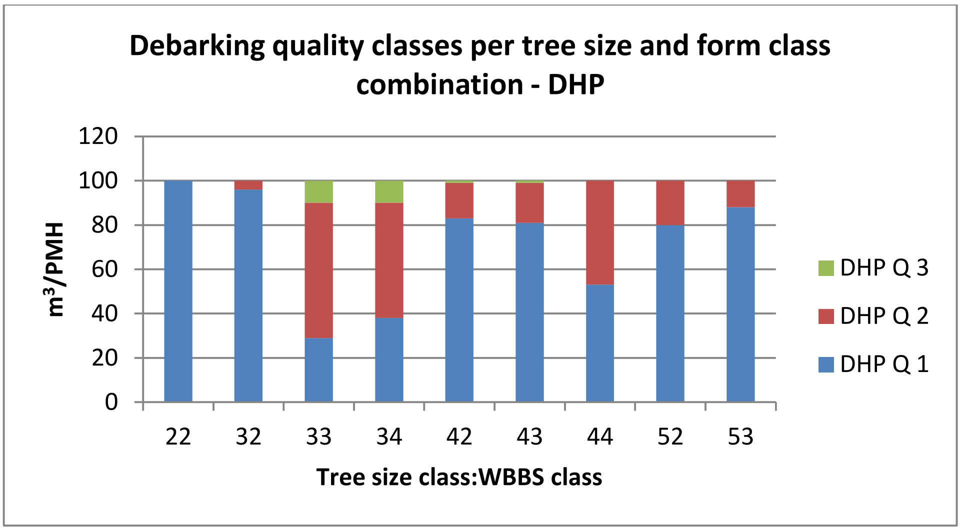

Figure 8: Debarking quality for the tree size and BWBS combinations of the DHP

All tree size classes with BWBS of 2 had very good debarking quality. All BWBS class 3 tree sizes also tended to have good debarking quality with the exception of tree size class 3, which had the worst debarking quality of all the combinations. BWBS class 4 had lower debarking quality levels, with approximately 50% being in debarking class 2. Debarking quality class 3 only occurred in tree size class 3, and the proportion was very low (approximately 10% of that sample). Optimal productivity within each tree size class of the DHP occurs when the operator has to pick up the tree up off the deck, and only feed it through the head once in one direction. The top is cut off and dropped. This results in very fast cycle times. Because the operators are pushed for productivity, as the BWBS class increases, they are hesitant to feed the tree through the head again, which would now require an additional pass to the butt and back to the top, regardless of whether the bark was removed in the second pass. The operator is therefore inclined to leave more bark on the tree with higher BWBS classes rather than feed the tree through the head again.

6 Harvester (CTL) productivity results

6.1 Harvester productivity for tree size and BWBS class combinations

Figure 9 shows the effect of tree size on the productivity of the harvester.

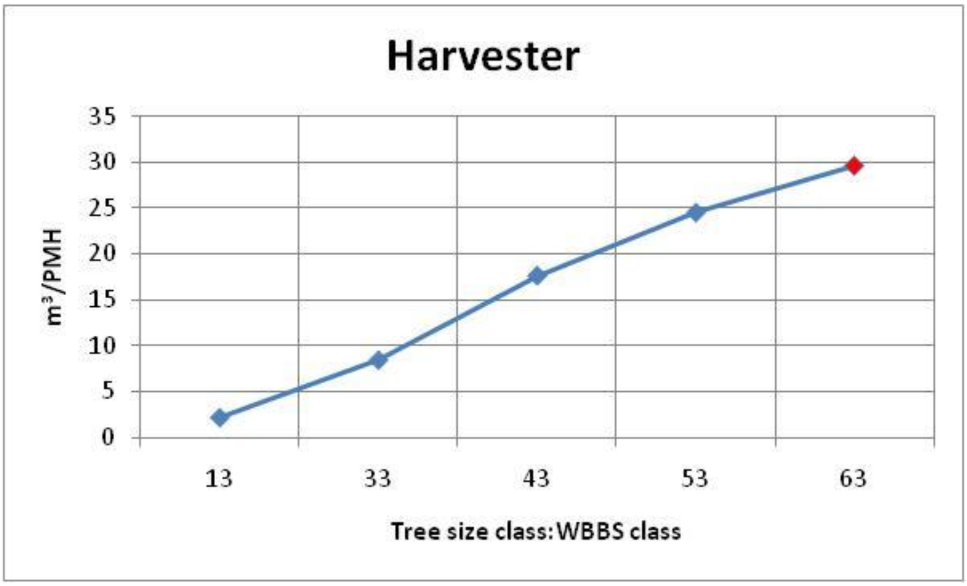

Figure 9: Harvester (CTL) system machine costs per PMH

All the tree size classes had BWBS class 3. It was not possible to manipulate BWBS with the harvester as the trees are processed immediately after felling. The productivity levels range from approximately 2.5 m^3 per PMH for tree size class 1, up to 30 m^3 per PMH for tree size class 6. Caution must also be exercised when looking at the smaller tree size classes as class 2 is absent. This was due to the error made during the allocation of trees into volume classes in the field. This error was discussed under “Shortcomings and sources of error” in the research design and methodology chapter. If there was a tree size class 2 and 3, the graph would be flatter with the lower productivities of class 1 to 3, and then start to rise rapidly from tree size class 4. Tree size class 6 had a very small sample size. The lack of variation in the BWBS class for different tree size classes was surprising, as often the smaller suppressed trees have a higher BWBS class. This did however make productivity comparisons between tree size classes easier. Even though the productivity from tree size class 4 is high, the increase is not as great as with the DHP due to the debarking element of the harvester consuming less of the cycle time.

6.2 Harvester debarking quality results

There is no figure to explain debarking quality as the trees were all debarked to debarking quality level 1. The good debarking levels achieved are due to trees being processed immediately after felling and good operator technique.

Annexure C

Harvesting systems costing summaries

CFDD System – Tree volume $0.15m^3$

SYSTEM	:	**CFDD**
OPERATION	:	**Stump to landing**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)					$2.60	217 500	2	2	7	300
Grapple Skidder (Tigercat 630D)					$2.89	217 500	2	2	4	300
CFDD (Morbark 2455)					$4.07	217 500	1	2	2	300
Bell 220E Telelogger					$1.20	217 500	2	2	4	300
Tracked loader with slasher deck (Tigercat T234)					$1.40	217 500	1	2	2	300
				Total	$12.16		8		20	
					$0.00		0		0	
				TOTAL	$12.16		8		20	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	combican	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		315 717	*US$s*
Annual HP payment		66 507	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	63 143	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		5 542	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	40.3%	
Machine hours per Day	6.4	*Hours*
Machine hours per Annum	1 932	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	7.76	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	*US$s*
1.5 Overheads	10.00%	25723	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	*US$/mhr*
Oil, Cost			2.67	*US$/mhr*
Tyres/Tracks/Rigging Cost			3.72	*US$/mhr*
Annual Fuel Costs			34 362	*US$s*
Annual Lube Cost			5 154	*US$s*
Annual Tyre/Track/Rigging Cost			7 188	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	*US$/mhr*
Annual Maintenance Cost	40 668	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.69	*US$/mhr*

5.1 Machine Requirements

Annual Volume	217 500	*m3*
Hourly Volume Required	112.57	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	6.00	*US$/hour*
No.Labourers/Shift	1.1	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	83 424	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Annual Contributions	0	*US$s*
Total Annual Crew Cost	83 949	*US$s*
Total Crew Cost per Machine Hr	43.45	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
bunch		*min*
place		*min*
move		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	56.3	*m3/mhr*
Machine Output per Day	363	*m3/day*
Machine Output per Annum	108 781	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.31	2 144	25 723	51 447	9.09%
FIXED COSTS	85.22	13 722	164 663	329 326	58.2%
Hp	34.42	5 542	66 507	133 014	23.5%
Crew	43.45	6 996	83 949	167 898	29.7%
Licence	7.35	1 184	14 207	28 415	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.91	7 714	92 572	185 143	32.7%
Fuel	17.78	2 863	34 362	68 723	12.1%
Lubrication	2.67	430	5 154	10 309	1.8%
Tyres	3.72	599	7 188	14 375	2.5%
Maintenance	21.05	3 389	40 668	81 336	14.4%
Relocation	2.69	433	5 200	10 400	1.8%
TOTAL COST / REVENUE	146.45	23 580	282 958	565 916	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.60	**Inc. Profit**	2.99
Number of Machines	2		
Number of Operators	7		
Machine Hours	3 864		
Capital Employed	631 434		
Residual Value	126 287		
Total Revenue	565 916		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Full tree extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc VAT		394 798	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		394 798	*US$s*
Annual Hp's		83 166	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	78 960	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 930	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	48.5%	
Machine hours per Day	7.8	*Hours*
Machine hours per Annum	2 328	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	6.44	*Years*

1.4 OVERHEADS

Annual Licence Fees		19 740	*US$s*
1.5 Overheads	10.00%	28529	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	*US$/mhr*
Oil, Cost			3.65	*US$/mhr*
Tyres/Tracks/Rigging Cost			0.00	*US$/mhr*
Annual Fuel Costs			56 654	*US$s*
Annual Lube Cost			8 498	*US$s*
Annual Tyre/Track/Rigging Cost			0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	*US$/mhr*
Annual Maintenance Cost	55 145	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.23	*US$/mhr*

5.1 Machine Requirements

Annual Volume	217 500	*m3*
Hourly Volume Required	93.43	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	24.44	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	46.8	*m3/mhr*
Machine Output per Day	363	*m3/day*
Machine Output per Annum	108 950	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	12.25	2 377	28 529	57 058	9.09%
FIXED COSTS	68.64	13 316	159 794	319 589	50.9%
Hp's	35.72	6 930	83 166	166 331	26.5%
Crew	24.44	4 741	56 889	113 778	18.1%
Licence	8.48	1 645	19 740	39 480	6.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	53.91	10 458	125 498	250 995	40.0%
Fuel	24.34	4 721	56 654	113 308	18.1%
Lubrication	3.65	708	8 498	16 996	2.7%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	4 595	55 145	110 291	17.6%
Relocation	2.23	433	5 200	10 400	1.7%
TOTAL COST / REVENUE	134.80	26 152	313 821	627 643	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.89	**Inc. Profit**	3.32
Number of Machines	2		
Number of Operators	4		
Machine Hours	4 656		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	627 643		

MACHINE DESCRIPTION : **CFDD (Morbark 2455)**
OPERATION : **Delimb, Debark full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		714 371	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		714 371	US$s
Annual HP payment		150 485	US$s

1.2 HP Calculation

Residual Value @	20.00%	142 874	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 540	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 287	US$s
1.5 Overheads	10.00%	80438	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			56.9	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	234	8	30	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			66.57	US$/hour
Oil, Cost			9.99	US$/hour
Tyres/Tracks/Rigging Cost			62.40	US$/hour
Annual Fuel Costs			207 708	US$s
Annual Lube Cost			31 156	US$s
Annual Tyre/Track/Rigging Cost			194 688	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	47.62	US$/mhr
Annual Maintenance Cost	148 589	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	217 500	m3
Hourly Volume Required	69.71	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	16.75	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark		min
other		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	69.8	m3/mhr
Machine Output per Day	726	m3/day
Machine Output per Annum	217 776	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	25.78	6 703	80 438	80 438	9.09%
FIXED COSTS	69.56	18 087	217 041	217 041	24.5%
Hp	48.23	12 540	150 485	150 485	17.0%
Crew	16.75	4 356	52 269	52 269	5.9%
Licence	4.58	1 191	14 287	14 287	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	188.25	48 945	587 341	587 341	66.4%
Fuel	66.57	17 309	207 708	207 708	23.5%
Lubrication	9.99	2 596	31 156	31 156	3.5%
Tyres	62.40	16 224	194 688	194 688	22.0%
Maintenance	47.62	12 382	148 589	148 589	16.8%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	283.60	73 735	884 820	884 820	100.0%

6.2 FLEET SUMMARY

US$ per m3	4.07	**Inc. Profit**	4.68
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	714 371		
Residual Value	142 874		
Total Revenue	884 820		

MACHINE DESCRIPTION : **Bell 220E Telelogger**
OPERATION : **Bundle tree lengths after debarking**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		80 500	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		80 500	US$s
Annual HP payment		16 958	US$s

1.2 HP Calculation

Residual Value @	20.00%	16 100	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		1 413	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	62.9%	
Machine hours per Day	10.1	Hours
Machine hours per Annum	3 021	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.97	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		1 610	US$s
1.5 Overheads	10.00%	11908	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	6.6	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyre front	0	0	0
Tyre rear	0	0	0
other	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	7.72	US$/mhr
Oil, Cost	1.16	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	23 327	US$s
Annual Lube Cost	3 499	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	5.37	US$/mhr
Annual Maintenance Cost	16 212	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.72	US$/mhr

5.1 Machine Requirements

Annual Volume	217 500	m3
Hourly Volume Required	72.00	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	17.30	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree volume		m3
Number trees per cycle		#
pull trees		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	36.000	m3/mhr
Machine Output per Day	363	m3/day
Machine Output per Annum	108 752	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	3.94	992	11 908	23 815	9.09%
FIXED COSTS	23.45	5 903	70 837	141 673	54.1%
Hp	5.61	1 413	16 958	33 915	12.9%
Crew	17.30	4 356	52 269	104 538	39.9%
Licence	0.53	134	1 610	3 220	1.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	15.97	4 020	48 238	96 477	36.8%
Fuel	7.72	1 944	23 327	46 655	17.8%
Lubrication	1.16	292	3 499	6 998	2.7%
Tyres	0.00	0	0	0	0.0%
Maintenance	5.37	1 351	16 212	32 424	12.4%
Relocation	1.72	433	5 200	10 400	4.0%
TOTAL COST / REVENUE	43.36	10 915	130 983	261 965	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.20	**Inc. Profit**	1.39
Number of Machines	2		
Number of Operators	4		
Machine Hours	6 042		
Capital Employed	161 000		
Residual Value	32 200		
Total Revenue	261 965		

MACHINE DESCRIPTION : **Tracked loader with slasher deck (Tigercat T234)**
OPERATION : **Slash to 5.5m lengths**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual HP payment		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	60.4%	
Machine hours per Day	9.7	Hours
Machine hours per Annum	2 901	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.17	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		5 718	US$s
1.5 Overheads	10.00%	27771	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	13.8	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Bar	1	714	350
Sprocket	0	0	0
Tracks	0	0	0
Chain	1	195	70
other			

Fuel,Cost	16.15	US$/mhr
Oil, Cost	2.42	US$/mhr
Tyres/Tracks/Rigging Cost	4.83	US$/mhr
Annual Fuel Costs	46 838	US$s
Annual Lube Cost	7 026	US$s
Annual Tyre/Track/Rigging Cost	13 999	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	66 354	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.79	US$/mhr

5.1 Machine Requirements

Annual Volume	217 500	m3
Hourly Volume Required	74.98	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	18.02	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree Volume		m3
		min
Slash		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	75.000	m3/mhr
Machine Output per Day	725	m3/day
Machine Output per Annum	217 570	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	9.57	2 314	27 771	27 771	9.09%
FIXED COSTS	47.67	11 524	138 293	138 293	45.3%
Hp	27.68	6 692	80 306	80 306	26.3%
Crew	18.02	4 356	52 269	52 269	17.1%
Licence	1.97	477	5 718	5 718	1.9%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.06	11 618	139 418	139 418	45.6%
Fuel	16.15	3 903	46 838	46 838	15.3%
Lubrication	2.42	585	7 026	7 026	2.3%
Tyres	4.83	1 167	13 999	13 999	4.6%
Maintenance	22.87	5 530	66 354	66 354	21.7%
Relocation	1.79	433	5 200	5 200	1.7%
TOTAL COST / REVENUE	105.30	25 457	305 482	305 482	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.40	**Inc. Profit**	1.62
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 901		
Capital Employed	381 224		
Residual Value	76 245		
Total Revenue	305 482		

CFDD System – Tree volume 0.075m^3

SYSTEM : CFDD
OPERATION : Stump to landing
STUDY FOR : MSc
PREPARED BY : McEwan

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)					$4.46	124 500	2	2	7	300
Grapple Skidder (Tigercat 630D)					$4.71	124 500	2	2	4	300
CFDD (Morbark 2455)					$7.11	124 500	1	2	2	300
Bell 220E Telelogger					$2.00	124 500	2	2	4	300
Tracked loader with slasher deck (Tigercat T234)					$2.33	124 500	1	2	2	300

	Cost	Equip #	Staff #
Total	$20.61	8	20
	$0.00	0	0
TOTAL	$20.61	8	20

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	combican	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		315 717	*US$s*
Annual HP payment		66 507	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	63 143	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		5 542	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	38.0%	
Machine hours per Day	6.1	*Hours*
Machine hours per Annum	1 824	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	8.22	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	*US$s*
1.5 Overheads	10.00%	25234	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	*US$/mhr*
Oil, Cost			2.67	*US$/mhr*
Tyres/Tracks/Rigging Cost			3.72	*US$/mhr*
Annual Fuel Costs			32 438	*US$s*
Annual Lube Cost			4 866	*US$s*
Annual Tyre/Track/Rigging Cost			6 785	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	*US$/mhr*
Annual Maintenance Cost	38 391	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.85	*US$/mhr*

5.1 Machine Requirements

Annual Volume	124 500	*m3*
Hourly Volume Required	68.26	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	6.00	*US$/hour*
No.Labourers/Shift	1.1	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	83 424	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Annual Contributions	0	*US$s*
Total Annual Crew Cost	83 949	*US$s*
Total Crew Cost per Machine Hr	46.02	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
bunch		*min*
place		*min*
move		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	34.2	*m3/mhr*
Machine Output per Day	208	*m3/day*
Machine Output per Annum	62 381	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**13.83**	**2 103**	**25 234**	**50 469**	**9.09%**
FIXED COSTS	**90.28**	**13 722**	**164 663**	**329 326**	**59.3%**
Hp	36.46	5 542	66 507	133 014	24.0%
Crew	46.02	6 996	83 949	167 898	30.2%
Licence	7.79	1 184	14 207	28 415	5.1%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**48.07**	**7 307**	**87 680**	**175 360**	**31.6%**
Fuel	17.78	2 703	32 438	64 876	11.7%
Lubrication	2.67	405	4 866	9 731	1.8%
Tyres	3.72	565	6 785	13 571	2.4%
Maintenance	21.05	3 199	38 391	76 782	13.8%
Relocation	2.85	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	**152.18**	**23 131**	**277 578**	**555 155**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	4.46	**Inc. Profit**	5.13
Number of Machines	2		
Number of Operators	7		
Machine Hours	3 648		
Capital Employed	631 434		
Residual Value	126 287		
Total Revenue	555 155		

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MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Full tree extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

FORESTRY SOLUTIONS

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	41.0%	
Machine hours per Day	6.6	Hours
Machine hours per Annum	1 970	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.61	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	26680	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	20.8	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	US$/mhr
Oil, Cost	3.65	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	47 947	US$s
Annual Lube Cost	7 192	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	46 670	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.64	US$/mhr

5.1 Machine Requirements

Annual Volume	124 500	m3
Hourly Volume Required	63.19	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	28.87	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	31.6	m3/mhr
Machine Output per Day	208	m3/day
Machine Output per Annum	62 258	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**13.54**	**2 223**	**26 680**	**53 361**	**9.09%**
FIXED COSTS	**81.11**	**13 316**	**159 794**	**319 589**	**54.4%**
Hp's	42.21	6 930	83 166	166 331	28.3%
Crew	28.87	4 741	56 889	113 778	19.4%
Licence	10.02	1 645	19 740	39 480	6.7%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**54.31**	**8 917**	**107 009**	**214 017**	**36.5%**
Fuel	24.34	3 996	47 947	95 894	16.3%
Lubrication	3.65	599	7 192	14 384	2.5%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	3 889	46 670	93 340	15.9%
Relocation	2.64	433	5 200	10 400	1.8%
TOTAL COST / REVENUE	**148.96**	**24 457**	**293 483**	**586 967**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	4.71	**Inc. Profit**	5.42
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 940		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	586 967		

MACHINE DESCRIPTION : **CFDD (Morbark 2455)**
OPERATION : **Delimb, Debark full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		714 371	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		714 371	US$s
Annual HP payment		150 485	US$s

1.2 HP Calculation

Residual Value @	20.00%	142 874	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 540	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 287	US$s
1.5 Overheads	10.00%	80438	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption		56.9	L/Hr
Fuel Cost		1.17	US$/L
Oil, % Fuel Cost		15%	
Oil Cost			US$/L
Tyres/Tracks/Rigging			

	Qty	Cost	Life
Chains	234	8	30
Drum	0	0	0
Tyres	0	0	0
other	0	0	0
other	0	0	0

Fuel, Cost	66.57	US$/hour
Oil, Cost	9.99	US$/hour
Tyres/Tracks/Rigging Cost	62.40	US$/hour
Annual Fuel Costs	207 708	US$s
Annual Lube Cost	31 156	US$s
Annual Tyre/Track/Rigging Cost	194 688	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	100%	
Maintenance Cost	47.62	US$/mhr
Annual Maintenance Cost	148 589	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	124 500	m3
Hourly Volume Required	39.90	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No. Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	16.75	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark		min
other		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	40.0	m3/mhr
Machine Output per Day	416	m3/day
Machine Output per Annum	124 800	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	25.78	6 703	80 438	80 438	9.09%
FIXED COSTS	69.56	18 087	217 041	217 041	24.5%
Hp	48.23	12 540	150 485	150 485	17.0%
Crew	16.75	4 356	52 269	52 269	5.9%
Licence	4.58	1 191	14 287	14 287	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	188.25	48 945	587 341	587 341	66.4%
Fuel	66.57	17 309	207 708	207 708	23.5%
Lubrication	9.99	2 596	31 156	31 156	3.5%
Tyres	62.40	16 224	194 688	194 688	22.0%
Maintenance	47.62	12 382	148 589	148 589	16.8%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	283.60	73 735	884 820	884 820	100.0%

