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Acknowledgements

The South African Ground Based Harvesting Handbook was initiated by Forest Engineering Southern Africa (FESA) in 2008 and funded by the Forest Industry Education and Training Authority (FIETA). The following people contributed to this first edition of the Handbook:

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Glynn Hogg  Mondi
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Benno Krieg  Komatiland Forests
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Francois Oberholzer  Forestry Solutions
Gary Olsen  Tigercat
Christian Potgieter  SGS South Africa
Johannes van Rooyen  PG Bison
Piet Schoombee  Sappi Forests
Alf Ueckermann  Mondi
Pieter de Wet  PG Bison
Stefan van Zyl  Sappi Forests
Timber harvesting offers many challenges to practitioners, harvesting planners and harvesting managers. Among these challenges is the selection and optimal application of harvesting equipment and systems for ground based harvesting operations. Ground based equipment and systems can operate successfully under a wide range of conditions, and the conditions suitable to each system can overlap considerably. Even though the choice between harvesting systems and equipment may result from personal or corporate preferences, and in other cases, the same equipment may be used on different sites; operating techniques must be changed to achieve desired results. Regardless of the selection process, understanding the operational, economic, environmental, ergonomic, safety and social ramifications of choosing a particular type of harvesting equipment is of paramount importance. While there are as many different ways to arrive at a decision as there are contractors, planners, and equipment owners, each decision should be based on a thorough understanding of the implications of selecting the different equipment types. Better understanding of this will lead to improved decisions and harvesting operations.

This Ground Based Harvesting Handbook has been compiled to be as comprehensive as possible and to suit all levels of work and expertise. The Handbook is intended to provide both a broad and detailed overview of the equipment capabilities and limitations and at the same time provide for other internal and external factors affecting ground based harvesting operations. The Handbook describes various equipment types and harvesting systems used in South Africa and internationally. It outlines harvesting site characteristics, operating techniques, external requirements and their effect on different types of harvesting equipment available currently. The Handbook was also written to allow for practical decision-making in operations, to allow experienced foresters, contractors and planners to broaden their exposure to harvesting equipment and systems, and to function as an educational and training resource manual for broad application in the South African Forestry Industry. From the outset it was recognised that this Handbook would likely serve a wider audience than South Africa; and as such the authors and editors maintained a generic approach and refrained from expanding on specific legalistic issues pertaining potentially only to South Africa. Although the Handbook provides information about the capabilities of the various harvesting equipment and systems, it does not link them directly to the requirements of any specific forest code or best practice guidelines. That task is left to the user of the Handbook, as a separate exercise.

The Handbook is divided into seven chapters. Chapters one and two provide a general introduction and overview of ground based harvesting and transport methods and systems; nomenclature and terms, and an introduction to supply chain management. Chapter three identifies specific ground based harvesting equipment from felling, processing, extraction to loading; which includes material handling. It specifies terminology and nomenclature pertaining to specific equipment, detail of capabilities, productivity indices, equipment applications and roles in ground based harvesting systems. Chapters four and five deal with machine and systems costing and an introduction into strategic, tactical and operational harvesting planning. Finally chapters six and seven address potential environmental impacts and mitigating factors plus guidelines, and health and safety in general. The glossary of terms is intended to be as comprehensive as possible in order to provide a standardised base for effective communication between different parties involved in timber harvesting.

The Editors
October 2010
Chapter 1

Introduction

Pierre Ackerman and Dirk Längin

1.1 Overview

A variety of ground based harvesting systems and equipment are available to timber companies and harvesting contractors today. In South Africa, these options can range from basic manual operations, semi-mechanised systems to fully mechanised operations. Two of the most important tasks faced by timber harvesters are to select the best harvesting system and equipment for a given site, and to use the selected equipment in the best way possible. Each of these systems can operate successfully under a wide range of conditions, and the conditions suitable to each system can overlap considerably. On many sites, several systems can be used successfully. Yet, the conditions on some sites may favour a single harvesting system. The selection process involves understanding the economic, social and environmental ramifications of choosing particular equipment for use on any given site. This process also involves recognising the capabilities of equipment and the potential interaction of equipment within a harvesting system. With a variety of factors to consider, each decision should be based on a thorough understanding of the implications of selecting the different equipment types. Improved knowledge of harvesting systems and equipment will lead to better decisions. The objective of this handbook is to help increase that knowledge and understanding.

1.2 Timber Harvesting and Transport

Forestry activities can be divided into two main stages; primary or biological production and secondary or technical production. Technical production, which includes forest technology, is historically separated into timber harvesting, forest work science, and the opening-up of forests, access development and construction. All activities required to transfer the standing tree, material suitable for conversion (stem wood, branches, wood from the roots, bark and residues), into suitable products for further processing at a required point of sale, are included in technical production. This stage involves interactions between man, machine and the environment. In more detail, the three subdivisions of forest technology include:

- **Work science**: an interdisciplinary applied science which aims to match the job and places of work with the human being. Physiological, psychological, sociological, technological, economical and organisational aspects are considered.

- **Forest access development** and forest road network maintenance: forest roads are the most suitable means of access for properly managed forests. Other means such as waterways, railways, cable ways or aircraft are technologically and ecologically more advanced than roads, but they do not fulfil all the requirements of efficient access development.
• Timber harvesting: the forest operation where trees are cut for utilisation by society or to produce stand/forest conditions specified by the owner, and all associated operations (e.g. planning, roads, layout, felling, conversion, extraction and long distance transport).

Forest technology thus involves an understanding of the relationship between people, technology, forest industries and the environment. The following figure shows this interrelationship and the difference in focus between the macro- and micro-environment in which these technologies are expected to operate (Figure 1.2-1).

![Diagram of forest technology](image)

**FIGURE 1.2-1: Forestry comprising biological and technical production.**

Timber harvesting and transport costs constitute an estimated 60% to 80% of the mill-delivered costs. As a result, operations are required to be performed efficiently and cost-effectively. Due to the speed of progression of harvesting and transport operations, it is crucial that operations are thoroughly planned and executed well in advance, as it is extremely difficult to rectify flaws in planning once the harvesting and transport of trees has commenced. Forest Engineering has a significant influence on the environment and there are a number of necessary and required steps to be taken to minimise these impacts. With the advent of certification in forestry some years ago, there has been a strong inclination towards environmentally sound forest practices from which forest technology is not excluded. The influence forest technology has on customer satisfaction and value added product is significant.

### 1.3 Harvesting Methods and Systems

The terms harvesting method and harvesting systems form the basis of understanding the discipline of timber harvesting and are defined as follows:

- **Harvesting method** is based on the form timber is delivered to roadside, and depends on the amount of processing or original form adaption the wood or raw material un-
dergoes in field. The harvesting site in this context is the area from which the timber originated.

- **Harvesting system** comprises the tools, equipment and machines used to harvest an area. The individual components of the system can change without changing the harvesting method.

### 1.3.1 Harvesting Methods

The following are accepted terms and definitions of the range of harvesting methods as practiced in South Africa:

- **Full tree (FT) method** occurs when trees are felled at an acceptable maximum stump height, and all biomass above the stump and a major portion of the stump are transported to roadside. This is one of the most widely used methods internationally and usually is part of a mechanised operation. It has limited application in South Africa.

- **Tree length (TL) method** occurs when trees are felled, debranched and topped in the compartment and only the bole extracted to roadside. This is one of the most widely used methods utilised, internationally and locally.

- **Cut-to-length (CTL) method** is where trees are felled, debranched, crosscut and topped in the compartment. The round wood assortments are then extracted to roadside and are one of the most widely used methods internationally. It is practised widely in Europe and Scandinavia as a means of reducing the environmental impacts associated with tree length method of extraction. The use of this method is increasingly rapidly in North America. This method is also called the short wood and/or assortment method.

By and large South African harvesting and transport techniques and systems have been manually orientated in pulpwood harvesting operations, and semi-mechanised operations in sawtimber harvesting. The traditional harvesting methods in South Africa revolve around three basic approaches: CTL, TL and FT harvesting. Cut-to-length is applied to hardwood and softwood pulpwood harvesting with some TL and FT harvesting being applied. Pine and eucalyptus sawtimber operations have evolved over the years from CTL methods, with the inclusion of some FT methods in later years. However, most of this sawtimber volume in South Africa is harvested according to the TL method.

### 1.3.2 Harvesting Systems

A harvesting system is composed of the tools, equipment and machines used to harvest an area of standing trees as described above. A typical cut-to-length system can, for example, employ a one-grip harvester which fells, debranches and merchandises trees in the stump area, and a forwarder to carry the logs to roadside. With the tree-length method a common system would include motor-manual felling, debranching and topping, tree-length skidding to roadside and roadside merchandising. A typical harvesting system used in full tree harvesting would include a feller buncher, grapple skidder and a processor.

To plan, implement, and operate cost-effective and safe harvesting operations, a systems approach must be followed. This approach will ensure the success of harvesting operations in terms of economics, social aspects, the environment, and technical feasibility. In striving for sustainability and sustainable forest management, choosing an appropriate and suitable harvesting system is not simple and is subject to a variety of variables. Timber harvesting is only a part of the forest supply chain which is in turn influenced by variables including silviculture regimes and/or processing plants requirements to name a few. However, it is important to remember that timber harvesting will have a significant influence on other parts of the forest supply chain.
To decide which technology is most appropriate for a harvesting system and/or method to be applied under specific conditions, the following eight decision dimensions of harvesting operations selection should be considered:

1. The forest supply chain;
2. The technical feasibility of harvesting systems;
3. Forest worker safety and ergonomic aspects;
4. Silviculture aspects and considerations;
5. Environmental considerations;
6. Forest products and product range;
7. Economic consideration of the operation;
8. Socio-political climate.

1.4 An International Overview of Harvesting Systems Development

Harvesting systems have developed to varying degrees worldwide over the last 50 years. In industrialised regions such as North America, Scandinavia, and the balance of Europe, these developments have been significant in improving the utilisation of raw materials and at the same time, improving productivity. The same cannot always be said of developing countries. These countries are faced with different challenges; shrinking forest areas, increased demand for tropical hardwoods, and less than optimal timber utilisation. In the northern hemisphere forest area is strongly increasing. Despite the large amount of timber extracted throughout the decades, forests in the northern hemisphere contain twice as much timber as they did at the start of the 20th century.

**FIGURE 1.4-1: Development of productivity in Swedish forest operations 1950-2000 through technological developments.**
The progression of systems development can be studied in earnest from the early 1950’s. Systems before 1950 remained reasonably static in design and improvements in productivity and technology only started to appear from middle of the century.

The period from 1950 to 1960 was characterised by manual and motor-manual systems and associated with the extensive use of animals, horses and oxen, with some low-key mechanised extraction equipment. Animal associated primary transport operations were assisted by skidding pans, sulksies and wheeled trailers. At this stage, the chainsaw had not made its mark with felling and bucking being done with axes, bow saws and crosscut saws. Mechanical equipment was not custom built. Instead, equipment originally designed for use in construction and adapted for forestry was mostly used. Productivity remained fairly static and large numbers of people worked in the forest producing limited volume.

With the introduction of the new generation lightweight professional chainsaw during the period between 1960 and 1970, forest work became far more concentrated with increased capability of harvesting greater volumes of timber with less effort and time. Productivity increased dramatically. At the same time the first custom-made dedicated forest machines primarily concerned with processing and primary transport operations started making an appearance in the forest. More and more agricultural tractors and semi-trailers were used and the articulated skidder was introduced from the USA and Canada. Productivity climbed from an average of 2m³/manday to around 7 and 8m³/manday in a short space of time.

The ten years between 1970 and 1980 saw a slow swing from predominantly tree length harvesting methods to cut-to-length methods and systems particularly in Europe and Scandinavia. Specialised felling equipment such as the feller buncher and harvester were being introduced to the forest. The two-grip harvester was in the process of being perfected and was coupled with forwarder operations (primary transport) in cut-to-length harvesting systems. The rapid improvement seen during the 1960’s was not evident during this era as a number of innovations were in the development phase and multiple handling was still evident; e.g. the two-grip harvester.

The 1980’s saw a rapid increase in productivity from about 10m³/manday to 14m³/manday. The reason for this increase was rapid introduction of the superior single-grip harvester into partial cuts or thinnings and clear cutting operations. In particular, increased productivity was seen for smaller dimension timber in Europe, Scandinavia and North America. As well, the first in-filed chipping operations were introduced. Logistics started to play and ever increasing role in the supply chain from stump to customer. Cable yarding machines started to be of smaller stature and shorter reaches in order to work in a partial cutting context.

The decade between 1990 and 2000 saw forest certification and the forest stewardship philosophy grow progressively stronger. This change had an immediate impact on harvesting systems in terms of reduced intrusion, increased and maintenance of biodiversity, and maintained sustainability (enviro-gentle technology). Intensive research and development was concentrated into machines such as the Plustech harvester and the so-called Harwarder. The objective remained to limit damage to the sites, and reduce the number of people working in the forest. Significant developments were made in terms of steep terrain harvesting. Technological improvements such as levelling cabs on harvesters, and forwarders able to negotiate steeper terrain were being introduced to the market.

In terms of improving utilisation, wood quality and pulp yields, chain-fail-delimber-debarker-chippers and chipping in-field behind full-tree operations are being used. Improved debarking of harvesters within the fast growing eucalyptus regimes and interior log scanning by the harvester became reality. Remote sensing, information and communication technologies (ICT), and sophisticated supply chain management techniques became the order of the day in controlling inventories and reducing the time envelope form stump to customer.

This process of development has, to a large extent, contributed to the significant increase in average productivity, expressed in terms of m³/manday, since the early 1960’s. Subsequently, the effect on the labour force has been significant. For example, some 40 years
ago there were 150 000 fully employed workers in the Swedish forest industry, while today the number is less than 25 000 and still declining. Yet, they harvest more now than they did (Axelsson, 1997).

The techniques used today are advanced and technically sophisticated, therefore requiring highly skilled and competent operators. Since forestry also is a complex business in itself, performing in lean decentralised organisations, education and training of its personnel is essential.

- The number of technical and organisational options has increased exponentially due to tremendous technological advances in the last two or three decades.
- The higher the degree of mechanisation implemented, the greater the impact of marginal decisions on operations and the cost factor.
- Highly mechanised operations may in turn create biological/ecological problems not experienced before, as well as ergonomically related stress points.

### 1.5 Timber Transport

Round wood timber transport remains a costly but integral part of the process of round wood procurement. Transport in South Africa typically occurs in the following phases; primary transport from stump by off-road extraction equipment, and subsequent secondary road or rail transport to processing sites around the country. The terminology, primary and secondary transport are accepted terminology for timber transport from the stump area to a roadside landing, and timber transport from roadside landing to the processing factory respectively. For a number of reasons some alternative phases of transport have been introduced in South Africa. To accommodate these additional phases, new terminology was developed. In order to be able to identify and cost the different phases of transport the following terminology was developed in addition to primary and secondary transport (Figure 1.4-1) and accepted by the South African Forestry Industry 2002 (Figure 1.5-1 and 1.6-1):

- **Primary transport (PT)** is the transport of timber from the stump area to a roadside landing which could be either centralised or continuous;
- **Extended primary transport (EPT)** is terrain transport past the roadside landing to an intermediate storage site or directly to the processing site;
- **Secondary transport (ST)** is the transport of wood from the roadside landing directly to a procession site;
- **Secondary intermediate transport (SIT)** is timber transport from a roadside landing to an intermediate storage site (wood does not reach the processing site in this phase of transport);
- **Secondary terminal transport (STT)** is timber transport form an intermediate storage site to the processing site (the final stage of transport).

Secondary pulpwood transport, in South Africa, has been historically divided into two components; namely shorthaul and longhaul transport. The concept of shorthaul, part of secondary transport, is not unique to South Africa; but the meaning assigned to the term is. Unfortunately, the term shorthaul is still widely used in the industry and executed mainly by tractor-trailer units. The use of the terminology shorthaul is confusing and there is a need to establish standard terminology. This lack of exact terminology has created difficulties in the actual quantification of the economic impact of this mode of transport. Difficulties arise particularly within pulpwood operations, and also the forest engineering value chain due to the overlapping of definitions in round wood. In most cases, additional transportation phases necessitate multiple handling and repeated storage of timber.
1.6 Supply Chain Management

Supply Chain Management (SCM) is a business management approach where the emphasis is on the integration of business processes across all boundaries within and between organisations. Within this integration, the entire supply chain is examined from raw material right through to final consumption (Pulkki, 2001). By breaking down barriers of communication and information flow within and between organisations and companies, the efficient use of production inputs (labour, raw material and capital) is achieved and the competitiveness of a company is ensured.

Otto and Kotzab (1999) defined SCM as the task of integrating organisational units along a supply chain, and coordinating materials, information and financial flows in order to fulfil (ultimate) customer demands with the aim of improving competitiveness of the supply chain as a whole. Christopher (1998) defined SCM as consisting of a network of cooperating organisations. Through upstream and downstream linkages, these networks are involved in the different processes and activities that produce value in the form of products and services to the ultimate consumer. This definition stresses that all the activities along a SC should be designed according to the needs of the customers, and consequently, the (ultimate) consumer is an integral part of a supply chain. The main focus is on the order fulfilment processes and corresponding material, financial and information flows.

Supply Chain Management avoids sub-optimisation of lower-level operations and processes that may put the over-all objectives of the organization at risk or limit future opportunities (Pulkki, 2001). Since the introduction of the term supply chain management in 1982 (Oliver and Webber, 1992), it has received ever-growing interest both in the literature as well as from industrial practice. A reason for this interest might be that SCM has so many facets and the tasks of accomplishing its aims are so demanding that it is more an ongoing endeavour than a short-term project.
The forest industry is of international and regional importance to countries like South Africa. Being heavily dependent on both an internal and highly competitive export market, the forest industry must ensure that its costs and revenues are competitive. This means that it has to improve or at least maintain the efficiency of all its operations. A general opinion in the forest industry today is that the potential lies in improved integration between different parts of the SC or wood-flow chain and the use of techniques to increase the utilisation of raw materials and production capacities (Stadtler, 2005).

The main participants involved in South Africa are the industrial forest-enterprises, with large (and small) forest assets as well as their own pulp and paper industries and sawmills. In general, the overall wood-flow or raw material supply chain, starts with standing trees in forests; continues with harvesting, merchandising, sorting, transportation to terminals, sawmills, pulp mills, paper mills and heating plants, conversion into products such as pulp, paper, lumber; and ends at different customers (Figure 1.5-1). In essence, we have just described the wood procurement chain, but it must be remembered that the supply chain extends from tree improvement, management planning, silviculture, past the wood procurement phase right through mill handling and processing and as mentioned to the final customer (Pulkki, 2001). This complexity is compounded by the section of the chain extending form the forest to the mill, since it is geographically widely dispersed and is very variable in regard to terrain, operating conditions and weather (Pulkki, 2001)

In addition, wood as the raw material has many quality characteristics. Although these characteristics can be affected by silvicultural and forest management activities in the long-term, wood procurement operations have a tremendous influence, following wood quality characteristics; wood density, species composition, chip size and distribution, moisture content, moisture uniformity or distribution, mechanical damage, log length and cross-cutting accuracy for example. By controlling the above factors, it has been shown that higher screened pulp yields are possible, improving paper quality, lowering chemical use for bleaching and improving wood/fibre recovery and utilization in wood procurement.

Customer orientation within the supply chain should be the focus of the forest industry. The concept of customer orientation is that the right kind of products (or raw material) should be delivered to the customer in the right quantity and at the right time (Pulkki, 2001, Stadtler, 2005). According to Pulkki (2001), SCM also strives to ensure that customers’ needs are satisfied through low cost, consistently high quality products, and through enhanced customer service. In this way, the customer has the opportunity to improve on the utilization of the raw material as well as obtaining increased efficiency in production planning. However, it must be
appreciated that these gains in turn dramatically increase demands placed on the logistics and production system providing the service. The capacities and capabilities on all sections of the overall supply chain in terms of quality and flexibility will therefore improve and this will give rise to a general improvement of knowledge of the supply chain.

The development of practical and robust decision support tools, based on optimisation models and methods, are an important prerequisite for producing a general view and efficient resolution of complex situations within which the forestry industry operates. Operations Research (OR) models and methods arising in supply chain are an example of the tools available to the forester. Compared to other industrial sectors in South Africa, forestry has relatively few advanced decision support systems and has put very little funding into research and development in this field.

It is imperative that decisions in wood procurement on harvesting systems and methods are based on total value chain cost and wood and/or fibre quality. This way, decisions made at the mill do not adversely affect wood procurement operations and conversely, the forest based decisions do not negatively affect mill processing or final product quality.

1.7 References


Chapter 2

Introduction to Ground Based Harvesting Systems and Methods

Dirk Längin, Pierre Ackerman and Gary Olsen

2.1 Operating Conditions

Terrain and terrain conditions have an influence on the harvesting method to be selected, the type of equipment to be employed and the planning intensity of harvesting operations. Ground based harvesting systems are usually limited by slope ranging between 0% and 60%, on which motor-manual operation can be carried out safely or on which wheeled or tracked machines can travel to carry out felling, processing and extraction of timber. Usually above 60% slope, aerial extraction, i.e., cable yarders and even helicopters, are required to carry out primary transport of timber from stump to roadside. Figures 2.1-1 and 2.1-2 provide a simplified overview of machines suitable for harvesting operations taking slope, tree size and extraction distance into account. Accordingly, wheeled machines can access slopes of up to 35%, and if suitably equipped with tracks or chains can negotiate slopes of up to 45%. Tracked harvesting equipment, particularly purpose built steep slope harvesters, are able to work on slopes up to 60%. However, this should only be attempted under ideal underfoot and ground roughness conditions. An example of extreme slope operations in mechanised ground based harvesting in slopes of 30 to 50% is the combination of a harvester and a forwarder which is fitted with a winch. This equipment was developed for use in steep areas of the European Alps (KWF, 2008) (Figures 2.1-3 and 2.1-4).

FIGURE 2.1-1: Conceptual overview of felling and processing equipment suitability dependent on tree size and slope.
Ground condition and ground roughness further limit equipment selection. Tracked machines for example are not able to cope with terrain characterised by extreme ground roughness, whereas wheeled machines are able to negotiate higher ground roughness indices.
2.2 Ground Based Harvesting Systems and Methods

The term harvesting in this handbook is associated with forest operations in which trees are cut for utilisation by society or to produce stand/forest conditions specified by the owner, and includes all associated operations such as harvest planning, roads layout, felling, conversion, extraction and long distance transport; and is synonymous to the term logging.

2.2.1 Harvesting System

The appropriate choice of a suitable system which reflects sustainable forest management is subject to a variety of selection criteria. It has to be remembered that timber harvesting is only a part of the forest value chain and can be influenced by silvicultural regimes or by requirements at processing plants; in turn forest harvesting will have significant influences on other parts of the forest value chain.

Due recognition of prevailing circumstances within the areas impacted, and harvest conditions must be established in order to make concise and correct decisions in systems selection. Systems selection cannot be done in isolation or without consideration of potential negative impacts on the individual criteria or without possible effects down the value chain.

In order to evaluate alternative systems to determine the economic feasibility, it is important to consider the total system rather than individual activities within a system.

2.2.2 Harvesting Method

A harvesting method is based on the form in which wood is delivered to roadside, and depends on the amount of processing the wood or raw material undergoes in the harvesting site. Processing is an important step in the value adding stage of forest harvesting and can include debranching, debarking or chipping. The work sequence in processing a standing tree is a succession of mutually dependent activities, which can be classified as follows:

- **Conversion group**: where the forms of the work object (the tree) is changed irreversibly.
- **Transportation group**: where the location of the work object is changed.
- **Storage group**: where inventory is awaiting transportation.
- **Terminal activities**: which are activities necessary to initiate or to finish the remaining processes without changing the state or location of the work object.

Processing or conversion activities can be executed at different locations:

- **The compartment**: Forest stand or tree growing area where the standing tree is transformed into a stem without conversion into assortments, or logs ready for either conversion or transport to a conversion site.
- **Skid road or machine trail**: An allocated open area within the stand, which allows the movement of machines for either processing, storage and transport or only transport. The skid road or machine trail typically allows travel at slow speeds over a surface, which provides only sufficient bearing capacity for particular and specified off-road equipment. Depending on terrain and soil conditions the skid path or route can be prepared with or without some measure of earthwork.
- **Forest road**: An allocation of space in the forest, which can be driven on with heavily laden road vehicles. These roads are not suitable for use by off-road equipment due to
their aggressive operating capabilities. These roads require specific bearing capacities to support increased loads over a number of axle groups. This also means that the roads can accommodate faster moving vehicles and can be used as a locality for conversion, storage and transport.

- **Centralised merchandising yards**: An area where technical equipment is permanently installed, full trees or tree-lengths are concentrated and different products are produced, marketed, and distributed. A merchandising yard has four basic functions: transport, handling, and storage; debranching, debarking, and crosscutting; measuring and grading; classifying, computing, storage and distribution (de Wet, 1995).

Various harvesting methods are used internationally, in which the original tree can be delivered to roadside are:

- The **complete tree** method includes the entire tree with all major roots moved to roadside. This method is seldom used in industrial forestry but is used in urban forestry context in which whole trees are removed and transported from one area to another.

- With the **full tree** method (FT) trees are felled at an acceptable maximum stump height and all biomass above the stump and a major portion of the stump is transported to the roadside. This is widely used internationally in multiple stem mechanised harvesting operations.

- The **topless full tree** method is a method in which trees are felled, topped and extracted to roadside. This is utilised where there is no market for small dimensions of timber.

- During the **tree-length** method (TL), trees are felled, debranched and topped in the compartment and only the bole is extracted to roadside.

- The **cut-to-length** methods (CTL) is when trees are felled, debranched (and debarked), crosscut and topped in the compartment. The roundwood assortments are extracted to roadside. CTL is widely used internationally as a means of reducing the environmental impacts associated with other tree length harvesting methods. This method is synonymous with international shortwood or assortment methods.

- In the **part tree** method, trees are felled, partially limbed, crosscut and transported to roadside. The top and pulpwood sections are not separated and have branches intact.

In South Africa the most commonly used methods used are FT, TL and CTL and are applied in both sawtimber and pulpwood operations. The TL method usually combines motor manual felling and extraction with cable or grapple skidders. The FT method usually comprises a feller-buncher and grapple skidder combination and is used in both sawtimber and pulpwood operations. CTL methods are used in both manual and motor-manual pulpwood and sawtimber operations.

Interest in clean and sustainable energy solutions will influence decisions in using forest harvesting residues and will increasingly influence decisions regarding the most cost effective method and system to use. The FT system is the system that would lend itself to bringing the forest residue to a central site where it can be processed and transported to energy generation plants. Collection of forest residues from a CTL harvesting method involves separate and additional processes. While collection of residues is being done in Scandinavia, it does not compare cost with the FT method where forest residue collection is already part of the harvesting and extraction process.
2.2.3 Harvesting Technology

The different stages of technological development of harvesting operation, ranging from purely manual to fully mechanised operations, can be subdivided into:

- Basic technology;
- Intermediate technology;
- Mechanised technology.

Harvesting operations based on basic technology make use of manual labour; examples are shown in Figures 2.2-1 and 2.2-2. Cheap and simple hand tools are used e.g. bow saws and axes, to cut, cross-cut or debranch trees. Manual or animal extraction of timber to roadside usually follows. This approach relies on local skills, muscle power and does not require high equipment capital input.

![FIGURE 2.2-1: Basic technology – hand rolling](Image1)
![FIGURE 2.2-2: Basic technology – manual bark stripping](Image2)

The transition from basic to intermediate technology is characterised by the introduction of equipment such as chainsaws, tractors, tractor trailer units and cable skidders (Figures 2.2-3 and 2.2-4). This phase is characterised by reduced manpower requirements and increased productivity per man-day of the harvesting systems.

![FIGURE 2.2-3: Intermediate technology – mechanical stacking](Image3)
![FIGURE 2.2-4: Intermediate technology – Short reach cable yarders](Image4)

So called semi-mechanised harvesting systems have been operating in South Africa since the 1990’s, mainly in *Eucalyptus* harvesting operations, where the debarking of *Eucalyptus* is mechanised with debarking heads on excavator carriers, and felling and extraction is carried out with basic or intermediate technology.
Recently, highly mechanised technology has been introduced into South African harvesting operations. These include harvesters and forwarders (Figures 2.2-5 and 2.2-6) in CTL harvesting operations, as well as in multiple stem FT systems, where feller-bunchers work with grapple skidders and processors. The successful and productive operation of these machines requires specialised skills and highly trained personnel.

2.3. Factors Affecting Productivity of Ground Based Harvesting Operations

The productivity of harvesting systems is the key criteria in achieving a financially sound harvesting operation. This should guarantee a return on investment for the harvesting contractor or company.

The success of operations is influenced by internal and external factors. External factors include the availability of skilled labour, government policies towards taxation, existing infrastructure, capital availability and interest rates. These external factors are beyond the control of any one employer. Internal factors, which are within the control of managers in a company, are the correct machine selection, energy consumption, training and control of personnel.

There are different ways to express productivity of activities or operations, dependent on inputs (fuel, person days, machine hours) and outputs (tonnes, m$^3$) factors.

Factors affecting the productivity of a forest harvesting system are:

1. Stand factors
   - Piece size of timber to be harvested
   - Stand information (including species, stand density, average dbh, tree volume, species, terrain and total volume to be harvested etc.)
   - Road spacing and road condition
   - Terrain
   - Weather and seasonal conditions
2. System factors
  • Bottlenecks, buffers, breakdowns, blunders and balances

3. Equipment factors
  • Technical capability of the machines or the system used and required resources

Equipment factors and their specific productivity within a harvesting system are discussed in detail in Chapter 3 of this handbook.

2.3.1 Stand Factors

2.3.1.1 Piece Size

The size of trees, or piece size, has an influence on the productivity of a harvesting operation. The so-called law of piece-volume states the relationship between time consumption per piece and volume per piece and describes the influence of piece size on time consumption, labour productivity and costs (Engelbrecht and Warkotsch, 1994). The number of logs making up a cubic metre depends on their individual sizes (Figure 2.3-1).

![Figure 2.3-1: Piece volume relationships.](image)

Time consumption per piece means the time needed to harvest a specific piece, respective log. The formula $t_p = a \cdot v + c$; where time consumption per piece ($t_p$) equals coefficient $a$ multiplied by the volume per piece ($v$) with the addition of coefficient $c$, indicates that there is a linear relationship between time consumption per piece and piece volume. In practice, it means that a smaller tree requires less time to fell than a larger tree.

The time per piece increases with piece/tree size, while the time per m$^3$ decreases with piece/tree size, i.e. the piece size is inversely proportional to the time required to produce 1 m$^3$ of timber. The formula $t_v = a + \frac{c}{v}$; where time consumption per unit volume ($t_v$) equals to the coefficient $a$ added to the ratio of the $c$ coefficient to volume per piece ($v$), indicates that the time consumption per unit volume decreases exponentially with an increasing piece-volume.

Figures 2.3-2 and 2.2-3 show the influence of piece volume on harvesting costs and wood value. Although time consumption per piece ($t_p$) is lower for small timber, as for instance pulpwood, the specific time consumption per unit volume ($t_v$) will decrease with an increase in timber size. Figure 2.3-4 shows the change in harvester productivity (m$^3$/hour) as the average tree size (m$^3$) gets larger.
FIGURE 2.3-2: Relationship between tree size and time consumption.

FIGURE 2.3-3: Relationship between tree size, wood value and harvesting costs.

FIGURE 2.3-4: Example of the relationship between average tree size and harvester productivity.
However, one must consider that there is a point at which large timber will have a negative effect on cost and productivity because the machine or harvesting method applied has certain physical capacities and can only handle timber up to certain dimensions.

### 2.3.1.2 Stand Information

In choosing equipment and methods for harvesting operations, in-depth knowledge of the composition of the stands with respect to volume and masses, species, stand density, average dbh or total volume is an important prerequisite. Knowledge of the m$^3$/ha, mass or volume of the trees or the size of limbs are also important for design and planning of machine use in forest operations. The m$^3$/ha to be harvested depends on:

- Stand density;
- Tree Size;
- Clear fell, thinning or partial cutting operation;
- Damage due to drought, fire, disease and machine damage.

Since the cost of harvesting and personnel requirements depend on the volume of timber removed per ha, this relationship should be taken in consideration at the planning stage (Figure 2.3-5).

#### FIGURE 2.3-5: Relationship between costs of harvesting and the volume of timber removed per hectare.

![Graph showing the relationship between costs of harvesting and the volume of timber removed per hectare.](image)

### 2.3.1.3 Road Spacing and Road Condition

An important part of harvesting is timber transport and harvesting must be planned in accordance with the transport mode. Harvest planning includes the planning of a road network system. A forest road network with a high density (expressed in m/ha), requires a large investment in roads. Such a network, however, is associated with close road spacing and thus reduced extraction or primary transport distances and costs. Conversely, a road network with a low road density requires lower investment in roads but is associated with longer primary transport distances and costs. At some point between these extremes an optimum spacing or road density exists, at which total (road and harvesting) costs are minimised (Figure 2.3-6).
The road density is determined by dividing total road length by the total land area (Figure 2.3-7).

Road density, however, gives no visual indication of how the network is laid out and simply converting from density to spacing, using the above formula, may be misleading. The formula should not solely be used as a method of determining the efficiency of the road network or in optimising a road network, although road spacing is an important tool that can be used to good effect in road and harvesting systems planning. For example, a grapple skidder can work economically over an average extraction distance ($S/4$) of 150 m, this relates to an effective road spacing ($S$) of 600 m and road density of 16.7 m/ha of forest.
2.3.1.4 Terrain

The condition of the terrain has a direct influence on the type of equipment used in a harvesting operation and also on the planning of such an operation. Important terrain features are the carrying capacity of the ground (ground conditions), the surface structure or obstacles (ground roughness) and the slope (Erasmus, 1994). Temperature, wind, rain or even snow may also have an influence on these operations. In order to describe terrain, a uniform “terrain classification” system is required. South Africa makes use of the “South African National Terrain Classification System for Forestry” (Erasmus, 1994), see Appendix 1 for details. The System uses three key features: ground condition, ground roughness and slope condition.

