A METHODOLOGY TO AID IN APPROPRIATE FOREST TECHNOLOGY DECISION-MAKING FOR DEVELOPING COUNTRIES

by

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Declaration

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

Abstract

Grobbelaar, F.R. 2000. *A methodology to aid in appropriate technology decision-making for developing countries*. M.Sc thesis. University of Stellenbosch.

In the process of selecting what we believe to be suitable technology for timber harvesting and transport, economics are usually the determining factor, whether in the form of capital investment or personnel cost.

Internationally we see a move towards mechanisation in forestry for various reasons: e.g., high wages, labour shortage, and occupational safety. The realities of South Africa highlights other issues requiring attention: e.g., high unemployment, skills' shortage, global competition, rampant AIDS pandemic, and a poor safety and security record. This should focus our attention on finding local solutions to the problem of finding suitable or appropriate technology to support South Africa's quest for sustainable development.

This thesis attempts to establish a methodology for the objective evaluation of alternative technologies for a specific timber harvesting situation, considering the economic, social and environmental implications.

Opsomming

Grobbelaar, F.R. 2000. *A methodology to aid in appropriate technology decisionmaking for developing countries*. M.Sc tesis. Universiteit van Stellenbosch.

Tydens die keuse van sogenaamde toepaslike tegnologie vir houtinoesting en –vervoer is ekonomie meestal die deurslaggewende faktor, hetsy verteenwoordig deur kapitaal belegging of personeelkoste.

Internasionaal is daar tans 'n neiging na meganisasie in bosbou vir 'n verskeidenheid redes: bv., hoë arbeidskoste, arbeidtekort, en beroepsveiligheid. Die werklikhede van Suid-Afrika beklemtoon egter ander sake wat daadwerklike optrede vereis: nl., hoë werkloosheid, gebrek aan vaardighede, internasionale mededinging, ernstige VIGS pandemie, en 'n swak veiligheid-en sekuriteit rekord. Dit behoort ons aandag te fokus op die vind van plaaslike oplossings tot die probleem met die keuse van geskikte of toepaslike tegnologie ter bevordering van Suid Afrika se strewe na volhoubare ontwikkeling.

Hierdie tesis poog om 'n metodiek te ontwikkel vir die objektiewe beoordeling van alternatiewe tegnologieë vir houtinoesting binne bepaalde omstandighede, met inagneming van ekonomiese, sosiale en omgewings implikasies.

Acknowledgements

I am indebted to the Department of Water Affairs and Forestry for its funding of the Appropriate Forest Technology Project of which this thesis forms a small section.

First and foremost my gratitude to my wife Nelleke, daughter Lizanne, and son Jan-Paul, for their continuous support during trying times.

Further gratitude to Professor Loren Kellogg, Professor Reino Pulkki, Dr. Eksteen Uys, Dr. Colin Smith, Mr. Russell Morkel, and Mr. Michal Brink, for their assistance during various stages of my study.

Professor Walter Warkotsch, first Chair of Forest Engineering at the University of Stellenbosch, who gave impetus to Forest Engineering education in South Africa, and nurtured my keen interest in the Forest Engineering discipline.

Other friends and colleagues I am indebted to for their support are Pierre Ackerman, Dr. Christo Marais, Brandt Coetzee, and Killian Manyuchi.

I wish to dedicate this thesis to the memory of a friend and colleague, Lionel Rowberry (jr), businessman and harvesting contractor in Swaziland, who was tragically killed on 14 October 1999.

Preface

The impetus behind the origin of this thesis is derived from the aching need for sustainable development in South Africa, best expressed in the words of our present State President:

"On an occasion such as this we should, perhaps, start from the beginning.

So let me begin.

I am an African.

I owe my being to the hills and the valleys, the mountains and the glades, the rivers, the deserts, the trees, the flowers, the seas and the ever changing seasons that define the face of our native land.

The constitution whose adoption we celebrate ... rejoices in the diversity of our people and creates the space for all of us voluntarily to define ourselves as one people.

The dismal shame of poverty, suffering and human degradation of my continent is a blight that we share ... leaves us in a persistent shadow of despair.