6.2 FLEET SUMMARY

US$ per m3	7.11	**Inc. Profit**	8.17
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	714 371		
Residual Value	142 874		
Total Revenue	884 820		

MACHINE DESCRIPTION : **Bell 220E Telelogger**
OPERATION : **Bundle tree lengths after debarking**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		80 500	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		80 500	US$s
Annual HP payment		16 958	US$s

1.2 HP Calculation

Residual Value @	20.00%	16 100	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		1 413	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	54.0%	
Machine hours per Day	8.6	Hours
Machine hours per Annum	2 594	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.78	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		1 610	US$s
1.5 Overheads	10.00%	11299	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	6.6	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyre front	0	0	0
Tyre rear	0	0	0
other	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	7.72	US$/mhr
Oil, Cost	1.16	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	20 029	US$s
Annual Lube Cost	3 004	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	5.37	US$/mhr
Annual Maintenance Cost	13 920	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.00	US$/mhr

5.1 Machine Requirements

Annual Volume	124 500	m3
Hourly Volume Required	48.00	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	20.15	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree volume		m3
Number trees per cycle		#
pull trees		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	24.000	m3/mhr
Machine Output per Day	208	m3/day
Machine Output per Annum	62 251	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	4.36	942	11 299	22 598	9.09%
FIXED COSTS	27.31	5 903	70 837	141 673	57.0%
Hp	6.54	1 413	16 958	33 915	13.6%
Crew	20.15	4 356	52 269	104 538	42.1%
Licence	0.62	134	1 610	3 220	1.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	16.25	3 513	42 154	84 307	33.9%
Fuel	7.72	1 669	20 029	40 058	16.1%
Lubrication	1.16	250	3 004	6 009	2.4%
Tyres	0.00	0	0	0	0.0%
Maintenance	5.37	1 160	13 920	27 840	11.2%
Relocation	2.00	433	5 200	10 400	4.2%
TOTAL COST / REVENUE	47.92	10 357	124 289	248 578	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.00	**Inc. Profit**	2.30
Number of Machines	2		
Number of Operators	4		
Machine Hours	5 188		
Capital Employed	161 000		
Residual Value	32 200		
Total Revenue	248 578		

MACHINE DESCRIPTION : Tracked loader with slasher deck (Tigercat T234)
OPERATION : Slash to 5.5m lengths
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual HP payment		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	54.1%	
Machine hours per Day	8.7	Hours
Machine hours per Annum	2 596	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.78	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		5 718	US$s
1.5 Overheads	10.00%	26361	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	13.8	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Bar	1	714	350
Sprocket	0	0	0
Tracks	0	0	0
Chain	1	195	70
other			

Fuel,Cost	16.15	US$/mhr
Oil, Cost	2.42	US$/mhr
Tyres/Tracks/Rigging Cost	4.83	US$/mhr
Annual Fuel Costs	41 918	US$s
Annual Lube Cost	6 288	US$s
Annual Tyre/Track/Rigging Cost	12 529	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	59 384	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.00	US$/mhr

5.1 Machine Requirements

Annual Volume	124 500	m3
Hourly Volume Required	47.95	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	20.13	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree Volume		m3
		min
Slash		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	48.000	m3/mhr
Machine Output per Day	415	m3/day
Machine Output per Annum	124 618	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.15	2 197	26 361	26 361	9.09%
FIXED COSTS	53.27	11 524	138 293	138 293	47.7%
Hp	30.93	6 692	80 306	80 306	27.7%
Crew	20.13	4 356	52 269	52 269	18.0%
Licence	2.20	477	5 718	5 718	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.27	10 443	125 319	125 319	43.2%
Fuel	16.15	3 493	41 918	41 918	14.5%
Lubrication	2.42	524	6 288	6 288	2.2%
Tyres	4.83	1 044	12 529	12 529	4.3%
Maintenance	22.87	4 949	59 384	59 384	20.5%
Relocation	2.00	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	111.69	24 165	289 974	289 974	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.33	**Inc. Profit**	2.68
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 596		
Capital Employed	381 224		
Residual Value	76 245		
Total Revenue	289 974		

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CFDD System – Tree volume 0.25m^3

SYSTEM	:	CFDD
OPERATION	:	Stump to landing
STUDY FOR	:	MSc
PREPARED BY	:	McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)					$2.04	269 500	2	2	7	300
Grapple Skidder (Tigercat 630D)					$2.37	269 500	2	2	4	300
CFDD (Morbark 2455)					$3.28	269 500	1	2	2	300
Bell 220E Telelogger					$0.93	269 500	2	2	4	300
Tracked loader with slasher deck (Tigercat T234)					$1.13	269 500	1	2	2	300
				Total	$9.76		8		20	
					$0.00		0		0	
				TOTAL	$9.76		8		20	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	37.0%	
Machine hours per Day	5.9	Hours
Machine hours per Annum	1 776	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	8.45	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	25017	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	15.2	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyres	1	9 300	2 500
Cutting disk	0	0	0
Cutting teeth	0	0	0
Other	0	0	0
Other	0	0	0

Fuel,Cost	17.78	US$/mhr
Oil, Cost	2.67	US$/mhr
Tyres/Tracks/Rigging Cost	3.72	US$/mhr
Annual Fuel Costs	31 584	US$s
Annual Lube Cost	4 738	US$s
Annual Tyre/Track/Rigging Cost	6 607	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	37 381	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.93	US$/mhr

5.1 Machine Requirements

Annual Volume	269 500	m3
Hourly Volume Required	151.75	m3/mhr
Number Of Machines Required	1.99	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.99	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	6.00	US$/hour
No.Labourers/Shift	1.1	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	83 424	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	83 949	US$s
Total Crew Cost per Machine Hr	47.27	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	76.1	m3/mhr
Machine Output per Day	451	m3/day
Machine Output per Annum	135 154	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	14.09	2 085	25 017	50 035	9.09%
FIXED COSTS	92.72	13 722	164 663	329 326	59.8%
Hp	37.45	5 542	66 507	133 014	24.2%
Crew	47.27	6 996	83 949	167 898	30.5%
Licence	8.00	1 184	14 207	28 415	5.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.15	7 126	85 510	171 019	31.1%
Fuel	17.78	2 632	31 584	63 169	11.5%
Lubrication	2.67	395	4 738	9 475	1.7%
Tyres	3.72	551	6 607	13 213	2.4%
Maintenance	21.05	3 115	37 381	74 762	13.6%
Relocation	2.93	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	154.95	22 933	275 190	550 380	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.04	**Inc. Profit**	2.35
Number of Machines	2		
Number of Operators	7		
Machine Hours	3 552		
Capital Employed	631 434		
Residual Value	126 287		
Total Revenue	550 380		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Full tree extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	50.5%	
Machine hours per Day	8.1	Hours
Machine hours per Annum	2 424	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.19	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	29026	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil, % Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel, Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			58 994	US$s
Annual Lube Cost			8 849	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	57 422	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.15	US$/mhr

5.1 Machine Requirements

Annual Volume	269 500	m3
Hourly Volume Required	111.17	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No. Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	23.47	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	55.6	m3/mhr
Machine Output per Day	449	m3/day
Machine Output per Annum	134 781	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.97	2 419	29 026	58 052	9.09%
FIXED COSTS	65.92	13 316	159 794	319 589	50.0%
Hp's	34.31	6 930	83 166	166 331	26.0%
Crew	23.47	4 741	56 889	113 778	17.8%
Licence	8.14	1 645	19 740	39 480	6.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	53.82	10 872	130 465	260 930	40.9%
Fuel	24.34	4 916	58 994	117 987	18.5%
Lubrication	3.65	737	8 849	17 698	2.8%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	4 785	57 422	114 845	18.0%
Relocation	2.15	433	5 200	10 400	1.6%
TOTAL COST / REVENUE	131.71	26 607	319 285	638 571	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.37	**Inc. Profit**	2.72
Number of Machines	2		
Number of Operators	4		
Machine Hours	4 848		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	638 571		

MACHINE DESCRIPTION : **CFDD (Morbark 2455)**
OPERATION : **Delimb, Debark full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		714 371	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		714 371	US$s
Annual HP payment		150 485	US$s

1.2 HP Calculation

Residual Value @	20.00%	142 874	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 540	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 287	US$s
1.5 Overheads	10.00%	80438	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	56.9	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Chains	234	8	30
Drum	0	0	0
Tyres	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	66.57	US$/hour
Oil, Cost	9.99	US$/hour
Tyres/Tracks/Rigging Cost	62.40	US$/hour
Annual Fuel Costs	207 708	US$s
Annual Lube Cost	31 156	US$s
Annual Tyre/Track/Rigging Cost	194 688	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	47.62	US$/mhr
Annual Maintenance Cost	148 589	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	269 500	m3
Hourly Volume Required	86.38	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	16.75	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark		min
other		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	86.4	m3/mhr
Machine Output per Day	899	m3/day
Machine Output per Annum	269 568	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	25.78	6 703	80 438	80 438	9.09%
FIXED COSTS	69.56	18 087	217 041	217 041	24.5%
Hp	48.23	12 540	150 485	150 485	17.0%
Crew	16.75	4 356	52 269	52 269	5.9%
Licence	4.58	1 191	14 287	14 287	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	188.25	48 945	587 341	587 341	66.4%
Fuel	66.57	17 309	207 708	207 708	23.5%
Lubrication	9.99	2 596	31 156	31 156	3.5%
Tyres	62.40	16 224	194 688	194 688	22.0%
Maintenance	47.62	12 382	148 589	148 589	16.8%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	283.60	73 735	884 820	884 820	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.28	Inc. Profit	3.78
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	714 371		
Residual Value	142 874		
Total Revenue	884 820		

MACHINE DESCRIPTION : **Bell 220E Telelogger**
OPERATION : **Bundle tree lengths after debarking**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		80 500	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		80 500	US$s
Annual HP payment		16 958	US$s

1.2 HP Calculation

Residual Value @	20.00%	16 100	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		1 413	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	56.2%	
Machine hours per Day	9.0	Hours
Machine hours per Annum	2 695	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.57	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		1 610	US$s
1.5 Overheads	10.00%	11444	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	6.6	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyre front	0	0	0
Tyre rear	0	0	0
other	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	7.72	US$/mhr
Oil, Cost	1.16	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	20 814	US$s
Annual Lube Cost	3 122	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	5.37	US$/mhr
Annual Maintenance Cost	14 465	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.93	US$/mhr

5.1 Machine Requirements

Annual Volume	269 500	m3
Hourly Volume Required	99.99	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	19.39	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree volume		m3
Number trees per cycle		#
pull trees		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	50.000	m3/mhr
Machine Output per Day	449	m3/day
Machine Output per Annum	134 768	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	4.25	954	11 444	22 887	9.09%
FIXED COSTS	26.28	5 903	70 837	141 673	56.3%
Hp	6.29	1 413	16 958	33 915	13.5%
Crew	19.39	4 356	52 269	104 538	41.5%
Licence	0.60	134	1 610	3 220	1.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	16.18	3 633	43 601	87 201	34.6%
Fuel	7.72	1 734	20 814	41 627	16.5%
Lubrication	1.16	260	3 122	6 244	2.5%
Tyres	0.00	0	0	0	0.0%
Maintenance	5.37	1 205	14 465	28 930	11.5%
Relocation	1.93	433	5 200	10 400	4.1%
TOTAL COST / REVENUE	46.70	10 490	125 881	251 762	100.0%

6.2 FLEET SUMMARY

US$ per m3	0.93	Inc. Profit	1.07
Number of Machines	2		
Number of Operators	4		
Machine Hours	5 391		
Capital Employed	161 000		
Residual Value	32 200		
Total Revenue	251 762		

MACHINE DESCRIPTION	:	**Tracked loader with slasher deck (Tigercat T234)**
OPERATION	:	**Slash to 5.5m lengths**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc VAT			381 224	US$s
Less Cost of Tyres/Tracks/Rigging			0	US$s
Plus additional equipment	slasher		0	US$s
	Truck 2ns hand		0	US$s
	trailer		0	US$s
	other		0	US$s
	other		0	US$s
Sub total additional equipment			0	US$s
Total Capital Employed			381 224	US$s
Annual HP payment			80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	59.9%	
Machine hours per Day	9.6	Hours
Machine hours per Annum	2 875	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.22	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		5 718	US$s
1.5 Overheads	10.00%	27649	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			13.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	714	350	
Sprocket	0	0	0	
Tracks	0	0	0	
Chain	1	195	70	
other				
Fuel,Cost			16.15	US$/mhr
Oil, Cost			2.42	US$/mhr
Tyres/Tracks/Rigging Cost			4.83	US$/mhr
Annual Fuel Costs			46 412	US$s
Annual Lube Cost			6 962	US$s
Annual Tyre/Track/Rigging Cost			13 872	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	65 750	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.81	US$/mhr

5.1 Machine Requirements

Annual Volume	269 500	m3
Hourly Volume Required	93.75	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	18.18	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree Volume		m3
		min
Slash		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	93.800	m3/mhr
Machine Output per Day	899	m3/day
Machine Output per Annum	269 630	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	9.62	2 304	27 649	27 649	9.09%
FIXED COSTS	48.11	11 524	138 293	138 293	45.5%
Hp	27.94	6 692	80 306	80 306	26.4%
Crew	18.18	4 356	52 269	52 269	17.2%
Licence	1.99	477	5 718	5 718	1.9%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.08	11 516	138 196	138 196	45.4%
Fuel	16.15	3 868	46 412	46 412	15.3%
Lubrication	2.42	580	6 962	6 962	2.3%
Tyres	4.83	1 156	13 872	13 872	4.6%
Maintenance	22.87	5 479	65 750	65 750	21.6%
Relocation	1.81	433	5 200	5 200	1.7%
TOTAL COST / REVENUE	105.80	25 345	304 138	304 138	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.13	**Inc. Profit**	1.30
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 875		
Capital Employed	381 224		
Residual Value	76 245		
Total Revenue	304 138		

CFDD System – Tree volume 0.40m^3

SYSTEM	:	CFDD
OPERATION	:	Stump to landing
STUDY FOR	:	MSc
PREPARED BY	:	McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)					$1.14	296 500	1	2	3	300
Grapple Skidder (Tigercat 630D)					$2.05	296 500	2	2	4	300
CFDD (Morbark 2455)					$2.98	296 500	1	2	2	300
Bell 220E Telelogger					$0.81	296 500	2	2	4	300
Tracked loader with slasher deck (Tigercat T234)					$0.96	296 500	1	2	2	300
				Total	$7.93		7		17	
					$0.00		0		0	
				TOTAL	$7.93		7		17	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	63.0%	
Machine hours per Day	10.1	Hours
Machine hours per Annum	3 024	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.96	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	30661	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	15.2	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyres	1	9 300	2 500
Cutting disk	0	0	0
Cutting teeth	0	0	0
Other	0	0	0
Other	0	0	0

Fuel,Cost	17.78	US$/mhr
Oil, Cost	2.67	US$/mhr
Tyres/Tracks/Rigging Cost	3.72	US$/mhr
Annual Fuel Costs	53 779	US$s
Annual Lube Cost	8 067	US$s
Annual Tyre/Track/Rigging Cost	11 249	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	63 649	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.72	US$/mhr

5.1 Machine Requirements

Annual Volume	296 500	m3
Hourly Volume Required	98.05	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	6.00	US$/hour
No.Labourers/Shift	1.1	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	83 424	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	83 949	US$s
Total Crew Cost per Machine Hr	27.76	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	98.1	m3/mhr
Machine Output per Day	989	m3/day
Machine Output per Annum	296 654	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.14	2 555	30 661	30 661	9.09%
FIXED COSTS	54.45	13 722	164 663	164 663	48.8%
Hp	21.99	5 542	66 507	66 507	19.7%
Crew	27.76	6 996	83 949	83 949	24.9%
Licence	4.70	1 184	14 207	14 207	4.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	46.94	11 829	141 943	141 943	42.1%
Fuel	17.78	4 482	53 779	53 779	15.9%
Lubrication	2.67	672	8 067	8 067	2.4%
Tyres	3.72	937	11 249	11 249	3.3%
Maintenance	21.05	5 304	63 649	63 649	18.9%
Relocation	1.72	433	5 200	5 200	1.5%
TOTAL COST / REVENUE	111.53	28 106	337 267	337 267	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.14	**Inc. Profit**	1.31
Number of Machines	1		
Number of Operators	3		
Machine Hours	3 024		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	337 267		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Full tree extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		394 798	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		394 798	*US$s*
Annual Hp's		83 166	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	78 960	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 930	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	44.6%	
Machine hours per Day	7.1	*Hours*
Machine hours per Annum	2 142	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	7.00	*Years*

1.4 OVERHEADS

Annual Licence Fees		19 740	*US$s*
1.5 Overheads	10.00%	27570	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	20.8	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil, % Fuel Cost	15%	
Oil Cost		*US$/L*
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel, Cost	24.34	*US$/mhr*
Oil, Cost	3.65	*US$/mhr*
Tyres/Tracks/Rigging Cost	0.00	*US$/mhr*
Annual Fuel Costs	52 136	*US$s*
Annual Lube Cost	7 820	*US$s*
Annual Tyre/Track/Rigging Cost	0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	*US$/mhr*
Annual Maintenance Cost	50 748	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.43	*US$/mhr*

5.1 Machine Requirements

Annual Volume	296 500	*m3*
Hourly Volume Required	138.40	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No. Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	26.55	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	69.2	*m3/mhr*
Machine Output per Day	494	*m3/day*
Machine Output per Annum	148 251	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	12.87	2 297	27 570	55 140	9.09%
FIXED COSTS	74.59	13 316	159 794	319 589	52.7%
Hp's	38.82	6 930	83 166	166 331	27.4%
Crew	26.55	4 741	56 889	113 778	18.8%
Licence	9.21	1 645	19 740	39 480	6.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	54.10	9 659	115 905	231 809	38.2%
Fuel	24.34	4 345	52 136	104 273	17.2%
Lubrication	3.65	652	7 820	15 641	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	4 229	50 748	101 496	16.7%
Relocation	2.43	433	5 200	10 400	1.7%
TOTAL COST / REVENUE	141.56	25 272	303 269	606 538	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.05	**Inc. Profit**	2.35
Number of Machines	2		
Number of Operators	4		
Machine Hours	4 285		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	606 538		

MACHINE DESCRIPTION : **CFDD (Morbark 2455)**
OPERATION : **Delimb, Debark full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		714 371	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		714 371	US$s
Annual HP payment		150 485	US$s

1.2 HP Calculation

Residual Value @	20.00%	142 874	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 540	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 287	US$s
1.5 Overheads	10.00%	80438	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			56.9	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	234	8	30	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			66.57	US$/hour
Oil, Cost			9.99	US$/hour
Tyres/Tracks/Rigging Cost			62.40	US$/hour
Annual Fuel Costs			207 708	US$s
Annual Lube Cost			31 156	US$s
Annual Tyre/Track/Rigging Cost			194 688	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	47.62	US$/mhr
Annual Maintenance Cost	148 589	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	296 500	m3
Hourly Volume Required	95.03	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	16.75	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark		min
other		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	95.1	m3/mhr
Machine Output per Day	989	m3/day
Machine Output per Annum	296 712	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	25.78	6 703	80 438	80 438	9.09%
FIXED COSTS	69.56	18 087	217 041	217 041	24.5%
Hp	48.23	12 540	150 485	150 485	17.0%
Crew	16.75	4 356	52 269	52 269	5.9%
Licence	4.58	1 191	14 287	14 287	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	188.25	48 945	587 341	587 341	66.4%
Fuel	66.57	17 309	207 708	207 708	23.5%
Lubrication	9.99	2 596	31 156	31 156	3.5%
Tyres	62.40	16 224	194 688	194 688	22.0%
Maintenance	47.62	12 382	148 589	148 589	16.8%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	283.60	73 735	884 820	884 820	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.98	Inc. Profit	3.43
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	714 371		
Residual Value	142 874		
Total Revenue	884 820		

MACHINE DESCRIPTION : **Bell 220E Telelogger**
OPERATION : **Bundle tree lengths after debarking**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		80 500	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		80 500	US$s
Annual HP payment		16 958	US$s

1.2 HP Calculation

Residual Value @	20.00%	16 100	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		1 413	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	47.8%	
Machine hours per Day	7.6	Hours
Machine hours per Annum	2 294	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.54	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		1 610	US$s
1.5 Overheads	10.00%	10872	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			6.6	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyre front	0	0	0	
Tyre rear	0	0	0	
other	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			7.72	US$/mhr
Oil, Cost			1.16	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			17 717	US$s
Annual Lube Cost			2 658	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	5.37	US$/mhr
Annual Maintenance Cost	12 313	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.27	US$/mhr

5.1 Machine Requirements

Annual Volume	296 500	m3
Hourly Volume Required	129.23	m3/mhr
Number Of Machines Required	1.99	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.99	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	22.78	US$/mhr

4.1 WORK STUDY ANALYSIS

Tree volume		m3
Number trees per cycle		#
pull trees		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	64.800	m3/mhr
Machine Output per Day	496	m3/day
Machine Output per Annum	148 677	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	4.74	906	10 872	21 745	9.09%
FIXED COSTS	30.87	5 903	70 837	141 673	59.2%
Hp	7.39	1 413	16 958	33 915	14.2%
Crew	22.78	4 356	52 269	104 538	43.7%
Licence	0.70	134	1 610	3 220	1.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	16.51	3 157	37 888	75 776	31.7%
Fuel	7.72	1 476	17 717	35 435	14.8%
Lubrication	1.16	221	2 658	5 315	2.2%
Tyres	0.00	0	0	0	0.0%
Maintenance	5.37	1 026	12 313	24 627	10.3%
Relocation	2.27	433	5 200	10 400	4.3%
TOTAL COST / REVENUE	52.13	9 966	119 597	239 195	100.0%