- **Ground conditions**: This factor includes the bearing capacity of the soil, which is determined *inter alia* by soil type, clay content and current moisture status.
- **Ground roughness**: This factor is concerned with the presence of obstacles to vehicle movement across the land surface.
- **Slope conditions**: These can be classified in terms of the gradient and topographic form of the slope.

A terrain classification system enables forest managers to assess the different types of terrain to be worked each year for accurate budgeting and cost control purposes and to deploy machinery on the sites best suited to their particular capabilities. The planning of harvesting operations and road construction involves considerable capital expenditure and has to be based on the long-term appraisal of the best harvesting systems for a forest. This, in turn, is heavily influenced by the ability of different machines to work on the different terrain types within the forest. Decisions on future machine purchases must be related to terrain (Erasmus, 1994).

2.3.2 System Factors

**The 5 B’s**

Many factors influencing the productivity of a harvesting system are a given and cannot be changed or influenced, but can be addressed through appropriate equipment selection. Other influencing factors must be addressed and/or improved through effective management e.g. equipment terminal times, training, machine availability and utilisation.

The 5B’s (Garland, 1989), used as a management tool, can assist in the success or failure of the logistic system. The 5B’s specifically address the human factor in harvesting systems. As harvesting becomes more and more mechanised, it is even more important for harvesting crews to generate ideas to help themselves work better together as a team. The 5B’s model emphasises three key concepts in making productivity improvements in mechanised logging operations: teamwork, communication and cross training. The following five points make up the model:

- **Bottlenecks**: Look where the system slows down and check the causes. Find ways to speed up the machine or function at the bottleneck. Workers can use their machines to help the bottleneck before the flow hits the bottleneck or after the flow goes through the bottleneck.
- **Balance**: Find what each machine can produce and strike a balance for the whole system at a high production level. Add machines or use machines differently (help one another). Logging systems that are out of balance have some machines working at full-speed while others are not fully used.
- **Buffers**: If possible, use buffers of wood between functions to smooth out production. Workers can adjust the size of buffers to fit conditions on the job. Buffers can absorb minor delays and maintenance downtime in the systems.
• **Breakdowns**: A mechanised operation doesn’t work well if workers wait to fix or maintain something after it breaks down. Preventive maintenance is essential, and so is having spare parts quickly available, e.g. hoses, belts, filters etc.

• **Blunders**: Operations with too many blunders go broke. Equipment misuse and abuse, running out of fuel, accidents, etc. seldom happen to excellent operators. They keep their minds on the operation.

### 2.4 Economic Considerations for Ground Based Harvesting System Selection

When deciding on the selection of a particular harvesting system the following economic and financial considerations must be taken into account:

- Production costs (R/tonne or R/m³);
- Market value of a product;
- Profit;
- Capital investment;
- Payback period (years);
- Return on investment (ROI).

Mechanised CTL methods, developed originally for northern hemisphere mixed stands, have proven successful in Europe and have been applied under plantation forestry conditions in recent years. However, CTL systems are sensitive to tree size and although employed in plantations in the southern hemisphere, further research is required to improve their viability in small *Eucalyptus* stands and where debarking of these trees is required in the compartment.

![Graph showing the relationship between tree size and harvesting costs.](image)

**FIGURE 2.4-1: Estimated harvester costs dependent on average tree size (R/m³).**

FT and TL harvesting methods were mainly developed in the southern United States, allowing for multiple stem handling. These methods are less sensitive to tree size and therefore more appropriate for smaller trees. Figure 2.4-1 shows the harvesting costs per tonne using a one-grip harvester depending on average tree size. Unfortunately, these methods cause greater environmental impact than the CTL method, and require either redistribution of forest residues or intensive fertilisation due to the removal of almost all biomass off the site. The FT method,
using feller bunchers to fell the compartment, on the other hand is less sensitive to coppice. Whereas harvesters used in CTL system have difficulties in felling double leaders in coppiced compartments.

Although a FT harvesting method using skidders requires a higher road density and intensive silviculture in redistributing harvesting residue, it is more cost effective than the other harvesting systems for smaller trees and below 20% slope.

2.5 Harvesting Systems Analysis

For communication (education, training, research and for operational instructions) and documentation, it is desirable to represent complex operational methods of timber harvesting in a concise manner but with maximum content and comprehensive information. At the least, it should be clear at which locality, in which sequence and with what equipment the activities are carried out. An important feature to include is the point at which the sale of the commodity takes place. This point indicates where the responsibility passes from one party to the next. For this purpose a schematic harvesting matrix is used.

The matrix (Figure 2.5-1) consists of rows depicting the different activities in the system and columns for the location for each activity. At the intersection of the activity row and its appropriate location column, symbols for equipment and people can be used as description of the specific activity. The matrix provides the following information:

- The locality of the activities (stand, strip road or forest road)
- The individual activities as undertaken sequentially (fell, debranch, extract, process and transport)
- Labour and equipment requirements per activity and also the state of conversion of the work object are represented by means of symbols

This method, developed by Warkotsch, graphically explains the proposed system in detail and in a concise manner for understanding.

![FIGURE 2.5-1: Systems matrix example, TL harvesting system.](image)
2.6 The Human Factor in Ground Based Harvesting Operations

The human aspect of forest engineering is referred to as forest ergonomics (or forest work science). Ergonomics is the scientific study of the relationship between humans and their working environment. It is an interdisciplinary applied science, which aims to match the job and places of work with the person. Ergonomics considers physiological, psychological, sociological, technological, economical and organisational aspects of the workplace. Through ergonomics, one does not only try to maintain and enhance the health and safety of the work environment, but also aims to improve the efficacy of working output in relation to the required input of a human being or a human being in control of a machine. Some important aspects of forest ergonomics are:

- Physiological basis for heavy forest work (e.g. energy intake of forest workers);
- Exposure of the human being in forest work to noise, vibration and the climate;
- Overall health and safety consideration of forest work – accident prevention and reduction;
- Ergonomic design and layout of machines;
- Relevant legislation for forest operations.

Forestry work is generally characterised by a combination of difficult and dangerous conditions. The terrain is often steep and broken; the climate harsh; the work itself physically demanding; and the tools are sharp, heavy and dangerous if not used and maintained properly. Since work sites are usually remote and isolated, facilities such as housing, food and drink, and first aid are often inadequate. Moreover, forestry work tends to have a low status and the people poorly paid (Poschen, 1993; Manyuchi, 2002).

Harvesting related accidents account for up to 70% of all accidents in forestry work. Activities with the highest rates of accidents include motor manual felling and cross-cutting, with chainsaws being the single most dangerous tool.

Mechanisation of forest work is seen as a way of improving working conditions by reducing the number of labourers exposed to these adverse conditions. Although mechanization has contributed to the solving some problems, it has created new issues of a more complex nature. New problems such as operator fatigue (Nicholls et al., 2003), whole-body vibration (Jack and Oliver, 2008), or fatigue from the monotony of repetitive work cycles should be taken into consideration for the design of machine cabins or for the shift layouts in mechanized harvesting operations (Gellerstedt, 1997, Messingerova et al., 2005). Various checklists exist to ensure that forest machines meet specified ergonomic and safety requirements.

Mechanisation of forest work has a negative effect in terms of reduced job opportunities due to the smaller workforce required for mechanised forest operations. Especially in developing countries such as South Africa, mechanisation must be carefully assessed in terms of worker health and safety, and in lost job opportunities and overall employment in the forest sector. These trade-off effects were observed in northern European countries where mechanisation of forest work was introduced in the late 1970’s. For example, in Finland, in 1982, 16 000 workers did 80% of the felling in the industry. With the advent of mechanisation, by 1993, 80% of felling was done by machines and only 4 000 workers were still employed in wood procurement. At the same time, a significant reduction in accidents in forest operations was recorded in Scandinavia, with a 73% risk reduction compared to chainsaw-based methods (Axelsson, 1998).

South African forestry operations have specific challenges with regards to their workforce and are, amongst others:

- High labour turnover (estimated 20-50%) and absenteeism rates (estimated 10-20%) (Figure 2.6-1);
• Forestry work regarded as a desperation employment form;
• Ninety percent of contractors’ workforce at forestry minimum wage;
• Nutritional deficits, rest break deficit and hydration deficiencies of manual labour (James, 2006);
• Problematic health conditions, impact of HIV/Aids (Basson et al., 2009);
• Working lifespan of debarkers, stackers and chainsaw operators at an estimated nine years (James, 2006).

![Figure 2.6-1: South African forestry operations labour turnover and absenteeism rates 2006 (Längin & Ackerman, 2007).](image)

### 2.6.1 Work Environment

Many factors have an influence on the working conditions of an operator or manual worker in the actual work environment. Due to the nature of forestry work, the most important aspects of the forest work environment to consider are workplace dimensions (e.g. operator cab), light, noise and vibration and temperature.

#### 2.6.1.1 Workspace Dimension

The dimension of a workspace refers to the height, depth and width of the standing, seated and lying person, depending on the specific work a person has to do. The design of a working place is dependent on two considerations: What is the task to be done and for whom do you make provision? The correct working height is one of the most critical factors in the design of work space. For standing or seated workers, all limbs, arms, and legs should be in a natural balanced position, or supported. The back should be straight, with the arms hanging naturally, the elbow just more than 90 degrees or resting comfortably on a well shaped surface. As standing is significantly more strenuous than sitting, provision should be made for changes and preference in position. For example, an addition of a bar or railing at ankle level as a footrest can improve a standing position and posture.
2.6.1.2 Light

People need light to fulfill and complete tasks successfully. Despite the ability of the human eye to regulate the amount of light entering it by manipulating the iris, there are still limits to its abilities. From a scientific point of view, light is the region of the electromagnetic spectrum that can be perceived by human vision, i.e., the visible spectrum, which is approximately the wavelength range of 0.4 m to 0.7 m. Generally, indoor lighting is up to 2000 lux, with an optimum for general office work at about 500 to 800 lux. Outdoor light can go up to 20 000 lux or more, which requires protection for the human eye. Outdoor light is especially relevant under forest work conditions.
2.6.1.3 Noise and Vibration

Noise is a disturbing sound. High noise levels affect the nervous system, cause discomfort, irritation, dizziness and fatigue, and make conversation difficult. Exposure to intense noise leads to temporary hearing loss and over years to permanent hearing loss.

Most modern harvesting machines, with the help of sound damping material as well as enclosed cabs, have been successful in significantly reducing noise. Hearing protection can prevent hearing loss. Ear plugs are more comfortable in hot weather than ear muffs. Hearing protection must be regularly cleaned for hygienic reasons. The silencing materials in ear muff must be regularly replaced.

Typical forestry worker occupational exposures to noise and vibration are:

- **Whole-body vibration** (following machines/tools: yarders, stackers, processors, shovels, trucks, mechanized cutters, bulldozers, graders);
- **Hand-arm vibration** (from machines mentioned in bullet one above and through control mechanisms, chain saws, bucking saws, debranching saws, cutoff saws, axes);
- **Noise exposure** (powered saws, heavy equipment, communications devices).

Of the health effects caused by hand-arm vibration, vibration-induced white finger (VWF) is the most common condition among operators of hand-held tools (Figure 2.6-4). The symptoms of VWF are aggravated when the hands are exposed to cold. Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS).

Whole-body vibration results in fatigue, insomnia, headache and “shakiness” shortly after or during exposure. The symptoms are similar to those that many people experience after a long car or boat trip. Studies show that whole-body vibration can increase heart rate, oxygen uptake and respiratory rate, and can produce changes in blood and urine. It can produce an overall ill feeling which is called “vibration sickness.” A decreased performance in workers exposed to whole-body vibration can be expected.

Research has shown that exposure to whole body vibration and shaking has a tiring effect on the operator and can have adverse effects on both health and work capacity. Three factors have
to be considered in an assessment of the influence of whole body vibration: the intensity and
frequency of the vibration, and the exposure time. The intensity of the vibration is dependent
on the nature of the ground, the design of the machine (suspension system, location of the cab
and the design of the cab seat) and the travelling speed. Vehicles must be designed to control
the transmission of whole body vibration to levels that will permit safe operation. The influence
of machine function on operator exposure to whole-body vibration in a cut-to-length harvester
was evaluated by Sherwin *et al.* (2004).

Machine operators are affected by vibrations transmitted by the seat, floor and steering wheel.
As a result, many operators suffer from pain in the lower back, chest region, neck, stomach and
other parts of the body. The severity of such health risks depends on daily working time, terrain
conditions, driving speed and machine design. Sudden impacts, for instance when driving over
a stump, are especially harmful. Vibration can be reduced by a good suspension system on the
machine and the seat, and by moving bigger loads at a lower speed rather than smaller loads
at higher speeds. Drivers should leave the machine and stretch their back and legs at least once
per hour. Ideally, drivers and helpers should change tasks at regular intervals.

Sound is what we hear, it is perceived as loudness and noise is unwanted sound. The differ-
ence depends on the listener and the circumstances. Sound is produced by vibrating objects
and reaches the listener’s ears as waves (frequency) in the air or other media. When an object
vibrates, it causes slight changes in air pressure (sound pressure). The two kinds of health ef-
effects of noise are non-auditory effects (stress related physiological effects, safety) and auditory
effects (hearing loss). Auditory effects include acoustic trauma; sudden hearing damage caused
by short burst of extremely loud noise such as a gunshot. Tinnitus is a ringing or buzzing in the
ear. Temporary hearing loss; also known as temporary threshold shift (TTS) which occurs im-
mediately after exposure to a high level of noise. There is gradual recovery when the affected
person spends time in a quiet place. Complete recovery may take several hours. Permanent
hearing loss also known as permanent threshold shift (PTS), progresses constantly as noise ex-
posure continues month after month and year after year. The hearing impairment is noticeable
only when it is substantial enough to interfere with routine activities. At this stage, a permanent
and irreversible hearing damage has occurred. Noise-induced hearing damage cannot be cured
by medical treatment and worsens as noise exposure continues.

### 2.6.1.4 Temperature

Temperature is the one ambient environmental factor everyone is aware of on a daily basis.
Not only does it influence decisions regarding dress, but also various activities performed.
Outside temperature is a given, and little can be done to eliminate this, except for coping
due to inherent personal tolerance levels. Temperature in the environment is determined
by the combined and cumulative effect of radiation, convection, conduction, evaporation
and relative humidity. For example, think of an operator in a closed vehicle in the sun. The
sun, road and buildings radiate heat and the hot air rises to the low roof. At the same time
the seats and metal parts conduct heat and little evaporation is possible because of the lack
of airflow, increasing the relative humidity. As a result temperatures in vehicles have been
recorded in excess of 60 °C.
2.7 **Ground Based Harvesting Equipment Classification**

2.7.1 **Classification**

Every activity within the harvesting sphere can be carried out by different operating machines or a combination of machines.

Machines can be classified in accordance with:

- **Mobility**
  - Function (task)
    - Type of function
      - Number of functions
        - One function
        - More functions

The mobility of a machine can be classified by:
- Machines held by hand and without a power source (e.g. tools);
- Machines held by hand which have a power sources (e.g. chainsaw);
- Machines can be driven (self propelled) or be remote controlled;
  - Can be used in all terrain;
  - Can be used on skid trails and forest roads only;
  - Be used on forest roads only;
- Stationary machines.
  (Exceptions are animals, aircrafts and helicopters)

2.7.2 **Categorisation**

Harvesting equipment can be grouped in three major categories:
- Felling and processing equipment;
- Primary transport equipment (extraction from stump to roadside);
- Loading equipment.

**Felling and processing**

Felling and processing consists of various processes that can be carried out in various ways. Depending on the final product requirements, one or more different activities can take place in different locations. For example, felling can occur in isolation (manual, motor manual felling or mechanical felling) or with the processing process as with a harvester.

**Primary Transport (extraction)**

Primary transport involves the transport of timber in varying assortments (state of conversion) from the stump to roadside landing or to the depot. This transport can be either done manually or mechanically either by picking the timber up off the ground (e.g. forwarder), or carrying it out, or dragging it along the ground (e.g. skidding). Primary transport can cater for any length of timber from log length to whole trees and complete trees.
Loading

Once timber has reached the roadside landing and is in the form required, CTL, TL or any intermediate stage, it normally requires further transport to either the final customer, to a secondary conversion or to a temporary holding site. This transport is known as secondary transport and some type of loading process is required to initiate this transport phase. As with primary transport, it can be executed manually or mechanically depending on the state of technology required or available or purely the limitations the piece size present.

A full description of machines and their applications is given in Chapter 3 of this handbook.

2.8 References


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Further relevant reading:


Chapter 3

Ground Based Harvesting Equipment

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### 3.1 Introduction

This chapter discusses the various tools and machines used for ground based harvesting in the South African forestry industry. Every machine has a specific function. This function is determined by the way it has been designed, specified and configured for a specific application. In their base form however, many machines start off being generic in design and can be used for various functions. Therefore a grapple skidder can for example be equally well used in a tree length and full tree harvesting system, or a forestry carrier can function as either a feller-buncher, a harvester, a processor or a loader.

The methodology used in this chapter is to describe the machine, and then to link the machine to a potential system in which it can function and will follow the typical felling, extraction, processing and loading sequence of the typical timber harvesting supply chain. The chapter will follow an approach from, within each group of machines, simpler technologies to more technologically advanced machines.

A general classification of machines described in this chapter is illustrated in Figure 3.1-1. The shading denotes where specific machines can be used for more than one function. To assist with the understanding of the process flows, links have been draw between machines usually associated with one another within their usual system application. The diagram does not attempt to follow the same sequence of machines as in the text, but rather to show their association and location in general. Manual operations such as, for example, felling with axes or bowsaw, or manual extraction do not feature in the handbook as they are not considered commercially viable in large scale timber harvesting applications.
3.2 Felling Equipment

Harvesting operations start in-field where and when the trees are felled. Felling operations set the foundation for all subsequent operations in general, but in particular operational productivity, fibre and value recovery and product quality. There are many felling machines available.

3.2.1 Motor-Manual Felling

Motor-manual felling is done using a chainsaw. Modern chainsaws are technologically advanced machines and require trained operators and a very specific operating procedure to be followed (as described in the Chainsaw Operator Handbook, ICFR, 2000). The size and characteristics of an appropriate chainsaw is a function of the following criteria.

- **Tree diameter**: The cutter bar length is primarily determined by tree diameter to be cut. The cutter bar length however determines the length of the chain, which again determines the required power of the saw. For any specific chainsaw, there is a limited range of cutter bar options available.

- **Tree species**: The species determine the hardness of the timber, which has a bearing of the required power output of the saw.

It is important that detailed attention is given to selecting the correct saw for the specific application at hand. However if a chainsaw is required to a variety of tasks; e.g. both clear fell and thinning of a number of species, a chainsaw should be specified for about 80% of the
most difficult task it is required to do. Larger saws are heavier, which has a negative ergonomic impact on the operator. Typical professional forestry saws range between the 60 to 80 cc class.

<table>
<thead>
<tr>
<th>Chainsaw Productivity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tree size</td>
</tr>
<tr>
<td>• Species</td>
</tr>
<tr>
<td>• Branching intensity and size</td>
</tr>
<tr>
<td>• Terrain</td>
</tr>
<tr>
<td>• Understory vegetation</td>
</tr>
<tr>
<td>• Climatic conditions, especially wind</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Low capital cost</td>
<td>• Most dangerous job in forestry</td>
</tr>
<tr>
<td>• Large application scope</td>
<td>• Strenuous manual work</td>
</tr>
<tr>
<td>• Wide application scope</td>
<td>• Long-term effects on human being (vibration, noise, etc)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Limitation/application matrix chainsaws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%)</td>
</tr>
<tr>
<td>Ground condition</td>
</tr>
<tr>
<td>Ground roughness</td>
</tr>
<tr>
<td>Piece size (m$^3$)</td>
</tr>
</tbody>
</table>

### 3.2.2 Mechanised Felling

Mechanised felling refers to where a machine is used to fell a tree. It is important for forestry professionals to understand the design criteria of the various technologies available in order to make an informed and economically justified decision regarding the most appropriate technology for a specific application. There are two primary choices; a machine that only fells trees, a felling machine, or a machine that is multi-functional (it fells and processes trees), a harvester. A machine that can both fell single and multiple trees at the same time is referred to as a feller buncher. Single or multiple tree felling functionality is mostly a function of the felling attachments and to a lesser degree a function of the carrier used. However a felling machine in principle consists of a carrier and an attachment. The correct combination of a suitable carrier with a suitable attachment will result in a purpose-built felling machine. Many carriers can be effectively used with a variety of attachments of different designs and from different manufacturers. The various concepts are described below.

### 3.2.2.1 Carriers

Carriers are defined as either track (Figure 3.2-1) or wheel (Figure 3.2-2) machines that are designed to carry specific attachments. It is important to realise that felling machine carriers although similar in appearance to some road construction equipment, are highly specialised and considerably different from their civil engineering counterparts (e.g. excavators and front end loaders carriers) and harvesting and road construction carriers (excavators) and differ mainly on the following detail:
• Under carriage design: Forestry machines are built to move in-field. In forestry operations that involves being able to straddle stumps and rocks etc. Their bodies are higher off the ground and considerably strengthened and protected. Track design, rollers and skid plates and sprocket can also differ.

• The hydraulic requirements of felling attachments are considerably higher than that of civil engineering counterparts. Consequently higher hydraulic flow and pressures are required, which in turn requires additional hydraulic pumping and cooling capacities. This is one of the major differences that can often not be seen immediately, but is critical to being successful in long-term forestry applications.

• Boom design and functionality is specifically designed for forestry machines. Booms are designed to lift trees and handle them. Due to the length of the trees, specific leverage, torsional forces are exerted on the booms and their attachment points, requiring specific engineering solutions to ensure long component life.

• Tyre, or under carriage construction or design. Wheel motors must be specifically designed and selected to facilitate the high amount of machine movement in rough terrain conditions. Civil construction machines are not required to move as much and do not have such high forces exerted on its wheel motors, axles and rims. For wheeled machines, the tyre size and construction also have specific bearing on the selection of wheel motors. Tractive effort and rim-pull a key considerations as design criteria.

3.2.2.2 Felling Attachments

Various felling attachments, or heads as they are more generally referred to, are available to fit to different carriers. The most common felling heads available are chain and bar, disc and shear.

Chain and bar (directional felling head)

These heads are defined by a chain-and-bar cutting mechanism similar to that of a chainsaw. These heads have fallen into disfavour due to the slow cutting speed and complexity of operation. They are characterised by:

• Being able to negotiate larger tree diameters;
• Relatively simple design and technology level;
• Difficult to use and thus require a skilled operator;
• Narrow cutting kerf and therefore result in less fibre loss;
- Slow cutting speeds;
- Relatively simple maintenance;
- Less hydraulic capacities requirements than with other heads;
- Sensitivity to terrain and soil conditions – the saw teeth blunt very easily when coming into contact with rocks and soil;
- Attachment mass that is fairly low allowing more effective lift capacity;
- Relatively high stump heights due to the head construction;
- Inability to control the rate of descent of the tree to the ground;
- Less power requirements and therefore lower fuel consumption.

**Disc head**

These heads have a spinning disc equipped with cutting teeth, similar to a circular saw placed horizontally. The disc is the most popular head used on felling machines as it is fast, allows low cuts and can accommodate some sand and stone related wear. They are characterised by:

- High cutting speed;
- Wide kerf width;
- Simple operation sequence;
- Relative low teeth maintenance;
- High hydraulic demand;
- Restricted disc size restricting maximum cutting diameter;
- Heavy heads reducing the effective lifting capacity of the carrier;
- Allowing trees to be cut and controlled in single or multi-stem operations;
- Higher power requirements and hence higher fuel consumption;
- They often have a large accumulation area.

Most of these heads have a static rotating disc. The operator has to move the head forward with the stick-boom to achieve a cut into the tree. Some brands however allow the disk to move independently of the head by means of hydraulic cylinders (pushing the saw forward and retracting it, allowing the head to remain in a fixed static position during the cut). These saws often can also stop/start the disc rather than having a constantly rotating disc. These saws are also referred to as intermittent disc-saws.
Shear head

This head is in principle of a large secateur (Figure 3.2-4). It has either one fixed and one moving blade or two moving blades. These heads are not used very frequently in South Africa due to their slow cutting speed and the potential of fibre damage. They are however becoming more popular in the northern hemisphere for harvesting of bio-energy plantations or in Australia for small tree harvesting and in fire-sensitive areas. They are characterised by:

- Application in smaller tree diameters;
- Fairly simple in design and technology;
- Narrow cutting kerf and therefore less fibre loss, but there can be damage the fibre at the cutting face;
- Cutting speed is slower than disc saws;
- Maintenance is relatively simple;
- Less hydraulic capacity required than some other heads;
- They are less sensitive to terrain and soil conditions.

3.2.2.3 Tilt and Rotation Function

Many of the above mentioned heads can be equipped with a tilting function or rotation wrist (on a vertical plane). Some wrists can rotate 30°, some 110° while others can be rotated continuously through 360°. The rotating function has the following advantages:

- It assists the operator to better align bundles for extraction;
- It allows the operator to place felled tree closer to the carrier;
- It allows operator to pick up fallen trees without having to manoeuvre the carrier, saving time. This is useful where tree break easily or when working in wind blown areas;
- It allows the operator to place loads alongside or behind the machine without having to slew 180° (useful in steep terrain).

3.2.2.4 Common Felling Attachments

Some of the above mentioned heads can be fitted have additional features. With single stem heads, felling heads that can only handle one stem at a time, the heads do not have (or have a limited) accumulation area or have a specially designed accumulation arm. Accumulating heads on the other hand, are specifically designed to allow multiple stems to be held in the head in a standing position. This has the advantage, when smaller trees are felled, that the operator can bundle a number of trees and therefore looses less time to place the timber on the ground making the operation more productive. Accumulating heads are frequently used in thinning applications or for small tree clear felling operations. A felling machine equipped is such a way that it can bunch trees together on the ground is referred to as a feller-buncher.

Specific head design is another factor to consider. The head has to be closely matched to the tree size, both tree length and diameter. This is especially true for larger tree sizes. Long trees need a taller head with a high post and the clamping arms to be spread well apart. This will ensure a better hold on the tree while standing in the head. The disc diameter should accommodate about 80 to 90% of the intended diameter spread of trees to be felled. The occasional larger tree can be cut by using a special cutting technique which however takes time and decreases the operator’s control of the tree after felling. Some of the techniques are briefly described below:
• Make a short cut, just above the normal intended cut from the opposite side of the tree, and then cut normally and push the tree over into the desired felling direction.

• Some heads have a side flap on the disc that can be hydraulically opened, This allows the operator to swing the side of the felling head into the tree to achieve a quick second cut, if the first cut was insufficient to bring the tree down.

![FIGURE 3.2-5: Continuous disc type felling head.]

3.2.2.5 Generic Felling Machines’ Features

A specific felling machine is a combination of a chosen carrier and a chosen head. The following basic felling machine options are available.

**Felling Machines**

*Drive-to-tree*

Machines characterised by a fixed boom attachment that requires the machine to drive to each tree to be felled. Mostly these machines are equipped with wheels, which allow them to drive at higher speeds. They are also more manoeuvrable than track based machines. Due to the fact that the machine has to drive to each tree, there is a larger potential environmental impact, e.g. soil compaction, soil displacement and root damage. Tyre based machines have a relatively small surface contact area between machine and the soil compared with track based machines. This results in a higher point loads on the soils, resulting in increased pressure per unit area. No rotate functions are available for this head configuration mainly due to machine stability concerns. It however needs to be noted that the capital outlay for these machines is typically lower than that of swing-to-tree machines.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More manoeuvrable</td>
<td>• Less stable</td>
</tr>
<tr>
<td>• Less capital intensive</td>
<td>• Lower lifting capacity</td>
</tr>
<tr>
<td>• Relatively easy to move between operations</td>
<td>• Lower terrain capability</td>
</tr>
<tr>
<td></td>
<td>• Higher soil impacts</td>
</tr>
<tr>
<td></td>
<td>• Less tree control in unstable and windy conditions</td>
</tr>
</tbody>
</table>
Swing-to-tree

Machines characterised by a fixedboom attachment that requires the machine to drive to each tree to be felled. Mostly these machines are equipped with wheels, which allow them to drive at higher speeds. They are also more manoeuvrable than track-based machines. Due to the fact that the machine has to drive to each tree, there is a larger potential environmental impact, e.g. soil compaction, soil displacement and root damage. Tyre-based machines have a relatively small surface contact area between machine and the soil compared with track based machines. This results in a higher point loads on the soils, resulting in increased pressure per unit area. No rotate functions are available for this head configuration mainly due to machine stability concerns. It however needs to be noted that the capital outlay for these machines is typically lower than that of swing-to-tree machines.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More stable hence safer</td>
<td>• Less manoeuvrable</td>
</tr>
<tr>
<td>• Higher lifting capacity – bigger trees</td>
<td>• More capital intensive</td>
</tr>
<tr>
<td>• Less soil damage</td>
<td></td>
</tr>
<tr>
<td>• Better tree control – less damage and better bundles</td>
<td></td>
</tr>
<tr>
<td>• Zero-tail swing machine can work in confined work spaces – e.g. thinnings</td>
<td></td>
</tr>
</tbody>
</table>

Boom selection

Various boom geometries and designs are available, depending on the intended reach and potential tree mass. For clear felling bigger trees, a short stronger boom is required with a higher lifting capacity. For thinnings and smaller trees, a longer boom can be used which will have lower lifting capacity but improved reach to easy selective cuts.

Levelling machines

In order to increase the slope stability and hence the capability, some machines offer a platform (turntable) levelling mechanism. This allows the operator to keep the cab level when working on slopes.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Machine more stable (hence safer and more productive), as the tree remains vertical after being felled</td>
<td></td>
</tr>
<tr>
<td>• Improved operator visibility</td>
<td></td>
</tr>
<tr>
<td>• More comfortable working environment for the operator</td>
<td></td>
</tr>
<tr>
<td>• Saves fuel as the counter weight of the machine does not have to overcome gravity when slewing</td>
<td></td>
</tr>
</tbody>
</table>
Tail-swing and zero tail-swing machines

Machine configurations can be selected either with an extended “tail” (where the platform is extended to hang over the tracks when slewing like an excavator), or without a “tail” (where the turn table turns inside the track width). Zero tail-swing machines have different boom mounting points allowing weight transfer to the rear of the platform and therefore stabilising the machine (preventing forward tipping).

<table>
<thead>
<tr>
<th>Advantages – tail</th>
<th>Advantages – zero tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More stable with big trees hence safer</td>
<td>• More manoeuvrable</td>
</tr>
<tr>
<td>• Can be used for bigger trees</td>
<td>• Can work in confined work spaces – e.g. thinnings</td>
</tr>
<tr>
<td>• Engine compartment is bigger allowing easier service assess</td>
<td></td>
</tr>
</tbody>
</table>

Felling machines

Productivity indices

• Tree size
• Terrain
• Climatic conditions, especially wind
• Previous management practices, e.g. coppice policy or ridging
• Type of felling machine and attachment

Limitation/application matrix chainsaws

(with tyre chains or bogey tracks if necessary)

<table>
<thead>
<tr>
<th></th>
<th>Wheeled</th>
<th>Track-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non levelling</td>
<td>Cab levelling</td>
</tr>
<tr>
<td>Slope (%) – up</td>
<td>&lt;35</td>
<td>&lt;40</td>
</tr>
<tr>
<td>Slope (%) – up</td>
<td>&lt;20</td>
<td>&lt;30</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 2</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Piece size (m³)</td>
<td>Up to 1.0 m³</td>
<td>Up to 3.0 m³</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

3.2.2.6 Harvesters

Harvesters are in-field machines designed to accomplish a combination of tasks in one application. Their main application is felling, debranching (and debarking) and merchandising of individual trees in one continuous uninterrupted consecutive action. It is possible to eliminate some of the processes and only use specific selected functions, such as felling alone, or felling and debranching only. The primary aim of this machine is to multi-function and it should not be used for felling only. This is one of the features that set it apart from processors.

A distinction needs to be made between purpose built harvesters and converted excavators fitted with harvester or processor heads. Converted excavators are used as they are often a cheaper
acquisition option. There are, however, some significant limitations of converted excavators, when compared to purpose-built machines. Some of these limitations are:

- Sub-optimal hydraulic flows and pressures;
- Sub-optimal hydraulic oil cooling capacities;
- Reduced boom reach;
- Poor ground clearance and restricted in-field movement;
- Inadequate operator protection – specifically Operator Protective Structure;
- Restricted visibility;
- Poor safety systems e.g. Operator Protective Structure;
- Boom geometry developed for digging and not for lifting.

Some of these limitations can be overcome by machine specific changes. It is important that these changes are done with the Original Equipment Manufacturer’s involvement.

**Machine Specific Features**

Harvesters are characterised by having highly specialised boom configurations that allow both sufficient reach and crane manoeuvrability in the confines of a forest. These cranes allow for boom tilt functions, extendable booms and other technologies that make them unique to the forestry applications.

The purpose of cranes for harvesters is to increase the reach of the machine. It enables the operator to take the attachment to the tree without having to drive to each tree. On harvesters two primary crane types are used:

- **Telescopic boom cranes** (also referred to as extension- or squirt-boom). These cranes have a stick boom that contains a secondary boom that can be hydraulically extended (Figure 3.2-6). The main purpose of the extension is to provide additional reach especially in thinning operations. Their disadvantage is a relative complex design, reduced robustness, hidden parts and potentially increased maintenance frequency.

- **Parallel boom cranes** (Figure 3.2-7) are easy to manoeuvre with great precision and high efficiency across the entire working area. These cranes are quick out to the tree and strong towards the machine with good close-range working characteristics. One of their main advantages is that it is relatively simple to move the attachment on a horizontal plane during operations. This is important before and after felling to ensure that the felling head is not pushed into the ground. They are simple to maintain due to a simple design.
**Head Configurations**

The primary objective of a harvester head is to fell, de-branch (debark) and/or merchandise individual trees. A harvester attachment should not be selected for its felling characteristics alone. Harvester head attachments can be categorised as follows:

- **Single-grip harvesters**: The head is characterised by its ability to fell, de-branch (debark) and cross-cut the tree in one process. All of the required functionality is located in one attachment.