However improbable it may sound to the sceptics, Africa will prosper! Whoever we may be, whatever our immediate interest, however much we carry baggage from our past, however much we have been caught by the fashion of cynicism and loss of faith in the capacity of the people, let us say today: Nothing can stop us now!"

Extracts from the speech of Thabo Mbeki, then Deputy-President, on the occasion of the adoption of South Africa's Constitution in May 1996 (Mbeki, 1998).

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1. INTRODUCTION

1.1 Background

South Africa is a developing country characterised by some of the best-developed infrastructure in Africa south of the Sahara desert. Unfortunately the rampant unemployment and resulting high crime rate poses a serious threat to the development and future stability of the country as a whole.

The forest industry in South Africa is a relevant role player with its key presence in the rural areas of the country. Together with agriculture it has a great potential impact on the sustainable development of rural areas, and a potential to reduce the rate of urbanisation through wealth creation and empowerment of the rural population.

The evaluation and selection of appropriate technology (AT) for the harvesting of timber is a key issue to be addressed to ensure the future relevance of the industry in supporting sustainable development within the greater South African economy.

1.2 Study objectives

The study's objective, to define a simple and systematic method of evaluation for selection of appropriate forest harvesting technology considering economic, social and environmental implications, is supported by the following goals: i.e.,

- to provide an overview of the decision-making environment;
- to design the decision methodology; and
- to test the proposed methodology in three case studies.

1.3 Justification for the study

Traditionally timber harvesting system selection considers the lowest cost option as the most appropriate technology. However in light of the socio-economic reality of the country, and its implications on future sustainable development and stability, lowest cost does not necessarily provide an adequate solution. The view is held that future stability and resulting sustainable development in South Africa requires focussed attention of government, as well as business, to the economic, social and environmental issues.

2. THE SOUTH AFRICAN FOREST HARVESTING DECISION-MAKING ENVIRONMENT

2.1 Socio-economic overview

2.1.1. The social environment

In South Africa there is a stark contrast between first world development and third world poverty.

2.1.1.1. Population growth

South Africa has a population of 40.5 million (CSS, 1998), with an annual post-1990 growth of 2.06%. The four major ethnic groups are 75% black, 13% white, 9% coloured, and 3% Asian (CSS, 1998). The stark reality of the South African population and the development disparity is that 35% of the total population is younger than 15 years compared to 21% in first world countries (Huntley *et al.*, 1989; CIA, 1999).

2.1.1.2. Disposable income

The disparity in disposable income is especially significant when comparing the white population with the black population. The white population (13% of the total population) earns 60% of the total disposable income (CSS, 1998). The coloured and Asian population shares in the total disposable income in proportion to their share of the total population.

Despite an increase in the number of wealthy black South Africans since the mid-1970's, the income for the poorest 40% of the black population has decreased significantly. The average household income for a white family is 12 times that of a black family. More than half the black population live below the poverty line (Encarta, 1997).

2.1.1.3. Land tenure

According to Huntley *et al.* (1989) 50 000 white farmers have access to 70% of the total agricultural land in South Africa, while 700 000 black farmers (largely previous homelands) have access to only 13% of the agricultural land. The resulting landholding disparity is 1 700 ha per white farmer compared to 22 ha per black farmer.

2.1.1.4. Health

The South African per capita water consumption ranges from 9 to 200 l/day compared to the World Health Organisation (WHO) minimum domestic water guideline of 50 l/day (Huntley *et al.*, 1989). More than 25% of South Africa's population do not have reasonable access to clean water (DWAF, 1999).

The birth rate for the total population is 3.22 children per woman. A comparison of life expectancy and infant mortality for the different population groups is shown in figure 1.