6.2 FLEET SUMMARY

US$ per m3	0.81	**Inc. Profit**	0.93
Number of Machines	2		
Number of Operators	4		
Machine Hours	4 589		
Capital Employed	161 000		
Residual Value	32 200		
Total Revenue	239 195		

MACHINE DESCRIPTION : **Tracked loader with slasher deck (Tigercat T234)**
OPERATION : **Slash to 5.5m lengths**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	slasher	0	*US$s*
	Truck 2ns hand	0	*US$s*
	trailer	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		381 224	*US$s*
Annual HP payment		80 306	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	76 245	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 692	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	51.5%	
Machine hours per Day	8.2	*Hours*
Machine hours per Annum	2 471	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	6.07	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		5 718	*US$s*
1.5 Overheads	10.00%	25783	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			13.8	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	714	350	
Sprocket	0	0	0	
Tracks	0	0	0	
Chain	1	195	70	
other				
Fuel,Cost			16.15	*US$/mhr*
Oil, Cost			2.42	*US$/mhr*
Tyres/Tracks/Rigging Cost			4.83	*US$/mhr*
Annual Fuel Costs			39 899	*US$s*
Annual Lube Cost			5 985	*US$s*
Annual Tyre/Track/Rigging Cost			11 925	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	*US$/mhr*
Annual Maintenance Cost	56 523	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.10	*US$/mhr*

5.1 Machine Requirements

Annual Volume	296 500	*m3*
Hourly Volume Required	119.99	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	21.15	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Tree Volume		*m3*
		min
Slash		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*m3*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	120.000	*m3/mhr*
Machine Output per Day	988	*m3/day*
Machine Output per Annum	296 535	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.43	2 149	25 783	25 783	9.09%
FIXED COSTS	55.96	11 524	138 293	138 293	48.8%
Hp	32.50	6 692	80 306	80 306	28.3%
Crew	21.15	4 356	52 269	52 269	18.4%
Licence	2.31	477	5 718	5 718	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.37	9 961	119 532	119 532	42.1%
Fuel	16.15	3 325	39 899	39 899	14.1%
Lubrication	2.42	499	5 985	5 985	2.1%
Tyres	4.83	994	11 925	11 925	4.2%
Maintenance	22.87	4 710	56 523	56 523	19.9%
Relocation	2.10	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	114.77	23 634	283 608	283 608	100.0%

6.2 FLEET SUMMARY

US$ per m3	0.96	**Inc. Profit**	1.10
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 471		
Capital Employed	381 224		
Residual Value	76 245		
Total Revenue	283 608		

CFDDC System – Tree volume 0.075m^3

SYSTEM DESCRIPTION : **CFDDC**
OPERATION : **Stump to Mill**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$3.96	121 500	2	2	4	300
Grapple Skidder (Tigercat 630D)						$4.79	121 500	2	2	4	300
CFDDC (Morbark 2355)						$10.68	121 500	1	2	2	300
				Total		R 19.43		5		11	
						R 0.00		0		0	
				TOTAL		R 19.43		5		11	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED			
Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s
1.2 HP Calculation			
Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS		
Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	37.1%	
Machine hours per Day	5.9	Hours
Machine hours per Annum	1 781	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	8.42	Years

1.4 OVERHEADS			
Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	21871	US$s

2.1 VEHICLE OPERATING COSTS				
Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			31 670	US$s
Annual Lube Cost			4 750	US$s
Annual Tyre/Track/Rigging Cost			6 625	US$s
2.2 VEHICLE MAINTENANCE COSTS				
Maint,% Cap.Cost/machine life (mhr's)			100%	
Maintenance Cost			21.05	US$/mhr
Annual Maintenance Cost			37 482	US$s
2.3 RELOCATION COSTS				
Number of moves per annum			4	#
Cost per Move			1 300	US$s
Annual Relocation Cost			5 200	US$s
Relocation Cost per Machine Hour			2.92	US$/mhr
5.1 Machine Requirements				
Annual Volume			121 500	m3
Hourly Volume Required			68.23	m3/mhr
Number Of Machines Required			1.99	#
Fleet Reserve			0%	
Exact Number of Machines Required			1.99	#
Rounded number of vehicles Required			2	#

3.1 LABOUR COSTS		
Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	29.35	US$/mhr
4.1 WORK STUDY ANALYSIS		
Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	34.2	m3/mhr
Machine Output per Day	203	m3/day
Machine Output per Annum	60 903	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	12.28	1 823	21 871	43 742	9.09%
FIXED COSTS	74.68	11 082	132 983	265 966	55.3%
Hp	37.35	5 542	66 507	133 014	27.6%
Crew	29.35	4 356	52 269	104 538	21.7%
Licence	7.98	1 184	14 207	28 415	5.9%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.14	7 144	85 727	171 453	35.6%
Fuel	17.78	2 639	31 670	63 339	13.2%
Lubrication	2.67	396	4 750	9 501	2.0%
Tyres	3.72	552	6 625	13 249	2.8%
Maintenance	21.05	3 123	37 482	74 964	15.6%
Relocation	2.92	433	5 200	10 400	2.2%
TOTAL COST / REVENUE	135.10	20 048	240 581	481 162	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.96	Inc. Profit	4.55
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 562		
Capital Employed	631 434		
Residual Value	126 287		
Total Revenue	481 162		

MACHINE DESCRIPTION	:	**Grapple Skidder (Tigercat 630D)**
OPERATION	:	**Tree length extraction**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	40.1%	
Machine hours per Day	6.4	Hours
Machine hours per Annum	1 923	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.80	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	26437	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			46 801	US$s
Annual Lube Cost			7 020	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	45 555	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.70	US$/mhr

5.1 Machine Requirements

Annual Volume	121 500	m3
Hourly Volume Required	63.18	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	29.58	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	31.6	m3/mhr
Machine Output per Day	203	m3/day
Machine Output per Annum	60 771	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.75	2 203	26 437	52 874	9.09%
FIXED COSTS	83.09	13 316	159 794	319 589	54.9%
Hp's	43.25	6 930	83 166	166 331	28.6%
Crew	29.58	4 741	56 889	113 778	19.6%
Licence	10.26	1 645	19 740	39 480	6.8%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	54.38	8 715	104 576	209 152	36.0%
Fuel	24.34	3 900	46 801	93 602	16.1%
Lubrication	3.65	585	7 020	14 040	2.4%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	3 796	45 555	91 109	15.7%
Relocation	2.70	433	5 200	10 400	1.8%
TOTAL COST / REVENUE	151.22	24 234	290 807	581 615	100.0%

6.2 FLEET SUMMARY

US$ per m3	4.79	**Inc. Profit**	5.50
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 846		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	581 615		

MACHINE DESCRIPTION : **CFDDC (Morbark 2355)**
OPERATION : **Delimb, Debark, Chip, Load**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		1 059 368	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		1 059 368	$
Annual HP payment		223 159	$

1.2 HP Calculation

Residual Value @	20.00%	211 874	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		18 597	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		21 187	$
1.5 Overheads	10.00%	117980	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			104.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	234	8	30	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			122.73	$/mhr
Oil, Cost			18.41	$/mhr
Tyres/Tracks/Rigging Cost			68.26	$/mhr
Annual Fuel Costs			382 927	$
Annual Lube Cost			57 439	$
Annual Tyre/Track/Rigging Cost			212 959	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	70.62	$/mhr
Annual Maintenance Cost	220 349	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	121 500	m3
Hourly Volume Required	38.94	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		39.1	m3/mhr
Machine Output per Day		407	m3/day
Machine Output per Annum		121 992	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	**37.81**	**9 832**	**117 980**	**117 980**	**9.09%**
FIXED COSTS	**96.45**	**25 077**	**300 928**	**300 928**	**23.2%**
Hp	71.53	18 597	223 159	223 159	17.2%
Crew	18.13	4 715	56 581	56 581	4.4%
Licence	6.79	1 766	21 187	21 187	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**281.69**	**73 239**	**878 873**	**878 873**	**67.7%**
Fuel	122.73	31 911	382 927	382 927	29.5%
Lubrication	18.41	4 787	57 439	57 439	4.4%
Tyres	68.26	17 747	212 959	212 959	16.4%
Maintenance	70.62	18 362	220 349	220 349	17.0%
Relocation	1.67	433	5 200	5 200	0.4%
TOTAL COST / REVENUE	**415.96**	**108 148**	**1 297 781**	**1 297 781**	**100.0%**

6.2 FLEET SUMMARY

$ per m3	10.68	**Inc. Profit**	12.28
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	1 059 368		
Residual Value	211 874		
Total Revenue	1 297 781		

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CFDDC System – Tree volume 0.15m^3

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SYSTEM DESCRIPTION : **CFDDC**
OPERATION : **Stump to Mill**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.91	147 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$3.68	147 500	2	2	4	300
CFDDC (Morbark 2355)						$8.80	147 500	1	2	2	300
				Total		R 14.39		4		9	
						R 0.00		0		0	
				TOTAL		R 14.39		4		8.8	

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MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	54.6%	
Machine hours per Day	8.7	Hours
Machine hours per Annum	2 622	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.72	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	25673	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			46 622	US$s
Annual Lube Cost			6 993	US$s
Annual Tyre/Track/Rigging Cost			9 752	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	55 178	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.98	US$/mhr

5.1 Machine Requirements

Annual Volume	147 500	m3
Hourly Volume Required	56.26	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	19.94	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	56.3	m3/mhr
Machine Output per Day	492	m3/day
Machine Output per Annum	147 595	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	9.79	2 139	25 673	25 673	9.09%
FIXED COSTS	50.73	11 082	132 983	132 983	47.1%
Hp	25.37	5 542	66 507	66 507	23.6%
Crew	19.94	4 356	52 269	52 269	18.5%
Licence	5.42	1 184	14 207	14 207	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.20	10 312	123 746	123 746	43.8%
Fuel	17.78	3 885	46 622	46 622	16.5%
Lubrication	2.67	583	6 993	6 993	2.5%
Tyres	3.72	813	9 752	9 752	3.5%
Maintenance	21.05	4 598	55 178	55 178	19.5%
Relocation	1.98	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	107.72	23 534	282 402	282 402	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.91	**Inc. Profit**	2.20
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 622		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	282 402		

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MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	32.8%	
Machine hours per Day	5.3	Hours
Machine hours per Annum	1 576	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	9.52	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	24643	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	US$/mhr
Oil, Cost	3.65	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	38 353	US$s
Annual Lube Cost	5 753	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	37 332	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	3.30	US$/mhr

5.1 Machine Requirements

Annual Volume	147 500	m3
Hourly Volume Required	93.59	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	36.10	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	46.8	m3/mhr
Machine Output per Day	246	m3/day
Machine Output per Annum	73 756	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	15.64	2 054	24 643	49 286	9.09%
FIXED COSTS	101.39	13 316	159 794	319 589	58.9%
Hp's	52.77	6 930	83 166	166 331	30.7%
Crew	36.10	4 741	56 889	113 778	21.0%
Licence	12.53	1 645	19 740	39 480	7.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	54.97	7 220	86 638	173 276	32.0%
Fuel	24.34	3 196	38 353	76 706	14.1%
Lubrication	3.65	479	5 753	11 506	2.1%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	3 111	37 332	74 664	13.8%
Relocation	3.30	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	172.00	22 590	271 076	542 151	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.68	**Inc. Profit**	4.23
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 152		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	542 151		

MACHINE DESCRIPTION : CFDDC (Morbark 2355)
OPERATION : Delimb, Debark, Chip, Load
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		1 059 368	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		1 059 368	$
Annual HP payment		223 159	$

1.2 HP Calculation

Residual Value @	20.00%	211 874	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		18 597	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		21 187	$
1.5 Overheads	10.00%	117980	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			104.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
Chains	234	8	30	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			122.73	$/mhr
Oil, Cost			18.41	$/mhr
Tyres/Tracks/Rigging Cost			68.26	$/mhr
Annual Fuel Costs			382 927	$
Annual Lube Cost			57 439	$
Annual Tyre/Track/Rigging Cost			212 959	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	70.62	$/mhr
Annual Maintenance Cost	220 349	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	147 500	m3
Hourly Volume Required	47.28	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		47.4	m3/mhr
Machine Output per Day		493	m3/day
Machine Output per Annum		147 888	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	37.81	9 832	117 980	117 980	9.09%
FIXED COSTS	96.45	25 077	300 928	300 928	23.2%
Hp	71.53	18 597	223 159	223 159	17.2%
Crew	18.13	4 715	56 581	56 581	4.4%
Licence	6.79	1 766	21 187	21 187	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	281.69	73 239	878 873	878 873	67.7%
Fuel	122.73	31 911	382 927	382 927	29.5%
Lubrication	18.41	4 787	57 439	57 439	4.4%
Tyres	68.26	17 747	212 959	212 959	16.4%
Maintenance	70.62	18 362	220 349	220 349	17.0%
Relocation	1.67	433	5 200	5 200	0.4%
TOTAL COST / REVENUE	415.96	108 148	1 297 781	1 297 781	100.0%

6.2 FLEET SUMMARY

$ per m3	8.80	**Inc. Profit**	10.12
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	1 059 368		
Residual Value	211 874		
Total Revenue	1 297 781		

CFDDC System – Tree volume 0.25m^3

SYSTEM DESCRIPTION : **CFDDC**
OPERATION : **Stump to Mill**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.47	186 000	1	2	2	300
Grapple Skidder (Tigercat 630D)						$2.97	186 000	2	2	4	300
CFDDC (Morbark 2355)						$6.98	186 000	1	2	2	300
				Total		R 11.42		4		9	
						R 0.00		0		0	
				TOTAL		R 11.42		4		8.8	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	50.9%	
Machine hours per Day	8.1	Hours
Machine hours per Annum	2 445	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.14	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	24873	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			43 474	US$s
Annual Lube Cost			6 521	US$s
Annual Tyre/Track/Rigging Cost			9 094	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	51 453	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.13	US$/mhr

5.1 Machine Requirements

Annual Volume	186 000	m3
Hourly Volume Required	76.09	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	21.38	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	76.1	m3/mhr
Machine Output per Day	620	m3/day
Machine Output per Annum	186 033	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.17	2 073	24 873	24 873	9.09%
FIXED COSTS	54.40	11 082	132 983	132 983	48.6%
Hp	27.21	5 542	66 507	66 507	24.3%
Crew	21.38	4 356	52 269	52 269	19.1%
Licence	5.81	1 184	14 207	14 207	5.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.35	9 645	115 742	115 742	42.3%
Fuel	17.78	3 623	43 474	43 474	15.9%
Lubrication	2.67	543	6 521	6 521	2.4%
Tyres	3.72	758	9 094	9 094	3.3%
Maintenance	21.05	4 288	51 453	51 453	18.8%
Relocation	2.13	433	5 200	5 200	1.9%
TOTAL COST / REVENUE	111.92	22 800	273 598	273 598	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.47	**Inc. Profit**	1.69
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 445		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	273 598		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		394 798	*US$s*
Annual Hp's		83 166	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	78 960	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 930	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	*#*
Machine Availability	100.0%	
Machine Utilisation	34.8%	
Machine hours per Day	5.6	*Hours*
Machine hours per Annum	1 673	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	8.97	*Years*

1.4 OVERHEADS

Annual Licence Fees		19 740	*US$s*
1.5 Overheads	10.00%	25143	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	*US$/mhr*
Oil, Cost			3.65	*US$/mhr*
Tyres/Tracks/Rigging Cost			0.00	*US$/mhr*
Annual Fuel Costs			40 706	*US$s*
Annual Lube Cost			6 106	*US$s*
Annual Tyre/Track/Rigging Cost			0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	*US$/mhr*
Annual Maintenance Cost	39 622	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	3.11	*US$/mhr*

5.1 Machine Requirements

Annual Volume	186 000	*m3*
Hourly Volume Required	111.20	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per Week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	34.01	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	55.6	*m3/mhr*
Machine Output per Day	310	*m3/day*
Machine Output per Annum	93 001	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	15.03	2 095	25 143	50 286	9.09%
FIXED COSTS	95.53	13 316	159 794	319 589	57.8%
Hp's	49.72	6 930	83 166	166 331	30.1%
Crew	34.01	4 741	56 889	113 778	20.6%
Licence	11.80	1 645	19 740	39 480	7.1%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	54.78	7 636	91 634	183 268	33.1%
Fuel	24.34	3 392	40 706	81 412	14.7%
Lubrication	3.65	509	6 106	12 212	2.2%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	3 302	39 622	79 244	14.3%
Relocation	3.11	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	165.35	23 048	276 571	553 143	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.97	**Inc. Profit**	3.42
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 345		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	553 143		

MACHINE DESCRIPTION	:	**CFDDC (Morbark 2355)**
OPERATION	:	**Delimb, Debark, Chip, Load**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		1 059 368	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		1 059 368	$
Annual HP payment		223 159	$

1.2 HP Calculation

Residual Value @	20.00%	211 874	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		18 597	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		21 187	$
1.5 Overheads	10.00%	117980	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			104.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	234	8	30	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			122.73	$/mhr
Oil, Cost			18.41	$/mhr
Tyres/Tracks/Rigging Cost			68.26	$/mhr
Annual Fuel Costs			382 927	$
Annual Lube Cost			57 439	$
Annual Tyre/Track/Rigging Cost			212 959	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	70.62	$/mhr
Annual Maintenance Cost	220 349	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	186 000	m3
Hourly Volume Required	59.62	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		59.7	m3/mhr
Machine Output per Day		621	m3/day
Machine Output per Annum		186 264	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	37.81	9 832	117 980	117 980	9.09%
FIXED COSTS	96.45	25 077	300 928	300 928	23.2%
Hp	71.53	18 597	223 159	223 159	17.2%
Crew	18.13	4 715	56 581	56 581	4.4%
Licence	6.79	1 766	21 187	21 187	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	281.69	73 239	878 873	878 873	67.7%
Fuel	122.73	31 911	382 927	382 927	29.5%
Lubrication	18.41	4 787	57 439	57 439	4.4%
Tyres	68.26	17 747	212 959	212 959	16.4%
Maintenance	70.62	18 362	220 349	220 349	17.0%
Relocation	1.67	433	5 200	5 200	0.4%
TOTAL COST / REVENUE	415.96	108 148	1 297 781	1 297 781	100.0%

6.2 FLEET SUMMARY

$ per m3	6.98	**Inc. Profit**	8.02
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	1 059 368		
Residual Value	211 874		
Total Revenue	1 297 781		

CFDDC System – Tree volume 0.40m^3

SYSTEM DESCRIPTION : CFDDC
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.23	210 000	1	2	2	300
Grapple Skidder (Tigercat 630D)						$2.55	210 000	2	2	4	300
CFDDC (Morbark 2355)						$6.18	210 000	1	2	2	300
				Total		R 9.96		4		9	
						R 0.00		0		0	
				TOTAL		R 9.96		4		8.8	

MACHINE DESCRIPTION : Wheeled Feller Buncher (Tigercat 720E)
OPERATION : Felling and bunching
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED			
Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s
1.2 HP Calculation			
Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s
1.3 OPERATING HOURS			
Total Days		365	
Weekend Days		52	
Statutory Leave Days		13	
Sick Leave Days		0	
Productive Days Lost to Weather/Mill Stops		0	
Total Annual Production Days		300	Days
Shift length		8	Hours
Number of Shifts per day		2	#
Machine Availability		100.0%	
Machine Utilisation		44.6%	
Machine hours per Day		7.1	Hours
Machine hours per Annum		2 141	Hours
Machine Life Hours		15 000	Hours
Machine Life Years		7.01	Years
1.4 OVERHEADS			
Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	23498	US$s

2.1 VEHICLE OPERATING COSTS				
Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			38 070	US$s
Annual Lube Cost			5 711	US$s
Annual Tyre/Track/Rigging Cost			7 963	US$s
2.2 VEHICLE MAINTENANCE COSTS				
Maint,% Cap.Cost/machine life (mhr's)			100%	
Maintenance Cost			21.05	US$/mhr
Annual Maintenance Cost			45 057	US$s
2.3 RELOCATION COSTS				
Number of moves per annum			4	#
Cost per Move			1 300	US$s
Annual Relocation Cost			5 200	US$s
Relocation Cost per Machine Hour			2.43	US$/mhr
5.1 Machine Requirements				
Annual Volume			210 000	m3
Hourly Volume Required			98.10	m3/mhr
Number Of Machines Required			1.00	#
Fleet Reserve			0%	
Exact Number of Machines Required			1.00	#
Rounded number of vehicles Required			1	#

3.1 LABOUR COSTS		
Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	24.42	US$/mhr
4.1 WORK STUDY ANALYSIS		
Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	98.1	m3/mhr
Machine Output per Day	700	m3/day
Machine Output per Annum	210 002	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	10.98	1 958	23 498	23 498	9.09%
FIXED COSTS	62.12	11 082	132 983	132 983	51.4%
Hp	31.07	5 542	66 507	66 507	25.7%
Crew	24.42	4 356	52 269	52 269	20.2%
Licence	6.64	1 184	14 207	14 207	5.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.65	8 500	102 001	102 001	39.5%
Fuel	17.78	3 173	38 070	38 070	14.7%
Lubrication	2.67	476	5 711	5 711	2.2%
Tyres	3.72	664	7 963	7 963	3.1%
Maintenance	21.05	3 755	45 057	45 057	17.4%
Relocation	2.43	433	5 200	5 200	2.0%
TOTAL COST / REVENUE	120.75	21 540	258 482	258 482	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.23	**Inc. Profit**	1.42
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 141		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	258 482		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED			
Machine Price,Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s
1.2 HP Calculation			
Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS		
Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	31.6%	
Machine hours per Day	5.1	Hours
Machine hours per Annum	1 518	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	9.88	Years