- **Two-grip harvester**: It has the same functionality as a single grip head, but its functions are split between two attachments and therefore two processes. The felling attachment is mounted on the crane, while the processing attachment is located on the machine.

<table>
<thead>
<tr>
<th>Single Grip vs Two-grip Harvesters</th>
<th>Advantages – single-grip</th>
<th>Advantages – double-grip</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages – single-grip</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simpler process – can focus on one attachment only</td>
<td></td>
<td>Less complex attachments</td>
</tr>
<tr>
<td>Uses only one attachment – more space on carrier</td>
<td>Can fell bigger trees further from the carrier</td>
<td></td>
</tr>
<tr>
<td>Fewer components and pumps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Productivity indices**

- Tree size and form
- Level of processing and required quality of products (e.g. debarking of eucalypts, number and specifications of assortments e.g. short vs long logs)
- Species
- Branching density and size
- Terrain
- Undergrowth
- Previous management practices e.g. coppicing
- Climatic conditions, especially wind

**Limitation/application matrix**

<table>
<thead>
<tr>
<th>(With tyre chains or bogey tracks if necessary)</th>
<th>6 or 8 Wheeled</th>
<th>Track-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non levelling</td>
<td>Levelling</td>
</tr>
<tr>
<td>Slope (%) – up</td>
<td>&lt;35</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;20</td>
<td>&lt;30</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 2</td>
<td></td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3</td>
<td></td>
</tr>
<tr>
<td>Piece size (m³) – (max depending on head and carrier choice)</td>
<td>Up to 0.6 m³</td>
<td>Up to 1.5 m³</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.2.2.7 Generic Machine Selection Criteria

There are numerous specialised machines available in modern harvesting operation, performing functions from felling to merchandising and cross-cutting. However, irrespective of the specific machine applications, there are some generic characteristics that are common to most machines and machine applications. When selecting a harvester, e.g. a single or two-grip, a choice has to be made on the type and the size of carrier, and rack or wheel configurations.

The following general machine features are important to consider when making system and equipment choices. There are two principle options – wheels or tracks.

**Tracks**

There are a couple of criteria to consider when selecting tracks for a track based carrier.

- **Track width:** The wider the track, the better its flotation and the lower its ground pressure (Figure 3.2-8). A wider track however is prone to bend or come off the undercarriage on uneven terrain of a typical forestry operation. Uneven pressure on the tracks over time can bend the track shoes. Track widths starts at about 45 cm for smaller machines and can be as wide as 90 to 100 cm. The heavier the machine, the wider and/or longer the track needs to be to support the machine mass. A general all-round forestry track should be about 60 cm wide.

- **Track shoe configuration, Grouser configuration:** Single grousers are the most aggressive with double or triple grousers being the least aggressive. A grouser is the vertical bars welded onto the individual track shoes that make up the whole track. Single grousers, using a single vertical bar, are equipped with higher and thicker bars, than either double- or triple grousers (Figure 3.2-9). Standard excavator type machines are supplied with a triple grouser shoe. The more grousers a track shoe has, the smaller and shallower the grouser is. Forestry machines in general should have either single or double grouser tracks. On steep difficult terrain a single grouser should be chosen. Levelling machines usually are specified with a single grouser track, while landing based machines and non-levelling machines often come with a double grouser track.

*FIGURE 3.2-8: A track-based harvester, showing the track shoes and uneven pressure on the track shoes.*
Wheels

Various tyre configurations are possible for felling and harvesting machines. They come in two specific types:

- **Tyres biased for traction**: These tyres are usually higher and are characterised by aggressive lugs. Their main purpose is to provide adequate traction (Figure 3.2-10).

- **Tyres biased for floatation**: These tyres are characterised by a less aggressive lug pattern and they are also have wider tyre profiles. These tyres are not recommended for the rear bogeys as they can compromise stability, especially side-way slippage (Figure 3.2-10).

The most common applications of harvesters (in South Africa) are in pulp clear fell and in thinning operations. Machine manoeuvrability and mobility is an important selection characteristic for harvesters. Terrain is one of the deciding criteria to consider; the more challenging the terrain, the more consideration should be given to tracks, except in rocks where a wheeled machine could be a better choice. Agility is another factor; a wheel-based machine will be faster, while a track-based machine turns tighter, but the tracks tend to extend behind the operator and often cannot be seen. For a thinning application the potential damage to the remaining stand also needs to be considered. Two important factors need to be considered:

- **Damage to the stems of the remaining stand**: A wheel-based machine generally will manoeuvre better mainly due to improved visibility and improved feel by the operator of where the wheels of the machine are.
• **Damage to the rooting system of the remaining stand:** Wheel-based machines have a softer footprint, especially when working on a needle mat. The grousers of track-based machines can damage a shallow root system.

Additional factors that need consideration:

• **Inter-compartment transport:** For frequent short distant shifting of machines, a tyre-based machine is advantageous.

• **Terrain:** A rocky terrain is not suited to track-based machines, as the tracks cannot ‘bite’ and therefore cannot provide sufficient grip. Rocks also increase wear of track links.

• Where **ground pressure** is critical however (such as in wet conditions), tracks may offer a better flotation and traction.

• **Replacement costs:** Of the tracks or wheels and their expected life cycle. Tracks are more expensive to replace, but have a longer life expectancy and do not get punctures. In the wrong application, they may not last at all. Track maintenance is also a specialised subject and requires specific skills and tools to do correctly. Bogey tracks can be used to increase the traction and flotation of a wheel-based machine and therefore simulate some of the characteristics of tracks.

• **Stability:** Due to the mass of the tracks, their foot-print and the typical design of a track-based machine, they are more stable than their wheel-based counterparts in most applications. This is particularly the case where machines can slide (on soft underfoot conditions) or sink away.

The correct match between equipment, terrain and potential tyre traction or flotation devices needs to be considered when selecting appropriate tyres.

<table>
<thead>
<tr>
<th>Wheeled vs Track-based Harvesters</th>
<th>Advantages – track-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Works well in rocky conditions</td>
<td>Better flotation – less compaction</td>
</tr>
<tr>
<td>Is quick to move between compartments – self drive</td>
<td>More grip/traction</td>
</tr>
<tr>
<td>Less site disturbance (if used correctly)</td>
<td>Greater stability</td>
</tr>
<tr>
<td></td>
<td>Can operate in steeper terrain</td>
</tr>
</tbody>
</table>

**Carrier Selection**

A purpose-built forestry carrier is typically costs more than its earth-moving counterpart. However, replacement cycles of purpose build machines are typically longer than those of the generic machines counterparts. Repair and maintenance of purpose built machines are in general also lower.

Purpose-built carriers are designed with their application in mind. The design criteria and therefore machine specification however differ for different applications. Purpose built machines have inherently higher long-term productivity rates when used for the application they were designed for. This is due to the fact that their construction, drive train, ergonomics, safety features and comfort are purpose made for a specific application. Figure 3.2-11 illustrates a high initial cost of the purpose-built machine due to a higher acquisition cost, but in the long-term is cheaper to maintain and operate than a non-purpose built machine.
Machine size

Generally the larger the carrier, the more stable the machine will be. This however depends on terrain, the inherent centre of gravity of the machine and the type of work it is intended to do.

- **Tree control**: Bigger carriers are designed with stronger booms and bigger hydraulic pumps. Each carrier is designed for a specific product size in mind. A bigger carrier will provide better control over the tree after it is cut. This could be an important criterion as the felling and pre-bunching affects the subsequent system capacities. Better tree control also decreases fibre damage and hence increases value recovery for value differentiated products.

- **Bigger machines**: However are often more cumbersome and less manoeuvrable. They are more difficult to move from site to site and may require special transport permits. Fuel consumption also generally increases with increased machine mass. On the positive side, for a specific application, choosing a bigger machine will reduce stresses on components and should lead to lower repair costs and possibly longer machine life.

It is important that the carrier and its attachment size be appropriately matched to its intended purpose. It is usually advisable to rather over design.
3.3 Extraction (Primary Transport)

Timber extraction refers to the process of moving timber from the stump to a location that is accessible to a different mode of transport. Usually this point is a landing or depot. This process is also referred to a primary transport (when timber is moved from stump to landing) and extended primary transport (when timber is moved to a depot). Refer to Chapter 2 for transport terminology. Extraction can be further subdivided into:

- **Skidding**: Where the timber is dragged on the ground. The timber can be either partially suspended or in full contact with the soil surface.
- **Forwarding**: Where timber is carried off the ground.

### 3.3.1 Manual Extraction

Manual extraction involves the carrying or rolling of timber from the stump to a skid road or forest road. Smaller logs are carried by one or two people, while larger logs were carried by a crew. The pre-bunching of logs by manual means is also very prevalent in pulpwood harvesting and/or where logs close to a road are first manually extracted with the balance being subjected to another means of extraction. Efficiency and safety can be improved by using lifting hooks, levers, other hand tools or by pulling logs with the aid of manual sulkies.

#### Manual extraction

**Productivity indices**

- Steepness of slope
- Uphill or down-hill
- Piece size (both dimensions and weight are important)
- Terrain (rocks, stumps, etc.)
- Extraction distance

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability of labour</td>
<td>Safety risk</td>
</tr>
<tr>
<td>Less sensitive to ground conditions</td>
<td>Poor ergonomics</td>
</tr>
<tr>
<td>Can be used in extreme slope conditions</td>
<td>Low productivity</td>
</tr>
<tr>
<td></td>
<td>High absenteeism and labour turn-over</td>
</tr>
<tr>
<td></td>
<td>Can only handle short logs</td>
</tr>
<tr>
<td></td>
<td>Limited physical endurance, cannot work at night – no full double-shift</td>
</tr>
</tbody>
</table>

#### Limitation/application matrix

| Slope (%) – up | <10 |
| Slope (%) – down | unlimited |
| Ground condition | 1 - 5 |
| Ground roughness | 1 - 4 |
| Piece size (m³) | <0.05 |
| Maximum extraction distance (m) | <100 |

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.3.2 Animals

In South Africa, horses, mules and oxen are still used for the primary transport of round wood. In spite of their relatively low production, they continue to play an important role where volumes and terrain prevent the use of expensive mechanical equipment. The use of draught animals is synonymous with low soil disturbance, soil compaction and damage to residual trees. Animal extraction operations are normally limited to pulpwood and light sawtimber logs. When planning for animal extraction operations, careful cognisance must be taken of their physical capacities and their care and maintenance.

Recommended practices for extraction with draught animals are the following:

- Planning for animal skidding must allow for short extraction distances (typically 200 m or less) and gentle slopes.
- Proper harnesses are essential in order to prevent injury to the animals and to avoid discomfort.
- Devices such as skidding pans, sledges and sulkies can greatly improve productivity in animals skidding because they reduce skidding resistance and thus permit larger loads to be pulled for longer distances.
- Animal must be fed, watered and rested at intervals while working.
- Depending upon climatic conditions, terrain, and other factors animals may not be able to work every day and may require relatively short days. Often a 20 to 25% reserve of animals is recommended in order to ensure that a sufficient number is available to work on any particular day.
- Regular veterinary care is essential whenever draught animals are used in forest work and feeding practices must ensure that the animal’s nutritional requirements are being met.

Animals, especially mules, horses and oxen, can operate quietly and provide the image of low-environmental impact, and thus are useful in areas of public concern. Additionally, members of the public who are opposed to “big business” or “heavy industry” are less-likely to be opposed to horse logging. For comprehensive information on the use of animals for extraction, refer to the Zaremba (1976).
### Animal extraction

#### Productivity indices

- Steepness of slope
- Piece size
- Terrain
- Extraction distance

#### Advantages

- Low environmental impact
- Reduced physical strain (compared to hand-rolling and chutes)

#### Disadvantages

- Limited physical endurance, cannot work at night – no full double-shift
- Limited log size
- Limited to medium slopes and relatively short extraction distances

#### Limitation/application matrix

<table>
<thead>
<tr>
<th>Slope (%) – up</th>
<th>&lt;15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – down</td>
<td>&lt;35</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 4</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Piece size (m$^3$)</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Maximum extraction distance (m)</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

---

### 3.3.3 Chutes

Traditional extraction methods of timber in steep terrain such as for example hand-rolling, are often strenuous, labour intensive, dangerous and characterised by low productivity. Advanced technology is often expensive, requires a high degree of skill and intensive training. Intermediate technology, like extracting by gravity, a technologically simple option, can be used in cases where other systems cannot be applied due to unfavourable terrain. Chutes are relatively inexpensive to buy and can produce good productivity if applied correctly.

A chute may be described as an inclined channel system in which timber is transported downhill. The principle is only applicable on gradients where the force of gravity exceeds the frictional resistance between the chute and the timber sliding down the chute. The first chutes were introduced in the eighties and since then substantial successes have been enjoyed.

Chutes in South Africa are generally of two types:

- **Half pipe or open chute**: Sections are joined en-to-end to form a continuous gutter. The chute is secured by ropes or legs or both. They are manufactured from Nylon, molybdenum disulphide (MOS$_2$) and plastics which are cast in a mould and therefore does not deform.

- **Round pipe chutes**: The one end of the chute section has a slight taper which allows the different sections to fit firmly into each other to form a tube. Legs provide stability. They are manufactured from High Density Polyethylene (HDPE).

Round pipe chutes have the following advantages over their open gutter type counterparts:

- Logs cannot jump out and they are therefore safer to operate;
- Downtime is reduced because of fewer line breakdowns;
• They can negotiate slight bends to avoid obstacles;
• Stabilisation is quicker and easy;
• Longer extraction distances.

A typical chute team will consist of four to eight workmen. One to four members of the team roughly align the timber to the chute, two to four of the team members feed the timber into the chute and one to two members of the team move the unused sections from the area already extracted to a new location. Using the chute at right angles to the slope (chuting straight down the slope), usually results in a higher production rate than chuting across the slope (traversing). Chuting declines should be managed so as not to exceed about 45%. Chuting in steeper terrain should be done by traversing (going diagonally across) the slope to reduce the steepness, thereby keeping the speed of the timber manageable. Chutes require good planning and a careful management of correct utilisation of slopes. Refer to the South African Chute Operators’ Manual.

**Chutes**

**Productivity indices**

- Slope
- Ground roughness
- Size of the timber
- Species
- Volume per hectare
- Extraction distance

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low capital investment</td>
<td>Not immediately prepared for work</td>
</tr>
<tr>
<td>Relatively simple concept</td>
<td>It is a very dangerous operation</td>
</tr>
<tr>
<td>Reduced physical strain (compared to hand-rolling)</td>
<td>Logs are presented in an untidy fashion at roadside and must be re-stacked for loading operation</td>
</tr>
<tr>
<td>Minimal maintenance required</td>
<td>Limited to medium to steep down-hill operations</td>
</tr>
<tr>
<td>Low environmental impact</td>
<td></td>
</tr>
</tbody>
</table>

**Limitation/application matrix**

<table>
<thead>
<tr>
<th>Slope (%) – up</th>
<th>Impossible</th>
</tr>
</thead>
</table>
| Slope (%) – down | <90  
Above 45% – traverse |
| Ground condition | 1 - 5  |
| Ground roughness   | 1 - 4   |
| Piece size (m³)   | <0.2  |
| Maximum extraction distance (m) | <150  |

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.3.4 Agricultural Tractors

Agricultural tractors are still widely used in South Africa not only for primary transport of timber, but also for extended primary transport to depot or railway siding. Agricultural tractors can be classified in two-wheel and four-wheel drive tractors. The two-wheel drive tractors usually in the small tractor class of 45 to 55 kW, the medium tractor class of 65 to 71 kW, should only be used in tractor trailer combinations. For skidding, four-wheel drive tractors, ranging from 55 kW up can be used. Agriculture tractors (all-wheel drive) can be used for skidding (with a-frame or winch attachment) or as forwarding equipment with a trailer attachment.

![Agricultural tractor modified for forestry application.](image)

FIGURE 3.3-1: An agricultural tractor modified for forestry application.

Modifications to the basic agricultural tractor are required before it is put to use in rugged forestry conditions (Figure 3.3-1):

- Basic ROPS/FOPS/OPS protection;
- Protective screens on all cab windows;
- Belly pans for underside protection;
- Valve stem protection;
- Radiator protection and engine side guards;
- Headlight guards;
- Ensure adequate brake system (on both the prime mover and the trailer);
- Mounted fire extinguisher;
- Additional front weights (and/or putting water in the tyres for steeper terrain);
- All tractors used for extended primary transport that are used on public roads have to comply with the latest Road Traffic Act.

3.3.4.1 Agricultural tractor attachments

Most of the attachments are mounted to the tractor’s three-point hitch and are driven from the PTO shaft of the tractor hydraulics.

Direct skidding (A-frame): With direct skidding, the method followed is to mount a slotted bar of angle iron to the tractor’s three-point hydraulic lift system, and to use alloy choker chains. The
one end of the chain is then wrapped around the thick end of the log and tightened through a sliding hook. The other end of the chain is slotted as short as possible into the angle iron bar, by placing a link in the bar slot. A number of logs can be hitched in this way. The ends of the logs must only be lifted enough to ensure that the log ends do not dig into the ground, but not so much negatively affect stability of the tractor. If the chain is hitched too long, little or no log lift will be possible. If the lift is too much the steering efficiency will be reduced since the front wheels will lift of the ground.

**Winch (single and double):** Single and double drum winches are available for attachment to the tractor and which can be driven from the tractor power-take-off. The winch drum capacity varies from 35 m to 130 m depending on drum sizes and cable thickness. The advantages of using a tractor-mounted winch are:

- Skid trails can be further apart; loads winched to the trail;
- Winch can be used to bring down hang-ups safely;
- The tractor can winch itself out of difficult situations;
- The cycle time is reduced when compared to direct skidding;
- Tag lines can be used

**Trailers:** A trailer, drawn by an agricultural tractor in excess of 70 kW, is used to transport logs to a landing or depot. The trailer could be self loading (bundle system) i.e., fitted with a timber loader or be loaded manually. Trailers used in forestry operations need to be equipped with integrated braking systems. Tractor trailer systems used for extended primary transport operations, typically travel around 25 km lead distances.

<table>
<thead>
<tr>
<th>Tractors</th>
<th>Productivity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Payload size</td>
</tr>
<tr>
<td></td>
<td>Extraction distance</td>
</tr>
<tr>
<td></td>
<td>Machine configuration</td>
</tr>
<tr>
<td></td>
<td>Terrain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be used for multiple tasks</td>
<td>Harvesting equipment is not custom fitted and has to be added at additional cost</td>
</tr>
<tr>
<td>Low capital cost</td>
<td>Ergonomically not suited to extraction operations</td>
</tr>
<tr>
<td>Easy back-up and parts availability</td>
<td>Lack of centre articulation, wide turning circle and rear wheels do not follow in the tracks of the front wheels</td>
</tr>
<tr>
<td></td>
<td>Kept as light as possible in their basic configurations. Weights have to be added to improve efficiency during timber extraction</td>
</tr>
<tr>
<td></td>
<td>On steeper slopes, tractor’s brake systems etc. may not support a safe working environment</td>
</tr>
<tr>
<td></td>
<td>Tractor are not designed to carry a load</td>
</tr>
</tbody>
</table>
Limitation/application matrix

(With tyre chains if necessary)

<table>
<thead>
<tr>
<th></th>
<th>Tractor-trailer</th>
<th>Skidding tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>&lt;20</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;20</td>
<td>&lt;35</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 2</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 2</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Piece size (m³)</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Maximum extraction distance (m)</td>
<td>&lt;1 500</td>
<td>&lt;250</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

### 3.3.5 Articulated Skidders

The articulated skidder is an important component in the primary transport of timber in South Africa. Skidders are specifically designed to pull (skid) trees from the point of felling to a landing site. They are heavy, robust machines, with their centre of gravity positioned well forward. Power to weight ratios has been chosen for efficient performance when skidding trees.

#### 3.3.5.1 Cable Skidders

Cable skidders (Figure 3.3-2) are defined as four-wheel drive, rubber-wheeled tractors with articulated steering that use a main winch and cable or chain chokers to assemble and hold a load. Cable skidders are used mostly with large, motor-manually felled timber. Productivity is severely reduced in smaller timber due to time losses associated with setting chokers on a large number of smaller stem, and the physical limitations to the number of chokers that can be handled or carried. Cable skidders are generally used in more difficult terrain and with larger tree volumes and/or scattered trees. Its ability to winch in loads located some distance form the skidder is an advantage in these applications.

![FIGURE 3.3-2: Articulated cable skidder.](image)

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South African Ground Based Harvesting Handbook
Taglines (Figure 3.3-3) can be used to increase a tractor or cable skidder output and productivity by reducing cycle times. Taglines are systems that use three separate sets of chains or cables, with multiple sliders with choker chains, which are attached to the skid cable through quick-coupling device, called a shortening clutch. This system allows choker-men to choke trees while the skidding machine is busy transporting another load. This improves the choking productivity especially in smaller trees, thereby reducing machine waiting time and machine cycle time. This results in improved system productivity. Bundle skidding refers to using a cable skidder to extract bundles of logs instead of tree lengths. These bundles are pre-stacked and the skid cable is wrapped around the bundle and then skidded to the landing.

### Skidders

#### Productivity indices

- Payload size
- Extraction distance
- Machine configuration
- Terrain

#### Advantages

- Greater flexibility due to their use over a wide variety of terrain conditions
- Relatively inexpensive, compared to grapple and clam-bunk skidders
- Operator training is easier than for grapple and clam-bunk skidders
- Flexible machine that can be used in most applications – a good all-rounder
- Improved stability on side slopes and rough terrain

#### Disadvantages

- Operator must dismount or have choker-men to choke or de-choke loads
- Choking and de-choking times are relatively long
- Double-shifting is difficult – need daylight to choke and de-choke
- Loads are dragged on the ground, creating potential problems at the landing or saw mill as far as abrasive dirt accumulation on the stems or logs. The drag also affects machine performance negatively

There are various wire rope options available as skid cables. Steel wire rope has historically been the dominant form of cable for use in skidding operations. The characteristics of wire rope (Figure 3.3-4), its application and care are outlined in detail in the South African Cable Yarding Safety and Operators Handbook (FESA, 2001). Over the last decade however, there has been an increased interest in the use of various synthetic ropes and their potential to be an alternative to steel wire ropes. This potential stems from the fact that synthetic rope has the inherent strength and quality of steel, but is significantly lighter and easier to use (Garland, et al., 2002).
Grapple skidders (Figure 3.3-5) are defined as all-wheel (4-wheel, 6-wheel or 8-wheel) drive, rubber-tyred designed tractors with articulated steering for pulling a load by lifting the log ends clear off the ground in by means of a grapple. Grapple skidders therefore require no cables, chokers or choker-men.

3.3.5.2 Grapple Skidders

Grapple skidders are better suited to work in combination with feller-bunchers, as the felled trees are pre-bunched or pre-bundled because it is time consuming to pick up individual trees. They are also valuable when working with big tree sizes as the choking of big trees is difficult. The size of the grapple is determined by tree size, terrain condition and the type of presentation to the machine, i.e. individual trees versus pre-bundled, or bunched trees. The grapple size in turn primarily decides the size of the skidder. Some grapple skidders are fitted with a winch attachment as well, which gives them the flexibility to bring difficult trees closer to the machine, or to be used in difficult terrain.

There are three types of grapples available (Figure 3.3-6); namely sorting and bunching and hybrid grapples. A sorting grapple is used in large timber where a full load involves one or a few stems. The shape of the grapple is specifically designed to ensure that only one or two logs can be securely gripped.
A bunching grapple is used for large loads of small stems. It is also preferred on rough ground for picking up uneven piles of scattered timber. The third type of grapple is a hybrid grapple and is designed to be used in both applications. It appears to be similar to the bunching grapple, but distinguishes itself primarily by the shape of the arms and the location and stroke of the arm cylinders. A grapple is hung on an “arch,” (Figure 3.3-7 to 3.3-9). Three arch configurations on grapple skidders facilitate an effective match of the skidder to a wide variety of skidding applications.

**Single arch**

This is a versatile attachment suitable for selection and clear felling applications. The effective arch reach consists of one arch pivot that allows for an up and down movement of the arch with a single set of cylinders. A typical application will include short cycles and/or larger diameter timber.

**Dual arch**

In addition to the up and down movement of the single function arch, the dual function arch allows for forward, above, below and backward movement from the horizontal plane. This is achieved by a second pivot point and a second set of cylinders. This extends the effective range the arch and provides extra reach for grabbing bundles. It also gains the ability to position loads closer to the skidder which aids skidder stability and traction. Typical applications would include longer cycles and more difficult terrain.
Swing boom

For this function, a grab is fitted to a “small” crane mounted on the skidder. It provides excellent reach to the rear and side for maximum skidder versatility. It is suitable for hard to reach timber on steep slopes, soft ground or selective clear fell and thinnings operations. The swing boom reduces cycle times by reducing the amount of manoeuvring of the skidder to reach logs or trees. Its main disadvantage is the limited grab sizes that can be fitted to a swing boom skidder.

![Swing boom system](image)

**Grapple skidders**

**Productivity indices**

- Payload size
- Extraction distance
- Machine configuration
- Terrain

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>The operator does not need to get on and off the machine to set chokers</td>
<td>More sensitive to terrain since the load cannot be</td>
</tr>
<tr>
<td>chains or cables</td>
<td>released to negotiate obstacles</td>
</tr>
<tr>
<td>Quick loading and unloading means shorter cycle times</td>
<td>Higher purchase prices</td>
</tr>
<tr>
<td>If equipped with a winch as well – a productive all-rounder</td>
<td>More costly to maintain</td>
</tr>
<tr>
<td>Night shifts are an option</td>
<td></td>
</tr>
</tbody>
</table>

**3.3.5.3 Clam-bunk Skidder**

A clam-bunk skidder (Figure 3.3-10) is defined as an all-wheel drive articulated rubber-wheeled or tracked vehicle for transporting full trees, or tree length by supporting the butt-end clear off the ground in an inverted clam or inverted grapple. Clam-bunk skidders are equipped with either a grapple loader for self-loading (Kellogg et al., 1993) or are loaded by a separate infield loader. For best results, trees should be neatly bunched and indexed at a low angle on skidding trails in the direction of transport, butt-ends forward.
Clam-bunk skidders are designed for high volume and long extraction distances, particularly when trees are large, terrain easy and the ground has suitable bearing capacity (Staaf and Wiksten, 1984.) These machines are increasingly being used in small tree sizes around the world. In difficult conditions, this configuration, equipped with bogey tracks and an eight-wheel drive, is very capable. They are also preferred in swampy and steep operations due to an 8-wheel drive and a good load distribution.

**Clam-bunk skidders**

**Productivity indices**

- Payload size
- Extraction distance
- Machine configuration
- Terrain

**Advantages**

- Achieve high payloads
- Not very sensitive to piece size
- High payloads allow economic long distance skidding
- Reduced soil compaction because infield traffic is minimised
- Low ground pressure (bogie combination and high flotation tyres) for mobility in soft ground
- Cleaner wood, two thirds of the load is lifted off the ground
- Potential for shift work
- Mechanisation advantages such as reduced physical stress and reduced accident risk

**Disadvantages**

- Long loading times of between 5 and 15 minutes
- Complex loader and loading operation means long training periods
- The machine is expensive
- Large machine size limits their use to clear felling
- Has no winch and, therefore, must approach to within loader reach of every tree. It also has no ability to winch past wet and adverse patches
- Terrain is a limiting factor
- Has significant landing implication due to single high payload deliveries
3.3.5.4 Tracked Skidder

Crawler tractors or tracked skidders, while not widely used in South Africa, are excellent timber extraction machines. Many different makes of crawler tractors are suitable for timber extraction (Figure 3.3-11). Crawlers used for skidding, range (classification according to Caterpillar) from small (55 kW and 7 800 kg) class tractors up to and including 175 kW (25 700 kg) class machines. The most commonly-used are in the 63 to 93 kW (8 150 to 12 900 kg) class. Some of these machines are factory built as skidders and do not need modifications. Some of the changes from a general purpose bulldozer to a skidder include:

- Skidding grapple or winch with arch.
- Under-body protection, radiator guarding and cab screening
- Deflector bars and modified track guides to prevent tracks from coming off during side-sloping (driving at an angle to the slope).

Some manufacturers are now making dedicated timber skidding crawlers equipped with cab protection, guarding, and modified vehicle geometry. Many of these crawlers are equipped with a “high-track” configuration with an elevated centre drive gear on a triangular-configured track. The tracks, which may be wider than normal, typically extend further behind the machine to better distribute the load and improve the centre of gravity. Crawlers that are equipped with a six-way bulldozer blade can be very useful for other operations, including road, skid trail, landing, and fire line construction, and site cleanup and preparation.
**Tracked Skidder**

**Productivity indices**

- Payload size
- Extraction distance
- Machine configuration
- Terrain

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Has a very tight turning-radius which allows the use of narrower skid trails and operating areas</td>
<td></td>
</tr>
<tr>
<td>- Better terrain capability</td>
<td></td>
</tr>
<tr>
<td>- Very stable</td>
<td></td>
</tr>
<tr>
<td>- Lower ground pressure</td>
<td></td>
</tr>
<tr>
<td>- High initial capital costs</td>
<td></td>
</tr>
<tr>
<td>- Slower travel speed</td>
<td></td>
</tr>
<tr>
<td>- The machine is expensive</td>
<td></td>
</tr>
<tr>
<td>- Higher soil disturbance when turning</td>
<td></td>
</tr>
</tbody>
</table>

**Limitation/application matrix**

*With tyre chains or bogey tracks if necessary*

<table>
<thead>
<tr>
<th></th>
<th>Cable skidder (120kW)</th>
<th>Grapple skidder (120kW)</th>
<th>Grapple skidder (6x6)</th>
<th>Clam-bunk skidder</th>
<th>Tracked skidder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>&lt;40</td>
<td>&lt;30</td>
<td>&lt;45</td>
<td>&lt;35</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;45</td>
<td>&lt;35</td>
<td>&lt;55</td>
<td>&lt;40</td>
<td>&lt;55</td>
</tr>
<tr>
<td>Ground condition (depend on tyre choice)</td>
<td>1 - 3</td>
<td>1 - 3</td>
<td>1 - 3</td>
<td>1 - 3(4)</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3</td>
<td>1 - 2</td>
<td>1 - 3</td>
<td>1 - 3(4)</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Maximum extraction distance (m)</td>
<td>&lt;350</td>
<td>&lt;500</td>
<td>&lt;600</td>
<td>&lt;1 000</td>
<td>&lt;200</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

### 3.3.6 Forwarders

Forwarders (Figure 3.3-12) are highly specialised machines used in thinning and clear-felling operations. They can be defined as a four-, six- or eight-wheel articulated machine used to transport logs, from the forest floor to a roadside landing. Forwarders are normally used as part of a CTL harvesting system, in combination with harvesters.

![Forwarder](image-url)
Forwarders are all-wheel drive and are equipped with a hydraulic knuckle boom loader and timber grapple. The rear of the forwarder consists of bunks to form the load bay to hold the logs. Load bay configurations are mainly determined by the lengths of the logs to be transported and the size of the machine itself. The logs are loaded onto the forwarder using a centre mounted hydraulic log crane. The position of the crane can however change to be mounted on the front part of the forwarder. The load is then extracted/forwarded to roadside where it is unloaded using the same crane. Forwarders can travel equally well forward or backward and the operator’s seat is reversible.

Forwarders come in a range of sizes and are classified by their load carrying capacity, which typically varies from 6 to 25 tonnes. Light-weight purpose-built forwarders utilised in commercial clear fell and thinning operations can handle payloads of up to 10 tonnes. Medium sized forwarders carry 12 to 14 tonnes with the largest class handling up to 25 tonnes. Some specialised bigger size forwarders are available.

Forwarders specifically differentiate themselves from skidders in that they pick the entire load off the ground. Forwarders are therefore regarded as low-impact machines as there are no dragging ruts and the load is supported by up to eight wheels. A forwarder also does not need any additional support machine, as it can load, transport and off-load itself. This makes it an ideal extraction tool for highly mechanised operations, or operations where additional machine could complicate the operation.