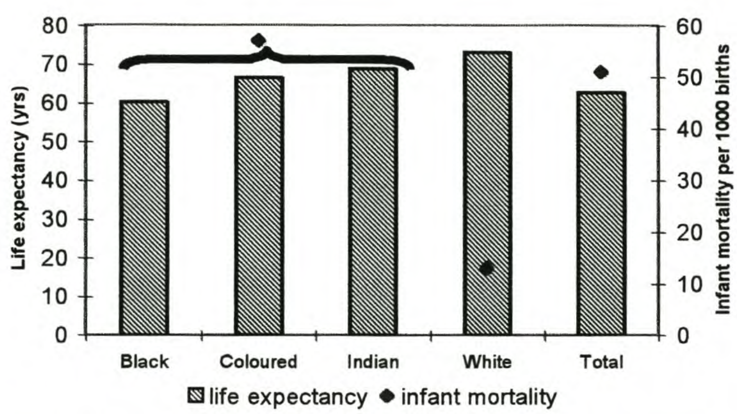


Figure 1. Expected life and infant mortality per population group in South Africa (CSS, 1998)

The Development Bank of Southern Africa (Bodde, 1996) estimated that 12 million South Africans (29.6%) will be infected by HIV by the year 2000, resulting in 5.2 million deaths from AIDS related diseases. The burden on our health care services is almost too horrific to contemplate and the cost to the country in economic terms resulting from the loss of economically active people will be devastating. Trends from other African countries indicate a life expectancy of 40 years, with half the workforce not surviving past the age of 30 (Finance Week, 1995). According to Slawski (1997), AIDS could affect at least 25% of the SA workforce, resulting in an annual 1% reduction in economic growth and a 5% drop in average productivity.

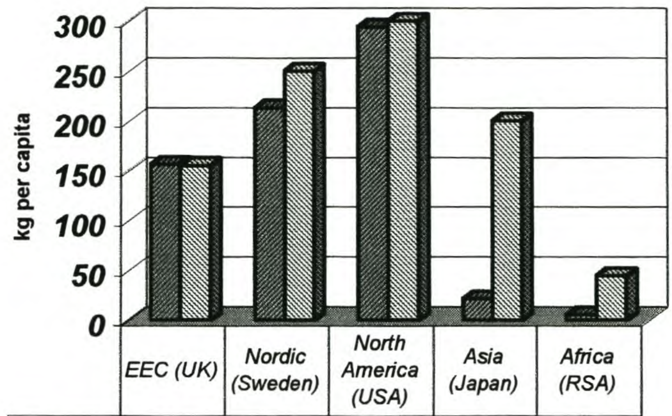
2.1.1.5. Energy

With only 4% of the population on the African continent, South Africa generates 60% of the electricity (Oxenham and Eberhard, 1990 *ex* Ham, 1998). However, fewer than 33% of the South African population has access to electricity in their homes (Dingley, 1994). Thus 11 million m^3 of firewood are required annually to meet the basic energy needs of low-income households in South Africa (Gandar, 1994). This is significant when compared to the annual South African commercial roundwood consumption of 18 million m^3 (FOA, 1998).

2.1.1.6. Education

According to CSS (1998) the literacy level[1] in South Africa is 82.2%. Another indicator of level of development (figure 2) shows the pulp, paper and paperboard consumption per capita of South Africa compared to the total continent and other regions (LHA, 1993). Although South Africa consumes nearly nine times more pulp, paper and paperboard products than the rest of Africa, its consumption is between a seventh and a quarter of the other countries measured.

[1] Literacy level is defined as the percentage of the population older than 15 that can read and write.



	EEC (UK)	Nordic (Sweden)	North America (USA)	Asia (Japan)	Africa (RSA)
Region	156	213	294	21	5
Country	155	250	300	200	44

Figure 2. Per capita pulp, paper and paperboard consumption by country and its region

2.1.1.7. Employment

Over the past decade 850 000 jobs have been lost in the non-agricultural formal sector (Reserve Bank, 1999). According to Cawker *et al.* (1993) the formal unemployment in South Africa is 45%, and expected to rise to 54% (9.8 million people) by the turn of the century.

In the period 1991 to 1995 the economically active population increased by 1.99% (CSS, 1998), of which only 7.8% found formal employment. To accommodate all new labour force entrants, requires an estimated annual economic growth of 5%.

Unemployment can be seen as the root cause of many social problems in South Africa: e.g., crime, promiscuity, substance abuse, and the spread of HIV.