1.4 OVERHEADS			
Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	24343	US$s

2.1 VEHICLE OPERATING COSTS				
Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			36 940	US$s
Annual Lube Cost			5 541	US$s
Annual Tyre/Track/Rigging Cost			0	US$s
2.2 VEHICLE MAINTENANCE COSTS				
Maint,% Cap.Cost/machine life (mhr's)			90%	
Maintenance Cost			23.69	US$/mhr
Annual Maintenance Cost			35 956	US$s
2.3 RELOCATION COSTS				
Number of moves per annum			4	#
Cost per Move			1 300	US$s
Annual Relocation Cost			5 200	US$s
Relocation Cost per Machine Hour			3.43	US$/mhr
5.1 Machine Requirements				
Annual Volume			210 000	m3
Hourly Volume Required			138.35	m3/mhr
Number Of Machines Required			2.00	#
Fleet Reserve			0%	
Exact Number of Machines Required			2.00	#
Rounded number of vehicles Required			2	#

3.1 LABOUR COSTS		
Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	37.48	US$/mhr

4.1 WORK STUDY ANALYSIS		
Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	69.2	m3/mhr
Machine Output per Day	350	m3/day
Machine Output per Annum	105 039	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	16.04	2 029	24 343	48 686	9.09%
FIXED COSTS	105.27	13 316	159 794	319 589	59.7%
Hp's	54.79	6 930	83 166	166 331	31.1%
Crew	37.48	4 741	56 889	113 778	21.2%
Licence	13.00	1 645	19 740	39 480	7.4%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	55.10	6 970	83 637	167 273	31.2%
Fuel	24.34	3 078	36 940	73 880	13.8%
Lubrication	3.65	462	5 541	11 082	2.1%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	2 996	35 956	71 912	13.4%
Relocation	3.43	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	176.41	22 315	267 774	535 549	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.55	**Inc. Profit**	2.93
Number of Machines	2		
Number of Operators	4		
Machine Hours	3 036		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	535 549		

MACHINE DESCRIPTION : **CFDDC (Morbark 2355)**
OPERATION : **Delimb, Debark, Chip, Load**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		1 059 368	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		1 059 368	$
Annual HP payment		223 159	$

1.2 HP Calculation

Residual Value @	20.00%	211 874	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		18 597	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		21 187	$
1.5 Overheads	10.00%	117980	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			104.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	234	8	30	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			122.73	$/mhr
Oil, Cost			18.41	$/mhr
Tyres/Tracks/Rigging Cost			68.26	$/mhr
Annual Fuel Costs			382 927	$
Annual Lube Cost			57 439	$
Annual Tyre/Track/Rigging Cost			212 959	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	70.62	$/mhr
Annual Maintenance Cost	220 349	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	210 000	m3
Hourly Volume Required	67.31	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		67.4	m3/mhr
Machine Output per Day		701	m3/day
Machine Output per Annum		210 288	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	37.81	9 832	117 980	117 980	9.09%
FIXED COSTS	96.45	25 077	300 928	300 928	23.2%
Hp	71.53	18 597	223 159	223 159	17.2%
Crew	18.13	4 715	56 581	56 581	4.4%
Licence	6.79	1 766	21 187	21 187	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	281.69	73 239	878 873	878 873	67.7%
Fuel	122.73	31 911	382 927	382 927	29.5%
Lubrication	18.41	4 787	57 439	57 439	4.4%
Tyres	68.26	17 747	212 959	212 959	16.4%
Maintenance	70.62	18 362	220 349	220 349	17.0%
Relocation	1.67	433	5 200	5 200	0.4%
TOTAL COST / REVENUE	415.96	108 148	1 297 781	1 297 781	100.0%

6.2 FLEET SUMMARY

$ per m3	6.18	**Inc. Profit**	7.11
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	1 059 368		
Residual Value	211 874		
Total Revenue	1 297 781		

CFDD&C System – Tree volume $0.075m^3$

SYSTEM DESCRIPTION	:	**CFDD&C**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$3.13	90 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$5.81	90 500	2	2	4	300
CFDD (Precision Husky 2300-4)						$9.90	90 500	1	2	2	300
Chipper (Presicion Husky 2366-KBL)						$6.46	90 500	1	2	2	300
				Total		R 25.30		5		11	
						R 0.00		0		0	
				TOTAL		R 25.30		5		11	

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MACHINE DESCRIPTION	:	**Wheeled Feller Buncher (Tigercat 720E)**
OPERATION	:	**Felling and bunching**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	combican	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		315 717	*US$s*
Annual HP payment		66 507	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	63 143	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		5 542	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	55.2%	
Machine hours per Day	8.8	*Hours*
Machine hours per Annum	2 647	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	5.67	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	*US$s*
1.5 Overheads	10.00%	25789	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	15.2	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil,% Fuel Cost	15%	
Oil Cost		*US$/L*

Tyres/Tracks/Rigging

	Qty	Cost	Life
Tyres	0	0	0
Cutting disk	0	0	0
Cutting teeth	1	9 300	2 500
Other	0	0	0
Other	0	0	0

Fuel,Cost	17.78	*US$/mhr*
Oil, Cost	2.67	*US$/mhr*
Tyres/Tracks/Rigging Cost	3.72	*US$/mhr*
Annual Fuel Costs	47 079	*US$s*
Annual Lube Cost	7 062	*US$s*
Annual Tyre/Track/Rigging Cost	9 848	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	*US$/mhr*
Annual Maintenance Cost	55 719	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	1.96	*US$/mhr*

5.1 Machine Requirements

Annual Volume	90 500	*m3*
Hourly Volume Required	34.19	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Annual Contributions	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	19.74	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
bunch		*min*
place		*min*
move		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	34.2	*m3/mhr*
Machine Output per Day	302	*m3/day*
Machine Output per Annum	90 537	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	9.74	2 149	25 789	25 789	9.09%
FIXED COSTS	50.23	11 082	132 983	132 983	46.9%
Hp	25.12	5 542	66 507	66 507	23.4%
Crew	19.74	4 356	52 269	52 269	18.4%
Licence	5.37	1 184	14 207	14 207	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.18	10 409	124 908	124 908	44.0%
Fuel	17.78	3 923	47 079	47 079	16.6%
Lubrication	2.67	588	7 062	7 062	2.5%
Tyres	3.72	821	9 848	9 848	3.5%
Maintenance	21.05	4 643	55 719	55 719	19.6%
Relocation	1.96	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	107.16	23 640	283 681	283 681	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.13	**Inc. Profit**	3.60
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 647		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	283 681		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	29.8%	
Machine hours per Day	4.8	Hours
Machine hours per Annum	1 432	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	10.48	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	23899	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption		20.8	L/Hr
Fuel Cost		1.17	US$/L
Oil,% Fuel Cost		15%	
Oil Cost			US$/L
Tyres/Tracks/Rigging			

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	US$/mhr
Oil, Cost	3.65	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	34 849	US$s
Annual Lube Cost	5 227	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	33 921	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	3.63	US$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	63.20	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	39.73	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	31.6	m3/mhr
Machine Output per Day	151	m3/day
Machine Output per Annum	45 250	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	16.69	1 992	23 899	47 798	9.09%
FIXED COSTS	111.59	13 316	159 794	319 589	60.8%
Hp's	58.08	6 930	83 166	166 331	31.6%
Crew	39.73	4 741	56 889	113 778	21.6%
Licence	13.79	1 645	19 740	39 480	7.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	55.31	6 600	79 196	158 393	30.1%
Fuel	24.34	2 904	34 849	69 697	13.3%
Lubrication	3.65	436	5 227	10 455	2.0%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	2 827	33 921	67 841	12.9%
Relocation	3.63	433	5 200	10 400	2.0%
TOTAL COST / REVENUE	183.59	21 907	262 890	525 780	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.81	**Inc. Profit**	6.68
Number of Machines	2		
Number of Operators	4		
Machine Hours	2 864		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	525 780		

MACHINE DESCRIPTION : **CFDD (Precision Husky 2300-4)**
OPERATION : **Delimb & Debark**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		734 324	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		734 324	$
Annual HP payment		154 688	$

1.2 HP Calculation

Residual Value @	20.00%	146 865	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 891	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	64.2%	
Machine hours per Day	10.3	Hours
Machine hours per Annum	3 082	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.87	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 686	$
1.5 Overheads	10.00%	81438	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			57.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Chains	312	8	40	
Other	0	0	0	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			67.74	$/mhr
Oil, Cost			10.16	$/mhr
Tyres/Tracks/Rigging Cost			62.40	$/mhr
Annual Fuel Costs			208 757	$
Annual Lube Cost			31 314	$
Annual Tyre/Track/Rigging Cost			192 292	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap Cost/machine life (mhr's)	100%	
Maintenance Cost	48.95	$/mhr
Annual Maintenance Cost	150 860	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.69	$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	29.37	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.36	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark, chip, Load		min
other		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	29.4	m3/mhr
Machine Output per Day	302	m3/day
Machine Output per Annum	90 599	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	26.43	6 786	81 438	81 438	9.09%
FIXED COSTS	73.32	18 830	225 955	225 955	25.2%
Hp	50.20	12 891	154 688	154 688	17.3%
Crew	18.36	4 715	56 581	56 581	6.3%
Licence	4.77	1 224	14 686	14 686	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	190.95	49 035	588 422	588 422	65.7%
Fuel	67.74	17 396	208 757	208 757	23.3%
Lubrication	10.16	2 609	31 314	31 314	3.5%
Tyres	62.40	16 024	192 292	192 292	21.5%
Maintenance	48.95	12 572	150 860	150 860	16.8%
Relocation	1.69	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	290.70	74 651	895 815	895 815	100.0%

6.2 FLEET SUMMARY

$ per m3	9.90	**Inc. Profit**	11.38
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 082		
Capital Employed	734 324		
Residual Value	146 865		
Total Revenue	895 815		

MACHINE DESCRIPTION : Chipper (Presicion Husky 2366-KBL)
OPERATION : Chip
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		589 848	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		589 848	$
Annual HP payment		124 253	$

1.2 HP Calculation

Residual Value @	20.00%	117 970	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 354	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	64.2%	
Machine hours per Day	10.3	Hours
Machine hours per Annum	3 082	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.87	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		11 797	$
1.5 Overheads	10.00%	53152	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			46.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Other	0	0	0	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			54.87	$/mhr
Oil, Cost			8.23	$/mhr
Tyres/Tracks/Rigging Cost			5.86	$/mhr
Annual Fuel Costs			169 097	$
Annual Lube Cost			25 364	$
Annual Tyre/Track/Rigging Cost			18 046	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	39.32	$/mhr
Annual Maintenance Cost	121 178	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.69	$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	29.37	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.36	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark, chip, Load		min
other		min
other		min
other		min
other		min
other 1		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	29.4	m3/mhr
Machine Output per Day	302	m3/day
Machine Output per Annum	90 599	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	17.25	4 429	53 152	53 152	9.09%
FIXED COSTS	62.51	16 053	192 631	192 631	32.9%
Hp	40.32	10 354	124 253	124 253	21.3%
Crew	18.36	4 715	56 581	56 581	9.7%
Licence	3.83	983	11 797	11 797	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	109.97	28 240	338 885	338 885	58.0%
Fuel	54.87	14 091	169 097	169 097	28.9%
Lubrication	8.23	2 114	25 364	25 364	4.3%
Tyres	5.86	1 504	18 046	18 046	3.1%
Maintenance	39.32	10 098	121 178	121 178	20.7%
Relocation	1.69	433	5 200	5 200	0.9%
TOTAL COST / REVENUE	189.73	48 722	584 668	584 668	100.0%

6.2 FLEET SUMMARY

$ per m3	6.46	**Inc. Profit**	7.43
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 082		
Capital Employed	589 848		
Residual Value	117 970		
Total Revenue	584 668		

CFDD&C System – Tree volume 0.15m^3

SYSTEM DESCRIPTION	:	**CFDD&C**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.99	137 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$3.85	137 500	2	2	4	300
CFDD (Precision Husky 2300-4)						$6.57	137 500	1	2	2	300
Chipper (Presicion Husky 2366-KBL)						$4.29	137 500	1	2	2	300
			Total			R 16.70		5		11	
						R 0.00		0		0	
			TOTAL			R 16.70		5		11	

MACHINE DESCRIPTION : Wheeled Feller Buncher (Tigercat 720E)
OPERATION : Felling and bunching
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	combican	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		315 717	*US$s*
Annual HP payment		66 507	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	63 143	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		5 542	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	50.9%	
Machine hours per Day	8.1	*Hours*
Machine hours per Annum	2 443	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	6.14	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	*US$s*
1.5 Overheads	10.00%	24864	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	15.2	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil,% Fuel Cost	15%	
Oil Cost		*US$/L*
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Tyres	0	0	0
Cutting disk	0	0	0
Cutting teeth	1	9 300	2 500
Other	0	0	0
Other	0	0	0

Fuel,Cost	17.78	*US$/mhr*
Oil, Cost	2.67	*US$/mhr*
Tyres/Tracks/Rigging Cost	3.72	*US$/mhr*
Annual Fuel Costs	43 441	*US$s*
Annual Lube Cost	6 516	*US$s*
Annual Tyre/Track/Rigging Cost	9 087	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	*US$/mhr*
Annual Maintenance Cost	51 414	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.13	*US$/mhr*

5.1 Machine Requirements

Annual Volume	137 500	*m3*
Hourly Volume Required	56.29	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Annual Contributions	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	21.40	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
bunch		*min*
place		*min*
move		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	56.3	*m3/mhr*
Machine Output per Day	458	*m3/day*
Machine Output per Annum	137 525	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**10.18**	**2 072**	**24 864**	**24 864**	**9.09%**
FIXED COSTS	**54.44**	**11 082**	**132 983**	**132 983**	**48.6%**
Hp	27.23	5 542	66 507	66 507	24.3%
Crew	21.40	4 356	52 269	52 269	19.1%
Licence	5.82	1 184	14 207	14 207	5.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**47.35**	**9 638**	**115 658**	**115 658**	**42.3%**
Fuel	17.78	3 620	43 441	43 441	15.9%
Lubrication	2.67	543	6 516	6 516	2.4%
Tyres	3.72	757	9 087	9 087	3.3%
Maintenance	21.05	4 284	51 414	51 414	18.8%
Relocation	2.13	433	5 200	5 200	1.9%
TOTAL COST / REVENUE	**111.97**	**22 792**	**273 505**	**273 505**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	1.99	**Inc. Profit**	2.29
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 443		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	273 505		

MACHINE DESCRIPTION	:	**Grapple Skidder (Tigercat 630D)**
OPERATION	:	**Tree length extraction**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT			394 798	*US$s*
Less Cost of Tyres/Tracks/Rigging			0	*US$s*
Plus additional equipment	radio		0	*US$s*
	other		0	*US$s*
	other		0	*US$s*
	other		0	*US$s*
	other		0	*US$s*
Sub total additional equipment			0	*US$s*
Total Capital Employed			394 798	*US$s*
Annual Hp's			83 166	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	78 960	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 930	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	30.6%	
Machine hours per Day	4.9	*Hours*
Machine hours per Annum	1 469	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	10.21	*Years*

1.4 OVERHEADS

Annual Licence Fees		19 740	*US$s*
1.5 Overheads	10.00%	24091	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	20.8	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil,% Fuel Cost	15%	
Oil Cost		*US$/L*
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	*US$/mhr*
Oil, Cost	3.65	*US$/mhr*
Tyres/Tracks/Rigging Cost	0.00	*US$/mhr*
Annual Fuel Costs	35 755	*US$s*
Annual Lube Cost	5 363	*US$s*
Annual Tyre/Track/Rigging Cost	0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	*US$/mhr*
Annual Maintenance Cost	34 802	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	3.54	*US$/mhr*

5.1 Machine Requirements

Annual Volume	137 500	*m3*
Hourly Volume Required	93.59	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	38.72	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	46.8	*m3/mhr*
Machine Output per Day	229	*m3/day*
Machine Output per Annum	68 759	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	16.40	2 008	24 091	48 183	9.09%
FIXED COSTS	108.76	13 316	159 794	319 589	60.3%
Hp's	56.61	6 930	83 166	166 331	31.4%
Crew	38.72	4 741	56 889	113 778	21.5%
Licence	13.44	1 645	19 740	39 480	7.4%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	55.21	6 760	81 120	162 240	30.6%
Fuel	24.34	2 980	35 755	71 509	13.5%
Lubrication	3.65	447	5 363	10 726	2.0%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	2 900	34 802	69 605	13.1%
Relocation	3.54	433	5 200	10 400	2.0%
TOTAL COST / REVENUE	180.37	22 084	265 006	530 012	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.85	**Inc. Profit**	4.43
Number of Machines	2		
Number of Operators	4		
Machine Hours	2 938		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	530 012		

MACHINE DESCRIPTION : **CFDD (Precision Husky 2300-4)**
OPERATION : **Delimb & Debark**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		734 324	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		734 324	$
Annual HP payment		154 688	$

1.2 HP Calculation

Residual Value @	20.00%	146 865	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 891	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 686	$
1.5 Overheads	10.00%	82164	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			57.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
Chains	312	8	40	
Other	0	0	0	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			67.74	$/mhr
Oil, Cost			10.16	$/mhr
Tyres/Tracks/Rigging Cost			62.40	$/mhr
Annual Fuel Costs			211 358	$
Annual Lube Cost			31 704	$
Annual Tyre/Track/Rigging Cost			194 688	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	48.95	$/mhr
Annual Maintenance Cost	152 739	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	137 500	m3
Hourly Volume Required	44.07	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		44.2	m3/mhr
Machine Output per Day		460	m3/day
Machine Output per Annum		137 904	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	$/month	$/year	$/year	of Total
OVERHEADS	26.33	6 847	82 164	82 164	9.09%
FIXED COSTS	72.42	18 830	225 955	225 955	25.0%
Hp	49.58	12 891	154 688	154 688	17.1%
Crew	18.13	4 715	56 581	56 581	6.3%
Licence	4.71	1 224	14 686	14 686	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	190.93	49 641	595 689	595 689	65.9%
Fuel	67.74	17 613	211 358	211 358	23.4%
Lubrication	10.16	2 642	31 704	31 704	3.5%
Tyres	62.40	16 224	194 688	194 688	21.5%
Maintenance	48.95	12 728	152 739	152 739	16.9%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	289.68	75 317	903 809	903 809	100.0%

6.2 FLEET SUMMARY

$ per m3	6.57	Inc. Profit	7.56
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	734 324		
Residual Value	146 865		
Total Revenue	903 809		

MACHINE DESCRIPTION : **Chipper (Presicion Husky 2366-KBL)**
OPERATION : **Chip**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		589 848	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		589 848	$
Annual HP payment		124 253	$

1.2 HP Calculation

Residual Value @	20.00%	117 970	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 354	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		11 797	$
1.5 Overheads	10.00%	53567	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	46.9	L/Hr
Fuel Cost	1.17	$/L
Oil,% Fuel Cost	15%	
Oil Cost		$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
Other	0	0	0
Disc Knives	12	24	50
Drum	0	0	0
Tyres	0	0	0
other	0	0	0

Fuel,Cost	54.87	$/mhr
Oil, Cost	8.23	$/mhr
Tyres/Tracks/Rigging Cost	5.86	$/mhr
Annual Fuel Costs	171 204	$
Annual Lube Cost	25 681	$
Annual Tyre/Track/Rigging Cost	18 271	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	39.32	$/mhr
Annual Maintenance Cost	122 688	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	137 500	m3
Hourly Volume Required	44.07	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
Number of trees/grab		#
other		
debranch, debark, chip, Load		min
other		min
other		min
other		min
other		min
other 1		min
other		min
cycle time	0.00	min
cycle time	0.00	hrs
Machine Output per Hour	44.2	m3/mhr
Machine Output per Day	460	m3/day
Machine Output per Annum	137 904	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	17.17	4 464	53 567	53 567	9.09%
FIXED COSTS	61.74	16 053	192 631	192 631	32.7%
Hp	39.82	10 354	124 253	124 253	21.1%
Crew	18.13	4 715	56 581	56 581	9.6%
Licence	3.78	983	11 797	11 797	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	109.95	28 587	343 043	343 043	58.2%
Fuel	54.87	14 267	171 204	171 204	29.1%
Lubrication	8.23	2 140	25 681	25 681	4.4%
Tyres	5.86	1 523	18 271	18 271	3.1%
Maintenance	39.32	10 224	122 688	122 688	20.8%
Relocation	1.67	433	5 200	5 200	0.9%
TOTAL COST / REVENUE	188.86	49 104	589 242	589 242	100.0%

6.2 FLEET SUMMARY

$ per m3	4.29	**Inc. Profit**	4.93
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	589 848		
Residual Value	117 970		
Total Revenue	589 242		

CFDD&C System – Tree volume 0.25m^3

SYSTEM DESCRIPTION : **CFDD&C**
OPERATION : **Stump to Mill**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.57	166 000	1	2	2	300
Grapple Skidder (Tigercat 630D)						$3.21	166 000	2	2	4	300
CFDD (Precision Husky 2300-4)						$5.44	166 000	1	2	2	300
Chipper (Presicion Husky 2366-KBL)						$3.55	166 000	1	2	2	300
				Total		R 13.77		5		11	
						R 0.00		0		0	
				TOTAL		R 13.77		5		11	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED			
Machine Price,Exc.VAT		315 717	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	combican	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		315 717	*US$s*
Annual HP payment		66 507	*US$s*
1.2 HP Calculation			
Residual Value @	20.00%	63 143	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		5 542	*US$s*

1.3 OPERATING HOURS		
Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	45.4%	
Machine hours per Day	7.3	*Hours*
Machine hours per Annum	2 181	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	6.88	*Years*