### Forwarders

**Productivity indices**
- Forwarding distance
- Payload
- Timber presentation during loading and offloading
- Operational application – thinning vs clear fell

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carries a large payload</td>
<td>Less efficient at shorter distances due to long loading and offloading cycles</td>
</tr>
<tr>
<td>Rutting and compaction is limited to forwarder trails</td>
<td>More unstable than skidder as payload is carried higher which raises centre of gravity</td>
</tr>
<tr>
<td>Less stand damage in thinning operations than with skidder</td>
<td>More expensive than ADT</td>
</tr>
<tr>
<td>High ergonomic standard, low impact on operator than with skidder</td>
<td></td>
</tr>
<tr>
<td>Highly productive operation if run in combination with harvester</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3.7 Articulated Timber Trucks

An Articulated Dump Truck (ADT) is, in principle, a modified articulated dump truck (or ATT - Articulated Timber Truck). These units are normally applied in an extended primary transport application, although they can be used for forwarding as well. They are available with or without cranes. When used in an extended primary transport application, it will typically be without a crane so as to maximise payload. Although they are big and powerful, they cannot be used as effectively for forwarding purposes. Their use is most common where a load is picked up in-field and transported over longer distances (extended primary transport). Depending on specific constraints and economics of the operation, a general guideline of a 20 km lead distance is appropriate.
ADT
Productivity indices

- Forwarding distance
- Payload
- Timber presentation during loading and offloading
- Operational application – thinning vs clear fell

Advantages | Disadvantages
---|---
- Carries a large payload | - Less efficient at shorter distances
- Can be used for extended primary transport from stump | - High impact on roads particularly especially in wet weather
- Has a relatively high on-road speed | - Does not have the same terrain capability as the forwarder
- Lower acquisition cost than a forwarder | - If used infield, may have a shorter life expectance than a forwarder

3.3.7.1 Comparison Between ADT’s and Forwarders

<table>
<thead>
<tr>
<th>Feature</th>
<th>Forwarder</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Low</td>
<td>Relatively high</td>
</tr>
<tr>
<td>Power-train</td>
<td>Hydraulic</td>
<td>Torque converter</td>
</tr>
<tr>
<td>Number of wheels</td>
<td>4, 6 or 8</td>
<td>6</td>
</tr>
<tr>
<td>Wheel mounting</td>
<td>Four singles, two singles and two bogies, four tandem bogies</td>
<td>Two tandem walking beams and two single front tyres</td>
</tr>
<tr>
<td>Seat mounting</td>
<td>Swivel mount</td>
<td>Forward facing</td>
</tr>
<tr>
<td>Centre of gravity</td>
<td>Low (stable)</td>
<td>High (unstable)</td>
</tr>
<tr>
<td>Safety</td>
<td>ROPS, OPS, FOPS</td>
<td>None (not tested for forestry application)</td>
</tr>
</tbody>
</table>

Limitation/application matrix of forwarders and ADT’s

<table>
<thead>
<tr>
<th>(With tyre chains or bogey tracks if necessary)</th>
<th>Forwarder 4x4</th>
<th>Forwarder 6x6</th>
<th>Forwarder 8x8</th>
<th>Articulated Dump Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>&lt;25</td>
<td>&lt;35</td>
<td>&lt;40</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;35</td>
<td>&lt;45</td>
<td>&lt;50</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 – 2</td>
<td>1 – 2</td>
<td>1 – 3</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 – 3</td>
<td>1 – 4</td>
<td>1 – 4</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Load size (ton)</td>
<td>6 – 10</td>
<td>8 – 12</td>
<td>11 – 20</td>
<td>20</td>
</tr>
<tr>
<td>Maximum extraction distance (m)</td>
<td>&lt;500</td>
<td>&lt;1 000</td>
<td>&lt;1 000</td>
<td>&lt;2 000</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.3.9 Shovel Logging

Shovel logging is a ground-based extraction technique developed in the Pacific North-western USA during the 1970’s for steep terrain extraction. Later it was also adopted in wet and swampy operations in the USA and Asia. It is a technique that involves a purpose-built self driven swing loader systematically traversing the compartment, grabbing the timber and swinging it sequentially closer to the landing with each pass. Shovel logging is typically used with a continuous roadside landing for maximum efficiency. Shovel logging (Figure 3.3-19) requires the use of a modified hydraulic excavator-based swing loader.

![Figure 3.3-19: Tracked, levelling swing boom shovel logger with heal-boom.](image)

Shovel logging can be considered as a reduced-impact technique for the following reasons:

- The trimber is not dragged along the ground, but rather lifted free off the ground and set into place every “swing”. This results in less soil disturbance than ground-based skidding.
- The machine typically only has to make one pass through an area. The logistics of a harvesting operation will typically require the swing loader to occasionally leave and re-enter the compartment for activities such as re-fuelling, maintenance, truck loading, etc.
- The ground pressure exerted by a swing loader is typically lower than that of a rubber-wheeled skidder due to the large contact area under the tracks.

Swing loaders used for shovel logging typically include the following modifications:

- Increased under-body and track protection;
- Longer-reach booms;
- Increased fuel tank capacity to limit movement in and out of the compartment for re-fuelling;
- Larger counterweights for use with large logs/trees;
- Wider tracks for reduced ground pressure and a wider footprint to improve stability;
- Double grouse track shoes instead of the typical triple grouser shoes used on excavators.

The shovel begins at typically the furthest corner of the compartment and systematically winds its way through the compartment, swinging the logs closer and closer to the roadside (Figure 3.3-20). Typically no more than four to five swings are executed per piece before it reaches the...
landing. However up to ten swings may be used in special circumstances. Each swing covers approximately 30-35 m depending on tree/piece, loader boom length and the topography. A parallel felling pattern is most efficient for shovel logging.

The opportunity may exist to combine shovel logging with other extraction methods such as grapple skidders or cable yarders to great effect. The shovel can bunch the timber adjacent to the designated skid trails where a grapple skidder will then pick up a proper load each turn. Shovel logging has proven to be an effective, productive, environmentally-friendly harvesting method that should not be overlooked by an organisation looking to employ reduced-impact harvesting techniques.

**Shovel logging**

**Productivity indices**

- Extraction distance – number of swings required
- Piece size
- Terrain – especially slope and rocks

**Advantages**

- Can be effectively used in wet conditions
- Same machine can be used on the landing – multi-task
- Low ground impact – only one pass

**Disadvantages**

- Limited terrain and slope applications
- Very piece-size sensitive

**Limitation/application matrix**

<table>
<thead>
<tr>
<th></th>
<th>Shovel logger non levelling</th>
<th>Shovel logger levelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>&lt;35</td>
<td>&lt;55</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;25</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 4</td>
<td>1 - 4</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Piece size (m³) · grab specific</td>
<td>&lt;2.0</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>Maximum extraction distance (m)</td>
<td>&lt;150 (3 “swings”)</td>
<td>&lt;150 (3 “swings”)</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.3.10 Tyres and Tracks

Ground pressure (Figure 3.3-13) is a function of machine mass and the dimension of the contact area between the machine and the ground, called the footprint. The footprint area of a machine is influenced by:

- **The number of wheels**: The greater the numbers of wheels, the more points are available to spread the load of the machine, hence the lower the resulting individual ground pressure of each tyre.

- **Tyre pressure**: The lower the pressure of the tyre, the greater the footprint of the tyre, the lower the resulting ground pressure.

- **Tyre dimensions (particularly width)**: As the tyre width increase, the footprint increases, which results in a decrease in ground pressure.

- **Tyre tread pattern**: Different tread patterns (lug angle, depth and spacing) impart different flotation, grip and self cleaning properties to the wheel. For example: A deeper lug depth will increase lug soil penetration, which will improve traction but also increase ground pressure on each lug.

![Figure 3.3-13: Ground pressure equivalents between conventional and flotation tyres.]

There are various methods to increase the traction or flotation of forestry tyres (Figure 3.3-14). Dual tyres and high flotation (wider) tyres are used to increasing the footprint of the machine. Although high flotation tyres can be used on both skidders and forwarders, the use of dual tyres is mostly associated with skidders. The additional machine width created by the use of dual or high flotation tyres has operational implications for management; e.g. when transporting the skidder on a low bed or entering plantations through gates as well as increased fuel consumption. The use of these tyres also makes the machine more difficult to manoeuvre.
The original objective of metal tracks fitted to wheeled bogies was to improve the flotation capabilities of the machine, not dissimilar to that of a military armoured tank. Such devices were first introduced to forwarders in the 1950’s in Scandinavia and have since gained favour for a number of reasons:

- Extending the effective harvesting season in the northern hemisphere during wet periods;
- Improving the traction and stability of wheeled equipment on steep terrain resulting in lower extraction costs where previously more expensive cable extraction methods had to be used;
- Because of reduced slippage of tyres and the reduction in the subsequent stresses in wheeled machine drivelines, there have been reduced driveline failures;
- The protection of tyres and hence extended tyre life. Tread and side walls are protected by the metal plates and punctures are greatly reduced.

Tyre chains as a traction improvement device have been around for decades and used with various degrees of success where standard tyres do not provide sufficient traction. Most important with chains is the maintaining sufficient tension on the chain net over the tyre (Figure 3.3-15). The chain links are subjected to high stresses when working and as a result, stretch. This slack needs to be regularly taken up in order to prevent the tyre from slipping inside of the chain net and causing tyre and possible drive line damage. Depending on the chain manufacturer chains are secured in different ways and often specialised tooling is required or supplied to mount and maintain chains. Chains are designed to expel dirt, soil, and forest debris that would typically accumulate inside of the chain. Chains are not very road friendly.
FIGURE 3.3-15: A ring type wheel chain.

The band tracks (Figure 3.3-16) were designed for forwarders and in particular for the rear bogie of the forwarder; although they are now commonly used on both the front and rear bogie.

FIGURE 3.3-16: Different types of band track designs.

As can be seen from Figure 3.3-16 the track involves metal plates (cross members) spanning over the width of the tyre and connected together with a heavy duty chain link type system. Typically the material used is special carbon manganese steel, alloyed with boron with indentation strength of 500 Brinell.

Different designs on the ends which provide protection to the tyre side walls vary from manufacturer to manufacturer. Suppliers will typically provide options depending on the application with greater protection or heavier design around the sidewall area especially in very rocky conditions or where there is a high frequency of stumps. It is important to note that most, if not all tracks, are designed around the forwarder tyres which typically have non-aggressive tread patterns and a relatively square tyre profile. Therefore tracks fit snugly over these tyres and are easily tensioned and maintained.

As with chains, bogie tracks also require regular maintenance. Special tools are required or recommended to install the tracks onto a bogie and then it is important maintain the correct tension in the track for best operation and extended track life. The links will stretch over time requiring the removal of links and a number of plates to take up the slack. An important operational consideration when working in steep slopes is that forwarders must preferably work up and down slopes (perpendicular to the contours). Traversing severe side slope with tracked bogies can cause the forwarder to slide sideways with potential negative results.

Individual tyre tracks are of the same design or technology as the bogie tracks except that they are mounted around individual tyres (Figures 3.3-17 and 3.3-18). Individual tracks are typically mounted to skidders on either only the front (also providing ballast to the skidder for balance) or on all four tyres. In some cases, provided there is sufficient clearance between tyres on a bogie one can mount individual tyre tracks on each tyre rather than the band track. Tension and maintenance as with the band tracks and chains is imperative.
Advantages are that both traction and flotation are increased. Disadvantages are that machines equipped with tracks over their tyres travel slowly and that track specifications will have an impact on the disturbance of soil. Aggressive tracks which are designed to give the greatest traction can disturb soil significantly. This is especially visible when a machine is turning onto the forest road from the compartment. The life of a typical forestry tyre is influenced by:

- The hardness of the Rubber compound;
- Lug design;
- Side wall strengthening;
- Soil roughness;
- Operating techniques or expertise;
- Type of machine; e.g., forwarder or skidder.
3.4 Processing Equipment

Common processing activities include de-branching, topping, cross-cutting, debarking and chipping. Processing can range from one activity at a particular location to multiple activities carried out simultaneously. The processing equipment can be mobile or fixed in an area such as a merchandising yard.

3.4.1 Manual and Motor-Manual Processing

Manual processing is defined as a change in the form of the tree or log by means of human effort and the use of non-powered tools. Where relatively inexpensive labour is available, manual processing is still considered to be one of the lowest cost methods in small trees. Additional advantages include low capital costs, employment generation, generally good timber quality, low environmental impact and relatively low fibre loss. However, safety is a concern, as accident rates tend to be higher than with other methods.

Manual de-branching is carried out using axes. As branch size and frequency increases, de-branching productivity decreases. With pine species (especially *Pinus patula*), a medium sized axe is used to remove the branches. This method is usually restricted to pulpwood sized trees. With *Eucalyptus* and *Acacia* (wattle) species, a small axe (hatchet) is used with which the bark is also removed. Often chainsaws work in combination with the manual de-branching by removing big branches or forks. Manual debarking of *Eucalyptus* and *Acacia* (Figure 3.4-1) involves the removal of the bark and cambium layer by a person using a small axe (hatchet).

![FIGURE 3.4-1: Manual debarking using a hatchet on *Eucalyptus*.](Figure 3.4-1)

![FIGURE 3.4-2: Motor-manual debranching using a chainsaw (Pulkki, 1999).](Figure 3.4-2)

Motor-manual processing refers to a processing method whereby the operator uses a chainsaw. De-branching, using a chainsaw to remove branches flush with the stem once the tree has been felled. The Scandinavian Nordfor felling method (Figure 3.4-2) of de-branching is the most common method used. Chainsaw de-branching is usually associated with (but not restricted to) motor-manual tree felling, where it is usually the same person felling and de-branching. Motor manual cross-cutting involves cutting a tree length into assortments using a chainsaw.
# Manual processing tools

## Productivity indices

- Sharpness of tools
- Piece size
- Species
- Branch size and frequency
- Terrain slope and ground roughness
- Labour health and fitness

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Job creation</td>
<td>• High labour turnover</td>
</tr>
<tr>
<td>• Low capital investment</td>
<td>• Safety risks</td>
</tr>
<tr>
<td></td>
<td>• Low productivity</td>
</tr>
<tr>
<td></td>
<td>• Ergonomically undesirable</td>
</tr>
</tbody>
</table>

## Limitation/application matrix

<table>
<thead>
<tr>
<th>Slope (%) – up</th>
<th>Shovel logger non levelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;60</td>
<td></td>
</tr>
</tbody>
</table>

| Slope (%) – down | <60 |

<table>
<thead>
<tr>
<th>Ground condition</th>
<th>1 - 5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Ground roughness</th>
<th>1 - 5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Load size (m³)</th>
<th>Depending on application</th>
</tr>
</thead>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

## 3.4.2 Mechanised Processing

### 3.4.2.1 Ring Debarkers

Ring debarkers have knives that hydraulically keep in contact with the tree surface as the tree passes through the machine (Figure 3.4-3). The tree can either be rotated as it passes through the debarker, or the knives turn around the tree on a rotor. The number of knives can vary according to the debarker’s application. Feed rollers push and pull the tree through the debarker. For high productivity, a constant supply of logs must be fed through the debarker. Ring debarkers are sensitive to piece size as only one log or tree is debarked at a time. In-field ring debarking has a limited application use in plantation forestry in South Africa although it is gaining some popularity.

![Figure 3.4-3: Mobile ring debarker.](image-url)
**Ring debarkers**

**Productivity indices**

- Bark adhesion: the ease with which the bark is removed from the bole of the tree is a function of sap-flow between the bark and the stem. The lower the sap flow, the higher the adhesion factor and the more difficult it will be to separate the bark from the stem.
- Piece size
- Quality requirements (especially bark and branch stubs)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allows semi mechanisation</td>
<td>Limited applications; species and short lengths</td>
</tr>
<tr>
<td>Improved quality with lower bark</td>
<td>Still dependant on hand feeding</td>
</tr>
<tr>
<td>adhesion (compare to manual)</td>
<td>Not self contained; needs to be towed around</td>
</tr>
<tr>
<td></td>
<td>Poor debarking quality with high bark adhesion; requiring re-work</td>
</tr>
</tbody>
</table>

**Limitation/application matrix**

<table>
<thead>
<tr>
<th>Limitation/application matrix</th>
<th>Ring debarker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>&lt;5 - depending on feeding system</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>&lt;5 - depending on feeding system</td>
</tr>
<tr>
<td>Ground condition</td>
<td>1 - 3 depending on feeding system</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>1 - 3 depending on feeding system</td>
</tr>
<tr>
<td>Load size (m³)</td>
<td>&lt;0.3 for in-field systems</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

### 3.4.2.2 Chainflail-Delimber (debrancher)-Debarkers (CFDD)

Chainflail-Delimber (debrancher)-Debarkers are used to debark and de-branch trees (Figure 3.4-4). They can be stationery (at mills or merchandising yards) or mobile, operate on a landing. They remove bark and branches by using hardened chain links, mounted on rotating drums that make contact with the bark and branches knocking them off. For high bark adhesion, two chains per attachment on the drum can be used. The number of flail drums per machine varies from two to four. More flail drums will result in better debarking and debranching quality, however too much flailing can cause damage an result in fibre loss. 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. With the larger CFDDs, the bark falls to the bottom of the debarker and is expelled by a hydraulic pusher.
Current commercial CFDDs are able to process more than one tree at a time, making them suitable for small tree multi-stem operations. They offer variable feed and flail drum speeds which allow a certain quality debarking without damaging the fibre. Because debranching and processing often take place on the roadside, it is difficult to handle the large amount of plantation residue (bark, foliage, branches, wood pieces and off-cuts) which is generated. To reduce the amount of potential residue production the tops and larger branches of trees are sometimes removed at the stump and not transported to the CFDD. If plantation residue is utilised (e.g. transported to a power generation plant for bioenergy), this system is ideal as residues can be fed straight from the CFDD to a transport vehicle or moved to one side of the landing for later processing and transport.

Chainflail-Delimber (debrancher)-Debarkers can also be mounted at the front of a front-end-loader type machine, similar in design to a purpose-built mulcher. The machine drives over the trees to carry out the processing function. These are not very common as the debranching and debarking effectiveness is limited. When a CFDD is combined with a chipping function, it is often referred to as a Chain-flail-delimber-debarker-chipper (CFDDC) (Figure 3.4-5). They require high timber volumes for economic operations and can produce chips of a quality suitable for most pulp mills.

Large engines are required to power the feed rollers, cranes, flail drums and chipping disk, which results in high fuel consumption. The feed speed should be kept constant to ensure that the trees are pushed against the chipper knives at a constant speed. CFDDCs can result in increased tree utilisation as the entire tree is chipped (including tops and larger branches).

In-field chipping is a hot operation (an operation where operational buffers are small or non-existent). Careful operational harvesting and logistical planning must ensure that the system is properly integrated and that the various machines involved are well balanced in terms of output.
It is also possible to have stand alone CFDD feeding into dedicated chippers. This allows the flexibility of being able to produce debranched and debarked tree lengths or chips. This can result in cleaner chips as monitoring of debarking quality is easier. Further to this, bark that does still make its way out of the CFDD out-feed can fall onto the ground instead of being chipped with the tree lengths. This can result in slightly higher chipping productivity. However, having two large machines working requires two operators, which can contribute to increased costs and to downtime.

Road infrastructure and condition are particularly important for these operations because chips cannot be stock piled. Direct loading and transport requires adequate all-weather roads. Due to the high volume of chips produced it is also preferable that high capacity trucks can reach the CFDD at the landing.

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

<table>
<thead>
<tr>
<th>Productivity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bark adhesion</td>
</tr>
<tr>
<td>• Piece size</td>
</tr>
<tr>
<td>• Number of activities (de-branch, debark, chip) combined into a single process</td>
</tr>
<tr>
<td>• Quality requirements especially bark and branch stubs (for CFDD) or chip quality (for CFDDC)</td>
</tr>
<tr>
<td>• Transport scheduling of the chips for CFDDC’s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Allows higher mechanisation, combines processes</td>
<td>• High capital outlay</td>
</tr>
<tr>
<td>• Improved quality with low bark adhesion (compare to manual)</td>
<td>• Plantation residue can be a problem</td>
</tr>
<tr>
<td>• Ensures that no waste is transported</td>
<td>• Complicated machine requiring specialised support</td>
</tr>
<tr>
<td>• Handling of waste improved</td>
<td>• A good road network is required</td>
</tr>
<tr>
<td>• Can improve chip quality</td>
<td></td>
</tr>
<tr>
<td>• Increased fibre yield for CFDDCs</td>
<td></td>
</tr>
</tbody>
</table>

**Limitation/application matrix**

<table>
<thead>
<tr>
<th>Ring debarker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
</tr>
<tr>
<td>Slope (%) – down</td>
</tr>
<tr>
<td>Ground condition</td>
</tr>
<tr>
<td>Ground roughness</td>
</tr>
<tr>
<td>Load size (m³)</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

**3.4.2.3 In-field Chipping**

This section refers to stand alone in-field chippers. The tree, log or harvesting residue is chipped using knives mounted to a rotating disk or drum. Disc chippers use less energy as momentum is used to help maintain the spinning action. They are also capable of chipping larger diameter
material. Drum chippers are the opposite, but are better able to chip shorter logs or timber off-cuts. Drum chippers are therefore often used when processing harvesting residue. Mobile chippers can range from small units, used for processing small sized harvesting residue, to big units for chipping whole trees. If the chips are being used to burn as an energy source, there would normally only be one chip chute. However, if it is desirable to remove undersize and oversize chips, then a waste chute is also used.

3.4.2.4 Slashers

Slashers cut bundled tree lengths into fixed log lengths, but can also be used to cut long logs into short logs (Figure 3.4-6). Slashers require a swing loader to power (via hydraulics) and feed the slasher, and remove and stack the processed log lengths. They are suitable in small tree operations using multi-stem operations where fixed log lengths are required.

FIGURE 3.4-6: Slashing of Eucalyptus tree lengths.

3.4.2.5 Tractor Mounted Processor

Tractor mounted processors are mounted on the three point linkage of an agricultural tractor of at least 75 kW power output (Figure 3.4-7). They can handle either logs or small tree lengths. Driven rollers feed the log/tree through the machine, which also has a crosscut saw for merchandising timber into logs. It is not a high productivity machine and is more suited to small-scale forestry or to very small ad-hoc operations.

FIGURE 3.4-7: Agricultural tractor mounted processor.
3.4.2.6 Processor and Harvester Heads

Both processor and harvester heads have the ability to perform a variety of functions that are very similar, even identical (Figure 3.4-8). The difference lies primarily in the application of the head, and to a smaller degree, in the technology on the head. A head used for felling and processing is referred to as a harvester head, while a head that is purely used to add value to an already felled tree is referred to as a processor head. From a technology point of view, the following subtle differences may be found (Figure 3.4-9 (a)):

- A harvesting head needs to have a felling saw (usually a bar-saw). Not all processors need one. Most harvesting and processor heads however have a saw on the base (bottom) of the head, when the head is lifted into its upright position.

- A harvesting head needs to have a function that can lift the head into an upright position to fell standing trees.

- Some processor heads have an optional “topping saw”. This is an additional bar saw mounted at the top of the head that helps cut short log lengths from the last section of the stem. This feature will often not be found on a harvesting head.

![Figure 3.4-8: Purpose built harvester head, processing at roadside landing.](image1)

![Figure 3.4-9(a): Harvester head with topping saw, de-branching knives and measuring wheel shown.](image2)
• Processor heads have slightly different de-branching knives. The knives for a processor head have slightly elongated tips, allowing them to pick up trees from the ground for processing versus the knives of a harvester head that are designed to just wrap around a tree (Figure 3.4-9 (b)).

![Debranching knives profile: Harvester head](image1)

![Debranching knives profile: Processor](image2)

**FIGURE 3.4-9 (b): De-branching knives profile of a harvester head and a processor**

Processor heads are usually included in fully mechanised processing operation. However, depending on the degree of technology and the method of processing, it is still possible for labour to be involved in the operation. This is normally where people would need to feed the processing machine and guide the trees or logs once processed. However, most processors have one operator who works from the confines of an enclosed cab. This results in a safer operation as the operator is less exposed. The use of processors results in higher technical labour productivity (TLP). Technical Labour Productivity is a simple yet effective measure of the number of labourers used for an operation. It is calculated by dividing the total system output by the total amount of man-days required to produce it.

Harvester or processor heads are mounted at the end of the stick boom of the carrier and have the following components (Figure 3.4-10):

- Felling/cross-cut saw and de-branching/debarking/grabbing arms/knives;
- Two to four feed/debarking rollers either track type rollers or wheel type rollers with the following features:
  - Thumb nails for an aggressive grip used on trees with thick bark;
  - Spikes for an aggressive grip but with lower damage to cambium;
  - Ridges and grooves (sometimes helically orientated on the roller) for debarking;
  - Chains for a fairly aggressive grip without cambium damage.
- Measuring wheels and topping saw.

![Feed/debarking rollers](image3)

**FIGURE 3.4-10: Feed/debarking rollers.**

Two examples of single-grip heads with different feeder rollers are shown in Figures 3.4-11 is a processor head and (b) is a harvester head.
Processor heads can be placed on various carriers. Processor heads can be mounted in different ways, depending on the type of head and the carrier. Most processors are mounted on the furthest point of the stick boom of an appropriate carrier. The attachment mount is similar to that of a loader grapple, which allows the attachment freedom of movement (to dangle) and to rotate. This form of attachment is sometimes referred to a dangle head. There are however processor heads that have a fixed mounting which can rotate in both a vertical and lateral plane (Figure 3.4-12).

Most modern heads are equipped with computer software that will assist with the log making process. The more complex the required log sorts (classes) are, the more value computerised tree optimisation software can add to the merchandising process. Single length pulp logs will have different (and less complicated) log specifications than multiple length and diameter saw log classes.

It is important to correctly match the processor head to its intended application. The tree size (diameter, length and weight) and its branch structure and form primarily determine the size and type of the processor head required. Big branches and branch whirls require high roller feed forces and feeding speeds to achieve satisfactory debranching quality. Putting a small tree into a large head is unproductive as the feeder rollers struggle to grip the small diameter stem and the debranching knives struggle to close sufficiently around the bole of the tree to enable flush
debranching. With big trees in small heads, the tree is physically too big for the de-branching knives and feeder rollers to grab it. Very large trees with big irregular branches are unsuitable for harvester or processor heads.

Due to the level of sophistication of these heads, the number of moving parts, and the various hydraulic and electronic components, they tend to be sensitive to harsh operating conditions and operator abuse. Operator training for good operational techniques is necessary. Preventative maintenance is critical.

### Processor/harvester attachments (heads)

#### Productivity indices

- Number of operational steps (tasks) combined (e.g. only debarking, or de-branching, debarking and merchandising)
- Species e.g., branchiness and form
- Piece size
- Landing constrains
- Quality requirements (especially bark and branch stubs)

#### Advantages

- Combines various tasks to be combined and mechanised
- Increase operational speed and number of shifts and hence productivity

#### Disadvantages

- High ownership and operating costs
- Some perceived quality limitations
- Needs larger timber volumes to be viable
- Mechanical availability can be a challenge

#### Limitation/application matrix

<table>
<thead>
<tr>
<th>Limitation/application matrix</th>
<th>Processor/harvesting heads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%) – up</td>
<td>Carrier dependant</td>
</tr>
<tr>
<td>Slope (%) – down</td>
<td>Carrier dependant</td>
</tr>
<tr>
<td>Ground condition</td>
<td>Carrier dependant</td>
</tr>
<tr>
<td>Ground roughness</td>
<td>Carrier dependant</td>
</tr>
<tr>
<td>Load size (m$^3$)</td>
<td>Carrier dependant</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

### 3.4.2.7 Debarking Processor Head

Some heads are purpose built for specific applications, such as debarking of eucalypts and wattle (Figure 3.4-13). The head is built with only feed rollers and debranching arms/knives. The processor operates by lifting the trees off the ground with the grapple arms/debranching knives. The stem is the fed forwards and backwards through the head, using the feed rollers until all branches and bark has been removed. These heads are slightly lighter and require lower hydraulic feeds and pressures, which implies that lighter carriers can be used. These heads can however be fitted to various carriers, but are most commonly found on modified excavators.
Debarking processor

Productivity indices

- Number of processes done (e.g. de-branching, debarking, etc.)
- Piece size
- Species
- Branch size and arrangements and bark adhesion strength
- Quality requirements, i.e. debarking standards, branch stubs, allowed cambium damage, etc.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combines processes</td>
<td>Higher operator skills required</td>
</tr>
<tr>
<td>Fewer operational steps and machines required</td>
<td>High capital outlay</td>
</tr>
<tr>
<td>Improves de-barking quality compared to manual processes</td>
<td>Requires an additional system to fell and merchandise</td>
</tr>
<tr>
<td></td>
<td>High through-put required</td>
</tr>
<tr>
<td></td>
<td>Trees can become dirt contaminated</td>
</tr>
</tbody>
</table>

Limitation/application matrix

<table>
<thead>
<tr>
<th>Debarking processor heads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower (% – up)</td>
</tr>
<tr>
<td>Shower (% – down)</td>
</tr>
<tr>
<td>Ground condition</td>
</tr>
<tr>
<td>Ground roughness</td>
</tr>
<tr>
<td>Load size (m³)</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.

3.4.2.8 Mechanical De-branching

*Stroke delimbers or (stroke-boom delimbers)* are track-based carriers that have been equipped with a complex array of booms and grabs that enable it to remove branches from the trees,
top the tree and optimise the tree into logs assortments. The delimer is able to process more than one tree at a time if the trees are small with few small branches.

The stroke delimer has a sliding boom (stroke-boom) with a grapple at the end. The grapple is used to pick up and grip the tree until a second fixed grapple grabs the butt of the tree. The boom is then extended along the trunk of the tree with the grab enclosing the trunk. The arms of this grab effect the de-branching action, similar to the arms of a harvester head. A topping saw, tops the tree when the minimum diameter point is reached. The bole of the tree is then drawn into the machine (pulled back by the retracting grab) and the measuring equipment determines when the right log length is reached, activating the cross-cutting saw. Stroke delimers are usually used on roadside landings and are fed with skidders (full-tree method) (Figure 3.4-14).

Pull-through (static) de-branchers are stationary de-branchers which are not capable of processing on their own. They are used in conjunction with another machine, often termed the auxiliary machine which is usually a skidder or loader. These auxiliary machines pull the tree lengths through the debranching knives. These machines are robust and less capital intensive. A loader however, must usually work in close proximity, which in turn reduces its versatility. Pull-through debranchers have relatively low productivity and are unsuited to handle many smaller stems at one time (multi-stem operations). They are also not an option when high quality debranching is required.

Internationally, there are many other processing methods used. These include:

- The bark is removed from very big *Eucalyptus* logs by running the outer edge of the grab (usually a crab-grab) of the loader along the log and/or dropping the log from a height to loosen the bark. This is only really viable in over-sized timber.
- Drum debarking includes large, high production and expensive machines that can process many logs at once. A dropping and tumble action allows logs to rub and hit against each other, and the drum walls, to remove bark.
- Cradle debarkers which are similar to a trough but rotating chains turn the logs which causes friction between the logs resulting in the bark being removed.
- High-pressure water blast the bark off rotating logs as they pass through the water jets.
- Gate debranchers where a grapple skidder reverses tree lengths through a steel grid with vertical bars to remove branches. It is a crude form of de-branching and will usually require re-work.
3.5 Handling Equipment

Handling refers to the activity where timber products are being handled primarily on landings and/or depots, either for stacking, sorting or loading purposes. There is a wide range of handling equipment available to suit almost any application. The type and size of the machine used will depend on the following:

- The terrain, operating conditions and layout of where handling takes place;
- Piece size and dimensions;
- Volume to be handling;
- Transport configurations.

3.5.1 Self Loaders

A self loader has a crane and grapple mounted to the chassis of the truck. It is either mounted just behind the cab or at the rear of the truck where it can reach both the truck and a potential trailer. A self-loader can operate independent of the rest of the harvesting operation and is therefore flexible, but has a reduced payload capability because of the additional mass of the crane.

<table>
<thead>
<tr>
<th>Loaders</th>
<th>Productivity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grab size</td>
</tr>
<tr>
<td></td>
<td>Piece size</td>
</tr>
<tr>
<td></td>
<td>State of conversion</td>
</tr>
<tr>
<td></td>
<td>Operating radius</td>
</tr>
<tr>
<td></td>
<td>Terrain conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can load timber from scattered locations without additional cost of operating a loader</td>
<td>Operator is exposed to the weather</td>
</tr>
<tr>
<td>Suited for low-volume operations</td>
<td>Reach and loading capacity of crane is less since they are smaller than independent loaders</td>
</tr>
<tr>
<td></td>
<td>Reduced payload capability because of the additional mass of the loader</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Limitation/application matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Debarking processor heads</strong></td>
</tr>
<tr>
<td>Slope (%) – up</td>
</tr>
<tr>
<td>Slope (%) – down</td>
</tr>
<tr>
<td>Ground condition</td>
</tr>
<tr>
<td>Ground roughness</td>
</tr>
<tr>
<td>Load size (m$^3$)</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.5.2 Three-wheel Log Loader

The three-wheel loader is a common sight in South African forestry harvesting operations and is used in a variety of applications such as loading, off-loading, stacking and sorting (Figure 3.5-1). It has a fixed angled boom fitted with a grab of limited reach. Visibility of the driver is restricted and the boom’s relatively short reach limits high stacking and loading of trailers from behind. They are well suited for short wood handling though. The three-wheel loader is not designed to pull trees and such activities will eventually damage the wheel motors and boom and grab linkages. The three-wheeler is characterised by limited ergonomics and operator protection systems compared to most modern harvesting handling equipment. Most have limited cab enclosure and also no certified ROPS, FOPS and OPS structures. The operator sits close to the engine and is exposed to high noise and heat exposure levels for extended periods of time. In addition the operator is exposed to dust and the elements during operations.

The three-wheel loader requires a reasonable level working terrain and can cause extensive damage to the ground due to the churning up of the soil during manoeuvring. These machines should be limited to working on landings, depots and sidings. They should not be used on forest roads due to its aggressive wheel action resulting in damage to the road surface in wet conditions. Although three-wheel loaders are not the safest or most comfortable machine, they have been very popular in South Africa.

<table>
<thead>
<tr>
<th>Three-wheeled loader Productivity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Grab size</td>
</tr>
<tr>
<td>• Piece size</td>
</tr>
<tr>
<td>• State of conversion</td>
</tr>
<tr>
<td>• Operating radius</td>
</tr>
<tr>
<td>• Terrain conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ease of maintenance</td>
<td>• Reach is limited</td>
</tr>
<tr>
<td>• Economical for low volume operations</td>
<td>• High soil impacts</td>
</tr>
<tr>
<td>• Highly mobile and manoeuvrable</td>
<td>• Poor safety and ergonomic design</td>
</tr>
<tr>
<td></td>
<td>• Small grapple size</td>
</tr>
<tr>
<td></td>
<td>• Road and landing surface damage especially in wet conditions</td>
</tr>
</tbody>
</table>

3.5.3 Track Based Loader (or Swing Loader)

The most common type of track based (or swing) loaders in South Africa is the excavator based loaders (Figure 3.5.3-1). A variety of options are available in terms of size and under carriage selection. Larger excavators are capable of lifting heavier loads to greater heights. As a general rule, the mobility of an excavator is restricted and they are not suited to travel whilst under load. Consequently, they are better suited to static operations, offloading from truck to stack or from truck to mill feed deck. The slewing (the turning of the turn table or upper structure) operation of an excavator allows for speed of operation and results in no damage to surface areas whilst working. The turning (using the tracks to turn the entire machine) action of an excavator can cause significant soil disturbance and should be minimised.
Track based loaders work well on high volume operations in confined space. They have the advantage over more sophisticated loaders that they are less expensive to acquire and there is a commonality of parts with their civil works counterparts. Dedicated forest loaders (track based) distinguish themselves primarily in the following from their excavator based counterparts:

- High ground clearance;
- Different track configuration (double grouser versus triple grousers);
- Purpose designed boom configurations made for lifting;
- Purpose made hydraulics to improve swing torque and also allow driving while handling;
- High cab location to improve visibility over high loads.