2.1.1.8. Safety and security

According to Barker (1995), the top three contributors to the high South African crime rate is unemployment (25%), poverty (21%) and drugs (8%).

Although largely a social issue, crime also has an important economic impact with regards to ever-increasing insurance costs, insufficient foreign and local investment, reduction in tourist numbers in afflicted areas, and emigration of professional people.

The future stability of most third world countries will largely depend on how successful their economies develop and how it affects the majority of the population.

2.1.2. The economic environment

The development in South Africa over the past century has resulted in a dual economy with strong first world and third world components, largely dependent on mineral export.

After World War 2 South Africa's industrial growth resulted from the production of previously imported consumer goods aimed primarily at the white South African market, and was largely protected by the lucrative export of gold and other precious metals. Initial growth was comparable with major industrialised economies with an average GDP growth of 4.9% between 1945 and 1974 (Gelb 1991). With the economy's inability to absorb the surplus labour and the manufacturing industry's dependence on imported equipment, the OPEC oil price shock in 1973 acted as the catalyst that triggered an economic crisis with growth dropping to 1.9% between 1974 and 1984. During the 1980's the population growth of 2.5% per annum over-shadowed the economic growth of 1.2%. The slow development of export capacity resulted in stagnation, rising production cost and declining investment. The economy proved to be rigid and inflexible, thus causing its own decline and collapse because it was unable to adapt.

Figure 3 shows the composition of the Gross Domestic Product (GDP) per economic sector in 1995. The average annual real growth in GDP in the post-War period is shown in Figure 4. Since 1992, South Africa experienced a gradual weakening of its currency (Figure 5), favouring exports at the expense of imported goods.

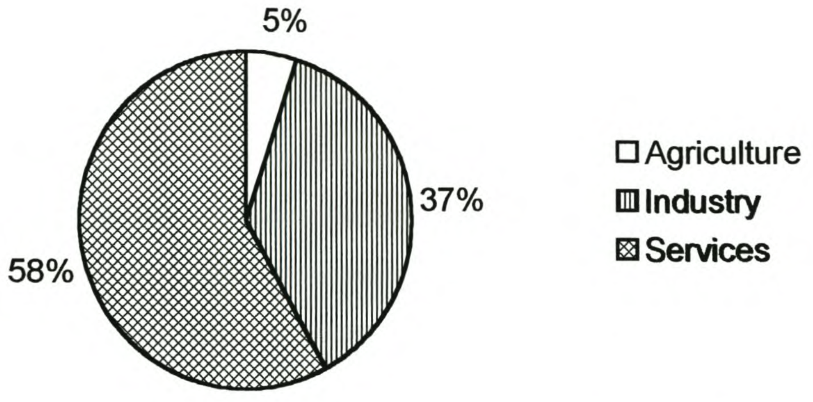


Figure 3. The Gross Domestic Product (GDP): composition per economic sector

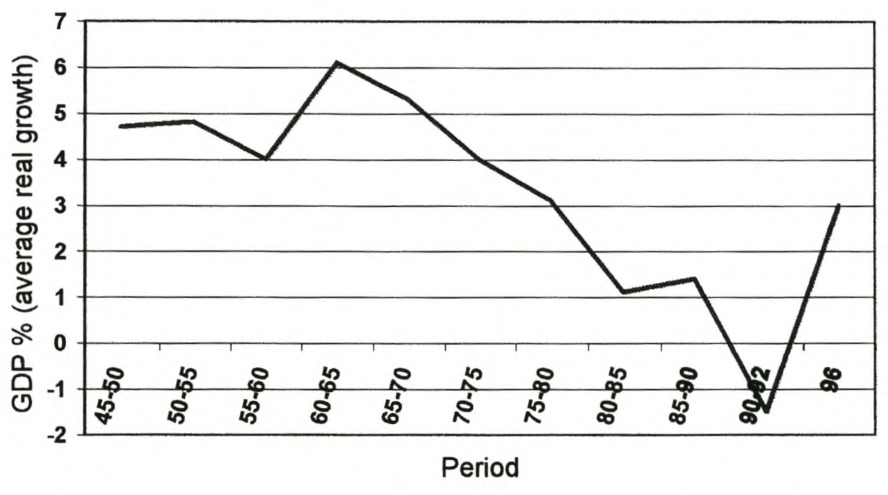


Figure 4. Annual post-war GDP growth (LHA, 1993 and CIA, 1999)