1.4 OVERHEADS			
Annual Licence Fees & insurance		14 207	*US$s*
1.5 Overheads	10.00%	23683	*US$s*

2.1 VEHICLE OPERATING COSTS				
Fuel Consumption			15.2	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	*US$/mhr*
Oil, Cost			2.67	*US$/mhr*
Tyres/Tracks/Rigging Cost			3.72	*US$/mhr*
Annual Fuel Costs			38 795	*US$s*
Annual Lube Cost			5 819	*US$s*
Annual Tyre/Track/Rigging Cost			8 115	*US$s*
2.2 VEHICLE MAINTENANCE COSTS				
Maint.% Cap.Cost/machine life (mhr's)			100%	
Maintenance Cost			21.05	*US$/mhr*
Annual Maintenance Cost			45 915	*US$s*
2.3 RELOCATION COSTS				
Number of moves per annum			4	#
Cost per Move			1 300	*US$s*
Annual Relocation Cost			5 200	*US$s*
Relocation Cost per Machine Hour			2.38	*US$/mhr*
5.1 Machine Requirements				
Annual Volume			166 000	*m3*
Hourly Volume Required			76.10	*m3/mhr*
Number Of Machines Required			1.00	#
Fleet Reserve			0%	
Exact Number of Machines Required			1.00	#
Rounded number of vehicles Required			1	#

3.1 LABOUR COSTS		
Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Annual Contributions	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	23.96	*US$/mhr*

4.1 WORK STUDY ANALYSIS		
Average Tree Volume		*m3*
fell		*min*
bunch		*min*
place		*min*
move		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Hour	76.1	*m3/mhr*
Machine Output per Day	553	*m3/day*
Machine Output per Annum	166 008	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**10.86**	**1 974**	**23 683**	**23 683**	**9.09%**
FIXED COSTS	**60.96**	**11 082**	**132 983**	**132 983**	**51.0%**
Hp	30.49	5 542	66 507	66 507	25.5%
Crew	23.96	4 356	52 269	52 269	20.1%
Licence	6.51	1 184	14 207	14 207	5.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**47.60**	**8 654**	**103 844**	**103 844**	**39.9%**
Fuel	17.78	3 233	38 795	38 795	14.9%
Lubrication	2.67	485	5 819	5 819	2.2%
Tyres	3.72	676	8 115	8 115	3.1%
Maintenance	21.05	3 826	45 915	45 915	17.6%
Relocation	2.38	433	5 200	5 200	2.0%
TOTAL COST / REVENUE	**119.42**	**21 709**	**260 509**	**260 509**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	1.57	**Inc. Profit**	1.80
Number of Machines	1		
Number of Operators	2		
Machine Hours	2 181		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	260 509		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		394 798	*US$s*
Annual Hp's		83 166	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	78 960	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 930	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	31.1%	
Machine hours per Day	5.0	*Hours*
Machine hours per Annum	1 493	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	10.05	*Years*

1.4 OVERHEADS

Annual Licence Fees		19 740	*US$s*
1.5 Overheads	10.00%	24213	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	*US$/mhr*
Oil, Cost			3.65	*US$/mhr*
Tyres/Tracks/Rigging Cost			0.00	*US$/mhr*
Annual Fuel Costs			36 329	*US$s*
Annual Lube Cost			5 449	*US$s*
Annual Tyre/Track/Rigging Cost			0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	*US$/mhr*
Annual Maintenance Cost	35 362	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	3.48	*US$/mhr*

5.1 Machine Requirements

Annual Volume	166 000	*m3*
Hourly Volume Required	111.20	*m3/mhr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	38.11	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	55.6	*m3/mhr*
Machine Output per Day	277	*m3/day*
Machine Output per Annum	83 001	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	16.22	2 018	24 213	48 427	9.09%
FIXED COSTS	107.04	13 316	159 794	319 589	60.0%
Hp's	55.71	6 930	83 166	166 331	31.2%
Crew	38.11	4 741	56 889	113 778	21.4%
Licence	13.22	1 645	19 740	39 480	7.4%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	55.16	6 862	82 340	164 680	30.9%
Fuel	24.34	3 027	36 329	72 658	13.6%
Lubrication	3.65	454	5 449	10 899	2.0%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	2 947	35 362	70 723	13.3%
Relocation	3.48	433	5 200	10 400	2.0%
TOTAL COST / REVENUE	178.42	22 196	266 348	532 696	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.21	**Inc. Profit**	3.69
Number of Machines	2		
Number of Operators	4		
Machine Hours	2 986		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	532 696		

MACHINE DESCRIPTION : **CFDD (Precision Husky 2300-4)**
OPERATION : **Delimb & Debark**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		734 324	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		734 324	$
Annual HP payment		154 688	$

1.2 HP Calculation

Residual Value @	20.00%	146 865	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		12 891	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 686	$
1.5 Overheads	10.00%	82164	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			57.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
Chains	312	8	40	
Other	0	0	0	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			67.74	$/mhr
Oil, Cost			10.16	$/mhr
Tyres/Tracks/Rigging Cost			62.40	$/mhr
Annual Fuel Costs			211 358	$
Annual Lube Cost			31 704	$
Annual Tyre/Track/Rigging Cost			194 688	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	48.95	$/mhr
Annual Maintenance Cost	152 739	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	166 000	m3
Hourly Volume Required	53.21	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		53.3	m3/mhr
Machine Output per Day		554	m3/day
Machine Output per Annum		166 296	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	26.33	6 847	82 164	82 164	9.09%
FIXED COSTS	72.42	18 830	225 955	225 955	25.0%
Hp	49.58	12 891	154 688	154 688	17.1%
Crew	18.13	4 715	56 581	56 581	6.3%
Licence	4.71	1 224	14 686	14 686	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	190.93	49 641	595 689	595 689	65.9%
Fuel	67.74	17 613	211 358	211 358	23.4%
Lubrication	10.16	2 642	31 704	31 704	3.5%
Tyres	62.40	16 224	194 688	194 688	21.5%
Maintenance	48.95	12 728	152 739	152 739	16.9%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	289.68	75 317	903 809	903 809	100.0%

6.2 FLEET SUMMARY

$ per m3	5.44	**Inc. Profit**	6.26
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	734 324		
Residual Value	146 865		
Total Revenue	903 809		

MACHINE DESCRIPTION : **Chipper (Presicion Husky 2366-KBL)**
OPERATION : **Chip**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		589 848	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		589 848	$
Annual HP payment		124 253	$

1.2 HP Calculation

Residual Value @	20.00%	117 970	$
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 354	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		11 797	$
1.5 Overheads	10.00%	53567	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			46.9	L/Hr
Fuel Cost			1.17	$/L
Oil,% Fuel Cost			15%	
Oil Cost				$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Other	0	0	0	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			54.87	$/mhr
Oil, Cost			8.23	$/mhr
Tyres/Tracks/Rigging Cost			5.86	$/mhr
Annual Fuel Costs			171 204	$
Annual Lube Cost			25 681	$
Annual Tyre/Track/Rigging Cost			18 271	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	39.32	$/mhr
Annual Maintenance Cost	122 688	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	$/mhr

5.1 Machine Requirements

Annual Volume	166 000	m3
Hourly Volume Required	53.21	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	$/hr
No.Drivers/Shift	1.1	#
Labour Wage	0.00	$/hr
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	$/day
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume			m3
Number of trees/grab			#
other			
debranch, debark, chip, Load			min
other			min
other			min
other			min
other			min
other	1		min
other			min
cycle time		0.00	min
cycle time		0.00	hrs
Machine Output per Hour		53.3	m3/mhr
Machine Output per Day		554	m3/day
Machine Output per Annum		166 296	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	$/month	$/year	$/year	of Total
OVERHEADS	17.17	4 464	53 567	53 567	9.09%
FIXED COSTS	61.74	16 053	192 631	192 631	32.7%
Hp	39.82	10 354	124 253	124 253	21.1%
Crew	18.13	4 715	56 581	56 581	9.6%
Licence	3.78	983	11 797	11 797	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	109.95	28 587	343 043	343 043	58.2%
Fuel	54.87	14 267	171 204	171 204	29.1%
Lubrication	8.23	2 140	25 681	25 681	4.4%
Tyres	5.86	1 523	18 271	18 271	3.1%
Maintenance	39.32	10 224	122 688	122 688	20.8%
Relocation	1.67	433	5 200	5 200	0.9%
TOTAL COST / REVENUE	188.86	49 104	589 242	589 242	100.0%

6.2 FLEET SUMMARY

$ per m3	3.55	**Inc. Profit**	4.08
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	589 848		
Residual Value	117 970		
Total Revenue	589 242		

CFDD&C System – Tree volume 0.40m^3

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

SYSTEM DESCRIPTION	:	CFDD&C
OPERATION	:	Stump to Mill
STUDY FOR	:	MSc
PREPARED BY	:	McEwan

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (R/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.30	191 000	1	2	2	300
Grapple Skidder (Tigercat 630D)						$2.72	191 000	2	2	4	300
CFDD (Precision Husky 2300-4)						$4.73	191 000	1	2	2	300
Chipper (Presicion Husky 2366-KBL)						$3.09	191 000	1	2	2	300
			Total			R 11.84		5		11	
						R 0.00		0		0	
			TOTAL			R 11.84		5		11	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	40.6%	
Machine hours per Day	6.5	Hours
Machine hours per Annum	1 947	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.70	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	22624	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	0	0	0	
Cutting disk	0	0	0	
Cutting teeth	1	9 300	2 500	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			34 633	US$s
Annual Lube Cost			5 195	US$s
Annual Tyre/Track/Rigging Cost			7 244	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	40 989	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.67	US$/mhr

5.1 Machine Requirements

Annual Volume	191 000	m3
Hourly Volume Required	98.08	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	26.84	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	98.1	m3/mhr
Machine Output per Day	637	m3/day
Machine Output per Annum	191 041	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	11.62	1 885	22 624	22 624	9.09%
FIXED COSTS	68.29	11 082	132 983	132 983	53.4%
Hp	34.15	5 542	66 507	66 507	26.7%
Crew	26.84	4 356	52 269	52 269	21.0%
Licence	7.30	1 184	14 207	14 207	5.7%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.89	7 772	93 261	93 261	37.5%
Fuel	17.78	2 886	34 633	34 633	13.9%
Lubrication	2.67	433	5 195	5 195	2.1%
Tyres	3.72	604	7 244	7 244	2.9%
Maintenance	21.05	3 416	40 989	40 989	16.5%
Relocation	2.67	433	5 200	5 200	2.1%
TOTAL COST / REVENUE	127.79	20 739	248 868	248 868	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.30	**Inc. Profit**	1.50
Number of Machines	1		
Number of Operators	2		
Machine Hours	1 947		
Capital Employed	315 717		
Residual Value	63 143		
Total Revenue	248 868		

MACHINE DESCRIPTION : **Grapple Skidder (Tigercat 630D)**
OPERATION : **Tree length extraction**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		394 798	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		394 798	US$s
Annual Hp's		83 166	US$s

1.2 HP Calculation

Residual Value @	20.00%	78 960	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 930	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	28.8%	
Machine hours per Day	4.6	Hours
Machine hours per Annum	1 380	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	10.87	Years

1.4 OVERHEADS

Annual Licence Fees		19 740	US$s
1.5 Overheads	10.00%	23631	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			33 585	US$s
Annual Lube Cost			5 038	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	23.69	US$/mhr
Annual Maintenance Cost	32 691	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	3.77	US$/mhr

5.1 Machine Requirements

Annual Volume	191 000	m3
Hourly Volume Required	138.40	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	41.22	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	69.2	m3/mhr
Machine Output per Day	318	m3/day
Machine Output per Annum	95 501	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**17.12**	**1 969**	**23 631**	**47 262**	**9.09%**
FIXED COSTS	**115.79**	**13 316**	**159 794**	**319 589**	**61.5%**
Hp's	60.26	6 930	83 166	166 331	32.0%
Crew	41.22	4 741	56 889	113 778	21.9%
Licence	14.30	1 645	19 740	39 480	7.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**55.44**	**6 376**	**76 514**	**153 029**	**29.4%**
Fuel	24.34	2 799	33 585	67 171	12.9%
Lubrication	3.65	420	5 038	10 076	1.9%
Tyres	0.00	0	0	0	0.0%
Maintenance	23.69	2 724	32 691	65 382	12.6%
Relocation	3.77	433	5 200	10 400	2.0%
TOTAL COST / REVENUE	**188.35**	**21 662**	**259 940**	**519 879**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	2.72	**Inc. Profit**	3.13
Number of Machines	2		
Number of Operators	4		
Machine Hours	2 760		
Capital Employed	789 596		
Residual Value	157 919		
Total Revenue	519 879		

MACHINE DESCRIPTION : **CFDD (Precision Husky 2300-4)**
OPERATION : **Delimb & Debark**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		734 324	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		734 324	$
Annual HP payment		154 688	$

1.2 HP Calculation

Residual Value @	20.00%	146 865	$
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		12 891	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	*Hours*
Machine hours per Annum	3 120	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	4.81	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 686	$
1.5 Overheads	10.00%	82164	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	57.9	*L/Hr*
Fuel Cost	1.17	*$/L*
Oil,% Fuel Cost	15%	
Oil Cost		*$/L*
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Chains	312	8	40
Other	0	0	0
Drum	0	0	0
Tyres	0	0	0
other	0	0	0

Fuel,Cost	67.74	*$/mhr*
Oil, Cost	10.16	*$/mhr*
Tyres/Tracks/Rigging Cost	62.40	*$/mhr*
Annual Fuel Costs	211 358	$
Annual Lube Cost	31 704	$
Annual Tyre/Track/Rigging Cost	194 688	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	48.95	*$/mhr*
Annual Maintenance Cost	152 739	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	*$/mhr*

5.1 Machine Requirements

Annual Volume	191 000	*m3*
Hourly Volume Required	61.22	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*$/hr*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*$/hr*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*$/day*
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	*$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
Number of trees/grab		#
other		
debranch, debark, chip, Load		*min*
other		*min*
other		*min*
other		*min*
other		*min*
other 1		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.00	*hrs*
Machine Output per Hour	61.3	*m3/mhr*
Machine Output per Day	638	*m3/day*
Machine Output per Annum	191 256	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	26.33	6 847	82 164	82 164	9.09%
FIXED COSTS	72.42	18 830	225 955	225 955	25.0%
Hp	49.58	12 891	154 688	154 688	17.1%
Crew	18.13	4 715	56 581	56 581	6.3%
Licence	4.71	1 224	14 686	14 686	1.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	190.93	49 641	595 689	595 689	65.9%
Fuel	67.74	17 613	211 358	211 358	23.4%
Lubrication	10.16	2 642	31 704	31 704	3.5%
Tyres	62.40	16 224	194 688	194 688	21.5%
Maintenance	48.95	12 728	152 739	152 739	16.9%
Relocation	1.67	433	5 200	5 200	0.6%
TOTAL COST / REVENUE	289.68	75 317	903 809	903 809	100.0%

6.2 FLEET SUMMARY

$ per m3	4.73	**Inc. Profit**	5.44
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	734 324		
Residual Value	146 865		
Total Revenue	903 809		

MACHINE DESCRIPTION : **Chipper (Presicion Husky 2366-KBL)**
OPERATION : **Chip**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		589 848	$
Less Cost of Tyres/Tracks/Rigging		0	$
Plus additional equipment	radio	0	$
	combican	0	$
	other	0	$
	other	0	$
	other	0	$
Sub total additional equipment		0	$
Total Capital Employed		589 848	$
Annual HP payment		124 253	$

1.2 HP Calculation

Residual Value @	20.00%	117 970	$
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		10 354	$

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	*Hours*
Machine hours per Annum	3 120	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	4.81	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		11 797	$
1.5 Overheads	10.00%	53567	$

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			46.9	*L/Hr*
Fuel Cost			1.17	*$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*$/L*
Tyres/Tracks/Rigging	Qty	Cost	Life	
Other	0	0	0	
Disc Knives	12	24	50	
Drum	0	0	0	
Tyres	0	0	0	
other	0	0	0	
Fuel,Cost			54.87	*$/mhr*
Oil, Cost			8.23	*$/mhr*
Tyres/Tracks/Rigging Cost			5.86	*$/mhr*
Annual Fuel Costs			171 204	$
Annual Lube Cost			25 681	$
Annual Tyre/Track/Rigging Cost			18 271	$

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	39.32	*$/mhr*
Annual Maintenance Cost	122 688	$

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	$
Annual Relocation Cost	5 200	$
Relocation Cost per Machine Hour	1.67	*$/mhr*

5.1 Machine Requirements

Annual Volume	191 000	*m3*
Hourly Volume Required	61.22	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*$/hr*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*$/hr*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*$/day*
Annual Normal Time	51 744	$
Annual Time and a Half	225	$
Annual Double Time	300	$
Annual Bonus	4 312	$
Annual Shift or Other Allowance	0	$
Total Annual Crew Cost	56 581	$
Total Crew Cost per Machine Hr	18.13	*$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume			*m3*
Number of trees/grab			#
other			
debranch, debark, chip, Load			*min*
other			*min*
other			*min*
other			*min*
other			*min*
other	1		*min*
other			*min*
cycle time		0.00	*min*
cycle time		0.00	*hrs*
Machine Output per Hour		61.3	*m3/mhr*
Machine Output per Day		638	*m3/day*
Machine Output per Annum		191 256	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	$/hr	*$/month*	*$/year*	*$/year*	*of Total*
OVERHEADS	17.17	4 464	53 567	53 567	9.09%
FIXED COSTS	61.74	16 053	192 631	192 631	32.7%
Hp	39.82	10 354	124 253	124 253	21.1%
Crew	18.13	4 715	56 581	56 581	9.6%
Licence	3.78	983	11 797	11 797	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	109.95	28 587	343 043	343 043	58.2%
Fuel	54.87	14 267	171 204	171 204	29.1%
Lubrication	8.23	2 140	25 681	25 681	4.4%
Tyres	5.86	1 523	18 271	18 271	3.1%
Maintenance	39.32	10 224	122 688	122 688	20.8%
Relocation	1.67	433	5 200	5 200	0.9%
TOTAL COST / REVENUE	188.86	49 104	589 242	589 242	100.0%

6.2 FLEET SUMMARY

$ per m3	3.09	Inc. Profit	3.55
Number of Machines	1		
Number of Operators	2		
Machine Hours	3 120		
Capital Employed	589 848		
Residual Value	117 970		
Total Revenue	589 242		

DHP System – Tree volume 0.075m^3

SYSTEM DESCRIPTION	:	DHP	
OPERATION	:	Stump to Mill	
STUDY FOR	:	MSc	
PREPARED BY	:	McEwan	

FORESTRY SOLUTIONS (PTY) LTD

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$3.53	90 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$3.73	90 500	1	2	2.2	300
DHP (Hitachi ZAxis200 with SP 591)						$13.16	90 500	3	2	6.6	300
Tracked loader (Tigercat T234 with slasher)						$3.11	90 500	1	2	2.2	300
				Total		$23.53		6		13.2	
						$0.00		0		0	
				TOTAL		$23.53		6		13.2	

FORESTRY SOLUTIONS (PTY) LTD

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	55.2%	
Machine hours per Day	8.8	Hours
Machine hours per Annum	2 647	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.67	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	29061	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			47 079	US$s
Annual Lube Cost			7 062	US$s
Annual Tyre/Track/Rigging Cost			9 848	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	55 719	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.96	US$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	34.19	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	5.68	US$/hour
No.Labourers/Shift	1.2	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	84 461	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	84 986	US$s
Total Crew Cost per Machine Hr	32.10	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	34.2	m3/mhr
Machine Output per Day	302	m3/day
Machine Output per Annum	90 537	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.98	2 422	29 061	29 061	9.09%
FIXED COSTS	62.59	13 808	165 700	165 700	51.8%
Hp	25.12	5 542	66 507	66 507	20.8%
Crew	32.10	7 082	84 986	84 986	26.6%
Licence	5.37	1 184	14 207	14 207	4.4%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.18	10 409	124 908	124 908	39.1%
Fuel	17.78	3 923	47 079	47 079	14.7%
Lubrication	2.67	588	7 062	7 062	2.2%
Tyres	3.72	821	9 848	9 848	3.1%
Maintenance	21.05	4 643	55 719	55 719	17.4%
Relocation	1.96	433	5 200	5 200	1.6%
TOTAL COST / REVENUE	120.75	26 639	319 669	319 669	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.53
Number of Machines	1
Number of Operators	2
Machine Hours	2 647
Capital Employed	315 717
Residual Value	63 143
Total Revenue	319 669

FORESTRY SOLUTIONS (PTY) LTD

MACHINE DESCRIPTION	:	**Grapple Skidder (Tigercat 630D)**
OPERATION	:	**Tree length extraction**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual Hp's		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	59.7%	
Machine hours per Day	9.6	Hours
Machine hours per Annum	2 866	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.23	Years

1.4 OVERHEADS

Annual Licence Fees		19 061	US$s
1.5 Overheads	10.00%	30720	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			69 735	US$s
Annual Lube Cost			10 460	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	65 544	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.81	US$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	31.58	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	19.85	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	31.6	m3/mhr
Machine Output per Day	302	m3/day
Machine Output per Annum	90 550	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	10.72	2 560	30 720	30 720	9.09%
FIXED COSTS	54.53	13 021	156 256	156 256	46.2%
Hp's	28.03	6 692	80 306	80 306	23.8%
Crew	19.85	4 741	56 889	56 889	16.8%
Licence	6.65	1 588	19 061	19 061	5.6%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	52.67	12 578	150 939	150 939	44.7%
Fuel	24.34	5 811	69 735	69 735	20.6%
Lubrication	3.65	872	10 460	10 460	3.1%
Tyres	0.00	0	0	0	0.0%
Maintenance	22.87	5 462	65 544	65 544	19.4%
Relocation	1.81	433	5 200	5 200	1.5%
TOTAL COST / REVENUE	117.93	28 160	337 915	337 915	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.73
Number of Machines	1
Number of Operators	2
Machine Hours	2 866
Capital Employed	381 224
Residual Value	76 245
Total Revenue	337 915