Dedicated machines are more expensive to acquire, but generally are better suited to the specific forest application, especially if the operations is in-field or on a landing. They also offer the added functionality of providing additional hydraulic ports for ancillary equipment without affecting its performance.

<table>
<thead>
<tr>
<th><strong>Track based loader</strong></th>
<th><strong>Productivity indices</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Grab size</td>
</tr>
<tr>
<td></td>
<td>• Piece size</td>
</tr>
<tr>
<td></td>
<td>• State of conversion</td>
</tr>
<tr>
<td></td>
<td>• Operating radius</td>
</tr>
<tr>
<td></td>
<td>• Terrain conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Can work under more adverse conditions than wheeled loaders</td>
<td>Track machines are more expensive to maintain</td>
</tr>
<tr>
<td>Provides a more stable platform</td>
<td>Excavator based loaders are not suited to travel while under load</td>
</tr>
<tr>
<td>Better suited to static operations</td>
<td>Cannot be moved from landing to landing rapidly</td>
</tr>
<tr>
<td>Can be used to shovel log</td>
<td>Needs large volumes to make them viable</td>
</tr>
<tr>
<td>Can travel over unprepared surface adjacent to road</td>
<td></td>
</tr>
<tr>
<td>Has further reach</td>
<td></td>
</tr>
<tr>
<td>Can work effectively on high embankments</td>
<td></td>
</tr>
</tbody>
</table>
3.5.4 Truck Mounted Loader

The truck mounted loader consists of a knuckle-boom crane loader driven by a slave engine fitted to an on-road carrier or truck (Figure 3.5-3). These loaders are typically mounted on forestry specific trucks. The loader can be powered by the carrier’s engine via a PTO (power take-off), although it is more common for a separate (or slave) engine to be fitted to the loader on the back of the truck. Truck mounted loaders can be supplied with cabs with improved ergonomics and safety for the operator. The truck is equipped with out-riggers (hydraulic side stabilizers) that prevent the truck from falling over when loads are swung over the side of the vehicle.

Mobility between handling zones is a major advantage of this type of loader. It is possible for one truck mounted loader to service a wide geographic area of operations. The loader is normally positioned between the log stack and the truck to be loaded. It is not mobile when loading. Another advantage of the truck-mounted loader is that it has a low impact on the forest road or surface of the landing site. It is therefore ideal for roadside operations.

**Truck mounted loader**

**Productivity indices**

- Grab size
- Piece size
- State of conversion
- Operating radius
- Terrain conditions

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Improved ergonomics and safety for operators</td>
<td>• Not mobile while loading</td>
</tr>
<tr>
<td>• Highly mobile</td>
<td>• Operator exposed to the elements, poor ergonomic crane seating</td>
</tr>
<tr>
<td>• Minimal impact on landing or road surface</td>
<td>• No operational flexibility needs high volumes to justify</td>
</tr>
<tr>
<td>• Has a good reach</td>
<td></td>
</tr>
</tbody>
</table>
3.5.5 Grapples

Various types of timber grapples are available. Grapple selection is a function of the type of loading equipment, the type of product (state of conversion), the expected terrain and the required volume throughput. Some of these grapples are discussed below (Figure 3.5-4).

- **Pulpwood grapples** are round grapples that are designed to take a number of logs in one grab. They are typically designed for short logs and have the ability to open wide. Their “tines” are designed to glide between the logs in order to take grabs out of big log piles without damaging the timber or disturbing the pile.

- **Big wood grapples** are designed to pick out individual trees and big logs from sorting decks. They are primarily used for sorting of timber, where single logs have to be taken from a selection for sorting or loading. They have pointed tines, which can damage timber.

- **Combi grapples** combine the functionality of pulpwood and big wood grapples. They sacrifice some of their specific functions, and are designed to be a more all-round grappler for flexibility and operational versatility.

- **Tree length grapples** are also referred to as heel boom loaders. A “heel” is an attachment fitted to the point of the stick-boom, that allows the operator additional control over the handling operation (Figure 3.5-5). This can be a static heel (one that the operator cannot move) or a live heel which has an additional hydraulic tilt functions on the “heel.” A heel-boom is able to handle longer lengths or tree lengths.

![Figure 3.5-4: Small- (left) and big wood (right) grapples.](image)

![Figure 3.5-5: A static heel loader](image)
• **Butt ‘n Top grapples** are grapples specifically designed with two sets of tines mounted at a distance from one another. These grapples have been primarily designed to load tree lengths. The grapple offers good tree stability that allows the operator to turn the load mid-air. They are used mostly in multi-stem tree length transport operations where full payloads can only be achieved if the butt ends and the tops of the trees can be mixed to ensure correct axle loading distributions. These grapples need to have at least a 25 to 30 tonne carrier to be used effectively.

### 3.5.6 Front-end-loader

A front-end loader is a self propelled wheeled machine equipped with log forks and are used on depots or at processing plants (e.g. mills) to load or unload trucks and for handling (Figure 3.5-6). They are also useful for handling very big timber. Front-end loaders tend to load faster than a knuckle boom loader, but require more space within which to operate in. Their mobility also makes them better suited for sorting logs by grade and/or length. These machines are mostly used in high volume off-loading operations or to feed logs from the sorting yard, where distances are a bit further.

Front-end loaders can be fitted with various types of timber grabs, depending on the specific application. The biggest advantage is their ability to travel reasonably fast over distances of up to 400 metres. Front end loaders are suited to tree length, long length and short length logs. Its biggest limitation is slope and should operate on slopes less than 5%. Although capable of working on uneven and muddy surfaces, front end loaders should ideally work on large, dry, level surfaces that have been planned specifically for timber to be sorted by grade, product and size.

![FIGURE 3.5-6: A front end loader.](image-url)
### Front-end-loader

**Productivity indices**

- Grab size
- Piece size
- State of conversion
- Operating radius
- Terrain conditions

### Advantages
- Ability to operate over longer distances
- Suited to handle different products e.g. tree and long and short lengths

### Disadvantages
- Require large and level surfaces
- More suited to landings then roadside operations
- Cannot work on slopes or rough under-foot conditions
- Will damage any unhardened surfaces
- Has no reach

### Limitation/application matrix

<table>
<thead>
<tr>
<th></th>
<th>Self loader</th>
<th>Three-wheeler</th>
<th>Tracked swing loader</th>
<th>Truck based loader</th>
<th>Front end loader</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slope (%) – up</strong></td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;25</td>
<td>&lt;10</td>
<td>&lt;5</td>
</tr>
<tr>
<td><strong>Slope (%) – down</strong></td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;25</td>
<td>&lt;10</td>
<td>&lt;5</td>
</tr>
<tr>
<td><strong>Ground condition</strong></td>
<td>On-road</td>
<td>1 - 2</td>
<td>1 - 4</td>
<td>On-road</td>
<td>On-depot</td>
</tr>
<tr>
<td><strong>Ground roughness</strong></td>
<td>On-road</td>
<td>1 - 2</td>
<td>1 - 3</td>
<td>On-road</td>
<td>On-depot</td>
</tr>
<tr>
<td><strong>Load size (m³)</strong></td>
<td>&lt;0.6</td>
<td>&lt;0.8</td>
<td>&lt;2.0</td>
<td>1.5</td>
<td>&lt;3.5</td>
</tr>
</tbody>
</table>

Limitations serve as a guide only and need to be determined by an experienced professional in the context of the operation.
3.6 Maintenance and Repairs

In South Africa machine ownership costs are high due to the cost of capital. This makes replacement of machines expensive, making it important to extend machine life as much as possible through sound machine and equipment maintenance principles.

Crisis management repair and maintenance strategies equate to break-down management. Break-downs are unscheduled machine stoppages caused by one or more machine failures. Break-down management should be minimised as it disrupts production flow and negatively impacts on the entire operational system flow and hence system costs. A good maintenance strategy has a positive influence on resale value. A well maintained machine’s appearance is pleasing, which also helps shape a positive perception from prospective buyer(s).

3.6.1 Maintenance Strategy

Appropriate maintenance strategies are determined by a variety of factors, some of these include:

- Machine value;
- Replacement strategy;
- Technology level / complexity;
- The type of value chain;
- OEM representation, dealer network, warranties and part stocking;
- Equipment match to application;
- Operating costs and equipment cost;
- Machine availability and utilisation requirements;
- In-sourcing versus outsourcing of maintenance function;
- OEM warranties and extended warranty options and conditions;
- ECU based maintenance;
- Managed ratio between pro-active maintenance and repairs (breakdowns).

Managing the ratio between maintenance and repairs is important when selecting the appropriate system; i.e. to have a clear idea as to what repairs and maintenance strategy to follow. One approach would be to set aside the minimum allotted amount of non-productive time to do the ‘required’ time-based services and to work the machine to its maximum. The initial advantage will be a high utilisation, but in the long-term, it will lead to increasing down times. An alternative (and probably better) approach is to determine fixed scheduled down-time intervals e.g. for every ten hours worked, one hour of scheduled maintenance to take place; this is also known as preventative maintenance service scheduling. Scheduled down-time is that planned time when the machine is scheduled for primarily preventative maintenance. This can coincide with other scheduled down-times, e.g. refuelling. Scheduled down-time could include pre-trip inspections, weekly greasing and washing, preventative checklist and maintenance, scheduled services at 100 h, 250 h, 500 h, 750 h and 1000 h and re-fuelling.

Preventative Maintenance service scheduling (PM) is one of the components of scheduled down-time as outlined above, and is the most important aspect of the long-term reliability (or availability) of the machine. If through a proper PM strategy, the reliability can be increased by e.g. 1 %, it would, in a fully utilised system, increase the annual (or long-term) production by the same margin. Preventative Maintenance is aimed at preventing unscheduled down-times and extending machine life during its initial life, but also during a possible rebuild. It serves to reduce maintenance costs.
3.6.2 Elements of Maintenance

The following elements are part of a comprehensive maintenance strategy:

- **Scheduled oil sampling** refers to taking an oil sample from different components (e.g. gearbox, differential, engine, hydraulic pumps, etc) and sending it to a specialised laboratory for analysis. Oil sampling is an important tool in predicting failures and wear patterns and need to be performed at set machine hour intervals. Different oils may require different sampling sequences.

- **Scheduled inspections** of equipment should include a specific inspection sheet with a set inspection cycle. This may be done on various levels. For example, the operator may use one inspection daily to do a pre- and post-trip inspection, while an artisan may have a different inspection list which is executed weekly.

- **Operator and artisan training** is important if early problem detection is to be successful. Specific attention needs to be given for indicative noises, tell-tale signs of pending failure and other abnormalities. It is important that the operator is attuned to the sound of his/her equipment and that they are trained to identify odd sounds and report them.

- **Repair management**: Failure to follow up inspection reports, or oil sample reports, or the delay in parts delivery is the detail that will determine the success of the maintenance program. Another issue that needs careful attention is the quality of parts use.

- **Record keeping**: “The job is not done, until the paper work is completed”. This also applies to repairs and maintenance. Accurate record keeping of inspections, service schedules component replacements and all the relating information is critical for a long-term machine use. This will help to keep accurate records of cost, down-time and also wear cycles of individual components. It will also assist which proper information when equipment replacement decisions are made. Previous equipment acquisitions can be vindicated or proven wrong through accurate repair and maintenance records.

- **Management discipline**: There needs to be a continuous focus and effort to ensure that preventative maintenance brings long term results. This needs to be achieved irrespective of climate or operational constraints and needs to be entrenched as a management philosophy.

3.6.3 Scheduled or Prescribed Servicing

Servicing of machines refers to the execution of OEM prescribed actions and replacements at set intervals. These actions mostly serve as preventative maintenance as they are designed to extend the life of affected components. The most common task for any service is the replacement of certain oils, the replacement of certain filters and other components designed to keep contaminants from harming the main components such as pumps, engines, drive-train, etc. Different OEM’s may follow different service schedules and intervals and it is important that they are followed to the letter. Generally, failing to adhere to the set schedules and tasks may void any remaining warranty on the machine. Typically service schedules can be either:

- **Interval based**: servicing done after a prescribed amount of hours worked. The most common interval is based on 250 machine hours, while modern technology is allowing longer intervals of up to 500 machine hours for some OEM’s. This scheduling is easy to plan as daily machine utilisation is fairly constant.

- **Condition Based Maintenance (CBM) or also referred to as ECU (Electronic Control Unit) based**: The onboard ECU (‘computer’) determines the interval of services based on set measurements and threshold parameters. Planning for these intervals is a bit more difficult and need better anticipation of needed parts. Earlier purchasing of parts and hence
a larger inventory is the disadvantage, while the advantage is a much better estimation of required filter conditions and replacements. In very dusty conditions, replacement may be needed earlier and can cause substantial damage if not picked up during interval based scheduling. The ECU will accurately determine replacement time!

- **Component based maintenance**: Referring to the scheduled replacement of larger components for example a clutch. Clutches are designed with a specific amount of usable wear material after which they need to be replaced. OEM’s often have specific expectations of life expectancy, and together with oil sampling and wear measurement, the correct replacement time can be predicted. For component based servicing it is important that components are rather replaced sooner, thus maybe with a 10 or 20% wear still left. Leaving them in service too long, thus with over 100% wear, could result in consequential damage to other components.

There are different types of services that need to be performed over the life of a machine. Mostly there are three or four different service prescriptions that must be followed in sequential order. At the end of the cycle it starts afresh. These service schedules are often referred to a Service A to D or small and larger services as they required different part replacement and hence amount of labour to do. A descriptive sequence is illustrated below (Table 3.6-1).

It is important to ensure that services are done within reasonable time of the prescribed schedule. Delayed services could cause damage to mayor components, either by oil that has lost its required viscosity, or by air and fuel filters which are blocked. This will cause either air or fuel starvation, which could damage injectors, piston sleeves, etc. Doing scheduled services early can be beneficial, especially if working conditions are difficult. While there are no hard rules, a generally accepted guideline is 50 machine hours. Most OEMs will accept some delay as forestry operations are often in remote areas. Every attempt should be made to keep the delay to within 50 machine hours.

**TABLE 3.6-1: A descriptive sequence of three service schedules.**

<table>
<thead>
<tr>
<th>Actual machine hours</th>
<th>Example of three service schedule program – based on 250 hour interval</th>
<th>Example of three service schedule program – based on 500 hour intervals</th>
<th>Example of three service schedule program – based on 250 hour intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>Service A</td>
<td>Service A</td>
<td>Service A</td>
</tr>
<tr>
<td>500</td>
<td>Service B</td>
<td>Service A</td>
<td>Service B</td>
</tr>
<tr>
<td>750</td>
<td>Service A</td>
<td>Service B</td>
<td>Service C</td>
</tr>
<tr>
<td>1000</td>
<td>Service C</td>
<td>Service B</td>
<td>Service C</td>
</tr>
<tr>
<td>1250</td>
<td>Service A</td>
<td>Service A</td>
<td>Service B</td>
</tr>
<tr>
<td>1500</td>
<td>Service B</td>
<td>Service A</td>
<td>Service B</td>
</tr>
<tr>
<td>1750</td>
<td>Service A</td>
<td>Service C</td>
<td>Service D</td>
</tr>
<tr>
<td>2000</td>
<td>Service C</td>
<td>Service C</td>
<td>Service A</td>
</tr>
<tr>
<td>2250</td>
<td>Service A</td>
<td>Service A</td>
<td>Service A</td>
</tr>
</tbody>
</table>

Being ‘penny-wise’ will result in the proverbial ‘pound-foolish’ punishment. Regular and good servicing is the foundation of machine reliability! Much research and design has been invested by OEMs to ensure reliable yet cost effective machine utilisation. Taking short cuts will definitely be detrimental to the machine in the long run.
Reusable components: Components have a designed life expectancy, which is a function of material choices, design criteria, machine application, operator skill, etc. During the life of most machines some form of large component failure or scheduled replacement is inevitable. The question arises; to rebuild or replace? There is no simple answer to this, but a couple of general comments are valid:

- **Costs**: Often rebuilding is cheaper, saving on the immediate replacement costs. Depending on the age of the equipment, the wear characteristics of surrounding components and the excepted remaining life this may be a viable option.

- **Delay time**: Is often an important issue to consider, especially if the OEM does not have parts in stock and delivery is delayed. Production pressures may force a rebuild, followed by a OEM rebuild (if necessary) replacement later.

- **Reliability**: It is often impossible for rebuilding specialists to use the exact material the OEM used for the component. OEMs often have special agreements with steel manufacturers and foundries that will manufacture specifically designed steel or metal blends that are not commonly available. Sometimes OEMs do not divulge the composition of materials as it is regarded as intellectual property. This is especially true for high technology components that are exposed to high stresses. Another concern often is making use that the rebuild component complies exactly with OEM specification. Minute differences may cause considerable damage to linked components.

- The rebuilding centres level of **appropriate experience** and machines. Some OEMs have approved rebuilding centres. This applies especially to engines and transmissions.

- **OEM own rebuilds** may be best option to consider as they originally designed and build the original components.

- **Warranty** on the rebuild. Make sure that an acceptable warranty is issued, that is close to that of the original (new) component.

It is always advisable to approach OEMs with rebuilding options. Some OEMs are more lenient with rebuilding components, especially when using an OEM approved rebuilding centres.

### 3.6.4 Breakdowns

Breakdowns are those events that cause unscheduled down time. They are typically unexpected and usually cause bottlenecks and delays in production. Breakdowns can be small (e.g. bursting a hydraulic pipe) and easy to fix, or large (e.g. transmission failure) which can take weeks to repair. Breakdowns are typified by being a nuisance which require some form of management time. Often alternative arrangements are required as other production equipment cannot stand unused. Breakdowns cannot be avoided altogether! Working with mechanical components and having people intervening (positively and negatively) inevitably will lead to unscheduled down-times. The preceding content is aimed at keeping these incidents as few as possible. It is important that a concerted effort is made to determine the cause of the failure. It needs to be remembered that there is seldom a single specific cause, or ‘root cause’. Usually a failure originated at some point, but is often the result of a chain or confluence of events; the result of a failure process. The question should always be: can a similar failure be prevented? A solution orientated approach is better than a fault finding approach!
3.7 References


Chapter 4

Harvesting System and Equipment Costing

Glynn Hogg, Benno Krieg, Pierre Ackerman and Dirk Längin

4.1 Introduction

Forest engineering (timber harvesting and transport) is the most expensive component of the forest value chain. Accurate cost calculation, quotation and management are thus key ingredients for successful business within this environment. This leads to the need for a thorough understanding of the various components, formulas, underlying logic and assumptions contributing to forest operation costing. Armed with this knowledge, the forest manager should be able to estimate, with a reasonable degree of accuracy, all costs related to his/her operation. Based on these estimations, comparisons between various harvesting options can be made, planning can be improved and control of machine utilisation can be more effective (Warkotsch, 1994).

Costing can be defined as the process of identifying, calculating and recording every item of expenditure incurred in forecasted or actual purchasing, maintaining, running and supporting the administrative and management functions of an operation, followed by a breakdown of the total operating costs into cost categories per unit time (R/hr), load (R/t), volume (R/m$^3$) and/or distance (R/km). It provides management with essential information on historic, current and future situations and alternatives for operational decision-making, as well as allowing for efficient and profitable operations based on relevant information.

The three categories of cost calculation methods, in order of increasing accuracy are (Warkotsch, 1994):

1. Pre-calculations – based on rough estimates and past experience and used for planning purposes;
2. Interim calculations – based on actual expenditure and pre-calculated values;
3. Re-calculations – based on actual expenditure once the operations are past.

4.2 Time Concepts and Calculations

For a complete understanding of forest operation costs, an awareness of machine time dynamics is required. Figure 4.2-1 shows a breakdown of time from the total time available to a system into various time components.
Total Time includes all time found in a calendar for the period which is being considered (Rickards et al., 1995). It takes a day as being made up of 24 hours, an hour as 60 minutes, a minute as 60 seconds, and so on. It is not influenced by how much the machine is used; it simply takes all elapsed time into account.

- **Scheduled Machine Hours (SMH)**: All time in which some form of work is scheduled to take place (including both normal work time and overtime). Work planned for these hours can be directly or indirectly related to the task to be carried out. SMH for a shift would be equal to the total planned shift length minus scheduled breaks (e.g. lunch).

- **Available Machine Hours (AMH)**: The portion of SMH for which the machine is fit and available for work. The machine is deemed unfit for work during breakdowns, repairs, maintenance, fuelling and greasing.

- **Productive Machine Hours (PMH)**: The portion of AMH during which the machine is actually productive (i.e. AMH minus delays).

**Availability and Utilisation**

*Availability* is the portion of SMH for which a machine is mechanically fit and able to do productive work, expressed as a percentage (van Daele, 2000). It gives information on machine reliability and how well the machine is maintained by the operator, maintenance staff and agents. A high availability value is thus indicative of a machine with little downtime. An effective preventive maintenance programme and attentive operating can help to minimise mechanical delays, thus increasing availability. Availability is calculated using the following formula:

\[
\text{Availability} \ (\%) = \frac{\text{AMH}}{\text{SMH}}
\]

AMH = Available Machine Hours
SMH = Scheduled Machine Hours
Utilisation is the portion of SMH for which the machine is actually used to perform the function for which it was intended, expressed as a percentage (van Daele, 2000). It is dependent on machine availability, the working method and the operator. A high utilisation represents a machine with good availability, no work shortage and an effective usage of AMH by the operator. Low utilisation could be as a result of poor availability, poor system balancing (leading to work scarcity), poor AMH usage by the operator (e.g. operator taking too many unscheduled breaks), or a combination of these factors. For correct time usage diagnosis, therefore, utilisation should always be interpreted together with availability.

\[
\text{Utilisation} \% = \frac{\text{PMH}}{\text{SMH}}
\]

PMH = Productive Machine Hours
SMH = Scheduled Machine Hours

It is important to note that utilisation is NOT a percentage of availability. Both availability and utilisation are percentages of the scheduled machine hours (SMH). Another point to note is that utilisation can never be greater than availability, because the productive machine hours form part of the available machine hours. In an ideal world, PMH and AMH would be equal, and thus the utilisation and availability percentages would be the same (meaning complete use of all available machine hours by the operator/s), but this is never the case in reality.

Availability and utilisation calculation triangles are shown in Figures 4.2-2 and 4.2-3 respectively. To use a calculation triangle, place a finger over the category one wants to calculate. The relationship between the other two categories will now show the calculation step that is required. A horizontal relationship requires multiplication and a vertical relationship, division.

If calculating the AMH of a machine with an availability of 90% which is scheduled to work for 10 hours per shift, we would use the availability triangle. Place a finger over “AMH”. Now there is a horizontal relationship between the other two categories (SMH and Availability) so the calculation for AMH is “SMH x Availability”.

\[
\text{AMH} = \text{SMH} \times \text{Availability} \% = 10 \times 90\% = 9 \text{ hours}
\]
Similarly, if calculating utilisation for a machine with which produces 192 PMH per month, within a scheduled 240 hours, we would use the utilisation triangle. Place a finger over the “Utilisation” category (Figure 4.2-3). The relationship between PMH and SMH is vertical, so the formula for Utilisation (%) is “PMH ÷ SMH”, expressed as a percentage.

\[
\text{Utilisation (\%)} = \frac{\text{PMH}}{\text{SMH}} = \frac{192}{240} = 0.8 = 80\%
\]

### 4.3 System Cost Components

When interpreting costs, it is important to consider the system as a unit (Grobbelaar, 2000). The reason for this is that a change made to a system activity/component may have a knock-on effect (positive or negative) which will not be factored in if the system is not viewed holistically. All cost categories (Figure 4.3-1) should be individually calculated and then added together to calculate the total system cost. For simplicity, cost breakdowns for only one machine and one person have been included in Figure 4.3-1. In reality however, as many of these resources as are necessary can be added.

#### 4.3.1 Machine Costs

Machine costs include all expenses directly associated with owning and using a machine. Two types of machine costs exist; namely fixed costs and variable costs (for formulas related to these two categories, refer Appendix 4). Figures 4.3-2 and 4.3-3 show the dynamics of fixed and variable costs per year and per productive machine hour respectively.
Fixed Costs

Machine ownership leads to fixed costs. These costs are incurred whether the machine works or not. They remain constant through time, and are charged to the owner on a monthly or annual basis. As such, they are expressed on a time basis in cost calculations (i.e. R/month or R/year). Fixed costs include interest, depreciation, insurance and license fees.

**Interest:** Also known as cost of capital, interest is the cost associated with investing money in a machine. The monthly/annual value assigned to this cost is expressed as constant, although in reality it could change over time with interest rate fluctuations (depending on whether the buyer decided on a fixed or variable interest rate). There are two categories of interest; namely balanced and calculated interest (Warkotsch, 1994). Balanced interest (also known as realised interest) is the actual interest to be paid on borrowed capital. Calculated interest (also known as speculative interest) is considered as the cost of investing money in a machine as opposed to depositing it in a savings account at a fixed interest rate. For comparison purposes of machine cost calculations, the calculated rate of interest should be used.

**Depreciation:** A machine has a limited economic life for which it can operate (affected by wear and tear, maintenance, operating techniques, accidents, new technology, etc.). Once this economic life has run its course, the machine will be worth little or nothing of its original purchase value. Depreciation is a method of accumulating funds for machine replacement throughout the life of the machine by writing its original depreciable value (i.e. machine purchase price minus the price of all non-depreciable items and accessories that come with the new machine) off to an expected residual (salvage) value. The straight-line method of depreciation is one of the more commonly used calculations, depreciating machine value in equal amounts over the machine life.
**Insurance**: This cost only considers insurance directly related to the machine, and can include fire, theft and third party insurance. Medical, life and business premises insurance are not included here (these are overhead costs). No calculation for insurance cost is required, as this value is determined by the insurance provider (often as a percentage of the machine’s book or market value). This value is expressed as constant per month/annum, although in reality it decreases over time as the machine’s value diminishes.

**License fees**: These include machine registration, machine licensing (if it is to use public roads), and the operator’s driver’s licence (if applicable). Once again, no calculation is required for this expense, as the values are dictated by the traffic authorities.

**Variable / Running Costs**

Variable (running) costs are incurred when the machine is working. These costs are dependent on machine utilisation and productivity and, as such, are charged on an hourly or production unit basis. They include fuel, oil and lubricants, repairs and maintenance, tyres and/or tracks and other non-depreciable equipment and accessories.

**Fuel cost**: This cost is driven by consumption and the unit price of fuel. The higher either of these values is, the higher the machine’s fuel cost will be. Consumption is determined by engine size, load factor (how hard the work is) (Grobbelaar, 2000), machine condition and operator habits.

**Oil and lubricants**: This cost is usually expressed as a percentage of the fuel cost per productive machine hour (PMH). The reason for this is that traditional forestry machines consumed a mixture of fuel and oil. Modern technology has resulted in this no longer being the case, however, since oil and lubricant costs are relatively low, the link to the fuel cost has stayed. Oils and lubricants in modern forestry equipment include engine oil, transmission oil, final drive oil, hydraulic oil, grease and filters. Factors influencing consumption of these items are the type of machine employed (e.g. equipment with complicated hydraulics leads to a higher oil consumption than equipment with simple or no hydraulics), environmental working conditions (temperature and dust) and maintenance.

**Repairs and maintenance**: This cost includes all money paid to keep the machine in running order. It incorporates all services, repairs, maintenance work and spare parts associated with this role. It is generally calculated using a “Repair and Maintenance factor”, which is a percentage of the machine purchase price over the life of the machine. As the machine gets older, repairs and maintenance will become more frequent and this cost will increase. The percentage is generally taken from experience, estimated, or can be calculated. If calculated, the anticipated repair and maintenance cost is divided by the machine purchase price, and the answer expressed as a percentage.

**Tyres and/or tracks**: Tyre and/or track life is usually shorter than machine life, meaning replacement has to be factored into machine costing. As such, these items are classified as non-depreciable items (they do not depreciate with the machine, but are written off over their own economic lives, according to usage). Factors influencing tyre and track life include operator driving habits, vehicle speed, operating conditions (slope, rough terrain), machine load (hardness of work) and maintenance (tyre pressure and track tension monitoring and other care). One should take note here that the term “tracks” refers only to tracked machines. Tracks and/or chains mounted on the tyres of wheeled machines are not costed here, but treated as non-depreciable ancillary equipment.

**Non-depreciable ancillary equipment and accessories**: Items such as cables, sliders, cutting chains, cutting bars, delimming knives, tyre chains, etc. which have to be replaced during the machine’s economic life make up this category. Like tyres and tracks, these items are classified as non-depreciable because they do not depreciate over time with the machine, but are
consumed according to their usage. Expected economic lives and prices for these items can be obtained from respective manufacturers.

4.3.2 **Personnel Costs**

The term “personnel” includes both machine operators and workers. These costs include basic wages, overtime, employee fringe benefits and paid travel time (if applicable). They are usually expressed on a cost to company per man-day basis, before tax deduction. Minimum basic wage and overtime wage are determined by legislation (see the Basic Conditions of Employment Act and Sectoral Determination 12). Overtime wage is usually expressed as a percentage of the basic wage rate in cost calculations (e.g. 200% of the normal rate for Sunday and public holiday work). Fringe benefits are indirect employment costs incurred by the employee, often calculated as a percentage of the direct wages paid to the employee for normal work time and overtime. They include pension plans, medical aid, unemployment insurance fund (UIF) contribution, workers compensation and paid leave. Travel time is a transport subsidy paid to the employee. It takes travel time to and from work into account. No-one is entitled by law to this remuneration, it is a fee seldom paid which, if incurred, is only done so at the basic hourly wage rate.

4.3.3 **Overhead Costs**

Overheads include all costs indirectly related to the system. Overhead costs sometimes serve more than one harvesting system (e.g. rental for an office from which administration for two different harvesting operations is carried out). In this case, a percentage is generally assigned to the overhead cost, based how much the overhead serves the system being costed. This leads to a weighted overhead costing. For a list of some of the more common overhead costs, as well as an example of a weighted overhead costing, see Section 4.4.

4.4 **System Costing**

System costing considers all facets of an operation which contribute to its cost (i.e. all fixed, variable, personnel and overhead costs making up the system). In such costings, the final system cost is generally expressed per unit of timber output (i.e. R/t or R/m³).

Depending on the degree of model sophistication required, costing can be done on either a spreadsheet programme (e.g. Microsoft Excel) or using programmed costing software (e.g. the South African Harvesting and Transport System Costing Model). One of the biggest advantages of using these products is that formulas automatically recalculate when input values are changed, making cost adjustment an easy exercise and minimising calculation errors. The walk-through example of a harvesting system costing exercise in the sections which follow was generated using both Excel and the South African Harvesting and Transport System Costing Model. It is made up of the following steps:

1. General information
2. Individual machine costing
3. System balancing
4. Personnel costing
5. Overhead costing
6. System cost summary

7. Company-to-contractor payments

The steps listed above have been discussed in the sections which follow. One should take note here that system costing is merely a combination of several individual costings (individual machine costing, individual personnel costing, overhead costing, etc.). If a unit cost calculation is required instead of an entire system costing, one can simply focus on that component which is required (e.g. an individual machine costing of a cable skidder). Alternatively, one could make a combination of individual costs within a system (e.g. costing a cable skidder, its operator and the labour which serve it). Costing is a flexible tool which should be used to produce the information management requires in the format which is most conducive to decision-making.

4.4.1 General Information

Details of system requirements and operating conditions are listed in the General Information section (Figure 4.4-1). Hypothetical conditions and generic cost inputs have been used in the examples and figures in this section. The examples have also not included ancillary equipment or personnel to ensure, as far as possible, ease of perusal.

![FIGURE 4.4-1: General information sheet.](image)

4.4.2 Individual Machine Costing

Within system costing, a single cost calculation exercise is carried out for every type of machine to be used in the system (if it is expected that more than one unit of a specific machine will be required for a job, only one machine should be costed in this step). Costing of additional equipment serving the system (supervisor bakkie, labour transport vehicle, service vehicle, etc.) would also performed in this step. For cost categories and calculation formulas required for
individual machine costing, see Appendix 4. Figures 4.4-2 and 4.4-3 show individual machine cost calculation examples using the South African Harvesting and Transport System Costing Model and a generic Microsoft Excel costing model respectively.

![Machine name (Forwarder): EXAMPLE](image)

**FIGURE 4.4-2: South African harvesting and transport individual machine costing example.**
Table 4.4-3: Microsoft Excel individual machine costing example.

<table>
<thead>
<tr>
<th>GENERAL INPUTS</th>
<th>COST OUTPUTS</th>
</tr>
</thead>
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<tr>
<td><strong>COST INPUTS</strong></td>
<td><strong>COST OUTPUTS</strong></td>
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<td><strong>GENERAL INPUTS</strong></td>
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<td>20 %</td>
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<tr>
<td>Maintenance and Repair Cost</td>
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<tr>
<td>60 %</td>
<td></td>
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<tr>
<td>Non-depreciable Items:</td>
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<tr>
<td>Number of tyres on machine</td>
<td></td>
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<tr>
<td>8 tyres</td>
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<td>Single Tyre Cost</td>
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<tr>
<td>30,000.00 Rand</td>
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<tr>
<td>Estimated Tyre Life</td>
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<td>5,000 PMH</td>
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<td>Tyre Chains Cost</td>
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<tr>
<td>0.00 Rand</td>
<td></td>
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<tr>
<td>Tyre Chains Life</td>
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<tr>
<td>0.00 PMH</td>
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<tr>
<td>Other non-depr. items cost</td>
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<tr>
<td>0.00 Rand</td>
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<td><strong>TOTAL COST</strong></td>
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<td><strong>TOTAL COST</strong></td>
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<td>R 24.05 R 577.29 R 2,753,652.60</td>
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4.4.3 System Balancing

System balancing involves calculation of the respective numbers of equipment units required for each activity within an operation, based on production. It can only be carried out for production equipment (i.e. machines that are directly involved in one or more activities within the value chain). Balancing of ancillary equipment (supervisor vehicles, labour transport vehicles, service vehicles, etc.) must be done by the manager. When a system is balanced, it means that the combined potential production of all machines within each activity of the operation is equal to or greater than the required production around which the system is to be balanced. Balancing can be carried out based on a specific machine/activity’s production, or on a specified volume to be harvested over a given time frame (usually dictated by the mill). If no timeframe is stipulated for the balancing exercise, the system should always be balanced around the most expensive activity/machine to ensure as far as possible that its utilisation within the system is maximised (i.e. it doesn’t spend time waiting for stock).