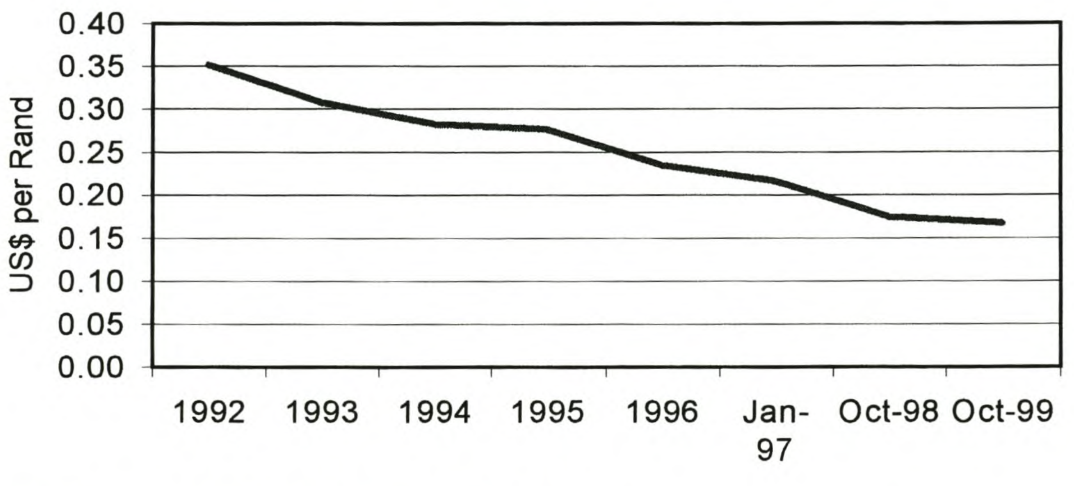


Figure 5. Exchange rate (CIA, 1999)

According to Huntley *et al.* (1989) an annual GDP growth of 2.4% is needed to maintain *per capita* income, 5.4% to root out unemployment, and 10% to root out poverty.

The export trade during 1996 was valued at US$29.2 billion, with the import trade valued at US$26.9 billion. Industrial equipment (machinery and transport equipment) amounted to 47% of imported goods (CIA, 1999).

Since 1994, the trade union movement, previously mainly a political vehicle for the disenfranchised non-white population, has been re-focussing on its collective bargaining role. This resulted in amended labour legislation in 1998.

One of the sad realities affecting the South African economy is the exodus of competent technical and professional people from the country. Driven mostly by the country's crime and safety disposition, it affects the country's ability to develop to the benefit of the whole population.

2.1.3. The natural environment

Situated between the cold Benguela current and the warm Agulhas current, South Africa has a wide range of temperate climatic regions and a rich diversity of plant and animal species (Huntley *et al.*, 1989). This has made tourism an important earner of foreign exchange. The six ecological biomes are listed in table 1.

Table 1. The biomes of South Africa (Rutherford, 1985)

Biomes	Area (ha) (million)	% of total	*MAP (mm)
Savanna	40.9	33.5%	> 235 mm
Nama-Karoo	34.6	28.3%	100 – 520 mm
Grassland	31.4	25.7%	400 – 2000 mm
Succulent Karoo	8.2	6.7%	20 – 290 mm
Fynbos	7.0	5.7%	210 - >3000 mm
Forest	0.0	0.0%	> 525 – 725 mm
Total	122.1	100.0%	497 mm (world ave 860)

* Mean annual precipitation.

Considering a potential annual evaporation of between 1 100 and 3 000 mm over most of the country and mean annual precipitation below world average, South Africa is by any standard an arid country, with water generally the largest limiting factor on development. The arid nature of the country is compounded by the alternating wet and dry spells of nine years each, resulting in high erosion hazard, eastward encroaching Karoo, and veld deterioration due to over-grazing (Huntley *et al.*, 1989).