MACHINE DESCRIPTION : **DHP (Hitachi ZAxis200 with SP 591)**
OPERATION : **Debranching and debarking Euc pulp (full trees)**
STUDY FOR : **MSc**
PREPARED BY : **Forestry Solutions**

FORESTRY SOLUTIONS (PTY) LTD

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		428 571	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		428 571	US$s
Annual HP payment		90 280	US$s

1.2 HP Calculation

Residual Value @	20.00%	85 714	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		7 523	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	64.8%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 110	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.82	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		17 143	US$s
1.5 Overheads	10.00%	36084	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil, % Fuel Consumption			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tracks	0	0	0	
Head	0	0	0	
other	0	0	0	
Fuel, Cost			22.23	US$/mhr
Oil, Cost			4.45	US$/mhr
Tyres/Tracks/Rigging Cost			4.90	US$/mhr
Annual Fuel Costs			69 136	US$s
Annual Lube Cost			13 827	US$s
Annual Tyre/Track/Rigging Cost			15 239	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	110%	
Maintenance Cost	31.43	US$/mhr
Annual Maintenance Cost	97 744	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	29.10	m3/hr
Number Of Machines Required	3.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	3.00	#
Rounded number of vehicles Required	3	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No. Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	17	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	9.7	m3/mhr
Machine Output per Day	101	m3/day
Machine Output per Annum	30 167	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	11.60	3 007	36 084	108 251	9.09%
FIXED COSTS	51.35	13 308	159 692	479 075	40.2%
Hp	29.03	7 523	90 280	270 840	22.7%
Crew	16.81	4 356	52 269	156 807	13.2%
Licence	5.51	1 429	17 143	51 429	4.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	64.68	16 762	201 146	603 439	50.7%
Fuel	22.23	5 761	69 136	207 408	17.4%
Lubrication	4.45	1 152	13 827	41 482	3.5%
Tyres	4.90	1 270	15 239	45 717	3.8%
Maintenance	31.43	8 145	97 744	293 231	24.6%
Relocation	1.67	433	5 200	15 600	1.3%
TOTAL COST / REVENUE	127.63	33 077	396 922	1 190 765	100.0%

6.2 FLEET SUMMARY

US$ per m3	13.16
Number of Machines	3
Number of Operators	7
Machine Hours	9 330
Capital Employed	1 285 713
Residual Value	257 143
Total Revenue	1 190 765

MACHINE DESCRIPTION : Tracked loader (Tigercat T234 with slasher)
OPERATION : Slash
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS (PTY) LTD

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		428 571	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		428 571	US$s
Annual HP payment		90 280	US$s

1.2 HP Calculation

Residual Value @	20.00%	85 714	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		7 523	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	39.3%	
Machine hours per Day	6.3	Hours
Machine hours per Annum	1 887	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.95	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		6 429	US$s
1.5 Overheads	10.00%	25571	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	17.3	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Consumption	15%	
Oil Cost		US$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
Bar	1	714	350
Sprocket	0	0	0
Tracks	0	0	0
Chain	1	195	70
other	0	0	0

Fuel,Cost	20.24	US$/mhr
Oil, Cost	3.04	US$/mhr
Tyres/Tracks/Rigging Cost	4.83	US$/mhr
Annual Fuel Costs	38 187	US$s
Annual Lube Cost	5 728	US$s
Annual Tyre/Track/Rigging Cost	9 104	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	25.71	US$/mhr
Annual Maintenance Cost	48 513	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.76	US$/mhr

5.1 Machine Requirements

Annual Volume	90 500	m3
Hourly Volume Required	47.97	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	27.71	US$/mhr

4.1 WORK STUDY ANALYSIS

Truck Volume		m3
ave log volume		min
Slash & Load		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	48.000	m3/mhr
Machine Output per Day	302	m3/day
Machine Output per Annum	90 558	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.55	2 131	25 571	25 571	9.09%
FIXED COSTS	78.97	12 415	148 977	148 977	53.0%
Hp	47.85	7 523	90 280	90 280	32.1%
Crew	27.71	4 356	52 269	52 269	18.6%
Licence	3.41	536	6 429	6 429	2.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	56.57	8 894	106 732	106 732	37.9%
Fuel	20.24	3 162	38 187	38 187	13.6%
Lubrication	3.04	477	5 728	5 728	2.0%
Tyres	4.83	759	9 104	9 104	3.2%
Maintenance	25.71	4 043	48 513	48 513	17.2%
Relocation	2.76	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	149.09	23 440	281 281	281 281	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.11
Number of Machines	1
Number of Operators	2
Machine Hours	1 887
Capital Employed	428 571
Residual Value	85 714
Total Revenue	281 281

DHP System – Tree volume 0.15m^3

SYSTEM DESCRIPTION : DHP
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS (PTY) LTD

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$2.20	142 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$2.44	142 500	1	2	2.2	300
DHP (Hitachi ZAxis200 with SP 591)						$5.58	142 500	2	2	4.4	300
Tracked loader (Tigercat T234 with slasher)						$1.71	142 500	1	2	2.2	300
				Total		$11.94		5		11	
						$0.00		0		0	
				TOTAL		$11.94		5		11	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

FORESTRY SOLUTIONS (PTY) LTD

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	52.7%	
Machine hours per Day	8.4	Hours
Machine hours per Annum	2 531	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.93	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	28536	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			45 015	US$s
Annual Lube Cost			6 752	US$s
Annual Tyre/Track/Rigging Cost			9 416	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	53 276	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.05	US$/mhr

5.1 Machine Requirements

Annual Volume	142 500	m3
Hourly Volume Required	56.30	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	5.68	US$/hour
No.Labourers/Shift	1.2	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	84 461	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	84 986	US$s
Total Crew Cost per Machine Hr	33.58	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	56.3	m3/mhr
Machine Output per Day	475	m3/day
Machine Output per Annum	142 506	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.27	2 378	28 536	28 536	9.09%
FIXED COSTS	65.46	13 808	165 700	165 700	52.8%
Hp	26.27	5 542	66 507	66 507	21.2%
Crew	33.58	7 082	84 986	84 986	27.1%
Licence	5.61	1 184	14 207	14 207	4.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	47.27	9 972	119 659	119 659	38.1%
Fuel	17.78	3 751	45 015	45 015	14.3%
Lubrication	2.67	563	6 752	6 752	2.2%
Tyres	3.72	785	9 416	9 416	3.0%
Maintenance	21.05	4 440	53 276	53 276	17.0%
Relocation	2.05	433	5 200	5 200	1.7%
TOTAL COST / REVENUE	124.01	26 158	313 895	313 895	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.20
Number of Machines	1
Number of Operators	2
Machine Hours	2 531
Capital Employed	315 717
Residual Value	63 143
Total Revenue	313 895

FORESTRY SOLUTIONS (PTY) LTD

MACHINE DESCRIPTION : Grapple Skidder (Tigercat 630D)
OPERATION : Tree length extraction
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual Hp's		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	63.5%	
Machine hours per Day	10.2	Hours
Machine hours per Annum	3 048	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.92	Years

1.4 OVERHEADS

Annual Licence Fees		19 061	US$s
1.5 Overheads	10.00%	31648	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	20.8	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Consumption	15%	
Oil Cost		US$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	US$/mhr
Oil, Cost	3.65	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	74 176	US$s
Annual Lube Cost	11 126	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	69 718	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.71	US$/mhr

5.1 Machine Requirements

Annual Volume	142 500	m3
Hourly Volume Required	46.75	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.66	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	46.8	m3/mhr
Machine Output per Day	475	m3/day
Machine Output per Annum	142 646	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.38	2 637	31 648	31 648	9.09%
FIXED COSTS	51.27	13 021	156 256	156 256	44.9%
Hp's	26.35	6 692	80 306	80 306	23.1%
Crew	18.66	4 741	56 889	56 889	16.3%
Licence	6.25	1 588	19 061	19 061	5.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	52.57	13 352	160 221	160 221	46.0%
Fuel	24.34	6 181	74 176	74 176	21.3%
Lubrication	3.65	927	11 126	11 126	3.2%
Tyres	0.00	0	0	0	0.0%
Maintenance	22.87	5 810	69 718	69 718	20.0%
Relocation	1.71	433	5 200	5 200	1.5%
TOTAL COST / REVENUE	114.21	29 010	348 125	348 125	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.44
Number of Machines	1
Number of Operators	2
Machine Hours	3 048
Capital Employed	381 224
Residual Value	76 245
Total Revenue	348 125

MACHINE DESCRIPTION : **DHP (Hitachi ZAxis200 with SP 591)**
OPERATION : **Debranching and debarking Euc pulp (full trees)**
STUDY FOR : **MSc**
PREPARED BY : **Forestry Solutions**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		428 571	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		428 571	US$s
Annual HP payment		90 280	US$s

1.2 HP Calculation

Residual Value @	20.00%	85 714	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		7 523	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		17 143	US$s
1.5 Overheads	10.00%	36147	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tracks	0	0	0	
Head	0	0	0	
other	0	0	0	
Fuel,Cost			22.23	US$/mhr
Oil, Cost			4.45	US$/mhr
Tyres/Tracks/Rigging Cost			4.90	US$/mhr
Annual Fuel Costs			69 358	US$s
Annual Lube Cost			13 872	US$s
Annual Tyre/Track/Rigging Cost			15 288	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	31.43	US$/mhr
Annual Maintenance Cost	98 057	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	142 500	m3
Hourly Volume Required	45.67	m3/hr
Number Of Machines Required	1.99	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.99	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	17	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	22.9	m3/mhr
Machine Output per Day	238	m3/day
Machine Output per Annum	71 448	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	11.59	3 012	36 147	72 293	9.09%
FIXED COSTS	51.18	13 308	159 692	319 384	40.2%
Hp	28.94	7 523	90 280	180 560	22.7%
Crew	16.75	4 356	52 269	104 538	13.1%
Licence	5.49	1 429	17 143	34 286	4.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	64.67	16 815	201 774	403 548	50.7%
Fuel	22.23	5 780	69 358	138 715	17.4%
Lubrication	4.45	1 156	13 872	27 743	3.5%
Tyres	4.90	1 274	15 288	30 576	3.8%
Maintenance	31.43	8 171	98 057	196 114	24.7%
Relocation	1.67	433	5 200	10 400	1.3%
TOTAL COST / REVENUE	127.44	33 134	397 613	795 225	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.58
Number of Machines	2
Number of Operators	4
Machine Hours	6 240
Capital Employed	857 142
Residual Value	171 428
Total Revenue	795 225

MACHINE DESCRIPTION : **Tracked loader (Tigercat T234 with slasher)**
OPERATION : **Slash**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

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1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		325 900	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		325 900	US$s
Annual HP payment		68 652	US$s

1.2 HP Calculation

Residual Value @	20.00%	65 180	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 721	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	39.6%	
Machine hours per Day	6.3	Hours
Machine hours per Annum	1 901	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.89	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		4 889	US$s
1.5 Overheads	10.00%	22160	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	17.3	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Consumption	15%	
Oil Cost		US$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
Bar	1	714	350
Sprocket	0	0	0
Tracks	0	0	0
Chain	1	195	70
other	0	0	0

Fuel,Cost	20.24	US$/mhr
Oil, Cost	3.04	US$/mhr
Tyres/Tracks/Rigging Cost	4.83	US$/mhr
Annual Fuel Costs	38 477	US$s
Annual Lube Cost	5 772	US$s
Annual Tyre/Track/Rigging Cost	9 173	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	19.55	US$/mhr
Annual Maintenance Cost	37 171	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.74	US$/mhr

5.1 Machine Requirements

Annual Volume	142 500	m3
Hourly Volume Required	74.96	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	27.50	US$/mhr

4.1 WORK STUDY ANALYSIS

Truck Volume		m3
ave log volume		min
Slash & Load		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	75.000	m3/mhr
Machine Output per Day	475	m3/day
Machine Output per Annum	142 571	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	11.66	1 847	22 160	22 160	9.09%
FIXED COSTS	66.18	10 484	125 809	125 809	51.6%
Hp	36.11	5 721	68 652	68 652	28.2%
Crew	27.50	4 356	52 269	52 269	21.4%
Licence	2.57	407	4 889	4 889	2.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	50.39	7 983	95 793	95 793	39.3%
Fuel	20.24	3 206	38 477	38 477	15.8%
Lubrication	3.04	481	5 772	5 772	2.4%
Tyres	4.83	764	9 173	9 173	3.8%
Maintenance	19.55	3 098	37 171	37 171	15.2%
Relocation	2.74	433	5 200	5 200	2.1%
TOTAL COST / REVENUE	128.23	20 314	243 763	243 763	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.71
Number of Machines	1
Number of Operators	2
Machine Hours	1 901
Capital Employed	325 900
Residual Value	65 180
Total Revenue	243 763

DHP System – Tree volume $0.25m^3$

SYSTEM DESCRIPTION : DHP
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

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Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.46	232 500	1	2	2	300
Grapple Skidder (Tigercat 630D)						$2.53	232 500	2	2	4.4	300
DHP (Hitachi ZAxis200 with SP 591)						$3.42	232 500	2	2	4.4	300
Tracked loader (Tigercat T234 with slasher)						$1.18	232 500	1	2	2.2	300
			Total			$8.60		6		13.2	
						$0.00		0		0	
			TOTAL			$8.60		6		13.2	

MACHINE DESCRIPTION : Wheeled Feller Buncher (Tigercat 720E)
OPERATION : Felling and bunching Euc full trees
STUDY FOR : MSc
PREPARED BY : McEwan

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NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	63.7%	
Machine hours per Day	10.2	Hours
Machine hours per Annum	3 058	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.91	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	30916	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			54 376	US$s
Annual Lube Cost			8 156	US$s
Annual Tyre/Track/Rigging Cost			11 374	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	64 356	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.70	US$/mhr

5.1 Machine Requirements

Annual Volume	232 500	m3
Hourly Volume Required	76.04	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	5.68	US$/hour
No.Labourers/Shift	1.2	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	84 461	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	84 986	US$s
Total Crew Cost per Machine Hr	27.79	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	76.1	m3/mhr
Machine Output per Day	776	m3/day
Machine Output per Annum	232 683	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**10.11**	**2 576**	**30 916**	**30 916**	**9.09%**
FIXED COSTS	**54.19**	**13 808**	**165 700**	**165 700**	**48.7%**
Hp	21.75	5 542	66 507	66 507	19.6%
Crew	27.79	7 082	84 986	84 986	25.0%
Licence	4.65	1 184	14 207	14 207	4.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**46.92**	**11 955**	**143 463**	**143 463**	**42.2%**
Fuel	17.78	4 531	54 376	54 376	16.0%
Lubrication	2.67	680	8 156	8 156	2.4%
Tyres	3.72	948	11 374	11 374	3.3%
Maintenance	21.05	5 363	64 356	64 356	18.9%
Relocation	1.70	433	5 200	5 200	1.5%
TOTAL COST / REVENUE	**111.22**	**28 340**	**340 079**	**340 079**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	1.46
Number of Machines	1
Number of Operators	2
Machine Hours	3 058
Capital Employed	315 717
Residual Value	63 143
Total Revenue	340 079

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MACHINE DESCRIPTION	:	**Grapple Skidder (Tigercat 630D)**
OPERATION	:	**Tree length extraction**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual Hp's		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	43.6%	
Machine hours per Day	7.0	Hours
Machine hours per Annum	2 091	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	7.17	Years

1.4 OVERHEADS

Annual Licence Fees		19 061	US$s
1.5 Overheads	10.00%	26783	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			20.8	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
front	0	0	0	
rear	0	0	0	
tracks Eco	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			24.34	US$/mhr
Oil, Cost			3.65	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			50 897	US$s
Annual Lube Cost			7 635	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	47 838	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.49	US$/mhr

5.1 Machine Requirements

Annual Volume	232 500	m3
Hourly Volume Required	111.17	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	27.20	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	55.6	m3/mhr
Machine Output per Day	388	m3/day
Machine Output per Annum	116 284	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	12.81	2 232	26 783	53 565	9.09%
FIXED COSTS	74.71	13 021	156 256	312 513	53.0%
Hp's	38.40	6 692	80 306	160 612	27.3%
Crew	27.20	4 741	56 889	113 778	19.3%
Licence	9.11	1 588	19 061	38 122	6.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	53.35	9 297	111 570	223 140	37.9%
Fuel	24.34	4 241	50 897	101 794	17.3%
Lubrication	3.65	636	7 635	15 269	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	22.87	3 987	47 838	95 676	16.2%
Relocation	2.49	433	5 200	10 400	1.8%
TOTAL COST / REVENUE	140.86	24 551	294 609	589 217	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.53
Number of Machines	2
Number of Operators	4
Machine Hours	4 183
Capital Employed	762 448
Residual Value	152 490
Total Revenue	589 217

MACHINE DESCRIPTION	:	**DHP (Hitachi ZAxis200 with SP 591)**
OPERATION	:	**Debranching and debarking Euc pulp (full trees)**
STUDY FOR	:	**MSc**
PREPARED BY	:	**Forestry Solutions**

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NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		428 571	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		428 571	*US$s*
Annual HP payment		90 280	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	85 714	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		7 523	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	*Hours*
Machine hours per Annum	3 120	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	4.81	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		17 143	*US$s*
1.5 Overheads	10.00%	36147	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	19	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil,% Fuel Consumption	20%	
Oil Cost		*US$/L*
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Bar	1	400	200
Chain	1	145	50
Tracks	0	0	0
Head	0	0	0
other	0	0	0

Fuel, Cost	22.23	*US$/mhr*
Oil, Cost	4.45	*US$/mhr*
Tyres/Tracks/Rigging Cost	4.90	*US$/mhr*
Annual Fuel Costs	69 358	*US$s*
Annual Lube Cost	13 872	*US$s*
Annual Tyre/Track/Rigging Cost	15 288	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	31.43	*US$/mhr*
Annual Maintenance Cost	98 057	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	1.67	*US$/mhr*

5.1 Machine Requirements

Annual Volume	232 500	*m3*
Hourly Volume Required	74.52	*m3/hr*
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	17	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
debranch / debark		*min*
crosscut		*min*
place		*min*
bunch		*min*
move		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Machine Hr	37.3	*m3/mhr*
Machine Output per Day	388	*m3/day*
Machine Output per Annum	116 376	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.59	3 012	36 147	72 293	9.09%
FIXED COSTS	51.18	13 308	159 692	319 384	40.2%
Hp	28.94	7 523	90 280	180 560	22.7%
Crew	16.75	4 356	52 269	104 538	13.1%
Licence	5.49	1 429	17 143	34 286	4.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	64.67	16 815	201 774	403 548	50.7%
Fuel	22.23	5 780	69 358	138 715	17.4%
Lubrication	4.45	1 156	13 872	27 743	3.5%
Tyres	4.90	1 274	15 288	30 576	3.8%
Maintenance	31.43	8 171	98 057	196 114	24.7%
Relocation	1.67	433	5 200	10 400	1.3%
TOTAL COST / REVENUE	127.44	33 134	397 613	795 225	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.42
Number of Machines	2
Number of Operators	4
Machine Hours	6 240
Capital Employed	857 142
Residual Value	171 428
Total Revenue	795 225

MACHINE DESCRIPTION : **Tracked loader (Tigercat T234 with slasher)**
OPERATION : **Slash**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

FORESTRY SOLUTIONS (PTY) LTD

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		325 900	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		325 900	US$s
Annual HP payment		68 652	US$s

1.2 HP Calculation

Residual Value @	20.00%	65 180	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 721	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	51.6%	
Machine hours per Day	8.3	Hours
Machine hours per Annum	2 479	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.05	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		4 889	US$s
1.5 Overheads	10.00%	24915	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			17.3	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	714	350	
Sprocket	0	0	0	
Tracks	0	0	0	
Chain	1	195	70	
other	0	0	0	
Fuel,Cost			20.24	US$/mhr
Oil, Cost			3.04	US$/mhr
Tyres/Tracks/Rigging Cost			4.83	US$/mhr
Annual Fuel Costs			50 176	US$s
Annual Lube Cost			7 526	US$s
Annual Tyre/Track/Rigging Cost			11 963	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	19.55	US$/mhr
Annual Maintenance Cost	48 473	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.10	US$/mhr

5.1 Machine Requirements

Annual Volume	232 500	m3
Hourly Volume Required	93.79	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	21.09	US$/mhr

4.1 WORK STUDY ANALYSIS

Truck Volume		m3
ave log volume		min
Slash & Load		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	93.800	m3/mhr
Machine Output per Day	775	m3/day
Machine Output per Annum	232 525	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	10.05	2 076	24 915	24 915	9.09%
FIXED COSTS	50.75	10 484	125 809	125 809	45.9%
Hp	27.69	5 721	68 652	68 652	25.0%
Crew	21.09	4 356	52 269	52 269	19.1%
Licence	1.97	407	4 889	4 889	1.8%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	49.75	10 278	123 338	123 338	45.0%
Fuel	20.24	4 181	50 176	50 176	18.3%
Lubrication	3.04	627	7 526	7 526	2.7%
Tyres	4.83	997	11 963	11 963	4.4%
Maintenance	19.55	4 039	48 473	48 473	17.7%
Relocation	2.10	433	5 200	5 200	1.9%
TOTAL COST / REVENUE	110.56	22 839	274 063	274 063	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.18
Number of Machines	1
Number of Operators	2
Machine Hours	2 479
Capital Employed	325 900
Residual Value	65 180
Total Revenue	274 063

DHP System – Tree volume $0.40m^3$

SYSTEM DESCRIPTION : DHP
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS (PTY) LTD

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Wheeled Feller Buncher (Tigercat 720E)						$1.67	324 000	2	2	4	300
Grapple Skidder (Tigercat 630D)						$1.91	324 000	2	2	4.4	300
DHP (Hitachi ZAxis200 with SP 591)						$2.45	324 000	2	2	4.4	300
Tracked loader (Tigercat T234 with slasher)						$0.88	324 000	1	2	2.2	300
			Total			$6.91		7		15.4	
						$0.00		0		0	
			TOTAL			$6.91		7		15.4	