To carry out a balancing exercise, the required system production is divided by each equipment unit’s production capability, thus establishing how many units are required. For example, in a cut-to-length operation, if required system production for the mill is 30 m$^3$/SMH, and a harvester produces 14 m$^3$/SMH and a forwarder produces 33 m$^3$/SMH, the balancing exercise will be as follows:

**TABLE 4.4-1: Balancing exercise example**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Required Production (m$^3$/SMH)</th>
<th>Unit Production (m$^3$/SMH)</th>
<th>Theoretical Number Required</th>
<th>Actual Number Required</th>
<th>System Utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvester</td>
<td>30</td>
<td>14</td>
<td>2.14</td>
<td>3</td>
<td>71%</td>
</tr>
<tr>
<td>Forwarder</td>
<td>30</td>
<td>33</td>
<td>0.91</td>
<td>1</td>
<td>91%</td>
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</table>

Theoretical Number Required = $\frac{\text{Required Unit Production}}{\text{Unit Production}}$

System Utilisation (%) = $\frac{\text{Theoretical Number Required}}{\text{Actual Number Required}}$

(decimal answer expressed as %)

In Table 4.4-1, “Theoretical number required” represents exactly how many units, operating at their individual capacities, are necessary to meet the required system production. “Actual number required” is simply a rounded up value of the “Theoretical number required”. Decimal values always have to be rounded up to the nearest whole number (rounding down would mean insufficient production potential for that activity). It is apparent that the harvesters will be under-utilised in this system. A total of 2.14 harvesters are required, so three will be purchased, meaning each harvester will only be utilised within the system at 71% of what it could be used (the rest of the time will be spent waiting for the forwarder to catch up, and waiting because the mill demand of 30 m$^3$/SMH is less than the combined equipment’s potential production of 42 m$^3$/SMH). Another way of looking at the harvesters’ under-utilisation is to say that two harvesters could work at full capacity, and the third would be under-utilised in the system by 86%. The forwarder will only be under-utilised by 9%. This 9% is also due to the mill’s requirements being lower than the production potential of the machine. For a well balanced system,
it is vital that the theoretical number required be as close to the actual number required as possible (leading to a high system utilisation value). The theoretical number required is influenced by working days per year, working hours per shift, shifts per day, machine utilisation and productivity. Increasing harvester utilisation, for example, could therefore result in only two harvesters being required and thus a far better harvester system utilisation. Realistic fine-tuning of working days per year, shifts per day, and hours per shift, utilisation and production inputs in machine costing models can often improve system utilisation dramatically, leading to better balanced systems and reduced costs.

4.4.4 Personnel Costing

As discussed in Section 4.3.2, the term “personnel” includes machine operators and workers. Identical calculation formulas are used for both. Personnel costs are simply calculated by adding together the basic wage, overtime wage, fringe benefits and paid travel time wage per man-day, as well as including any incentives the person may receive. Formulas for the respective labour cost calculations can be found in Appendix 4. One should bear in mind here the difference between paid days per annum (all days for which an employee is required to be compensated in a year) and working days per annum (days which the employee actually works; this excludes considerations such as sick leave, statutory leave, compassionate leave and days spent in training).

4.4.5 Overhead Costing

This part of the costing exercise involves listing and finding the total cost of all overheads serving the system. As mentioned in Section 4.3.3, an overhead may serve more than one system. In this case, the overhead cost is multiplied by a percentage (which represents how much the overhead serves the system being costed) to ascertain the cost that should be ascribed to the system. The formula for total overhead cost calculation can be found in Appendix 4.

4.4.6 System Cost Summary

This summary section is a compilation of all components of the system costing exercise to this point. The figures calculated in this step are the primary reason for the costing exercise being carried out. Calculation outputs generally include the number of machines, operators and labour required for each activity, as well as the number of units of additional equipment and the number of times all equipment units will be replaced. Added to this, a cost summary for the operation is also calculated, and expressed in Rands per unit time and unit timber (Figure 4.4-4).
4.4.7 Company-to-Contractor Payments

Risk, incentives and profit make up the three categories of company-to-contractor payments (i.e. mark-up) over and above the baseline system costing. Respective values for these three remunerations are agreed upon by the company and contractor during rate negotiations. They are all expressed as percentages of total system cost (i.e. percentages of the sum of all fixed, variable, personnel and overhead costs making up the system). Not all of these payment categories will necessarily be included in the rate; it is up to the parties involved to decide how they will be incorporated.

Risk payment is defined by the potential threat of unexpected situations (e.g. extended machine breakdown period, labour strike, etc.) to a system (Figure 4.4-5). Fixed costs and overheads generally carry the highest risk, personnel carry an intermediate risk and variable costs carry the lowest risk. The reason for this is that fixed costs and overheads are paid irrespective of whether or not the machine works. Factors such as labour turnover, strikes and one-month payment periods make labour a risk, but not to the same degree as fixed costs. Variable costs are only incurred if the machine works, so there is not much risk regarding these.

Due to the varying risk levels per cost category, some companies and contractors choose to assign risk percentages per cost category, allocating a higher percentage to the system’s fixed costs that to its variable costs for example. It is important to keep in mind that risk payment should be determined by looking at both the expected frequency and the potential impact of unfavourable situations.

Risk payment should not be seen as an additional profit, but as a form of insurance to be used if unfavourable situations occur.

Incentives are included in contracts as add-on bonus clauses if targets are met or exceeded. Some contracts don’t make use of incentives, but rather pay the same rate per unit timber for target excesses as for normal production, others choose to use incentives.
Profit is the payment which the contractor receives over and above the total system cost (excluding risk and incentives). This value is what makes contracting an economically viable option for the contractor. These finances should not have to be used to pay off any system costs.

### FIGURE 4.4-5: Risk, incentives and profit calculation example.

#### 4.5 Cost Reduction per Unit Timber

Costs are usually expressed per unit of timber produced. In this relationship, cost per unit time is the numerator and the quantity of timber produced in the same amount of time is the denominator. To reduce the cost per unit timber, therefore, at least one of two things needs to happen. Either machine cost per hour needs to be reduced or production per hour needs to increase, or both. Machine cost per hour can be reduced through adjustments to cost drivers (variables which directly influence machine cost, such as utilisation, working hours, shifts, etc.). Production can be increased through improved operating methods (minimising unnecessary movements and activities).

\[
\text{R/m}^3 = \frac{\text{R/PMH}}{\text{R/m}^3 / \text{PMH}} \\
\]  
Numerator \quad \text{Decrease required for } \text{R/m}^3 \text{ reduction}  
Denominator \quad \text{Increase required for } \text{R/m}^3 \text{ reduction}

In terms of the cost reduction procedure mentioned above, it is important to note that different cost categories require different changes for cost reductions. Fixed and overhead costs can be reduced per unit timber by working the machine for more hours (meaning the fixed payment amount per month is divided by more work hours, and thus more timber). This is where multiple shifts, extended shifts lengths, weekend work, etc. can become economically justifiable. Variable and personnel costs per unit timber are reduced through improved operating practices (getting more out of the machine for the same amount of input). For the same amount of fuel, for example, an operator may be able to produce more timber by eliminating
an unnecessary machine movement within a work cycle. Similarly, for personnel costs, if an operator works with improved operating techniques, his/her wage per man-day will be divided by an increased amount of timber produced for the day, thus resulting in a reduction in his/her cost per unit timber.

4.6 Conclusion

Costing is undoubtedly one of the most important management components of forest engineering. Amongst other things, it can be used for budgeting, quoting, rate discussions, alternative system comparisons, equipment replacement decisions, system monitoring, cost predictions and loan applications. Costing is, however, only useful if inputs and calculations are accurate. Added to this, a good understanding of cost categories and cost drivers is required by the manager for costs to be interpreted correctly and appropriate decisions and changes to the system can be made.

4.7 References and Further Reading


Chapter 5

Harvest Planning

François Oberholzer

5.1 Introduction

The comprehensive planning of timber harvesting operations is critical in the modern forestry company.

Planning is deciding in advance what to do, how to do it and who should do it. It involves selecting from alternative future courses of action for the entire company, or for different departments or sections within it. It attempts to reduce uncertainty to acceptable levels.

There are many different types of plans in forestry that extend over different time periods. This chapter deals with the various levels of planning in timber harvesting operations and details how to execute each level.

5.2 Objectives of Harvest Planning

Harvesting is only one element of the total forestry value chain. It is important that harvest planning does not lead to local optimisation at the expense of the greater forest engineering or forestry value chain. Therefore harvest planning cannot be carried out in isolation. The planner considers a multitude of factors and deals with a variety of stakeholders in trying to achieve the planning objectives. Planning needs to be carried out by competent people that can manage their time, are technically strong in their subject matter, are open-minded, versatile, understand what planning tools and technologies (e.g. GIS) are available, and how to get the best out of them. Additional complexities that the harvesting planner must deal with are the focus on safety, health issues, local communities, increased fire occurrences, environmental impacts and quality concerns.

The objective of harvest planning is to select and implement a harvesting system that minimises the total cost from planting to processing, but is balanced with other objectives such as environmental, quality and social issues.

There are four levels of planning; namely strategic planning, tactical planning, annual planning, and operational planning (Figure 5.2-1). Harvest planning is a holistic, continuous process, where all levels need to be considered.
5.3 **Strategic Planning** *(Timeframe: Rotation Age)*

The further a plan extends into the future, the more uncertain the planning becomes. This makes longer term planning more challenging. Strategic planning is an integral part of the strategic management philosophy. It is initiated at a corporate level, but further down the structure issues such as the market requirements and matching these with the timber resources are evaluated in practice. This ensures that the company structure blends with the set strategies by recognizing international trends in the harvesting and transport spheres (Brink et al., 1998).

The strategic plan could include decisions regarding system selection, manual versus mechanised operations, strategic alliances with certain suppliers, and long-term availability of timber.

An essential requirement for strategic harvest planning is the development of a comprehensive management plan. The harvest plan is only one part of a complete forest management plan, and harvest planning cannot be done in isolation from the overall management plan; the two are complementary and should be undertaken simultaneously by an interdisciplinary planning team that includes foresters, harvesting specialists, road engineers, conservationists and other specialists.

5.4 **Tactical Harvest Planning** *(Timeframe three to five years)*

The tactical plan is compiled within the strategic objectives set for the company. Tactical planning focuses on the macro environment.

The tactical plan allows for the balancing of terrain conditions with equipment and the scheduling of operations over a three to five year period. It is important to note that the major objective of the tactical plan is to ensure that equipment will be fully utilised over its useful life and that human resource needs have been catered for (Brink et al., 1998).
The most important aspects that a tactical harvesting plan should consider are:

- Balancing timber volume over the set time frame;
- Roads infrastructure requirements;
- Markets for logs and products;
- Selection of equipment (harvesting and transport);
- Harvesting systems and site machine matching;
- Influence of silviculture operations and environmental factors in general;
- Selection of suitable harvesting contractors if the operations are to be outsourced;
- Recruitment and training of workers / operators.

In order to carry this out effectively, information is needed on the timber resources (from strategic plan), markets (strategic plan), proximity of compartments to each other, equipment availability, equipment costs and productivity figures, terrain conditions, transport distances and transport costs and productivity.

The following steps should be considered in the compilation of a Tactical Harvest Plan:

**Step 1: Determine the needs of the customer**

The tactical planning process starts by evaluating the needs of all potential customers and identifying the market requirements and then working back to the standing tree.

Once the markets are understood and the wood resources balanced with these needs over time (both in terms of volume and value), the upstream activity planning can proceed in more detail.

**Step 2: Obtain compartment information**

A schedule of the available compartments over a full rotation of the working plan unit (plantation) is generated.

Basic compartment information used at this stage could include:

- Compartment number;
- Species;
- Working circle;
- Available Volumes (per compartment / per ha);
- Compartment area (ha);
- Compartment age;
- Average tree size;
- Stems per hectare;
- Terrain;
- Pruning height if applicable;
  - Product mixes;
  - Compartment conditions;
  - Management practices (including e.g. old stumps, planting rows, etc.).

A three to five year harvesting schedule map is essential for the planning exercise and will show:

- The Working Plan Unit that is being planned;
- The specific farms or plantations and compartment boundaries;
• The roads network, gravel source and depot locations;
• Road network with average extraction and transport distances;
• The rail and siding network (if applicable);
• Slope information.

**Step 3: Choose equipment to match the site**

Information regarding the terrain of each compartment needs to be gathered to enable decisions concerning equipment and systems acquisition. The South African National Terrain Classification System is used as the basis for these decisions. This classification system, considers three broad areas that affect ground based vehicles moving in the compartment:

- Slope;
- Ground roughness;
- Ground conditions.

Additional information such as the soil’s susceptibility to compaction and erosion are also required and could well change equipment selection that was purely based on the terrain classification.

Refer to Guidelines for Forest Engineering Practices in South Africa (FESA, 1999) for a detailed breakdown of the recommended terrain conditions associated with the various methods of felling, conversion and extraction.

Combining the above information into tables and maps provides information on where certain equipment and systems can operate and where they cannot. There will be overlap between where these systems can operate. Various possible systems are therefore selected based on the physical capabilities of the machines selected within each system and matching these with the descriptive terrain data.

The planner then proceeds to compare the various systems by carrying out in-field checks, and confirms spatially where each system can physically function.

Annual production rates should be calculated for each activity and machine in the system, and each system is then balanced. The various systems can then be compared to determine the most suitable for the company’s requirements. The final selection between the systems should not only consider cost, but also factors related to safety, environmental, quality and social issues.

An example of a five year schedule including stand data, descriptive terrain classification and functional terrain classification (systems) is provided in Table 5.4-1. In this example, a harvester and forwarder were selected for flat areas and cable systems for steep areas.
TABLE 5.4-1: Example of a basic tactical harvesting plan.

| Adjusted harvest year | Original harvest year | Compt | Spec | Ha | Vol | Ground Cond (1 - 5) | Ground Rough (1 - 5) | < 20 % | 21 % - 30 % | 31 % - 35 % | 36 % - 40 % | 41 % - 50 % | > 50 % | Wet/ Dry | Transp Dist | Harv/ Forw | Cable |
|-----------------------|-----------------------|-------|------|----|-----|-------------------|---------------------|--------|-------------|--------|-------------|--------|----------|---------|-----------|--------|
| 2009                  | 2009                  | C55   | Ppat | 12.6 | 2,509 | 1                 | 1                   | 55     | 34          | 11     | 0           | 0      | Yes      | 12      | 2,509     | 0      |
| 2009                  | 2009                  | F3    | Ppat | 31.4 | 10,091 | 2                 | 1                   | 36     | 12          | 16     | 24          | 12     | Yes      | 99      | 6,427     | 3,664  |
| 2009                  | 2009                  | F11   | Ppat | 61.7 | 14,449 | 1                 | 1                   | 35     | 25          | 19     | 0           | 10     | Yes      | 108     | 11,358    | 3,091  |
| 2009                  | 2009                  | F12   | Ppat | 44.6 | 9,301  | 1                 | 1                   | 65     | 29          | 6      | 0           | 0      | Yes      | 106     | 9,301     | 0      |
| 2009                  | 2009                  | F21   | Ppat | 19.1 | 4,212  | 4                 | 2                   | 8      | 0           | 18     | 26          | 12     | No       | 113     | 1,103     | 3,109  |
| 2009                  | 2009                  | F22   | Ppat | 11.3 | 3,284  | 3                 | 2                   | 23     | 14          | 13     | 24          | 26     | No       | 114     | 1,657     | 1,627  |
| 2009                  | 2010                  | F23   | Ppat | 24.9 | 5,469  | 4                 | 1                   | 12     | 30          | 0      | 11          | 35     | No       | 113     | 2,284     | 3,185  |
| 2009                  | 2009                  | F30   | Ppat | 32.1 | 5,158  | 4                 | 3                   | 32     | 5           | 13     | 12          | 34     | No       | 121     | 2,603     | 2,555  |
| 2009                  | 2009                  | F31B  | Pell | 6.4  | 963    | 3                 | 1                   | 0      | 0           | 0      | 34          | 59     | 7        | No      | 119       | 0       |
| 2009                  | 2011                  | F33   | Pell | 36.5 | 8,361  | 3                 | 2                   | 11     | 10          | 0      | 15          | 51     | 13       | No      | 109       | 1,718   |
| 2009                  | 2009                  | K32   | Ppat | 22.0 | 2,764  | 2                 | 2                   | 17     | 12          | 6      | 41          | 22     | 2        | Yes     | 57        | 955     |
| 2009                  | 2009                  | L6    | Ppat | 46.2 | 8,332  | 2                 | 1                   | 61     | 12          | 11     | 8           | 8      | Yes      | 33      | 7,034     | 1,298  |

Step 4: Identify wet or dry periods and associated compartments

Some compartments can only be harvested in certain seasons; this could be due to the following reasons:

- The soil conditions in the compartment become too poor for ground based vehicle movement;
- The access roads to the compartment are not suitable for wet weather traffic;
- Certain Eucalyptus and Acacia compartments only debark at certain times of the year;
- Market requirements and scheduling.

The compartments are then divided into rain season and dry season compartments. There needs to be sufficient compartments to harvest during the rainy season or an imbalance will occur in a calendar year. This could necessitate further movement of compartments within the tactical planning period. Accessibility to the compartment has a higher priority rating than access in the compartment because transport in wet weather conditions is more restrictive than the harvesting operation, especially when using depots.

Step 5: Consolidation (Grouping) of compartments

The Tactical Harvesting Plan is focused on the consolidation of compartments into felling plan blocks. Compartments should be grouped as far as possible to be able to justify road infrastructure upgrades and limit inter-compartment machine movement. The more mechanised an operation, the more critical it is to consolidate compartments, to minimise equipment relocation costs.

With consolidations, company policy guides the planner as to how many years a compartment can be moved either forward or later, from its allocated felling year. Grouping is done by optimising the following variables:

- Annual volume capacity for each harvesting system;
- Annual allocation of wet and dry compartments to allow for sufficient supplies in the wet months;
- Balanced supply of various products to the market (where relevant);
- Transport distances need to be balanced within a year and between years to ensure optimal transport fleet utilisation;
- Balancing of equipment requirements based on slope.
Step 6: Scheduling of compartments over the tactical planning period

After identification of seasonality, production figures, and the allocation of various resources, a refined harvesting schedule can be drawn up for a three to five year period.

5.5 Annual Plan of Operation (APO)

The annual plan of operations is prepared to provide the foundation for annual budgeting and also for phasing of compartments to be harvested. The first year of the tactical harvesting plan is the basis of the APO and provides all relevant information surrounding terrain conditions and harvesting systems. The tactical harvesting plan is reviewed after every year.

Monthly production figures can be used to develop a scheduling system, e.g. a Gant chart that allows a visual reference of the APO (Table 5.5-1).

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</tbody>
</table>

The APO and the tactical harvesting plan are used to schedule roads to be built or upgraded. Enough time should be allowed for roads to settle after construction or an upgrade. Generally, roads should be allowed to settle for at least six (6) months before harvesting commences.
5.6 Operational Harvest Planning (OHP)

The tactical harvesting plan and APO form the foundation for accurate operational harvesting planning. During operational harvesting planning, decisions taken during tactical planning are converted into detailed plans. A full, detailed operational plan is carried out per compartment according to the schedules in the APO. The detailed plan considers harvesting and timber transport operations, as well as the contractors required (if applicable). The information required includes a tactical harvesting plan, APO, detailed information on the compartment being harvested, equipment costs and road and rail infrastructure conditions.

The more important objectives of operational harvesting plan include:

- Identifying possible harvesting impacts;
- Ensuring harvesting system costs are minimised;
- Matching the equipment and systems to the terrain;
- Identifying special management zones (SMZ’s);
- Identifying factors which can affect the safety and productivity of people and equipment;
- Ensure good product quality.

A good operational plan will consist of:

**A planning map.** A large scale map (≤ 1:2500) that shows contours or GIS slopes in different colours as per the national terrain classification system is required. Often slope classes are grouped together to reflect the main harvesting systems terrain handling capabilities and reduce the “business” of the map. Aerial photographs are valuable for identifying physical features. Computer-based imagery has also become a popular and valuable tool. A map legend is necessary on the map and the use of colour increases the map’s effectiveness.

Information that should be shown on these maps includes:

- Compartment information such as boundaries, roads, landings and depots;
- Environmental information such as SMZ’s, streams and stream crossings, riparian areas and birds nests;
- Structures such as power lines and fences;
- Operational information such as where certain extraction equipment will operate (polygons within the compartment), direction of felling, extraction routes and transport routes;
- Safety risk areas such as sink holes, drop offs and blind or reverse camber corners on roads on transport routes.

**A harvesting document.** The harvesting document comes in many formats, with each company having its own requirements. The documents provide information which could include:

- Stand data such as tree species, tree and compartment volume, planting espacement, stems per hectare and product spread;
- SMZ’s – the management requirements of the specific SMZ’s identified;
- Safety distances and special safety zones;
- The different harvesting and transport systems used and the equipment within each system, including a brief description of each; also the expected productivity of each machine/system and the length of time it is expected to operate at the compartment, including the start and end dates;
- The markets to which the different products are going, including distances to these markets;
- The different depots that will be used with the transport distances to reach them;
• Slash management prescriptions;
• Stumps heights and stump treatments (for *Eucalyptus*, whether to coppice or not);
• Special fire protection requirements;
• Any legal considerations (e.g. power lines, servitude roads, felling next to major roads);
• A pre-harvesting agreement signed by relevant stakeholders at least two weeks before harvesting commences;
• A post-harvesting agreement signed when all the timber has been removed from the compartment, and once again when all the timber has been taken from depots and landings to the market;
• Operational checklists, audits and corrective action documentation;
• Additional information on safety evacuation procedures, demarcated areas, communications, security (e.g. timber marking), machine repairs and contingency measures in adverse weather conditions.

It is often practical to include much of the information on the map itself. Many foresters even utilise the back of the map. This makes in-field use of the information easier as the relevant information is condensed. It is important that supervisors and equipment operators are involved in the planning process.

Operational harvesting plans are carried out in steps consisting of:
1. Preliminary office work;
2. Field work;
3. Office work – production and cost information;
4. Daily production control;
5. Signing off of the compartment.

### 5.6.1 Preliminary Office Work

In this phase, the planner prepares the relevant data into a format which can be used for meaningful planning. This is carried out in the following steps:

*Step 1:* A map of the relevant compartment is sourced (Figure 5.6-1).

*Step 2:* Confirm whether all Areas of Special Interest (ASI) and SMZ’s (Special Management Zones) occurring in the selected compartments are marked. Flag those that need to be checked during the in-field reconnaissance. Check the status of ASI’s and SMZ’s and check whether any need EIA’s (Environmental Impact Assessments) or SIA’s (Social Impact Assessments) completed before operations commence in their vicinity.
**Step 3:** The species, age, Spha, tree sizes and products are obtained for the relevant compartment.

**Step 4:** Identify the relevant systems available to use in the harvesting of the particular compartment.

**Step 5:** Using industry, company and machine manufacturer guidelines, allocate the appropriate harvesting system/s to the compartment. This requires experience, which the planner needs to apply to keep the plan economical and practical. In most circumstances, apply the 80:20 rule with system allocation, but never exceed the manufacturer’s specifications for any machine. The Guidelines for Forest Engineering Practices in South Africa (FESA, 1999) can be used as a guide for equipment terrain limitations.

**Step 6:** Draw up a draft operational planning map considering the harvesting system/s that have been allocated and matched to the topography of the compartment. The following sequence must be followed:

- Identify the entry and exit point for transport equipment to and from the compartment. Indicate the directions with arrows (→) on the roads shown on the map. Avoid unnecessary transport distances.
- Identify the cut-off points for the various systems to be used in the compartment, if more than one will be used.
- Identify possible landing and depot locations, considering both the constraints of extraction equipment as well as loading and turning space for log trucks.
- Draw in preferred extraction routes to the various landings or depots. Consider the physical constraints of the extraction units when drawing in the extraction routes. Avoid, as far as practicable, routes across slopes, sharp corners, river crossings and other obstacles that have been identified. This designated skid trail planning will ensure trail locations that match equipment selection, harvesting method and transport direction. Use up arrows (↑’s) with the point of the arrow (↑) indicating the direction of travel with a load.
5.6.2 Field Work

Field work refers to the verification of the draft plan in the field. This is the most time-intensive phase as it can take up to 80% of the total planning time.

The planner selects at least two of the following three employees to be represented during the field reconnaissance exercise; the supervisor, the extraction machine operator, and the felling machine operator. The team verifies the draft plan by consensus. The interaction of any activity on the others must drive the team to reach workable and practical solutions.

The activities must be completed in the sequence described below:

1. Confirm that the entry and exit routes for the transport equipment are usable and that the roads leading into the compartment are in an acceptable condition.
2. Check that the roads bordering on the compartment are in an acceptable condition for the transport mode being used.
3. Inspect the cut-off points for various systems. Measure the slopes wherever in doubt and amend the cut-off points on the map. Mark/flag system boundaries in-field.
4. Inspect the position of each landing on the draft map and amend, where necessary. Landings must consider transport access, merchandising activities required on the landing and access to the landing by the extraction equipment. Mark/flag all landings infield.
5. Locate and mark designated skid trails in locations that minimises adverse environmental impacts (Figure 5.6-2).
6. Inspect the position of each extraction route and amend where necessary. Extraction routes must compliment the physical constraints of the equipment being used and lead into selected landings. Mark/flag extraction routes in-field.
7. Once extraction routes have been established, felling direction must be considered. Identify any special felling techniques that will be required to achieve the required felling direction, where applicable.
8. Identify and mark a safe area where machines can be parked during high fire risk days.
9. Identify and mark an area where refuelling vehicles and other equipment can be kept.
10. Ensure that landings are selected that provide sufficient working space.

FIGURE 5.6-2: Designated skid trail layout patterns (adapted from FAO, 2004).
11. Keep extraction routes to less than 15% of the total area of the compartment.

12. Do not draw in felling directions that could lead to trees falling into rivers, indigenous forests and any other SMZ’s unless unavoidable and properly motivated.

13. While conducting the in-field reconnaissance, consciously look for the following:
   - nesting trees of birds of prey
   - historical, archaeological and paleontological sites
   - SMZ’s
   - Other obstacles that would influence the harvesting operation, such as sink holes, large rocks and wet patches.

14. If any of the factors in the bullet above are identified during the field reconnaissance, then mark these on the map (Figure 5.6-3).

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**5.6.3 Office Work – Production and Cost Information**

This activity refers to finalising the map, the calculation of production standards for the different equipment in the system/s, the balancing of the activities in the system/s and a cost calculation of the harvesting operation. This activity is completed by the planner on his/her own, without the remainder of the planning team.

The following two activities occur:

**Finalising the map.** The map is refined after the field visit. Special instructions to the forester, supervisor or operator can be indicated on the map. As shown in (Figure 5.6-4), harvester operators can be instructed to begin the compartment by clearing the bottom road first (label 1), then the bottom boundaries (label 2), and so forth. After boundaries have been cut open, the wet area at the bottom of the compartment (label A) should be harvested first, provided the area did not become water logged after rains.
Production and cost information. The following sub-activities occur:

- The production levels of each of the pieces of equipment in the system/s, are determined using the APO information and the relevant Best Operating Practices (BOP’s) for each piece of equipment;
- The most expensive/highest production machine is selected and the other equipment around this machine;
- The daily capacity of the system/s is determined;
- The period required to complete the total operation is calculated;
- The cost of the operation is calculated using the relevant in-house costing system/policy;
- The completed operational harvesting plan is signed off according to in-house policies and procedures (pre-harvesting agreement).

Legend to map symbols:
1. Open the boundary along the road first to create stacking space;
2. Open the edge with the SMZ second to ensure difficult trees are dealt with;
3. Open the edge with the SMZ third to ensure difficult trees are dealt with;
4. Open the edge with the neighbouring compartment fourth to ensure boundary is created that will not be crossed;
5. Open the boundary along the road fifth to create stacking space;
6. Open the edge with the neighbouring compartment sixth to ensure boundary is created that will not be crossed;

A. Fell low lying area next to SMZ first while weather is favourable;
B. Fell adjacent block second – minimise unnecessary vehicle travel time;
C. Fell adjacent block third – minimise unnecessary vehicle travel time;
D. Fell adjacent block fourth – minimise unnecessary vehicle travel time;
E. Fell adjacent block fifth – minimise unnecessary vehicle travel time;
F. Fell adjacent block sixth – minimise unnecessary vehicle travel time.

5.6.4 Daily Management and Production Control

This activity refers to the daily management of the operation and the measurement of actual production against that which was planned. In-field deviations from the plan occur regularly, due to changing weather, customer demands and machine breakdowns. The necessary amendments need to be made on the operational harvesting plan, should any significant changes occur. Either the harvesting supervisor or the harvesting forester can make these changes. The weather, fire status, deviations to plans, safety risks and environmental risks are all examples of things that need to be monitored due to their effect on the plan.

Often, a formal harvesting operational audit is carried out while harvesting is taking place. This formal process is used to supplement the normal management visits, as important factors could easily be overlooked.

5.6.5 Signing off of the Compartment on Operational Harvesting Plan

Once the harvesting operation has been completed, the operational harvesting plan is signed off (post-harvesting agreement) to indicate that the compartment is ready to be handed over to the manager responsible for replanting it. Any non-conformances (e.g. utilisable timber left in-field) will result in the compartment not being signed off and corrective actions issued.

5.7 Conclusion

Every company has their own planning policies and procedures. Some require different levels of planning intensity. However, the planning principles remain the same. Different machines and systems all have their own planning complexities. The forester will be expected to research the machines and systems used and become familiar with their operating peculiarities.

5.8 References


Chapter 6

Environmental Impacts of Ground Based Harvesting Systems

Christie Potgieter

6.1 Introduction

With stringent environmental legislation and most of the plantations in South Africa carrying some form of environmental certification, the identification of environmental impacts of a harvesting operation has become a necessity during daily operations. With the limited growth potential of the forest industry in South Africa due to legislative limitations and growing pressure on the availability of suitable land, it is more important than ever to protect the country’s natural resource base for a sustainable future forest crop.

Environmental impact not only pertains to the natural environment; and when assessments are made the environment should be viewed in all its facets, which include the natural environment, social environment as well as the economic environment incorporating management goals, policies, procedures and legislative parameters.

Best Management Operating Practices (BMOP) have not always been considered part of normal operating procedures and were thought to be implemented specifically to prevent or minimise damage to the physical environment. This is no longer the case, and with recent developments, Best Operating Practice guidelines have become part of day-to-day operating procedures, and are aimed to address all aspects of the operation. The concept behind BMOP is that such practices should minimise any deviations in forest development from the range of conditions following natural disturbance. The purpose of BMOP is to provide resource managers with options to consider when operating on sensitive sites. The BMOP included in most guidelines should not be considered the only management practices that may be used to prevent, minimise or mitigate site damage.

Best Management Operating Practices aim to:

• Minimise negative environmental and other impacts associated with harvesting operations;
• Optimise timber harvesting production rates;
• Maximise rate of timber growth in plantation;
• Protect the health and safety of workers and the public (Elias, undated);
• Minimise the risk of environmental damage during harvesting operations on soft ground. This may increase operational costs but can be justified by the need to protect soils and prevent erosion and subsequent siltation of watercourses;
• Implement preventive rather than rehabilitation methods;
• Match harvesting systems to site conditions to reduce the risk of soil damage and water pollution;
• Update some previously identified issues and describes some new techniques (Murga-troyd, 2005).

6.2 Environmental Guidelines

The environmental statement of the South African Forestry Industry as set out in the 2002 Environmental Guidelines for Commercial Forestry Plantations in South Africa reads as follows:

Objectives: The South African Forestry Industry is committed to Integrated Environmental Management (IEM) to ensure that:

• Development takes place in the most economic and environmentally acceptable way;
• Resources are managed in a manner which will ensure the sustainability of the forestry enterprise;
• People on whom the Industry depends may work in safety and live under conditions of acceptable quality.

Principles: The South African Forest Industry is committed to upholding the Principles that are contained in the National Forests Act (Act No. 84 of 1998) and which are the driving force for Sustainable Forest Management (SFM) in South Africa.

Values: Some of the values associated with the Principles of Sustainable Forest Management are:

• Soil quality, quantity and nutrient status;
• Water quality, quantity and wetland habitat;
• Biological diversity and ecosystem function;
• Forest Health Protection against pests, diseases and fire;
• Economic Optimal yield and value of timber and non-timber products and services;
• Social Occupational health and safety, training and human resource development, access to resources and opportunities and cultural values;
• Research improved productivity and environmental management;
• Legislation compliance.

6.3 Environmental Considerations

Timber harvesting in forest plantations can cause damage to the following:

• On soil by soil compaction, soil erosion and hydrocarbon spills (which leach out into water bodies);
• On remaining stand or future trees by tree root damage, tree stem damage and tree crown damage (Loeffler, 1989 in Elias, undated);
• On harvested timber by lower quality of harvested timber and harvesting waste.

According to Elias (undated), severe damage on soil and the remaining stand will cause further extensive environmental damage in the form of infertile soil (soil erosion, compaction), reduced
water quality (sedimentation), and will decrease the quality and productivity of the future stand.

For sustainable forest management of plantations, soil compaction and damage to tree roots, tree stems and tree crowns caused by timber harvesting should be minimised as much as possible (Elias, undated). This can be achieved through:

- Landscape planning of plantation area;
- Good road network system (haul road and skid road network) and good harvesting plan;
- Correct and accurate marking of trees for thinning;
- Wide rubber-tires or tracks and low impact timber harvesting technologies;
- Implementation of directional felling, felling pattern and improved timber harvesting techniques;
- Use lighter, more flexible machines, which have a low specific ground pressure;
- Implementation of reduced impact techniques (e.g. bunching by choking method, winching as long as possible by tractor winch and skidding only on skid trail);
- On sensitive sites (e.g. moist or wet site), limiting the machine movement on the skid trails and reinforcement of the skid trails with a layer of debris from harvested trees;
- Education and training.