Of the total of 122 million ha of land, almost 101 million ha are farmland of which 16.6 million ha are considered arable. Increasing focus on biodiversity, economic benefits to communities from conservation, land rehabilitation and water supply, emphasise the importance of the natural environment to economic and social development in South Africa.

Population growth, combined with mass urbanisation, has caused high levels of pollution due to an inability to sufficiently manage waste products. To this end it also becomes a sociological issue, stressing the interdependence of the three core values: i.e., environment, economics and sociological.

2.2. Forestry overview

2.2.1. The scope of forestry in South Africa

Plantation forestry is mainly established in the savanna and grassland biomes, with a smaller occurrence in the fynbos and forest biomes. Exotic softwood and hardwood plantations cover a total of 1.3% of the South African land area, mainly utilising non-arable land (Figure 6). Of the total timber plantation area of 1.52 million ha (FOA, 1998), 63% are owned or managed by large private corporations, 24% are in private hands (farm-forestry), and 13% are under management of the Department of Water Affairs and Forestry and small rural individuals on communal land.

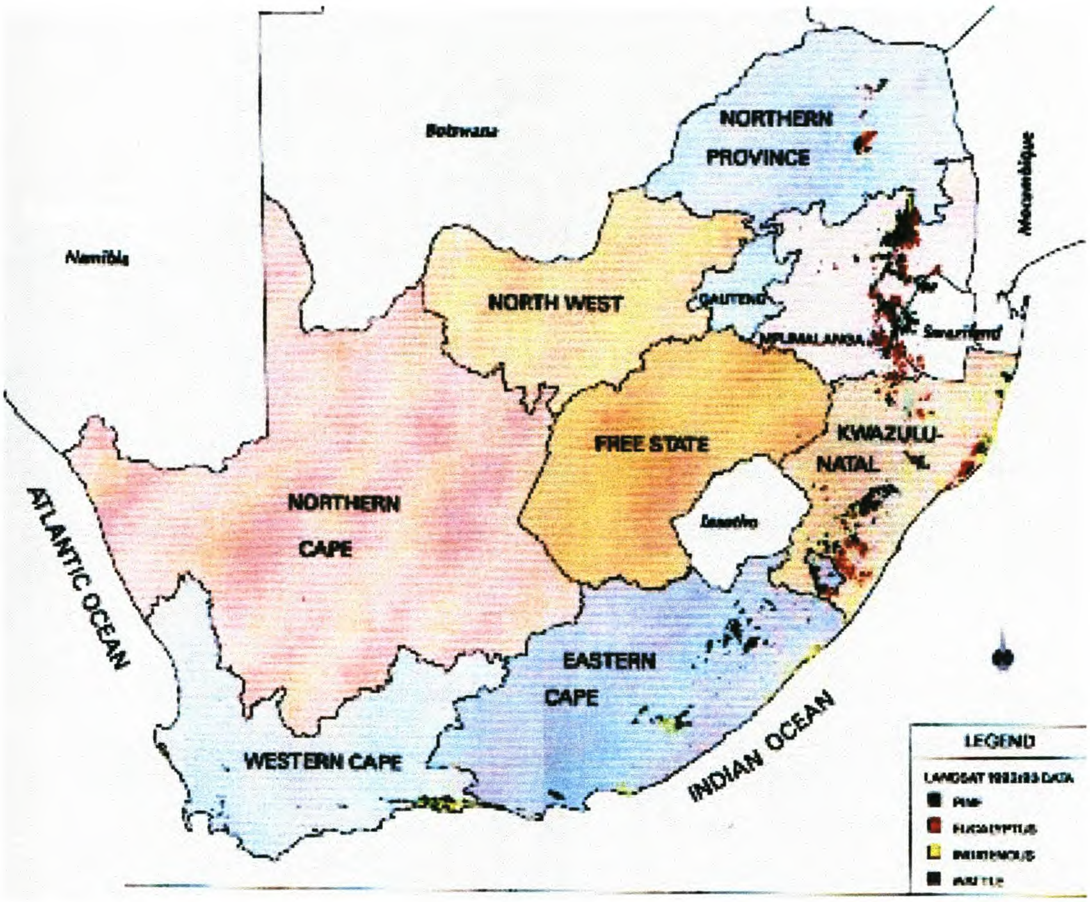


Figure 6. Afforested area in South Africa (DWAF, 1998)