MACHINE DESCRIPTION : **Wheeled Feller Buncher (Tigercat 720E)**
OPERATION : **Felling and bunching Euc full trees**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

FORESTRY SOLUTIONS (PTY) LTD

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		315 717	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	combican	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		315 717	US$s
Annual HP payment		66 507	US$s

1.2 HP Calculation

Residual Value @	20.00%	63 143	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 542	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	34.4%	
Machine hours per Day	5.5	Hours
Machine hours per Annum	1 651	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	9.08	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 207	US$s
1.5 Overheads	10.00%	24557	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			15.2	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Consumption			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Tyres	1	9 300	2 500	
Cutting disk	0	0	0	
Cutting teeth	0	0	0	
Other	0	0	0	
Other	0	0	0	
Fuel,Cost			17.78	US$/mhr
Oil, Cost			2.67	US$/mhr
Tyres/Tracks/Rigging Cost			3.72	US$/mhr
Annual Fuel Costs			29 368	US$s
Annual Lube Cost			4 405	US$s
Annual Tyre/Track/Rigging Cost			6 143	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	21.05	US$/mhr
Annual Maintenance Cost	34 758	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	3.15	US$/mhr

5.1 Machine Requirements

Annual Volume	324 000	m3
Hourly Volume Required	196.20	m3/mhr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	5.68	US$/hour
No.Labourers/Shift	1.2	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	84 461	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Annual Contributions	0	US$s
Total Annual Crew Cost	84 986	US$s
Total Crew Cost per Machine Hr	51.46	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
bunch		min
place		min
move		min
other		min
other		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	98.1	m3/mhr
Machine Output per Day	540	m3/day
Machine Output per Annum	162 002	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	14.87	2 046	24 557	49 115	9.09%
FIXED COSTS	100.34	13 808	165 700	331 400	61.3%
Hp	40.27	5 542	66 507	133 014	24.6%
Crew	51.46	7 082	84 986	169 972	31.5%
Licence	8.60	1 184	14 207	28 415	5.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	48.37	6 656	79 875	159 750	29.6%
Fuel	17.78	2 447	29 368	58 737	10.9%
Lubrication	2.67	367	4 405	8 811	1.6%
Tyres	3.72	512	6 143	12 286	2.3%
Maintenance	21.05	2 897	34 758	69 516	12.9%
Relocation	3.15	433	5 200	10 400	1.9%
TOTAL COST / REVENUE	163.58	22 511	270 132	540 265	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.67
Number of Machines	2
Number of Operators	4
Machine Hours	3 303
Capital Employed	631 434
Residual Value	126 287
Total Revenue	540 265

FORESTRY SOLUTIONS (PTY) LTD

MACHINE DESCRIPTION	:	**Grapple Skidder (Tigercat 630D)**
OPERATION	:	**Tree length extraction**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		381 224	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		381 224	US$s
Annual Hp's		80 306	US$s

1.2 HP Calculation

Residual Value @	20.00%	76 245	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 692	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	48.9%	
Machine hours per Day	7.8	Hours
Machine hours per Annum	2 347	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.39	Years

1.4 OVERHEADS

Annual Licence Fees		19 061	US$s
1.5 Overheads	10.00%	28083	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	20.8	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Consumption	15%	
Oil Cost		US$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
front	0	0	0
rear	0	0	0
tracks Eco	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	24.34	US$/mhr
Oil, Cost	3.65	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	57 121	US$s
Annual Lube Cost	8 568	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	22.87	US$/mhr
Annual Maintenance Cost	53 689	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.22	US$/mhr

5.1 Machine Requirements

Annual Volume	324 000	m3
Hourly Volume Required	138.04	m3/mhr
Number Of Machines Required	1.99	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.99	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	24.24	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	69.2	m3/mhr
Machine Output per Day	541	m3/day
Machine Output per Annum	162 426	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.96	2 340	28 083	56 167	9.09%
FIXED COSTS	66.57	13 021	156 256	312 513	50.6%
Hp's	34.21	6 692	80 306	160 612	26.0%
Crew	24.24	4 741	56 889	113 778	18.4%
Licence	8.12	1 588	19 061	38 122	6.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	53.08	10 382	124 578	249 156	40.3%
Fuel	24.34	4 760	57 121	114 243	18.5%
Lubrication	3.65	714	8 568	17 136	2.8%
Tyres	0.00	0	0	0	0.0%
Maintenance	22.87	4 474	53 689	107 377	17.4%
Relocation	2.22	433	5 200	10 400	1.7%
TOTAL COST / REVENUE	131.61	25 743	308 918	617 836	100.0%

6.2 FLEET SUMMARY

US$ per m3	1.91
Number of Machines	2
Number of Operators	4
Machine Hours	4 694
Capital Employed	762 448
Residual Value	152 490
Total Revenue	617 836

MACHINE DESCRIPTION : **DHP (Hitachi ZAxis200 with SP 591)**
OPERATION : **Debranching and debarking Euc pulp (full trees)**
STUDY FOR : **MSc**
PREPARED BY : **Forestry Solutions**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

FORESTRY SOLUTIONS (PTY) LTD

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		428 571	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		428 571	US$s
Annual HP payment		90 280	US$s

1.2 HP Calculation

Residual Value @	20.00%	85 714	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		7 523	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		17 143	US$s
1.5 Overheads	10.00%	36147	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	19	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Consumption	20%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Bar	1	400	200
Chain	1	145	50
Tracks	0	0	0
Head	0	0	0
other	0	0	0

Fuel,Cost	22.23	US$/mhr
Oil, Cost	4.45	US$/mhr
Tyres/Tracks/Rigging Cost	4.90	US$/mhr
Annual Fuel Costs	69 358	US$s
Annual Lube Cost	13 872	US$s
Annual Tyre/Track/Rigging Cost	15 288	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	31.43	US$/mhr
Annual Maintenance Cost	98 057	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	324 000	m3
Hourly Volume Required	103.85	m3/hr
Number Of Machines Required	2.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	2.00	#
Rounded number of vehicles Required	2	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	17	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	52.0	m3/mhr
Machine Output per Day	541	m3/day
Machine Output per Annum	162 240	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.59	3 012	36 147	72 293	9.09%
FIXED COSTS	51.18	13 308	159 692	319 384	40.2%
Hp	28.94	7 523	90 280	180 560	22.7%
Crew	16.75	4 356	52 269	104 538	13.1%
Licence	5.49	1 429	17 143	34 286	4.3%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	64.67	16 815	201 774	403 548	50.7%
Fuel	22.23	5 780	69 358	138 715	17.4%
Lubrication	4.45	1 156	13 872	27 743	3.5%
Tyres	4.90	1 274	15 288	30 576	3.8%
Maintenance	31.43	8 171	98 057	196 114	24.7%
Relocation	1.67	433	5 200	10 400	1.3%
TOTAL COST / REVENUE	127.44	33 134	397 613	795 225	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.45
Number of Machines	2
Number of Operators	4
Machine Hours	6 240
Capital Employed	857 142
Residual Value	171 428
Total Revenue	795 225

MACHINE DESCRIPTION : Tracked loader (Tigercat T234 with slasher)
OPERATION : Slash
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		325 900	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	slasher	0	US$s
	Truck 2ns hand	0	US$s
	trailer	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		325 900	US$s
Annual HP payment		68 652	US$s

1.2 HP Calculation

Residual Value @	20.00%	65 180	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		5 721	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	56.3%	
Machine hours per Day	9.0	Hours
Machine hours per Annum	2 700	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.55	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		4 889	US$s
1.5 Overheads	10.00%	25970	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption				17.3	L/Hr
Fuel Cost				1.17	US$/L
Oil,% Fuel Consumption				15%	
Oil Cost					US$/L
Tyres/Tracks/Rigging					
	Qty	Cost	Life		
Bar	1	714	350		
Sprocket	0	0	0		
Tracks	0	0	0		
Chain	1	195	70		
other	0	0	0		
Fuel,Cost				20.24	US$/mhr
Oil, Cost				3.04	US$/mhr
Tyres/Tracks/Rigging Cost				4.83	US$/mhr
Annual Fuel Costs				54 657	US$s
Annual Lube Cost				8 199	US$s
Annual Tyre/Track/Rigging Cost				13 031	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	90%	
Maintenance Cost	19.55	US$/mhr
Annual Maintenance Cost	52 802	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.93	US$/mhr

5.1 Machine Requirements

Annual Volume	324 000	m3
Hourly Volume Required	119.99	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	19.36	US$/mhr

4.1 WORK STUDY ANALYSIS

Truck Volume		m3
ave log volume		min
Slash & Load		min
other		min
other		min
other		min
other		min
other		min
other		min
other		m3
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Hour	120.000	m3/mhr
Machine Output per Day	1080	m3/day
Machine Output per Annum	324 038	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	9.62	2 164	25 970	25 970	9.09%
FIXED COSTS	46.59	10 484	125 809	125 809	44.0%
Hp	25.42	5 721	68 652	68 652	24.0%
Crew	19.36	4 356	52 269	52 269	18.3%
Licence	1.81	407	4 889	4 889	1.7%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	49.58	11 157	133 889	133 889	46.9%
Fuel	20.24	4 555	54 657	54 657	19.1%
Lubrication	3.04	683	8 199	8 199	2.9%
Tyres	4.83	1 086	13 031	13 031	4.6%
Maintenance	19.55	4 400	52 802	52 802	18.5%
Relocation	1.93	433	5 200	5 200	1.8%
TOTAL COST / REVENUE	105.79	23 806	285 668	285 668	100.0%

6.2 FLEET SUMMARY

US$ per m3	0.88
Number of Machines	1
Number of Operators	2
Machine Hours	2 700
Capital Employed	325 900
Residual Value	65 180
Total Revenue	285 668

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Harvester (CTL) System – Tree volume 0.075m^3

SYSTEM DESCRIPTION : Harvester system
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$23.01	78 500	5	2	11	300
Forwarder (Tigercat 1075)						$5.83	78 500	1	2	2.2	300
				Total		$28.84		6		13.2	
						$0.00		0		0	
				TOTAL		$28.84		6		13.2	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

FORESTRY SOLUTIONS

1.1 CAPITAL EMPLOYED

Machine Price, Exc VAT		357 143	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		357 143	*US$s*
Annual HP payment		75 233	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	71 429	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 269	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.4%	
Machine hours per Day	10.5	*Hours*
Machine hours per Annum	3 140	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	4.78	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	*US$s*
1.5 Overheads	10.00%	32838	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil, % Fuel Cost			20%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel, Cost			22.23	*US$/mhr*
Oil, Cost			4.45	*US$/mhr*
Tyres/Tracks/Rigging Cost			4.90	*US$/mhr*
Annual Fuel Costs			69 804	*US$s*
Annual Lube Cost			13 961	*US$s*
Annual Tyre/Track/Rigging Cost			15 386	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	*US$/mhr*
Annual Maintenance Cost	82 240	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	1.66	*US$/mhr*

5.1 Machine Requirements

Annual Volume	78 500	*m3*
Hourly Volume Required	25.00	*m3/hr*
Number Of Machines Required	5.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	5.00	#
Rounded number of vehicles Required	5	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No. Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	17	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
debranch / debark		*min*
crosscut		*min*
place		*min*
bunch		*min*
move		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Machine Hr	5.0	*m3/mhr*
Machine Output per Day	52	*m3/day*
Machine Output per Annum	15 700	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.46	2 736	32 838	164 189	9.09%
FIXED COSTS	45.15	11 816	141 788	708 941	39.3%
Hp	23.96	6 269	75 233	376 167	20.8%
Crew	16.65	4 356	52 269	261 345	14.5%
Licence Insurance	4.55	1 190	14 286	71 429	4.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.42	15 549	186 591	932 954	51.7%
Fuel	22.23	5 817	69 804	349 019	19.3%
Lubrication	4.45	1 163	13 961	69 804	3.9%
Tyres	4.90	1 282	15 386	76 932	4.3%
Maintenance	26.19	6 853	82 240	411 200	22.8%
Relocation	1.66	433	5 200	26 000	1.4%
TOTAL COST / REVENUE	115.03	30 101	361 217	1 806 084	100.0%

6.2 FLEET SUMMARY

US$ per m3	23.01
Number of Machines	5
Number of Operators	11
Machine Hours	15 700
Capital Employed	1 785 715
Residual Value	357 143
Total Revenue	1 806 084

MACHINE DESCRIPTION : Forwarder (Tigercat 1075)
OPERATION : Extraction of logs to roadside
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	22	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	4	7 200	0
rear	4	7 200	0
tracks Eco	1	19 500	0
other	0	0	0
other	0	0	0

Fuel,Cost	25.74	US$/mhr
Oil, Cost	3.86	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	80 309	US$s
Annual Lube Cost	12 046	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	78 500	m3
Hourly Volume Required	25.16	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	25.2	m3/mhr
Machine Output per Day	262	m3/day
Machine Output per Annum	78 624	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.83
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume 0.15m^3

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SYSTEM DESCRIPTION	:	**Harvester system**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$12.45	111 000	4	2	8.8	300
Forwarder (Tigercat 1075)						$4.13	111 000	1	2	2.2	300
				Total		$16.57		5		11	
						$0.00		0		0	
				TOTAL		$16.57		5		11	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

FORESTRY SOLUTIONS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	60.2%	
Machine hours per Day	9.6	Hours
Machine hours per Annum	2 891	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.19	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	US$s
1.5 Overheads	10.00%	31397	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
			22.23	US$/mhr
			4.45	US$/mhr
			4.90	US$/mhr
Annual Fuel Costs			64 260	US$s
Annual Lube Cost			12 852	US$s
Annual Tyre/Track/Rigging Cost			14 164	US$s

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2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	75 709	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.80	US$/mhr

5.1 Machine Requirements

Annual Volume	111 000	m3
Hourly Volume Required	38.40	m3/hr
Number Of Machines Required	4.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	4.00	#
Rounded number of vehicles Required	4	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	18	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	9.6	m3/mhr
Machine Output per Day	93	m3/day
Machine Output per Annum	27 751	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**10.86**	**2 616**	**31 397**	**125 589**	**9.09%**
FIXED COSTS	**49.05**	**11 816**	**141 788**	**567 152**	**41.1%**
Hp	26.03	6 269	75 233	300 934	21.8%
Crew	18.08	4 356	52 269	209 076	15.1%
Licence Insurance	4.94	1 190	14 286	57 143	4.1%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**59.57**	**14 349**	**172 185**	**688 740**	**49.9%**
Fuel	22.23	5 355	64 260	257 040	18.6%
Lubrication	4.45	1 071	12 852	51 408	3.7%
Tyres	4.90	1 180	14 164	56 658	4.1%
Maintenance	26.19	6 309	75 709	302 834	21.9%
Relocation	1.80	433	5 200	20 800	1.5%
TOTAL COST / REVENUE	**119.48**	**28 781**	**345 370**	**1 381 482**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	12.45
Number of Machines	4
Number of Operators	9
Machine Hours	11 563
Capital Employed	1 428 572
Residual Value	285 714
Total Revenue	1 381 482

MACHINE DESCRIPTION	:	Forwarder (Tigercat 1075)
OPERATION	:	Extraction of logs to roadside
STUDY FOR	:	MSc
PREPARED BY	:	Forestry Solutions

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			22	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	4		0	
rear	4		0	
tracks Eco	1		0	
other	0	0	0	
other	0	0	0	
			25.74	US$/mhr
			3.86	US$/mhr
			0.00	US$/mhr
Annual Fuel Costs			80 309	US$s
Annual Lube Cost			12 046	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	111 000	m3
Hourly Volume Required	35.58	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	35.7	m3/mhr
Machine Output per Day	371	m3/day
Machine Output per Annum	111 384	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	4.13
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume 0.25m^3

SYSTEM DESCRIPTION	:	**Harvester system**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$8.03	126 000	3	2	6.6	300
Forwarder (Tigercat 1075)						$3.64	126 000	1	2	2.2	300
				Total		$11.67		4		8.8	
						$0.00		0		0	
				TOTAL		$11.67		4		8.8	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	57.6%	
Machine hours per Day	9.2	Hours
Machine hours per Annum	2 763	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.43	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	US$s
1.5 Overheads	10.00%	30661	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption		19	L/Hr
Fuel Cost		1.17	US$/L
Oil,% Fuel Cost		20%	
Oil Cost			US$/L
Tyres/Tracks/Rigging			

	Qty	Cost	Life
Bar	1	400	200
Chain	1	145	50
Tyres	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	22.23	US$/mhr
Oil, Cost	4.45	US$/mhr
Tyres/Tracks/Rigging Cost	4.90	US$/mhr
Annual Fuel Costs	61 425	US$s
Annual Lube Cost	12 285	US$s
Annual Tyre/Track/Rigging Cost	13 540	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	72 369	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.88	US$/mhr

5.1 Machine Requirements

Annual Volume	126 000	m3
Hourly Volume Required	45.60	m3/hr
Number Of Machines Required	3.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	3.00	#
Rounded number of vehicles Required	3	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	19	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	15.2	m3/mhr
Machine Output per Day	140	m3/day
Machine Output per Annum	42 000	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.10	2 555	30 661	91 982	9.09%
FIXED COSTS	51.31	11 816	141 788	425 364	42.0%
Hp	27.23	6 269	75 233	225 700	22.3%
Crew	18.92	4 356	52 269	156 807	15.5%
Licence Insurance	5.17	1 190	14 286	42 857	4.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.65	13 735	164 818	494 455	48.9%
Fuel	22.23	5 119	61 425	184 276	18.2%
Lubrication	4.45	1 024	12 285	36 855	3.6%
Tyres	4.90	1 128	13 540	40 619	4.0%
Maintenance	26.19	6 031	72 369	217 106	21.5%
Relocation	1.88	433	5 200	15 600	1.5%
TOTAL COST / REVENUE	122.06	28 106	337 267	1 011 801	100.0%

6.2 FLEET SUMMARY

US$ per m3	8.03
Number of Machines	3
Number of Operators	7
Machine Hours	8 289
Capital Employed	1 071 429
Residual Value	214 286
Total Revenue	1 011 801

MACHINE DESCRIPTION : Forwarder (Tigercat 1075)
OPERATION : Extraction of logs to roadside
STUDY FOR : MSc
PREPARED BY : McEwan

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

FORESTRY SOLUTIONS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			22	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
front	4	7 200	0	
rear	4	7 200	0	
tracks Eco	1	19 500	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			25.74	US$/mhr
Oil, Cost			3.86	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			80 309	US$s
Annual Lube Cost			12 046	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	126 000	m3
Hourly Volume Required	40.38	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	40.5	m3/mhr
Machine Output per Day	421	m3/day
Machine Output per Annum	126 360	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.64
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume 0.40m^3

SYSTEM DESCRIPTION	:	**Harvester system**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$5.87	161 500	3	2	6.6	300
Forwarder (Tigercat 1075)						$2.84	161 500	1	2	2.2	300
				Total		$8.70		4		8.8	
						$0.00		0		0	
				TOTAL		$8.70		4		8.8	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	50.5%	
Machine hours per Day	8.1	Hours
Machine hours per Annum	2 425	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	6.18	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	US$s
1.5 Overheads	10.00%	28710	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			22.23	US$/mhr
Oil, Cost			4.45	US$/mhr
Tyres/Tracks/Rigging Cost			4.90	US$/mhr
Annual Fuel Costs			53 918	US$s
Annual Lube Cost			10 784	US$s
Annual Tyre/Track/Rigging Cost			11 885	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	63 525	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	2.14	US$/mhr

5.1 Machine Requirements

Annual Volume	161 500	m3
Hourly Volume Required	66.58	m3/hr
Number Of Machines Required	3.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	3.00	#
Rounded number of vehicles Required	3	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	22	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	22.2	m3/mhr
Machine Output per Day	179	m3/day
Machine Output per Annum	53 846	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	US$/month	US$/year	US$/year	of Total
OVERHEADS	11.84	2 392	28 710	86 130	9.09%
FIXED COSTS	58.46	11 816	141 788	425 364	44.9%
Hp	31.02	6 269	75 233	225 700	23.8%
Crew	21.55	4 356	52 269	156 807	16.6%
Licence Insurance	5.89	1 190	14 286	42 857	4.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.91	12 109	145 311	435 934	46.0%
Fuel	22.23	4 493	53 918	161 755	17.1%
Lubrication	4.45	899	10 784	32 351	3.4%
Tyres	4.90	990	11 885	35 655	3.8%
Maintenance	26.19	5 294	63 525	190 574	20.1%
Relocation	2.14	433	5 200	15 600	1.6%
TOTAL COST / REVENUE	130.20	26 317	315 810	947 429	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.87
Number of Machines	3
Number of Operators	7
Machine Hours	7 276
Capital Employed	1 071 429
Residual Value	214 286
Total Revenue	947 429

MACHINE DESCRIPTION : **Forwarder (Tigercat 1075)**
OPERATION : **Extraction of logs to roadside**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	22	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L

Tyres/Tracks/Rigging

	Qty	Cost	Life
front	4	7 200	0
rear	4	7 200	0
tracks Eco	1	19 500	0
other	0	0	0
other	0	0	0

Fuel,Cost	25.74	US$/mhr
Oil, Cost	3.86	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	80 309	US$s
Annual Lube Cost	12 046	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	161 500	m3
Hourly Volume Required	51.76	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	51.8	m3/mhr
Machine Output per Day	539	m3/day
Machine Output per Annum	161 616	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.84
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume $0.075m^3$