6.3.1 Site Productivity and Sensitive Sites

Site productivity is a key indicator of forest ecosystem health. In order to maintain site productivity, attention must be paid to the interaction between the physical properties of the site. Examples of these properties could be soil texture, moisture, fertility and topography with environmental conditions, weather, season and the types of forest operations which are practiced on the site. The impact of the same treatments on different sites will differ depending on the sensitivity of the site to disturbance under a similar set of environmental conditions. Damage due to forest operations can affect long-term site productivity. The contributing factors (site, operations and environmental conditions), their interactions and their potential impacts on the environment are described in various publications. When selecting Best Operating Management Practices, there are general principles to understand, site-specific information to acquire and operational factors to consider. All sites are subject to alteration by forest operations. Under most conditions and standard operating practices, the alterations to these sites do not result in site damage.

The term “sensitive sites,” as used in general guidelines, refers to those sites which have a high probability of one or more types of damage occurring if managed according to standard operating practices. Some sites become more sensitive to damage under a specific set of environmental conditions. For example, loamy soils are sensitive to rutting when saturated. Other sites may be susceptible to certain types of damage regardless of environmental condition. Very shallow soils over bedrock are often susceptible to significant nutrient loss as a result of full tree harvesting, if forest residue is not returned in-field. In most cases, sensitive sites can be operated on without causing damage through site-specific planning and implementation of forest operations.

The use of skidding equipment in timber harvesting can cause severe impacts on soil but has many advantages such as extracting long and heavy logs, optimum use of available harvest time and reduction of defects in timber production quality and therefore an increase in the added value of the timber (Naghdi, 2009).

Effective management of machine mobility, control of site disturbances and moderation of potential site damage due to harvesting equipment traffic require characterisation of the effects of the site-machine interaction. This interaction should take into account the influence of
machine variables on a wide range of forest terrains that may be encountered. One aim is to understand the behaviour of the machine-site interaction, provide threshold values to improve equipment mobility and efficiency, and restrict possible damage to an acceptable level. Relevant and recent research on eco-efficient limitations of tree conversion and timber extraction are discussed by Pentek (2008).

6.3.2 Compaction

Compaction is the increasing of soil bulk density primarily by the application of pressure through use of heavy equipment in forest operations. When soils are compacted, natural soil structure is damaged or destroyed, resulting in reduced porosity. Soil compaction is normally associated with soil rutting but is differentiated from rutting by the extent and intensity of impact. Compaction occurs over broader areas but does not necessarily result in the visible depressions associated with rutting. Rutting is the creation of trenches or furrows in the ground by breaking through the forest floor (slash, litter and humus layers) and compacting or displacing mineral or organic soil. Ruts are the result of having exerted ground pressures in excess of the bearing capacity of the soil. They are normally associated with the use of heavy wheeled or tracked harvesting equipment. Puddling is a specialised form of disturbance that results in a compacted surface mineral soil layer. Puddling results from the destruction of soil structure in fine textured soils when these soils are exposed to the impact of rainfall (Archibald, 1997).

6.3.2.1 Impacts of Compaction

Compaction of forest soil may impact sites by:

- Reducing porosity of the soil resulting in greater amounts of surface runoff and less infiltration of rainfall or melt water; movement of water and nutrients within the soil profile (hydraulic conductivity) may also be impaired;
- Increasing the bulk density of the soil to the point where root penetration is inhibited;
- Causing surface soil to warm up less quickly in the springtime, effectively shortening the growing season for new seedlings and causing silviculture operations to be delayed;
- Impeding gas exchange between roots and soil (smothering);
- Reducing the overall productive capacity of an area.

In addition, the creation of ruts may impact a site by:

- Reducing the productive area of a site, by causing deformation of the forest floor and/or by creating an opportunity for water pond formation (i.e., less area available for immediate renewal);
- Compacting the soil on the sides and beneath the rut such that water infiltration is impeded;
- Inhibiting rooting and gas exchange;
- Impeding lateral drainage of water on wetter sites;
- Contributing to erosion and soil displacement if ruts are located on slopes (Archibald, 1997).

6.3.2.2 Mitigating Impacts of Compaction
Site impacts can be minimised by the correct placement of skidding or forwarding routes and anticipating potential compaction or rutting by preparing these routes to receive the planned traffic without damaging the surface to the extent where costly rehabilitation is needed. Figures 6.3-1 and 6.3-2 show the condition of extraction routes where mitigation strategies have and have not been applied.

The following are some areas where amelioration techniques could be applied:

- Extraction routes - brush mat construction and maintenance;
- Drain and watercourse crossings;
- Forest to road approaches (Figure 6.3-3);
- Roadside stacking (Figure 6.3-4);
- Roadside drainage (Figure 6.3-5).
6.3.3 Erosion

Erosion is the accelerated movement of soil materials by the actions of water, wind or gravity. Surface erosion is normally the result of erodible mineral soils being exposed to the elements of wind and water. Gravitational erosion usually occurs on a more massive scale in the form of landslides, creeps and flows; this phenomenon is common on steep slopes and is categorised by the pattern of movement and the duration of the event. In general, the potential for erosion increases as percentage slope, length of slope and percentage of silt contained in the soil increases.

6.3.3.1 Impacts of Erosion

Soil erosion may impact a site by:

- Reducing productivity through the removal of nutrient rich, upper soil layers;
- Rendering certain severely eroded sites unproductive because of the resultant orientation of soil (i.e. exposed bedrock, steep gullies, nutrient poor exposed sub-soil materials or sub-soil materials smothering productive profiles);
- Destroying vegetation through catastrophic erosion such as land slides;
- Degrading water quality and fish habitat by depositing soil particles and nutrients into streams and water bodies;
- Damaging or destroying soil structure in fine textured soils and depositing structure less eroded soil materials (Archibald, 1997).
6.3.3.2 Mitigating Impacts of Erosion

If erosion becomes visible after harvesting operations, the following techniques may be used to mitigate further damage to the site:

- Identify ruts or furrows on slopes that are channelling runoff and causing erosion;
- Limit further erosion by filling these ruts with slash, debris, or non-erodible soil;
- Divert mid-slope ruts with cross drains, obstacles, or berms (i.e. water bars) (Figure 6.3-6);
- Ensure prompt regeneration of exposed erodible slopes (Archibald, 1997).

![Extraction route rehabilitation](image)

**FIGURE 6.3-6: Extraction route rehabilitation (FSA Environmental Guidelines).**

6.3.4 Nutrient Loss

The removal of biomass, in any combination of stem wood, bark or branch harvesting, can cause a significant increase in nutrient loss from commercial timber plantations. Ensuring long-term site productivity of forest plantations is a key issue for forestry management. Managers need to secure a continued supply of tree biomass components, while understanding the impact of various harvesting operations on plantation nutrient reserves. It is imperative to quantify the biomass and nutrient stocks and their removal during operations such as harvesting, burning and various forms of site preparation.

The balance of a forest ecosystem is disturbed when timber is harvested. When the foliage and/or trunks are removed, the disturbance is aggravated. The nutrient losses on the long term and the fertility of the forest soil may decrease as a bigger share of the biomass is constantly removed in the harvesting cycles. The cycle of nutrients between soil and vegetation is an essential part of the forest ecosystem (Figure 6.3-7). A part of the nutrients taken up by trees returns back to the soil with forest litter, but a larger part is accumulated as biomass. This part is released only when the biomass starts to decompose after the death of the tree. The circulation is not totally closed as leaching causes nutrient loss, but disintegration of minerals and fallout from the atmosphere increase the amount of nutrients available.
Part of the total nutrient capital on a forest site is held in tree biomass, particularly in branches and foliage. On nutrient-poor sites, the percentage of total site nutrients found in the above-ground parts of trees is much greater than on richer sites. Forest operations on these nutrient-poor sites may reduce total nutrient capital to critical levels, resulting in extended nutrient replacement time.

### TABLE 6.3-1: Quantities of biomass and nutrients in 11-year-old stand of *Eucalyptus saligna* (Poggiani, 1985).

<table>
<thead>
<tr>
<th>Tree components</th>
<th>Biomass t/ha</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves</td>
<td>4,0</td>
<td>49,6</td>
<td>4,8</td>
<td>29,3</td>
<td>106,7</td>
<td>11,8</td>
</tr>
<tr>
<td>Branches</td>
<td>13,8</td>
<td>31,7</td>
<td>11,1</td>
<td>40,0</td>
<td>296,3</td>
<td>23,3</td>
</tr>
<tr>
<td>Bark</td>
<td>9,5</td>
<td>25,1</td>
<td>25,1</td>
<td>12,2</td>
<td>47,9</td>
<td>30,5</td>
</tr>
<tr>
<td>Wood</td>
<td>158,5</td>
<td>112,5</td>
<td>30,1</td>
<td>72,9</td>
<td>103,0</td>
<td>15,8</td>
</tr>
<tr>
<td>Total</td>
<td>185,9</td>
<td>219,0</td>
<td>58,1</td>
<td>190,5</td>
<td>954,3</td>
<td>81,4</td>
</tr>
</tbody>
</table>

### TABLE 6.3-2: Quantities of biomass and nutrients in 14-year-old *Pinus caribaea var. hondurensis* (Poggiani, 1985).

<table>
<thead>
<tr>
<th>Tree components</th>
<th>Biomass t/ha</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves</td>
<td>10,4</td>
<td>100,7</td>
<td>5,8</td>
<td>44,0</td>
<td>19,7</td>
<td>7,7</td>
</tr>
<tr>
<td>Branches</td>
<td>10,5</td>
<td>23,0</td>
<td>1,4</td>
<td>11,8</td>
<td>13,6</td>
<td>4,2</td>
</tr>
<tr>
<td>Bark</td>
<td>18,4</td>
<td>43,6</td>
<td>2,2</td>
<td>34,2</td>
<td>13,2</td>
<td>3,7</td>
</tr>
<tr>
<td>Wood</td>
<td>114,3</td>
<td>137,1</td>
<td>6,8</td>
<td>60,5</td>
<td>57,1</td>
<td>18,3</td>
</tr>
<tr>
<td>Total</td>
<td>153,6</td>
<td>304,5</td>
<td>16,2</td>
<td>150,6</td>
<td>103,7</td>
<td>33,9</td>
</tr>
</tbody>
</table>
The litter layer is an important source of nutrients, and organic matter and their management during forest operations has major impacts on nutrient cycling, especially in short rotation forestry (O’Connell and Sankaran, 1997 in Tiarks et al., 1998). However, interactions of organic matter with other components in the system may complicate the response to biomass additions (Nambiar, 1996a in Tiarks et al., 1998). For example, the amount of nitrogen (N) in soil organic matter is much greater than in the biomass, so loss of N depends more on the amount of soil N mineralised than N removed in logging slash (Smethurst and Nambiar, 1990a in Tiarks et al., 1998). By measuring selected soil properties and tree growth, the processes involved may be understood to enable slash management decisions based on expected biological responses. A conceptual basis for relating harvesting and site management intensity and various operational practices is shown in Figure 6.3-8.

FIGURE 6.3-8: Harvest intensity of management (Nambiar and Brown, 1997a in Tiarks et al., 1998).

Negative growth impacts in intensively managed plantations should not all be attributed to harvesting, but rather to the total management inputs or regime followed for a particular site. The greatest impacts from management inputs are due to operations associated with harvesting, site preparation, planting and early silviculture, including fertilisation and weed control (Nambiar and Brown, 1997a in Tiarks, 1998). Intensity of harvesting and site preparation methods affect the types and amount of slash remaining on the site.

While the stem wood is usually of greatest economic interest, other biomass may be removed as well. Tops may be utilised for firewood or biofuel, piled within the plantation or burned in order to improve regeneration, facilitate weed control or lower fire hazard. Nutrient distribution in trees is affected by age, species and site, but generally, the foliage and branches contain a major portion of the nutrients, if compared to their total biomass (Tiarks et al., 1998), refer to Tables 6.3-1 and 6.3-2 above.

Tree-length harvesting leaves the slash (and the nutrients contained therein) in the felled area where it must be further treated for re-establishment or fire protection. Full-tree harvesting requires that slash be treated at the landing/roadside or returned in-field. In areas with access to co-generation facilities, the slash can be chipped and used for the production of clean electricity or heat. Full-tree harvesting removes both nutrients and soil cover from the site and can be harmful to the long-term health of the area if no further ameliorating action is taken. However, depending on the species, many of the branches are often broken off in handling so the end result may be more similar to tree-length harvesting.
6.3.4.1 Impacts of Nutrient Loss

It is widely believed that nutrient removals due to logging are not significant on most sites. Natural nutrient cycles replenish lost nutrient capital with minimal impact on ecosystems. The length of this recovery period is a function of the degree of site nutrient depletion and the rate of nutrient replacement. On some sites, nutrient loss due to logging is significant due to minimal nutrient capital stored on the sites, except in the trees themselves. On these sites nutrient loss may:

- Slow the growth and ultimately the yield of trees in subsequent rotations;
- Reduce overall tree and stand vigour (increase stress) thereby increasing vulnerability to disease and insect infestation.

6.3.5 Productive Land Removal

During forest operations some productive land is removed from production on a long-term or permanent basis as a result of the construction of roads, landings, and as a result of smothering by piles of slash or other debris.

With improvements and mechanisation of harvesting operations it is possible to embark on a road reduction exercise to improve productive land utilisation and to rehabilitate unused roads and landings. Legislative compliance adds to the loss of land due to delineations of water courses and emphasises the need to manage available productive land in a responsible way.

The removal of productive land reduces the overall productivity of harvest blocks and management units. Unlike other forms of site damage, land loss is a total removal of the affected lands from production rather than a reduction of productivity. It is in the best interest of the forest industry to limit these self imposed losses of productive land to maintain long-term yields (Archibald, 1997).

6.3.6 Hydrological Cycle

Water moves through the soil, plants, animals and atmosphere of a forested ecosystem in pathways termed the hydrological cycle. Forest operations may have a negative influence on the hydrological cycle in terms of site productivity and site re-growth in both the short- and long-term.

6.3.6.1 Impacts on the Hydrological Cycle

Typical hydrological impacts resulting from forest operations include:

- **Rising water table**: Removal of tree cover by harvesting can result in the water table on some lower land sites coming close to or above the surface of the soil, as the effect of transpiration by trees is reduced or eliminated. This effect is greatest immediately after harvesting. In extreme cases, where this condition persists for several years, poor re-vegetation and/or substantial changes in plant cover may result (e.g., creation of grass and sedge meadows). A rising water table effectively reduces the rooting zone available for plants and trees. On sites where the water table is already at the surface of the soil, harvesting may have the opposite effect and may cause the site to dry out slightly as a result of increased evaporation. These sites in general will be delineated in South Africa and not be replanted due to the National Water Legislation’s restrictions on plantation establishment close to rivers and wetlands.

- **Surface drying**: Well-drained soils may be subject to excessive surface drying when forest cover is removed due to greatly accelerated evaporation rates. On some sites, loss of organic material due to the effect of drying winds is possible under these conditions.
• **Disruption of lateral water flow through the soil:** Road construction, rutting and occasionally furrowing resulting from site preparation can cause the lateral drainage/movement of water in soil to be interrupted or altered. This can result in pond formation or other changes in the position of the water table (e.g. strategically placed furrows or ruts can effectively drain some forest sites). The lateral flow of water is a major source of nutrient flow on some sites (telluric flow) and disruption of this flow may result in areas becoming depleted of nutrient reserves (Archibald, 1997).

• **Disruption of infiltration rates in soil:** Soil compaction, rutting and smothering by road and landing construction can effectively reduce or eliminate water infiltration into the soil and thereby impact site productivity. Conversely, the removal of forest cover can increase the amount of water which percolates down through soil horizons and therefore may increase the leaching of nutrient cations.

• **Increased water yield:** Extensive forest harvesting in a catchment can greatly increase the flow of water (i.e., greater stream flow and possibly greater surface flow resulting in potential erosion problems) (Archibald, 1997). With increasing water flows, nutrient loading into streams and water bodies is likely to have a negative effect on river ecosystems. Heavy spring thunderstorms and downpours over clear-felled areas could result in increased erosion, nutrient leaching and downstream flooding.

### 6.3.7 Special Management Zones (SMZ) – Water Ways

Harvesting impacts on streams could be significant if not managed. Land and water processes are closely linked around upper catchment streams and drainage lines. These small streams are the source of water and nutrients for larger water bodies downstream. Harvesting (tree removal and ground disturbance) alters organic matter inputs, nutrient inputs, and sediment loading. These changes may impact on aquatic insects (which play a critical ecological function in nutrient processing and food chain Figure 6.3-9); fish habitat (which can be changed by sediment loading Figure 6.3-10), water clarity, physical structure and complexity; and land-water ecological linkages.

**FIGURE 6.3-9: Aquatic habitat.**
Various temporary crossing techniques are depicted in Figures 6.3-11 to 6.3-14 and it should be noted that in all cases rehabilitation of the site is needed after completion of the harvesting operation.

A systematic approach to identify SMZ’s and to determine management interventions is shown in Figure 6.3-15.
6.4 Social Impact Considerations

“Forestry continues to be one of the most hazardous industrial sectors in most countries. Around the world, there are often discouraging trends of rising accident rates and a high incidence of occupational diseases and of early retirement among forestry workers. However, clear evidence shows that good safety and health performance in forestry is feasible. Many ILO constituents recognize that safety at work is not only an ethical imperative, but that it makes “money sense”. In forestry, it is also a prerequisite for environmentally sound management and utilization of natural resources. Significantly, these governments, enterprises, employers’ and workers’ organisations are willing to do something about it” (ILO, 1998).

The above quote from the International Labour Organisation serves to highlight the significance placed on the social impact of forestry on all continents. Employers should establish and maintain procedures to systematically identify the risks to safety and health which may affect, or arise from, forestry activities. Identification should include hazards and risks actually and potentially leading to occupational accidents and diseases, incidents and emergency situations. For each task and activity a risk evaluation should be carried out. Any risks should be identified and recorded. Procedures should be maintained to evaluate risks and effects from identified hazards against screening criteria, taking account of the frequency with which they occur and the likely severity of consequences for safety and health. Based on the results of risk evaluation, enterprises should define objectives for the reduction of such risks to as low a level as possible, and devise and implement corresponding preventive measures. These should include the routine application of site inspection and planning as well as of the principles of work organization (ILO, 1998).
A recent trend in ground based harvesting systems in South Africa is to move away from traditional motor manual felling systems towards mechanised harvesting or combined systems. Therefore, it is becoming increasingly important to address all aspects of the environmental impact of harvesting operations. When a shift from labour-intensive to mechanised operations is planned, the principles of environmental impact assessments should be utilised to ensure all aspects are covered and all eventualities addressed. Social impact assessments are therefore becoming an integral part of forestry planning tools. Social impacts should be considered when major changes to harvest systems are planned as well as during normal operations, e.g. where major hauling on dusty gravel roads is to be undertaken near villages in rural areas or towns. Consultations with all stakeholders must be an inherent part of daily operations and exclusion leads to conflict and tedious negotiations which can be avoided with the correct approach during the planning phases of operations.

Social impacts are impacts of developmental interventions on the human component of the environment. Such impacts not only need to be identified and measured, but also managed in such a way that the positive attributes are enhanced and the negative aspects minimised.

### 6.4.1 Social Impact Assessment (SIA)

Social Impact Assessment is based on the assumption that development interventions have social implications, and it is imperative that decision makers understand the consequences of their decisions before they act. Social Impact Assessments give affected people the opportunity to participate in designing their future, Social Impact Assessment and help to make the project responsive to social development concerns. Developmental initiatives informed by social assessment enhance inclusion and build ownership while minimising and compensating for adverse social impacts on the affected community.

Social Impact Assessment can be defined in terms of efforts to assess or estimate, in advance, the social consequences that are likely to follow specific policy actions (including programs and the adoption of new policies). It is a process that provides a framework for prioritising, gathering, analysing, and incorporating social information and participation into the design and delivery of developmental interventions. It ensures that development interventions are informed, taking into account the key relevant social issues, and incorporating a participation strategy for involving a wide range of stakeholders.

The Principles for Social Impact Assessment can be described as follows:

- **Involve the diverse public:** Identify and involve all potentially affected groups and individuals.
- **Analyse impact equity:** Clearly identify who will win and who will lose and emphasize vulnerability of under-represented groups;
- **Focus the assessment:** Deal with issues and public concerns that really count, not those that are just easy to count;
- **Identify methods and assumptions and define significance:** Describe how the SIA is conducted, what assumptions are used and how significance is determined;
- **Provide feedback on social impacts to project planners:** Identify problems that could be solved with changes to the proposed action or alternatives;
- **Establish monitoring and mitigation programs:** Manage uncertainty by monitoring and mitigating adverse impacts;
- **Identify data sources:** Use published scientific literature, secondary data and primary data from the affected area;
- **Plan for gaps in data:** Evaluate the missing information, and develop a strategy for proceeding.
6.5 **Environmental Impact Assessment (EIA)**

A well designed Operational Harvesting Plan contains all the aspects of an EIA and is aimed to address all aspects of the physical environmental protection, social (safety) and financial (yield, productivity and cost per m²) during operations.

Timber harvesting is one of the major human interferences to the forest causing environmental disturbance and should therefore be properly planned and executed. To minimise damage to the forest ecosystem in plantations under intensive forest management, landscape planning should be incorporated in the sustainable yield management. Landscape Planning or sometimes called “Landscape Ecosystem Management” is a relatively new management concept (Hagner, 1999 in Elias, undated), and aims to:

- Safeguard stream margins and water bodies;
- Protect indigenous biodiversity in natural areas;
- Conserve threatened species if they are found in the forest plantation.

Information is provided in many publications on site planning, selection of machines, brush mat construction and maintenance, forest road approaches/drainage and roadside stacking. Within a well-planned harvesting operation, a range of operational techniques are available to avoid or minimise the risk of soil erosion and siltation. Some of these involve civil engineering interventions and may need to be planned at an early stage. Although site managers may have a limited choice of equipment, it is important that the impact of particular equipment on the site is considered so that additional protective measures are adequately planned for. In some cases, due to the risk of damage, a different system or machine may be required to that originally proposed. Therefore, good site planning is very important before selecting the appropriate equipment (Murgatroyd, 2005).

A cost and benefit analysis (Table 6.4-1) is another method for determining the impact of a harvesting operation on the various components of the environment and resources of a company. This method has the added advantage of reflecting monetary costs. When values are placed against the various operational components, the (monetary) cost can be weighed up against (monetary) benefits to give either a positive or a negative value which can aid decision-making and indicate where efforts should be concentrated.
### TABLE 6.4-1: Example of a summary of the costs and benefit analyses of a thinning operation. (Hammond et al. 2000)

**Key operational elements of Reduced-Impact Harvesting and its costs and benefits.**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Benefits</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Training</strong></td>
<td>• Productivity</td>
<td>• Training course</td>
</tr>
<tr>
<td></td>
<td>• Reduced damage</td>
<td>• Higher wage demands</td>
</tr>
<tr>
<td></td>
<td>• Fewer accidents</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Less equipment damage</td>
<td></td>
</tr>
<tr>
<td><strong>Harvest planning</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Skid trail alignment</strong></td>
<td>• Drainage</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Reduced soil erosion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Efficient access to harvestable trees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PCTs retained</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimised damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimised area loss</td>
<td></td>
</tr>
<tr>
<td><strong>Mapping of skid trail alignment (SMT)</strong></td>
<td>• Drainage</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Reduced soil erosion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Efficient access to harvestable trees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PCTs retained</td>
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</tr>
<tr>
<td></td>
<td>• Minimised damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimised area loss</td>
<td></td>
</tr>
<tr>
<td><strong>Tree marking (TMT)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trees to be harvested</strong></td>
<td>• Optimise immediate timber revenues</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td><strong>Potential crop trees</strong></td>
<td>• Optimise future timber revenues</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td><strong>NTFP</strong></td>
<td>• Other sources of revenue</td>
<td>• Foregone timber revenues</td>
</tr>
<tr>
<td></td>
<td>• Biodiversity conservation</td>
<td></td>
</tr>
<tr>
<td><strong>Protected trees/Buffer zones</strong></td>
<td>• Better relations with local residents</td>
<td>• Foregone timber revenues</td>
</tr>
<tr>
<td></td>
<td>• Biodiversity conservation</td>
<td>• Promotion of competing non-commercials</td>
</tr>
<tr>
<td></td>
<td>• Keep open optional values</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Meet international standards</td>
<td></td>
</tr>
<tr>
<td><strong>Data analysis, digitising (GIS Unit)</strong></td>
<td>• Optimised planning</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td><strong>Review of Final Harvesting Map by verification, cross-checks</strong></td>
<td>• Correct errors</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td><strong>Harvesting operation</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Skid trail preparation</strong></td>
<td>• Minimised soil damage</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Minimised area loss</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td><strong>Log landing preparation</strong></td>
<td>• Minimised soil damage</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Minimised area loss</td>
<td></td>
</tr>
<tr>
<td><strong>Tree felling and measurement</strong></td>
<td>• Reduced accidents</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Reduced losses to PCTs</td>
<td>• Training course</td>
</tr>
<tr>
<td></td>
<td>• Reduced forest gaps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Enhanced skidding productivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Improved recovery</td>
<td></td>
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<tr>
<td><strong>Log extraction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Winching: long winch distance</strong></td>
<td>• Reduced soil damage</td>
<td>• Staff</td>
</tr>
<tr>
<td></td>
<td>• Reduced stand damage</td>
<td>• Training course</td>
</tr>
<tr>
<td></td>
<td>• Reduced skidder fuel use</td>
<td>• Winch cables</td>
</tr>
<tr>
<td><strong>Skidding</strong></td>
<td>• Reduced soil damage</td>
<td>• Foregone timber</td>
</tr>
<tr>
<td></td>
<td>• Reduced stand damage</td>
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<tr>
<td></td>
<td>• Reduced equipment damage</td>
<td></td>
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<tr>
<td></td>
<td>• Reduced accidents</td>
<td></td>
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<tr>
<td></td>
<td>• Increased productivity</td>
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</tbody>
</table>
### Post-harvesting operation

<table>
<thead>
<tr>
<th>Operation</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation of cross drains and</td>
<td>• Reduced soil erosion</td>
</tr>
<tr>
<td>sediment traps</td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td>Treatment of compacted areas</td>
<td>• Reduced soil erosion</td>
</tr>
<tr>
<td></td>
<td>• Improved recovery</td>
</tr>
<tr>
<td></td>
<td>• Staff and equipment</td>
</tr>
<tr>
<td></td>
<td>• Planting material</td>
</tr>
<tr>
<td>Damage assessment</td>
<td>• Compliance with international standards</td>
</tr>
<tr>
<td></td>
<td>• Correct errors</td>
</tr>
<tr>
<td></td>
<td>• Assess yield expectations</td>
</tr>
<tr>
<td>Verification</td>
<td>• Access to restricted markets</td>
</tr>
<tr>
<td></td>
<td>• Price premium on certified products</td>
</tr>
<tr>
<td></td>
<td>• Fees</td>
</tr>
</tbody>
</table>

### 6.6 Monitoring

Monitoring needs to be carried out at intervals according to the requirements of the labour inspectorate, inspecting body or the organization to which it is accredited. Monitoring inspections need not be as time-consuming as initial compliance inspections, and they should focus predominantly on issues raised in the previous inspection (ILO, 2005).

Monitoring in harvesting operations is generally done by:

- Using checklists – operational staff (1st party audit);
- In-house staff (2nd party audit);
- A certifying agent (3rd party audit) on behalf of a certification body.

The objective of environmental auditing is to check compliance of performance against a set of standards, and as such should be:

- Socially responsible;
- Environmentally sustainable
- Economically viable; and
- Compliant with legal requirements.

### 6.7 References and Further Reading


Further Reading on South African Perspective to Site Nutrition and Conditions


Chapter 7

General Health and Safety of Ground Based Harvesting Operations

Andie Immelman, Andie Immelmann, Corrie Bieldt, Spikes Joubert, Piet Schoombee, Alf Ueckermann

7.1 Introduction

Effective and pro-active safety management is good business practice. A safe harvesting operation is associated with an efficient harvesting operation, not only because it reduces the potential for loss, but also because it increases production, improves the working environment and adds to an overall improvement in worker attitude and moral.

The purpose of this chapter is to provide insight into the components of a health and safety (H&S) management system as well as to demonstrate how these components function in ensuring that ground based harvesting operations are conducted safely. This chapter focuses only on generic safety components of the harvesting health and safety management system. Refer to equipment supplier safety guidelines for more information on specific safety related issues e.g. chainsaw safety.

7.2 General Health and Safety Planning

In order for the health and safety (H&S) management system to be effective it needs to be planned, implemented, monitored and reviewed.

7.2.1 Overview of Legal Requirements

The purpose of this section is to list some of the legal requirements that form the first step in the health and safety planning process.

Duty of Care: This term relates to the broad responsibilities, expressed in general terms, of a wide range of persons who are involved in harvesting work or work environment. Employers have a common law duty to ensure that they take reasonable care for the safety of all their employees.

Therefore, the employer is responsible for making sure contractors or employees working on the company’s premises carry out all their tasks in compliance with the relevant health and safety legislation, and in particular, reference is made to the Occupational Health and Safety Act No 85 of 1993, Compensation for Occupational Injuries and Diseases Act No 130 of 1993 and the Basic Conditions of Employment Act).
**General Duties of the Employer:** In the Occupational Health and Safety Act No. 85 of 1993, the general duties of the employer are set out in Section 8. Refer to the Occupational Health and Safety (OHS) Act No. 85 of 1993 for more detail.

**General Duties of Employers and Self-employed Persons to Persons Other Than Their Employees:** In the Occupational Health and Safety Act No. 85 of 1993, the general duties of the employers and self-employed persons to persons other than their own employees are set out in Section 9. Refer to the Occupational Health and Safety Act No. 85 of 1993 for more detail.

**General Duties of Employees (Section 14 of the Act):** In the Occupational Health and Safety Act No. 85 of 1993, the general duties of the employee are set out in Section 14 and read as follows:

- Take care of their health and safety and of others who may be affected by their activities;
- Co-operate with the employer in respect of health and safety matters;
- Carry out any lawful order given to him, and obey the health and safety rules and procedures laid down by his employer or by anyone authorised thereto by his employer, in the interest of health or safety;
- Report any unsafe or unhealthy situation as soon as possible;
- Report any injury or incident as soon as possible, but not later than the end of his shift.

**Acts or Omissions by Employees or Mandataries (Section 37):** Section 37 provides that the employer shall be vicariously liable for all transgressions of employees unless they were, at the time, acting without permission, or without the connivance of the employer, or were acting outside the scope of their authority, or that all reasonable steps had been taken to prevent such foreseeable risks becoming a reality.

The employer is also liable for the wrongful acts of mandataries, including contractors and subcontractors employed, unless an agreement is made with such contractors that they will be responsible for the implementation of the Act (Section 37(2)). Unless a 37(2) agreement is in place, contractors will be regarded as the employees of the company. Section 37(2) agreements will however not relieve the company from all liability through the ultimate control principle. Should the employer see that the contractor is in some way breaching the terms and conditions of the Act, the employer must take action to have the contractor rectify the situation and failing to do so may result in both the contractor and employer being charged.

**Compensation for Occupational Injuries and Diseases Act No. 130 of 1993:** The Compensation for Occupational Injuries and Diseases Act (COID) makes provision for compensation to be paid out to injured employees. In the COID Act, the right of employees to compensation is set out in Section 22 (1). Refer to the COID Act for additional information.

### 7.2.2 Risk Assessment

Risk assessments form an important part of any health and safety management system. No risk control measures can be developed until specific risks have been identified and assessed. Risk refers to the probability that injury or damage will occur. Risk assessments refer to the process of identifying undesired events and their causes, as well as the analysis of the likelihood and potential consequences of these events. These assessments are used to make a value judgment as to whether these events are acceptable or not. Risk assessments consist of a number of steps and include the following:

- Identification of hazards;
- Risk analysis;
- Value judgment of the risk.
Identification of hazards

The first, and most critical, step in managing risk is identifying the hazard. If a hazard is not identified it will not be assessed and therefore no control measures will be implemented.

Hazard identification is a systematic process for establishing what can go wrong (cause) and what harm or loss may result from the incident. There are many different methods that one can use to identify hazards for example: Checklists, incident investigation reviews, critical task analysis, planned job observations, etc.

Risk analysis

Once a hazard has been identified, the risk that it poses to the harvesting operation must be determined. This can be done by using any type of risk rating criteria matrix.

Value judgment of the risk

Once the extent of the risk is known, a decision has to be made whether the risk is acceptable or not. When considering risk tolerability, all risks fall into one of three categories namely:

- **Negligible**: The level of risk is negligible and nothing further needs to be done to mitigate the risk;
- **As low as reasonably practicable**: Action is required to reduce the risk to an acceptable level;
- **Unacceptable**: The risk is unacceptably high, regardless of the benefits gained from taking the risk and action is required to eliminate the risk.

7.2.3 Objectives and Targets

Once the risk assessment process is completed, one must develop objectives with targets on how to deal with each significant risk. Often the objectives and targets are included as part of the risk assessment worksheet. The objectives set must be systematic, realistic, achievable, measurable, and have a time frame linked to them.

7.2.4 Critical Task Analysis

Critical task analysis (CTA) is the process whereby each task involved in the harvesting process is assessed to determine its criticality and potential for causing harm or loss. CTA is performed once the risk assessment is completed. The activities identified in the risk assessment must be included in the CTA process.

Factors affecting the criticality of harvesting tasks involve:

- The severity of incidents arising out of each specific task;
- The frequency at which each task is performed;
- The probability at which the incidents involved with specific task will manifest itself.

Critical task analysis is an important tool for all harvesting managers as it can be used to pinpoint high risk tasks and activities which may require more regular inspections, stringent supervision, and focused training interventions.
7.3 Implementing Risk Control Strategies

Risk control in harvesting involves implementing methods to control harvesting risks by controlling the frequency (the number of times a loss producing event occurs within a given period of time), as well as the severity (the degree of harm or damage as a result of the loss producing event). It is important to note that the employer is responsible for ensuring that any method chosen to control risk is working.