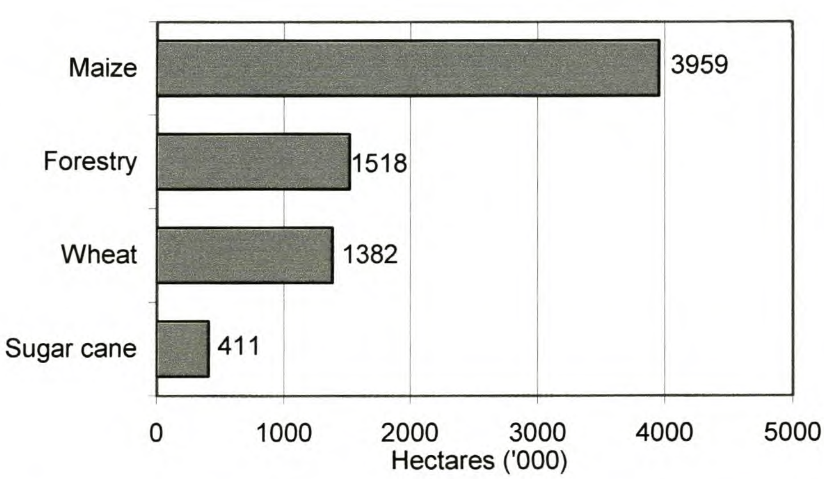


Figure 7. South African land-use comparison (FOA, 1998)

Figure 7 shows the land-use of forestry in South Africa compared to the three most important agricultural crops. Despite the importance of the forest industry, a sharp decline in new afforestation has been observed over the past seven years (figure 8), with small-growers ("subsistence forestry") accounting for the bulk of the new afforestation.

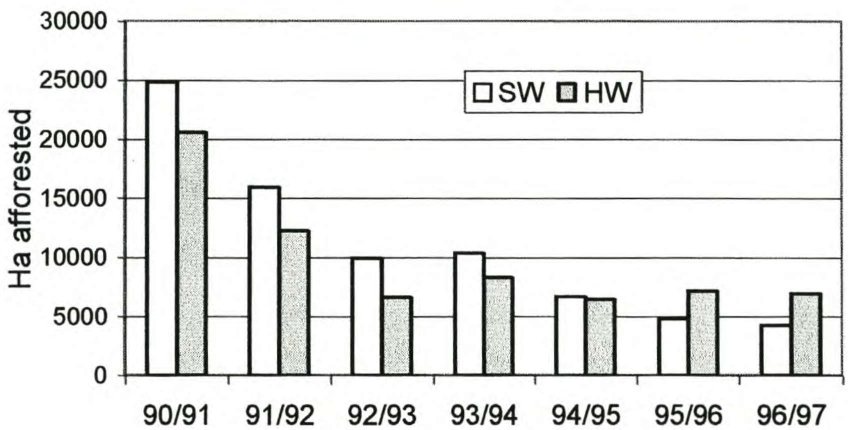


Figure 8. Annual new afforestation between 1990 and 1997 (FOA, 1998)

2.2.2. Historical development

Figure 9 shows the development of the plantation forestry industry in South Africa and Swaziland between 1876 and 1994.

Over-exploitation of South Africa's natural forest resources dates back to 1652 with the arrival of the first Europeans. Since then the commercial, environmental and social values of forestry have alternately played important roles in shaping the plantation-based forestry industry (Olivier, 1996). This included the pioneer planting of exotic species to reduce dependence on indigenous timber, employment creation for social upliftment in two social experiments, and afforestation control through the permit system to protect critical water catchment areas.