SYSTEM DESCRIPTION : **Harvester system**
OPERATION : **Stump to Mill**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$23.01	78 500	5	2	11	300
Forwarder (Tigercat 1075)						$5.83	78 500	1	2	2.2	300
				Total		$28.84		6		13.2	
						$0.00		0		0	
				TOTAL		$28.84		6		13.2	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.4%	
Machine hours per Day	10.5	Hours
Machine hours per Annum	3 140	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.78	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	US$s
1.5 Overheads	10.00%	32838	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			22.23	US$/mhr
Oil, Cost			4.45	US$/mhr
Tyres/Tracks/Rigging Cost			4.90	US$/mhr
Annual Fuel Costs			69 804	US$s
Annual Lube Cost			13 961	US$s
Annual Tyre/Track/Rigging Cost			15 386	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	82 240	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.66	US$/mhr

5.1 Machine Requirements

Annual Volume	78 500	m3
Hourly Volume Required	25.00	m3/hr
Number Of Machines Required	5.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	5.00	#
Rounded number of vehicles Required	5	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	17	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	5.0	m3/mhr
Machine Output per Day	52	m3/day
Machine Output per Annum	15 700	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	10.46	2 736	32 838	164 189	9.09%
FIXED COSTS	45.15	11 816	141 788	708 941	39.3%
Hp	23.96	6 269	75 233	376 167	20.8%
Crew	16.65	4 356	52 269	261 345	14.5%
Licence Insurance	4.55	1 190	14 286	71 429	4.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.42	15 549	186 591	932 954	51.7%
Fuel	22.23	5 817	69 804	349 019	19.3%
Lubrication	4.45	1 163	13 961	69 804	3.9%
Tyres	4.90	1 282	15 386	76 932	4.3%
Maintenance	26.19	6 853	82 240	411 200	22.8%
Relocation	1.66	433	5 200	26 000	1.4%
TOTAL COST / REVENUE	115.03	30 101	361 217	1 806 084	100.0%

6.2 FLEET SUMMARY

US$ per m3	23.01
Number of Machines	5
Number of Operators	11
Machine Hours	15 700
Capital Employed	1 785 715
Residual Value	357 143
Total Revenue	1 806 084

MACHINE DESCRIPTION : **Forwarder (Tigercat 1075)**
OPERATION : **Extraction of logs to roadside**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		571 139	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		571 139	*US$s*
Annual Hp's		120 312	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	114 228	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		10 026	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	*Hours*
Machine hours per Annum	3 120	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	4.81	*Years*

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	*US$s*
1.5 Overheads	10.00%	41640	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			22	*L/Hr*
Fuel Cost			1.17	*US$/L*
Oil,% Fuel Cost			15%	
Oil Cost				*US$/L*
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
front	4	7 200	0	
rear	4	7 200	0	
tracks Eco	1	19 500	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			25.74	*US$/mhr*
Oil, Cost			3.86	*US$/mhr*
Tyres/Tracks/Rigging Cost			0.00	*US$/mhr*
Annual Fuel Costs			80 309	*US$s*
Annual Lube Cost			12 046	*US$s*
Annual Tyre/Track/Rigging Cost			0	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	*US$/mhr*
Annual Maintenance Cost	118 797	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	1.67	*US$/mhr*

5.1 Machine Requirements

Annual Volume	78 500	*m3*
Hourly Volume Required	25.16	*m3/mhr*
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*Hrs*
Basic Hours/week/driver	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	2 205	*US$s*
Annual Double Time	2 940	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	56 889	*US$s*
Total Crew Cost per Machine Hr	18.23	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Lead Distance		*km*
Volume per Load		*m3*
travel empty		*km/hr*
Load		*min*
travel loaded		*km/hr*
Off Load		*min*
Travel time empty	#DIV/0!	*min*
Travel time loaded	#DIV/0!	*min*
Load	0.00	*min*
Off Load	0.00	*min*
cycle time	#DIV/0!	*min*
cycle time	#DIV/0!	*hrs*
Machine Output per Hour	25.2	*m3/mhr*
Machine Output per Day	262	*m3/day*
Machine Output per Annum	78 624	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.83
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume 0.15m^3

SYSTEM DESCRIPTION : Harvester system
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$12.45	111 000	4	2	8.8	300
Forwarder (Tigercat 1075)						$4.13	111 000	1	2	2.2	300
				Total		$16.57		5		11	
						$0.00		0		0	
				TOTAL		$16.57		5		11	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	60.2%	
Machine hours per Day	9.6	Hours
Machine hours per Annum	2 891	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.19	Years

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	US$s
1.5 Overheads	10.00%	31397	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			19	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			20%	
Oil Cost				US$/L
Tyres/Tracks/Rigging				
	Qty	Cost	Life	
Bar	1	400	200	
Chain	1	145	50	
Tyres	0	0	0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			22.23	US$/mhr
Oil, Cost			4.45	US$/mhr
Tyres/Tracks/Rigging Cost			4.90	US$/mhr
Annual Fuel Costs			64 260	US$s
Annual Lube Cost			12 852	US$s
Annual Tyre/Track/Rigging Cost			14 164	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	75 709	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.80	US$/mhr

5.1 Machine Requirements

Annual Volume	111 000	m3
Hourly Volume Required	38.40	m3/hr
Number Of Machines Required	4.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	4.00	#
Rounded number of vehicles Required	4	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	18	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	9.6	m3/mhr
Machine Output per Day	93	m3/day
Machine Output per Annum	27 751	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	**10.86**	**2 616**	**31 397**	**125 589**	**9.09%**
FIXED COSTS	**49.05**	**11 816**	**141 788**	**567 152**	**41.1%**
Hp	26.03	6 269	75 233	300 934	21.8%
Crew	18.08	4 356	52 269	209 076	15.1%
Licence Insurance	4.94	1 190	14 286	57 143	4.1%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	**59.57**	**14 349**	**172 185**	**688 740**	**49.9%**
Fuel	22.23	5 355	64 260	257 040	18.6%
Lubrication	4.45	1 071	12 852	51 408	3.7%
Tyres	4.90	1 180	14 164	56 658	4.1%
Maintenance	26.19	6 309	75 709	302 834	21.9%
Relocation	1.80	433	5 200	20 800	1.5%
TOTAL COST / REVENUE	**119.48**	**28 781**	**345 370**	**1 381 482**	**100.0%**

6.2 FLEET SUMMARY

US$ per m3	12.45
Number of Machines	4
Number of Operators	9
Machine Hours	11 563
Capital Employed	1 428 572
Residual Value	285 714
Total Revenue	1 381 482

MACHINE DESCRIPTION : **Forwarder (Tigercat 1075)**
OPERATION : **Extraction of logs to roadside**
STUDY FOR : **MSc**
PREPARED BY : **Forestry Solutions**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption			22	L/Hr
Fuel Cost			1.17	US$/L
Oil,% Fuel Cost			15%	
Oil Cost				US$/L
Tyres/Tracks/Rigging	Qty	Cost	Life	
front	4		0	
rear	4		0	
tracks Eco	1		0	
other	0	0	0	
other	0	0	0	
Fuel,Cost			25.74	US$/mhr
Oil, Cost			3.86	US$/mhr
Tyres/Tracks/Rigging Cost			0.00	US$/mhr
Annual Fuel Costs			80 309	US$s
Annual Lube Cost			12 046	US$s
Annual Tyre/Track/Rigging Cost			0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	111 000	m3
Hourly Volume Required	35.58	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	35.7	m3/mhr
Machine Output per Day	371	m3/day
Machine Output per Annum	111 384	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	4.13
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume $0.25m^3$

SYSTEM DESCRIPTION	:	**Harvester system**
OPERATION	:	**Stump to Mill**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$8.03	126 000	3	2	6.6	300
Forwarder (Tigercat 1075)						$3.64	126 000	1	2	2.2	300
				Total		$11.67		4		8.8	
						$0.00		0		0	
				TOTAL		$11.67		4		8.8	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price,Exc.VAT		357 143	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		357 143	US$s
Annual HP payment		75 233	US$s

1.2 HP Calculation

Residual Value @	20.00%	71 429	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		6 269	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	57.6%	
Machine hours per Day	9.2	Hours
Machine hours per Annum	2 763	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	5.43	Years

1.4 OVERHEADS

Annual Licence Fees & insurance	14 286	US$s

1.5 Overheads

1.5 Overheads	10.00%	30661	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	19	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	20%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
Bar	1	400	200
Chain	1	145	50
Tyres	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	22.23	US$/mhr
Oil, Cost	4.45	US$/mhr
Tyres/Tracks/Rigging Cost	4.90	US$/mhr
Annual Fuel Costs	61 425	US$s
Annual Lube Cost	12 285	US$s
Annual Tyre/Track/Rigging Cost	13 540	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	US$/mhr
Annual Maintenance Cost	72 369	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.88	US$/mhr

5.1 Machine Requirements

Annual Volume	126 000	m3
Hourly Volume Required	45.60	m3/hr
Number Of Machines Required	3.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	3.00	#
Rounded number of vehicles Required	3	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	days
Basic Hours/week	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	225	US$s
Annual Double Time	300	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	52 269	US$s
Total Crew Cost per Machine Hr	19	US$/mhr

4.1 WORK STUDY ANALYSIS

Average Tree Volume		m3
fell		min
debranch / debark		min
crosscut		min
place		min
bunch		min
move		min
other		min
other		min
other		min
cycle time	0.00	min
cycle time	0.000	hrs
Machine Output per Machine Hr	15.2	m3/mhr
Machine Output per Day	140	m3/day
Machine Output per Annum	42 000	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.10	2 555	30 661	91 982	9.09%
FIXED COSTS	51.31	11 816	141 788	425 364	42.0%
Hp	27.23	6 269	75 233	225 700	22.3%
Crew	18.92	4 356	52 269	156 807	15.5%
Licence Insurance	5.17	1 190	14 286	42 857	4.2%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.65	13 735	164 818	494 455	48.9%
Fuel	22.23	5 119	61 425	184 276	18.2%
Lubrication	4.45	1 024	12 285	36 855	3.6%
Tyres	4.90	1 128	13 540	40 619	4.0%
Maintenance	26.19	6 031	72 369	217 106	21.5%
Relocation	1.88	433	5 200	15 600	1.5%
TOTAL COST / REVENUE	122.06	28 106	337 267	1 011 801	100.0%

6.2 FLEET SUMMARY

US$ per m3	8.03
Number of Machines	3
Number of Operators	7
Machine Hours	8 289
Capital Employed	1 071 429
Residual Value	214 286
Total Revenue	1 011 801

MACHINE DESCRIPTION : **Forwarder (Tigercat 1075)**
OPERATION : **Extraction of logs to roadside**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	22	L/Hr
Fuel Cost	1.17	US$/L
Oil,% Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	4	7 200	0
rear	4	7 200	0
tracks Eco	1	19 500	0
other	0	0	0
other	0	0	0

Fuel,Cost	25.74	US$/mhr
Oil, Cost	3.86	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	80 309	US$s
Annual Lube Cost	12 046	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	126 000	m3
Hourly Volume Required	40.38	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No.Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	40.5	m3/mhr
Machine Output per Day	421	m3/day
Machine Output per Annum	126 360	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	3.64
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Harvester (CTL) System – Tree volume 0.40m^3

SYSTEM DESCRIPTION : Harvester system
OPERATION : Stump to Mill
STUDY FOR : MSc
PREPARED BY : McEwan

FORESTRY SOLUTIONS
Growing Lifetime Partnerships

Locality / Activity	Stand	Extraction route	Roadside Landing	Forest Road	Millyard	Cost (US$/m3)	Annual System Production	Equip #	# of shifts	Staff #	Working days / annum
Harvester (Hitachi ZAxis200 with SP591)						$5.87	161 500	3	2	6.6	300
Forwarder (Tigercat 1075)						$2.84	161 500	1	2	2.2	300
				Total		$8.70		4		8.8	
						$0.00		0		0	
				TOTAL		$8.70		4		8.8	

MACHINE DESCRIPTION : **Harvester (Hitachi ZAxis200 with SP591)**
OPERATION : **Fell, delimb, debarking, crosscut and stack Euc pulp**
STUDY FOR : **MSc**
PREPARED BY : **McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

FORESTRY SOLUTIONS

1.1 CAPITAL EMPLOYED

Machine Price, Exc.VAT		357 143	*US$s*
Less Cost of Tyres/Tracks/Rigging		0	*US$s*
Plus additional equipment	radio	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
	other	0	*US$s*
Sub total additional equipment		0	*US$s*
Total Capital Employed		357 143	*US$s*
Annual HP payment		75 233	*US$s*

1.2 HP Calculation

Residual Value @	20.00%	71 429	*US$s*
Interest per annum		8.00%	
Payment period		60	*months*
Monthly payment		6 269	*US$s*

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	*Days*
Shift length	8	*Hours*
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	50.5%	
Machine hours per Day	8.1	*Hours*
Machine hours per Annum	2 425	*Hours*
Machine Life Hours	15 000	*Hours*
Machine Life Years	6.18	*Years*

1.4 OVERHEADS

Annual Licence Fees & insurance		14 286	*US$s*
1.5 Overheads	10.00%	28710	*US$s*

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	19	*L/Hr*
Fuel Cost	1.17	*US$/L*
Oil,% Fuel Cost	20%	
Oil Cost		*US$/L*

Tyres/Tracks/Rigging

	Qty	Cost	Life
Bar	1	400	200
Chain	1	145	50
Tyres	0	0	0
other	0	0	0
other	0	0	0

Fuel,Cost	22.23	*US$/mhr*
Oil, Cost	4.45	*US$/mhr*
Tyres/Tracks/Rigging Cost	4.90	*US$/mhr*
Annual Fuel Costs	53 918	*US$s*
Annual Lube Cost	10 784	*US$s*
Annual Tyre/Track/Rigging Cost	11 885	*US$s*

2.2 VEHICLE MAINTENANCE COSTS

Maint,% Cap.Cost/machine life (mhr's)	110%	
Maintenance Cost	26.19	*US$/mhr*
Annual Maintenance Cost	63 525	*US$s*

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	*US$s*
Annual Relocation Cost	5 200	*US$s*
Relocation Cost per Machine Hour	2.14	*US$/mhr*

5.1 Machine Requirements

Annual Volume	161 500	*m3*
Hourly Volume Required	66.58	*m3/hr*
Number Of Machines Required	3.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	3.00	#
Rounded number of vehicles Required	3	#

3.1 LABOUR COSTS

Driver Wage	9.80	*US$/hour*
No.Drivers/Shift	1.1	#
Labour Wage	0.00	*US$/hour*
No.Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	*days*
Operating Hours/Week	96.0	*days*
Basic Hours/week	90.0	*Hrs*
Total Overtime per week	6.0	*Hrs*
Time and a Half per week	3.0	*Hrs*
Double Time per Week	3.0	*Hrs*
Shift or Other Allowance	0.00	*US$/day*
Annual Normal Time	51 744	*US$s*
Annual Time and a Half	225	*US$s*
Annual Double Time	300	*US$s*
Annual Bonus	0	*US$s*
Annual Shift or Other Allowance	0	*US$s*
Total Annual Crew Cost	52 269	*US$s*
Total Crew Cost per Machine Hr	22	*US$/mhr*

4.1 WORK STUDY ANALYSIS

Average Tree Volume		*m3*
fell		*min*
debranch / debark		*min*
crosscut		*min*
place		*min*
bunch		*min*
move		*min*
other		*min*
other		*min*
other		*min*
cycle time	0.00	*min*
cycle time	0.000	*hrs*
Machine Output per Machine Hr	22.2	*m3/mhr*
Machine Output per Day	179	*m3/day*
Machine Output per Annum	53 846	*m3/year*

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	11.84	2 392	28 710	86 130	9.09%
FIXED COSTS	58.46	11 816	141 788	425 364	44.9%
Hp	31.02	6 269	75 233	225 700	23.8%
Crew	21.55	4 356	52 269	156 807	16.6%
Licence Insurance	5.89	1 190	14 286	42 857	4.5%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	59.91	12 109	145 311	435 934	46.0%
Fuel	22.23	4 493	53 918	161 755	17.1%
Lubrication	4.45	899	10 784	32 351	3.4%
Tyres	4.90	990	11 885	35 655	3.8%
Maintenance	26.19	5 294	63 525	190 574	20.1%
Relocation	2.14	433	5 200	15 600	1.6%
TOTAL COST / REVENUE	130.20	26 317	315 810	947 429	100.0%

6.2 FLEET SUMMARY

US$ per m3	5.87
Number of Machines	3
Number of Operators	7
Machine Hours	7 276
Capital Employed	1 071 429
Residual Value	214 286
Total Revenue	947 429

MACHINE DESCRIPTION	:	**Forwarder (Tigercat 1075)**
OPERATION	:	**Extraction of logs to roadside**
STUDY FOR	:	**MSc**
PREPARED BY	:	**McEwan**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES, SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.1 CAPITAL EMPLOYED

Machine Price, Exc. VAT		571 139	US$s
Less Cost of Tyres/Tracks/Rigging		0	US$s
Plus additional equipment	radio	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
	other	0	US$s
Sub total additional equipment		0	US$s
Total Capital Employed		571 139	US$s
Annual Hp's		120 312	US$s

1.2 HP Calculation

Residual Value @	20.00%	114 228	US$s
Interest per annum		8.00%	
Payment period		60	months
Monthly payment		10 026	US$s

1.3 OPERATING HOURS

Total Days	365	
Weekend Days	52	
Statutory Leave Days	13	
Sick Leave Days	0	
Productive Days Lost to Weather/Mill Stops	0	
Total Annual Production Days	300	Days
Shift length	8	Hours
Number of Shifts per day	2	#
Machine Availability	100.0%	
Machine Utilisation	65.0%	
Machine hours per Day	10.4	Hours
Machine hours per Annum	3 120	Hours
Machine Life Hours	15 000	Hours
Machine Life Years	4.81	Years

1.4 OVERHEADS

Annual Licence Insurance Fees		22 846	US$s
1.5 Overheads	10.00%	41640	US$s

2.1 VEHICLE OPERATING COSTS

Fuel Consumption	22	L/Hr
Fuel Cost	1.17	US$/L
Oil, % Fuel Cost	15%	
Oil Cost		US$/L
Tyres/Tracks/Rigging		

	Qty	Cost	Life
front	4	7 200	0
rear	4	7 200	0
tracks Eco	1	19 500	0
other	0	0	0
other	0	0	0

Fuel, Cost	25.74	US$/mhr
Oil, Cost	3.86	US$/mhr
Tyres/Tracks/Rigging Cost	0.00	US$/mhr
Annual Fuel Costs	80 309	US$s
Annual Lube Cost	12 046	US$s
Annual Tyre/Track/Rigging Cost	0	US$s

2.2 VEHICLE MAINTENANCE COSTS

Maint, % Cap. Cost/machine life (mhr's)	100%	
Maintenance Cost	38.08	US$/mhr
Annual Maintenance Cost	118 797	US$s

2.3 RELOCATION COSTS

Number of moves per annum	4	#
Cost per Move	1 300	US$s
Annual Relocation Cost	5 200	US$s
Relocation Cost per Machine Hour	1.67	US$/mhr

5.1 Machine Requirements

Annual Volume	161 500	m3
Hourly Volume Required	51.76	m3/mhr
Number Of Machines Required	1.00	#
Fleet Reserve	0%	
Exact Number of Machines Required	1.00	#
Rounded number of vehicles Required	1	#

3.1 LABOUR COSTS

Driver Wage	9.80	US$/hour
No. Drivers/Shift	1.1	#
Labour Wage	0.00	US$/hour
No. Labourers/Shift	0.0	#
Contributions	0.0%	
Operating Days/Week	6.0	days
Operating Hours/Week	96.0	Hrs
Basic Hours/week/driver	90.0	Hrs
Total Overtime per week	6.0	Hrs
Time and a Half per week	3.0	Hrs
Double Time per Week	3.0	Hrs
Shift or Other Allowance	0.00	US$/day
Annual Normal Time	51 744	US$s
Annual Time and a Half	2 205	US$s
Annual Double Time	2 940	US$s
Annual Bonus	0	US$s
Annual Shift or Other Allowance	0	US$s
Total Annual Crew Cost	56 889	US$s
Total Crew Cost per Machine Hr	18.23	US$/mhr

4.1 WORK STUDY ANALYSIS

Lead Distance		km
Volume per Load		m3
travel empty		km/hr
Load		min
travel loaded		km/hr
Off Load		min
Travel time empty	#DIV/0!	min
Travel time loaded	#DIV/0!	min
Load	0.00	min
Off Load	0.00	min
cycle time	#DIV/0!	min
cycle time	#DIV/0!	hrs
Machine Output per Hour	51.8	m3/mhr
Machine Output per Day	539	m3/day
Machine Output per Annum	161 616	m3/year

6.1 SUMMARY

	PER MACHINE			FLEET	%
	US$/hr	*US$/month*	*US$/year*	*US$/year*	*of Total*
OVERHEADS	13.35	3 470	41 640	41 640	9.09%
FIXED COSTS	64.12	16 671	200 047	200 047	43.7%
Hp's	38.56	10 026	120 312	120 312	26.3%
Crew	18.23	4 741	56 889	56 889	12.4%
Licence Insurance	7.32	1 904	22 846	22 846	5.0%
Permit & Toll fees	0.0		0	0	0.0%
VARIABLE COSTS	69.34	18 029	216 352	216 352	47.2%
Fuel	25.74	6 692	80 309	80 309	17.5%
Lubrication	3.86	1 004	12 046	12 046	2.6%
Tyres	0.00	0	0	0	0.0%
Maintenance	38.08	9 900	118 797	118 797	25.9%
Relocation	1.67	433	5 200	5 200	1.1%
TOTAL COST / REVENUE	146.81	38 170	458 039	458 039	100.0%

6.2 FLEET SUMMARY

US$ per m3	2.84
Number of Machines	1
Number of Operators	2
Machine Hours	3 120
Capital Employed	571 139
Residual Value	114 228
Total Revenue	458 039

Annexure D

University of Pretoria declaration of originality

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DECLARATION OF ORIGINALITY

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