7.3.1 Training

An employee’s lack of knowledge or skill is one of the basic causes of accidents. Because training is seen as one of the most powerful tools in controlling risk, it is important that training programmes cover both skills and knowledge transfer.

The OHS Act and its regulations set out specific requirements for training in occupational health and safety, and for training-related record keeping that employers must comply with. For example, employers are required to provide induction training for all new employees. Employers must also ensure that members of safety committees and safety representatives receive relevant training.

Employees should be trained to apply systems of work and work practices that are safe. An employer should ensure that all employees have been adequately trained and instructed to perform their work safely before allowing them to work in harvesting operations. Employees should be made aware of any dangers involved with their work and of any safety precautions that should be taken to avoid accident or injury.

Every employee who uses any machinery or equipment such as a forwarder, feller buncher, harvester, skidder, etc. needs adequate information and training on how to use it safely. Employees should be provided with competent supervision while they use this equipment unless they have attained a level of competency in operating safely without supervision. It is important to document operator’s certification and accreditation, as well as any training provided to them including the nature of training, the date the training was given and the names of the persons who were trained.

Training should be done by accredited training providers. If no accredited trainers are available it is required that manufacturers and/or suppliers of equipment provide adequate training to the operators.

7.3.2 Legal Appointments

Various legal appointments are required in terms of the OHS Act requirements. The most pertinent ones to the harvesting operations are:

- Health and Safety (H&S) representatives;
- H&S committee members;
- H&S committee chairperson;
- Incident investigator;
- First Aiders;
- Hazardous Chemical Substance Controllers.

Legal appointment templates can be obtained from foresters or H&S consultants.
7.3.3 Personal Protective Equipment (PPE)

Engineering and management controls can reduce and even eliminate many occupational health and safety hazards. Whenever these techniques can solve H&S hazards, they are more desirable than the use of Personal Protective Equipment (PPE). All of the health and safety hazards in a harvesting operation cannot be removed but the potential damage from hazards can be minimised by providing employees with PPE.

Personal Protective Equipment provides a protective barrier between the hazard and the employee. If the PPE device fails or is improperly used, the employee will be directly exposed to the hazard. Personal protective equipment is the “last line of defence” and needs to be used properly and in accordance with established standards. In order to manage PPE correctly it is important to ensure the following:

• Choose the most appropriate PPE for each hazard;
• Issue PPE to employees and keep a record of this;
• Provide training on the correct use of PPE;
• Care for all PPE in a hygienic way;
• Monitor PPE use;
• Supply PPE to employees free of charge.

7.3.4 Written Safe Work Procedures (WSWP) and Best Operating Practices (BOP)

Written safe work procedures (WSWP), best operating practices (BOP), and standard operating practices (SOP) are useful documents that a harvesting manager can consult when conducting a harvesting operation. WSWP’s and BOP’s are documents containing step-by-step guidelines as to how each task is to be performed, what hazards are involved with the tasks, and what the specific PPE is required.

7.3.5 Emergency Planning

Emergency planning involves the identification of potential emergency scenarios, the development of adequate emergency response plans, and the communication of such response plans to all employees so that everyone knows what to do in case of an emergency. The emergency plan should be in written format and in order to be prepared for emergency scenarios in harvesting operations, the plan should include the following:

• Identification of all potential emergency situations;
• For each emergency situation, a list of the actions which should happen in a step-by-step format;
• Assignment/designation of people to conduct specific tasks e.g. first aider, supervisor etc;
• An emergency telephone list;
• Plan of how the emergency plan will be communicated to all employees;
• The emergency plan must be tested by performing or practicing an emergency drill.
7.3.6 Health and Safety (H&S) Representatives and Committees

A health and safety representative is an employee elected by other employees to represent them on matters relating to health and safety at work. Where companies employ 20 or more people, a designated health and safety representative must be appointed in writing. One health and safety representative must be available for every 50 employees conducting harvesting work. Refer to the OHS Act, section 18 for detail on the duties of the health and safety representative.

A health and safety committee must be formed where two or more health and safety representatives are appointed. A health and safety committee is a forum for discussing health and safety issues at work and should meet at least once every three months. Minutes must be kept of all issues discussed during the meeting.

7.3.7 Communication

Good communication on harvesting operations is critical. Often harvesting operations take place in remote areas where access to an injured employee is difficult. Good communication with emergency services as well as management is essential. Ensure that cell phone or radio communication with emergency services and management is available at all times.

7.3.8 Ergonomics

Ergonomics can be defined as the design of the workplace, equipment, machine, tool, product, environment, and system while taking into consideration human's physical, physiological, biomechanical, and psychological capabilities. Most forestry work is done outside in difficult weather (heat, cold and rain) and on difficult terrain (slopes and underbrush). Forestry work is further characterised by a high accident rate. Machines must be designed and manufactured so that they are adapted to the workers. In addition, workers need training on the efficient use and maintenance of different machines.

The design of access for forestry and agricultural machines has been considered by various organisations. For example, Sweden has produced ergonomic guidelines for forestry, transport and materials handling machinery. Golsse (1994) published the revised FERIC ergonomic checklist for Canadian forest machinery and South Africa has produced ergonomic guidelines for harvesting equipment (FESA, 1997).

For more information on ergonomics please refer to the publication International Labour Office (1992).


7.3.9 First Aid

First aid is important as it can mean the difference between a minor injury or a costly disabling injury or death. A requirement for organisations is that they must take all reasonable steps to ensure that employees receive prompt first aid.

A first aid box must be available where five or more employees are employed in a harvesting operation. Although legislation only lays down the minimum requirement in terms of the number of first aid boxes, one must be realistic in terms of providing first aid boxes. Remember, first aid is the first treatment an employee will receive when they suffer an injury. The aim is therefore to
have enough first aid boxes at in-field operations to ensure quick, prepared response to injuries. The first aid box must contain the contents as listed under the annexure of the Occupational Health and Safety Act.

In view of the dangerous work associated with timber harvesting operations it will be prudent to exceed the required number of trained first aiders and kits available in-field. In the event of an injury in the work place, the first aider may be exposed to blood and other body fluids which may contain potentially infectious agents such as bacteria and viruses.

It is mandatory that all persons involved in the cleaning up operations at an accident scene are properly trained and are provided with the necessary personal protective equipment. Medical waste is generated when the injury is treated. Biological fluids and first aid waste must be managed and disposed of. This must be done in such a way as to avoid infection to the first aider and other exposed persons or contamination of the work place.

7.4 **Measurement and Monitoring**

To be effective, harvesting risk control strategies/methods must be monitored and planned, and the outcomes measured. Various tools and methods exist to measure and monitor the effectiveness of the implemented risk reduction/control measures. The main risk control measures will be discussed below. However, note that many different risk control measures exist. Each harvesting company must decide on which risk control measures will be planned, implemented, and measured.

7.4.1 **Inspections and Checklists**

Regular and thorough inspections, conducted on a pre-determined frequency provide a way to reduce potential losses by identifying harvesting hazards before they result in incidents. Adequate and thorough inspections provide significant benefits to the harvesting operation by providing the opportunity for:

- Identifying and correcting improper harvesting practices;
- Verifying equipment conditions;
- Identifying and reinforcing correct harvesting practices;
- Identifying the effectiveness of corrective actions.

For an inspection to be effective, it must accomplish the following:

- Identify harvesting hazards;
- Identify corrective measures;
- Allocate persons responsible for carrying out/implementing the recommended corrective action;
- Allocate due dates by when recommended corrective actions should be implemented.

Several checklists are available to conduct inspections. Use company-specific documentation or source applicable checklist from the internet.

7.4.2 **Planned Job Observations**

Planned job observations (PJO) fulfil an important role in the identification of harvesting related hazards. A planned job observation is a technique that allows harvesting supervisors to deter-
mine whether a person executes a task in the same manner as he/she was trained to do. Two
types of planned job observations exist:

- Informal observation;
- Formal observation.

Informal job observations are used in a day-to-day manner while the harvesting supervisor is
executing his/her daily routine tasks. The supervisor naturally looks at how people do their
jobs as he/she passes through the compartment. If the supervisor is attentive he/she will easily
notice mistakes and immediately rectify them.

Formal job observations are planned observations whereby the supervisor observes whether or
not an employee is executing a task in compliance with the standard task procedures (WSWP’s/
BOP’s) and in the manner in which the person was trained. Non-compliance indicates that
further training of the employee is required or that the task procedure should be upgraded.

Planned job observations are executed as follows:

**Step 1:** Select a task and a worker – select a critical task and identify workers that are new, poor
performers or known risk takers.

**Step 2:** Prepare for the observation – before conducting a planned job observation, ensure that
the selected employee is fully trained in the task that is to be observed, and ensure that the
observer knows the task procedure in detail. Brief the worker on the aim of the observation as
well as the importance of the task that is being observed.

**Step 3:** Conduct the observation – when conducting the observation, undertake the following:
- Stay out of the worker’s way;
- Allow the worker sufficient workspace;
- Do not be a distraction;
- Do not intervene unless it is vitally important;
- Give the observation undivided attention.

**Step 4:** Summarise the observation – summarise the observation and discuss the results with
the observed worker. Make notes of any comments or suggestions made by the workers as this
may prove valuable in updating the work standard.

### 7.4.3 Investigations

When a harvesting accident occurs, it is important to investigate it thoroughly as the outcome
of the investigation can pinpoint the specific causes of the accident. The outcome of the inves-
tigation will assist harvesting managers in implementing measures to prevent future accidents.
An investigation of a harvesting accident should follow a logical process.

**Step 1:** Perform initial response.

The supervisor must take charge of the scene and ensure the following is done immediately:
- Render first aid;
- Secure the scene to prevent secondary accidents and to preserve the evidence;
- Notify emergency agencies (as per emergency plan telephone list).

**Step 2:** Gather the facts.

The investigation must be held as soon as possible before the facts become forgotten or dis-
torted. Identify the following:
• Who was involved (people)?
• What equipment was involved (parts)?
• What were the environmental conditions (e.g. wind, rain etc)?
• What processes were involved?
• What paper evidence is available?

**Step 3**: Determine the cause.

• Use methods to identify the cause of the accident. Different methods are available such as the Root Cause Analysis Technique and the Five Why Questioning process. The 5 Why Technique is a brainstorming type technique for indentifying root causes of incidents through questioning why events occurred or conditions existed.

The Root Cause Technique (RCAT) is a tool that can assist investigators to structure the evidence and analyse the component causes when investigating an incident.

• It guides investigators through the key steps of the investigation process.
• The comprehensive listing of causes helps investigators as the right kinds of questions;
• It assures that investigators will identify underlying or root causes;
• It helps to link the causes of the incident to effective remedial actions.

**Step 4**: Develop remedial actions.

• Based on the outcome of the cause analysis, remedial actions must be developed and implemented to rectify the non-conformances as well as to prevent future occurrence of similar accidents.

### 7.5 Health and Safety (H&S) System Review

In order for the H&S management system to be effective it needs to be planned, implemented, monitored and reviewed. Reviewing the management system will identify shortcomings that can be rectified before resulting in major injuries, damage or loss.

A review is necessary to ensure that the management system is still suitable, adequate and effective. The following processes can be used in an H&S systems review.

#### 7.5.1 Corrective and Preventative Actions

Corrective and preventative action reports are vital pieces of information that can be used during the review process. These reports contain information on non-conformances that took place in the operation and what measures were implemented to rectify the non-conformances.

By reviewing the corrective action reports, one can ascertain whether the management system effectively addressed all the high risk areas. If several reoccurring non-conformances are noted in the corrective and preventative report then it could point out gaps in the management system.

#### 7.5.2 Statistical Analysis and Trends

Injury statistics and trends can be used as an indicator of the effectiveness of the management system. However, injury statistics are not very accurate due to under reporting and are a reactive measurement i.e. the accident has to occur to be able to be measured.
7.5.3 Audits

Internal audits of the harvesting operation are very useful when reviewing the effectiveness of the management system. Internal audit reports provide accurate data on non-conformances identified. These reports should be reviewed and used to make improvements to the H&S management system.

7.6 Conclusion

In order to run a safe harvesting operation, it is important that once a hazard has been identified, and the resulting risk analysed, that the particular organisation attempt, as far as is reasonably practical, to avoid or terminate the risk exposure. If this is not possible, the organisation should then do everything possible to treat the risk exposure, by implementing effective control measures, in order to reduce the likelihood of the risk resulting in injury, damage, or loss.

7.7 References


# Appendix 1

*National Terrain Classification System for Forestry (ICFR Bulletin Series 11/1994)*

<table>
<thead>
<tr>
<th>Slope Class</th>
<th>Gradient Percent</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-11</td>
<td>Level</td>
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<tr>
<td>2</td>
<td>12-20</td>
<td>Gentle</td>
</tr>
<tr>
<td>3</td>
<td>21-30</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>31-35</td>
<td>Steep 1</td>
</tr>
<tr>
<td>5</td>
<td>36-40</td>
<td>Steep 2</td>
</tr>
<tr>
<td>6</td>
<td>41-50</td>
<td>Steep 3</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 50</td>
<td>Very steep</td>
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</table>

**Ground Conditions**

<table>
<thead>
<tr>
<th>Ground Conditions</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Very good</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Good</td>
<td></td>
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<td>Moderate</td>
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<tr>
<td>Poor</td>
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<td></td>
</tr>
<tr>
<td>Very poor</td>
<td></td>
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**Ground Roughness**

<table>
<thead>
<tr>
<th>Ground Roughness</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Smooth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slightly uneven</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uneven</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very rough</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
Appendix 2

Conversion of Slope % to Degrees

- Slope (%)
- Slope (degrees)

Conversion of Slope % to Degrees
## Appendix 3

### Cost Categories and Formulas (adapted from Franklin, 1997)

#### FIXED COSTS

<table>
<thead>
<tr>
<th>COST</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest</td>
<td>$\text{AAI} \times i$</td>
</tr>
<tr>
<td>Where: $\text{AAI} = ((P \times ((EEL \div \text{PMH/year}) +1)) + (SV \times ((EEL \div \text{PMH/year}) - 1))) \div (2 \times (EEL \div \text{PMH/year}))$</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>$(P - \text{Non-depr} - SV) \div (EEL \div \text{PMH/year})$</td>
</tr>
<tr>
<td>Insurance</td>
<td>(to be obtained from insurance broker)</td>
</tr>
<tr>
<td>License</td>
<td>(to be obtained from traffic department)</td>
</tr>
</tbody>
</table>

#### VARIABLE COSTS

<table>
<thead>
<tr>
<th>COST</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>$\text{Fuel price/litre} \times \text{Fuel consumption/PMH}$</td>
</tr>
<tr>
<td>Oil and lubricants</td>
<td>$\text{Fuel Cost/PMH} \times \text{Oil and lubricant % of fuel cost}$</td>
</tr>
<tr>
<td>Repairs and Maintenance</td>
<td>$(P \times R) \div \text{EEL}$</td>
</tr>
<tr>
<td>Tyres and/or Tracks</td>
<td>$((\text{EEL} \div \text{Tyre life in PMH}) \times \text{Cost of 1 set of tyres}) - \text{Cost of 1 set of tyres} \div \text{EEL}$</td>
</tr>
<tr>
<td>Other non-depreciable items</td>
<td>$\sum ((\text{EEL} \div \text{Non-dep. item life in PMH}) \times \text{Non-dep. item cost}) \div \text{EEL}$</td>
</tr>
</tbody>
</table>

#### PERSONNEL COSTS

<table>
<thead>
<tr>
<th>COST</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Wage</td>
<td>$\text{Basic wage/hr} \times \text{Basic hrs worked/day}$</td>
</tr>
<tr>
<td>Overtime</td>
<td>$\text{Basic wage/hr} \times \text{Overtime wage %} \times \text{Overtime hrs/day}$</td>
</tr>
<tr>
<td>Paid Travel Time</td>
<td>$\text{Basic wage/hr} \times \text{Travel hrs/day}$</td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>$(\text{Basic wage/day} \times \text{Benefit %}) + (\text{Overtime wage/day} \times \text{Benefit %})$</td>
</tr>
</tbody>
</table>

#### OVERHEAD COSTS

<table>
<thead>
<tr>
<th>COST</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Overheads</td>
<td>$\sum (\text{Overhead Cost} \times \text{Overhead percentage use in the system})$</td>
</tr>
</tbody>
</table>

* The cost of one set of tyres is subtracted in the “depreciation” and “tyres” formulas because the machine comes standard with a new set of tyres, so the first set of tyres need not be purchased, and its price is reflected within the purchase price of the machine.

**Note:** Fixed costs are measured in R/annum, variable costs in R/PMH, personnel costs in R/man-day and overhead costs in R/month or R/annum.
<table>
<thead>
<tr>
<th>Where:</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAI</td>
<td>Average Annual Investment – Investment amount on which interest will be paid per annum (Rand).</td>
</tr>
<tr>
<td>EEL</td>
<td>Expected Economic Life of the machine – Anticipated working life span of the machine (PMH).</td>
</tr>
<tr>
<td>i</td>
<td>Interest rate – The rate for money (either borrowed or your own), which should be charged against the capital invested in the machine (%)</td>
</tr>
<tr>
<td>Non-depr</td>
<td>Non-depreciable items – The total value of all machine attachments at the time of purchase which do not depreciate with the machine. These include tyres, tracks, cables, sliders, cutting chains, cutting bars, delimbing knives, tyre chains, etc.</td>
</tr>
<tr>
<td>P</td>
<td>Purchase Price – The delivered amount paid for the machine, including all attachments, accessories, modifications, delivery charges and taxes (Rand).</td>
</tr>
<tr>
<td>R</td>
<td>Repair and maintenance factor (% of P for EEL).</td>
</tr>
<tr>
<td>SV</td>
<td>Salvage Value – Estimated market value that the machine will be sold for at the end of its expected economic life (Rand).</td>
</tr>
</tbody>
</table>
Glossary

A

**Absenteeism** – is a habitual pattern of absence from a duty or obligation. This can be expressed as the number of days absent without reason as a percentage of total days of work.

**Accumulation area (feller-buncher)** – area where multiple tree length can be accumulated before the load is put onto the ground.

**Accumulating head** – specifically designed harvesting head that can accumulate multiple stems in a standing position until a desired load is reached and then placed on the skid trail.

**Articulated timber trucks (ATT)** – a modified articulated dump truck (ADT) applied in an extended primary transport role; available with or without cranes.

**Attachment** – device that can be attached to a boom or crane to perform a specific task; namely, grapples, harvesting heads or debarking heads, etc.

**Availability** – the percentage of time that the machine is fit and available for work. Also refer to machine utilisation.

B

**5 B’s** – a management tool to assist in measuring the success or failure of a timber logistics system. The 5 B’s are: bottlenecks, balance, buffers, breakdowns and blunders.

**Band tracks (bogie tracks)** – tracks that are mounted across the two bogie wheels of a machine to aid traction and protect the rubber wheels of the bogie.

**Bark adhesion** – an index of ring debarker productivity, since the ease with which bark is removed from the bole is a function of sap-flow between the bark and the stem.

**Basic technology** – use of manual labour, cheap and simple hand tools (i.e.: bow saws and axes) to cut, cross-cut or debranch trees. Manual or animal extraction of timber to the roadside usually follows.

**Best operating practices (BOP)** – written standards and productivity targets for operations in particular situation/conditions.

**Brinell scale** – characterises the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece.

**Bundle skidding** – extracting bundles of logs with a skidder.

**Bunching grapple** – a grapple used for the extraction of a large number of smaller diameter stems.
Cable skidder – a four-wheel drive, rubber-wheeled tractor with articulated steering machine that uses a main winch and cable and/or chain chokers to assemble and hold a load.

Carrier – either wheeled or track mounted machines that are designed to carry specific attachments.

Centralised merchandising yard – an area where processing equipment is permanently installed to process full trees or tree-lengths.

CFDDC (Chain flail-delimber-debarker chipper) - an integrated machine which includes the functions of debranching, debarking and chipping.

CFDD (Chain flail-delimber-debarker) – an integrated machine which includes the functions of debranching and debarking.

Chute – an inclined channel system in which timber is transported downhill.

Clam-bunk skidder – an articulated rubber-wheeled or tracked vehicle for transporting full trees or tree length by supporting the butt-end clear off the ground in an inverted bunk or grapple.

Continuous disc saw – a continuous spinning disc equipped with cutting teeth that cut a tree, similar to a circular saw placed horizontally.

Complete tree method – entire tree, including the major roots, are extracted to roadside.

Cradle debarker – a machine where rotating chains turn the logs which causes friction between the logs resulting in the bark being removed.

Crawler tractor – a track mounted skidder/tractor used to extract timber from stump to roadside.

Cut-to-length method – trees are felled, limbed, topped and crosscut in the compartment. The round wood assortments are then extracted to roadside.

Dangle head – an attachment mount that allows the freedom of movement of the attachment (to dangle).

Dbh – tree diameter at breast height (1.3 m).

Debarking – removal of bark and cambium layer.

De-branching – remove branches flush with the stem once the tree has been felled.

Direct drive – see torque converter.

Drive-to-tree machine – machines with a fixed boom attachment that requires the machine to drives to each tree to be felled; this machine is usually equipped with rubber tyres.

Drum debarking – large, high production machines that can process many logs at once; a dropping and tumble action makes the logs rub and hit against each other and the drum walls to remove the bark.

Dual arch – a grapple skidder attachment that allows for up, down, forward, and backward movement. There are two pivot points and two sets of cylinders. The dual arch provides greater reach than the single arch.
**E**

**Ergonomics** – the study of the relationship between humans and their working environment that takes into consideration physiological, psychological, sociological, technological, economical, and organisational aspects of the workplace.

**Excavator** – track based machine that has been converted to perform forestry applications.

**Extended primary transport** – terrain transport past the roadside landing to an intermediate storage site or directly to the processing site.

**F**

**Falling Object Protection Structures (FOPS)** – an international standard to ensure that falling objects do not deform the cab and cause injury to the cab occupant; can withstand full trees falling on them.

**Feller buncher** – a machine that can both fell single and accumulate multiple trees.

**Felling head** – see attachment.

**Fire detection and suppression system** – automatically triggered or manually activated systems that will discharge fire suppressant at high pressure into the engine compartment to extinguish any possible flames.

**Footprint** – the size of the combined contact area between the machine and the ground.

**Fixed head** - an attachment that is not free to move and is controlled by the operator of the machine.

**Forwarder** – a four-, six-, or eight-wheel machine used to transport logs off the ground from the stump area to a stacking area alongside the forest road.

**Forest access development** – the development of forest roads as a means to access plantations or forests to harvest, transport, conduct silvicultural activities and for forest protection.

**Forest road** – an allocation of space in the forest, which can be driven on with heavily laden road vehicles. A forest road can accommodate fast and slow moving vehicles and can be used as a locality for conversion, storage and transport.

**Frequency** – is the rate at which the source produces sound waves (hertz Hz =1 cycle/s. Frequency is the number of times per second that a vibrating body completes one cycle of motion, hertz Hz =1 cycle per second).

**Front-end loader** – a self propelled wheeled machine equipped with log forks; used on depots or at processing plants (e.g. mills) to load or unload trucks and for general timber handling.

**Full tree method** – trees are felled and transported to roadside with branches and top intact.
**Gate delimber** – a steel grid with vertical bars which remove branches from the stem as the tree lengths are reversed through by a skidder.

**Grapple skidder** – a four-wheel drive, rubber-wheeled purpose designed tractor with articulated steering for pulling a load by lifting the log ends clear off the ground by means of a grapple.

**Ground condition** – the bearing capacity of the soil, which is determined *inter alia* by soil type, clay content and current moisture status.

**Ground roughness** – the presence of obstacles which may or may not inhibit vehicle movement across the land surface.

**Grouser** – the horizontal bars welded onto the individual track shoes to facilitate traction and stability of the machine.

**Hand-arm vibration syndrome (HAVS)** – collective effects of vibration caused changes in tendons, muscles, bones and joints of a human body.

**Handling (timber)** – the activity where timber products are being handled primarily on landings and/or depots and can include stacking, sorting and/or loading.

**Harvester** – a machine built to accomplish a combination of tasks in one application. The main application is felling, de-branching (and debarking) and merchandising of individual trees without having to handle them twice.

**Harvesting method** – the form in which wood is delivered to roadside, and depends on the amount of processing the wood or raw material undergoes in the harvesting site.

**Harvesting system** – the tools, equipment and machines used to harvest an area. The individual components of the system can change without changing the harvesting method.

**Harwarder** – a combination machine performing both a harvesting and forwarding function.

**Heel-boom (loader)** – an attachment fitted to the point of the stick-boom, that allows the operator additional control over the timber handling operation; used in tree-length loading mainly.

**Harvester head** – an attachment head used for felling, de-branching (and debarking) and processing timber.

**Heel** – see heel-boom loader.

**High flotation tyres** – wide tyres designed for use in wet or sensitive areas.

**Hot operation** – an operation where the operational buffers are small or non-existent.

**Hydrostatic** – a drive train option where hydraulics, as opposed to mechanical drives, is used to drive the machines; most forwarders are driven this way.

**Hybrid grapple** – a combination of a sorting and bunching grapple.
**Intermediate technology** – use of equipment such as chainsaws, tractors, tractor-trailer units and skidders for timber harvesting.

**Integrated braking system** – a system which allows the tractor operator to brake tractor and trailer simultaneously by applying a single foot brake pedal on the tractor.

**Intermittent disc-saws** – an intermittently powered spinning disc (only spins when required and powered) equipped with cutting teeth that cut a tree, similar to a circular saw placed horizontally.

**Knuckle-boom crane** – a crane that articulates in the middle of its span.

**Labour turnover** – the rate at which an employer gains or loses employees during the course of a month or year.

**Law of piece-volume** – the relationship between time consumption per piece and volume per piece and describes the influence of piece size on time consumption, labour productivity and costs.

**Levelling machines** – machines with a platform (turntable) and a cab levelling mechanism usually for use on steep slopes.

**Logging** – synonymous to the term timber harvesting.

**Logistics** – management of the flow of goods, information or other resources in a cycle between the point of origin and the point of consumption that meets the requirements of the customer.

**Longhaul (transport)** – the transport of timber from roadside or depot to saw or pulp mill. See secondary (intermediate or terminal) transport.

**Loudness** – see sound intensity.

**Lugs** – the make-up of the tyre surface that adds to its aggressiveness for use in different applications.

**Lux** – the SI unit of illuminance and luminous emittance; used as a measure of intensity as perceived by the human eye of light that hits or passes through a surface.

**Machine trail** – see skid road.

**Mechanised technology** – use of machines such as harvesters, forwarders, feller bunchers, grapple skidders and processors in a timber harvesting system.

**Merchandise** – to process timber into assortments desired by the market.

**Motor-manual felling** – tree felling with a chainsaw.
**Operator Protective Structure (OPS)** – the international agreed upon standard to ensure that machine operators are adequately protected by stopping foreign objects from penetrating the cab (grills or fully enclosed cabs).

**Operator fatigue** – can be both mental and physical fatigue; mental being the inability of the person to think clearly or concentrate on the task at hand adequately.

**Operations Research (OR)** – a process of using applied mathematics and science to establish an optimal or near optimal solutions to complex decision-making systems.

**Parallel boom** – a simple crane system that only has one joint and can easily be moved in and out on the horizontal plane.

**Personal Protective Equipment (PPE)** – protective clothing issued to help prevent occupational injuries.

**Plantation residue** – bark, foliage, branches, wood pieces and off-cuts which are generated by harvesting and processing.

**Preventative maintenance** – scheduled maintenance that is used to prevent unnecessary and unplanned breakdowns of machines and equipment.

**Processor head** – a head used to add value to an already felled tree through debranching, debarking and/or merchandising the stem.

**Processing** – changing the form of the tree between the felling activity and delivery to the mill, through debranching, debarking and merchandising the stem.

**Part tree method** – trees are felled, partially limbed, crosscut and transported to roadside. The top and pulpwood sections are not separated and have branches intact.

**Person days** – the amount of work a person can do in a day.

**Piece size** – the size of and individual stem, log or unit of timber to be handled.

**Primary transport** – the transport of timber from the stump area to a roadside landing. The landing could be either centralised or continuous.

**Productivity** – the measure of output from a process or operation, measured in output per unit time.

**Pulpwood** – small size timber used for mechanical or chemical pulping to produce paper and other products.
Ring debarker – a machine with knives that hydraulically keep in contact with the tree surface as the tree passes through the debarker.

Road density – the total road length in an area divided by the total land area; expressed in m/ha.

Road network – a network of roads within an area for a particular purpose; represented in m/ha.

Road spacing – the theoretical distance between roads in a given area; represented in metres (m).

Roll Over Protective Structures (ROPS) – an international standard to ensure that if a machine rolls over that the cab is not damaged and the cab occupant injured.

Secondary intermediate transport – timber transport from a roadside landing to an intermediate storage site (wood does not reach the processing site in this phase of transport).

Secondary transport – timber transport from an intermediate storage site to the processing site (the final stage of transport).

Semi-mechanised – harvesting systems where some activities (i.e. debarking) are mechanized and other activities (i.e. felling and extraction) are carried out with basic or intermediate technology.

Service access – how a machine is constructed to ensure that it is easy to access when servicing the machine and for maintenance purposes.

Shear felling head – Normally two hydraulically operated knives which will sever a stem. The head has either one fixed and one moving blade or two moving blades.

Shortwood – see cut-to-length harvesting method.

Single arch – a grapple skidder attachment suitable for selection and clearfelling applications. The effective arch reach consists of one arch pivot that allows for an up and down movement of the arch with a single set of cylinders.

Skid road – an allocated open area within the stand, which allows the movement of machines for either processing, storage and transport or only transport.

Slasher – normally bar and chain technology which allows the bulk cross-cutting of a large quantity of trees or logs in fixed log lengths.

Shovel logging – a ground-based extraction technique that involves a purpose-built self driven swing loader that systematically traverses the compartment, grabbing the timber and swinging it sequentially closer to the landing with each pass.

Slewing – the turning of the turntable or upper structure of an excavator.

Sound intensity – perceived as loudness, measured in decibel at the A-weighting of the frequency range to best model the sensitivity of the human ear (dBA).

Sound pressure – is the amount of air pressure fluctuation a noise source creates.
Sorting grapple – a grapple used in large diameter timber where a full load involves one or two stems.

Shortening clutch – a quick coupling to attach two different sections of cable.

Spark arrester – a specific system in place to reduce the exhaust emission temperature.

Single-grip harvester – a harvester with one head attachment with the ability to fell, de-branch (and debark) and cross-cut the tree in one process.

Spha – stems per hectare (also S/ha).

Standard Operating Procedures (SOP) – the minimum standard required for the particular operation or job.

Stroke-boom delimber – see “stroke delimber”.

Stroke delimber – a track-based carrier that has been equipped with a complex array of booms and grabs that enable it to remove branches from the trees, top the tree.

Stand density – total number of trees in the whole stand area.

Supply Chain Management (SCM) – business management approach where the emphasis is on the integration of business processes across all boundaries within and between organisations.

Swing boom – a machine where the grab is fitted to a small mounted crane allowing reach on either side of the machine.

Swing-to-tree machines – usually a tracked machine with a longer boom configuration mounted on a turntable able to move the boom to specific trees without moving the machine.

Tagline – a cable skidder system that uses three separate sets of chains with multiple sliders with choker chains which are attached to the skid cable through a quick-coupling device called a shortening-clutch.

Tail Swing – a machine usually excavator based where weight is transferred to the back of the body extending over the tracks.

Tail Swing (zero) – weight distribution is optimized on a machine in a platform (turntable) so that the rear of the machine stays within the tracked area.

Technical labour productivity (TLP) – a measure of the number of workers used for an operation; calculated by dividing the total system output by the total amount of man-days required to produce it.

Telescopic boom crane – a crane with a stick boom that contains a secondary boom that can be hydraulically extended; also referred to as extension or squirt boom.

Three-wheel loader – a three-wheeled machine with a fixed angled boom fitted with a grab with limited reach; used for loading, off-loading, stacking and sorting.
**Timber extraction** – the process of transporting harvested timber from a position within a compartment to a point at roadside for further processing or loading.

**Timber grapple** - a specific grapple designed for loading timber products.

**Timber harvesting** – the forest operation where trees are cut for utilisation by society or to produce stand/forest conditions specified by the owner, and all associated operations (e.g. planning, roads, layout, felling, conversion, extraction and long distance transport).

**Topping saw** – an additional chain and bar saw mounted at the top of the head (usually a processor head) that can cut a short log lengths from the last section of the stem.

**Topless full tree method** – trees are felled and topped, the stem without the top is then extracted to roadside.

**Torque Converter** – a drive train option that employs a form of mechanical power transfer from the engine to the tyres.

**Track shoes** – individual parts that make up the whole track on a track machine.

**Traversing** – moving diagonally across the slope.

**Tree length method** – trees are felled, limbed and topped in the compartment and only the bole extracted to roadside.

**Truck mounted loader** – a knuckle-boom crane loader driven by a slave engine fitted to an on-road carrier truck.

**Turntable** – the point of rotation between the machine and the carrier.

**Two-grip harvester** – a harvester with two head attachments, the felling attachment is mounted on the crane while the processing attachment is located on the machine.

**Tyre chains** – chains that are fitted to rubber tyres to increase traction and tyre life.

**Tyre tracks** – similar to bogie track but are tracks mounted on individual wheels.

**U**

**Utilisation** – the percentage of time that a machine is actually in use for the task it is designed for as a percentage of total time scheduled for work; also refer to the definition of machine availability.

**V**

**Vibration-induced white finger (VWF)** – vibration-induced disorder that affects blood vessels, nerves, muscles and joints of the wrist, hands and arms. This can cause numbness of the fingers, loss of movement of the appendage and cause fingers to change colour.
Whole-body vibration – the effect of vibration on the whole body and its associated negative health impacts.

Whole tree method – all biomass above the stump and a major portion of the stump are removed to roadside.

Workplace dimensions – the height, depth and width of the standing, seated and lying person, depending on the specific work a person has to do.

Written Safe Work Procedures (WSWP) – written instructions of safe working methods for a particular job or operation.