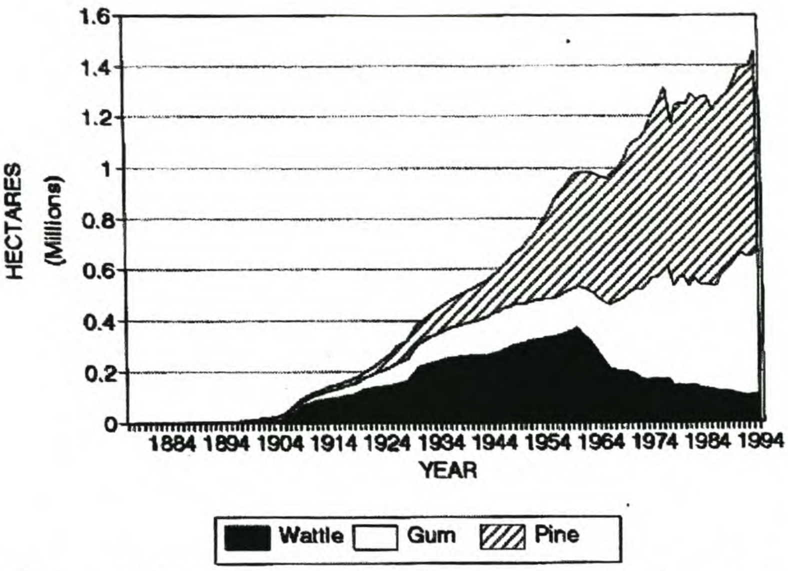


Figure 9. Commercial afforestation in South Africa and Swaziland 1876 to 1994 (Olivier, 1996)

The period 1994 to 1999 highlighted the changing environment within which the forestry industry operates. Changes include the privatisation of state forestry assets; outsourcing (contracting) of operations; new legislation; depressed international markets, growing AIDS threat; increasing focus on biodiversity, sustainability and the conservation of our natural heritage; labour skills and qualifications development; and future land taxation.

2.2.3. Roundwood demand

In 1996/97 18.1 million m^3 roundwood (Brink, 1998), valued at almost R1.8 billion (FOA, 1998), were sold from South African timber plantations. The average long-term growth in annual roundwood demand is expected to be 2.5% for hardwood, and 2.3% for softwood (LHA, 1993). Figure 10 shows the growth in total demand till 2020 for two annual GDP growth scenarios: i.e., 1.5% and 2.5%.

The greatest growth is expected to be in the pulpwood demand, with an almost 100% growth between 1999 and 2020. No growth in mining timber and a 50% growth in lumber and other commodities are expected (figure 11).

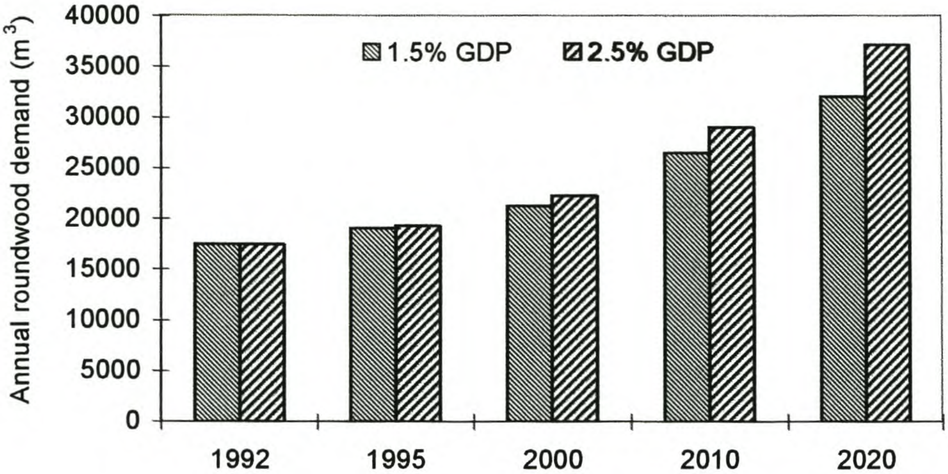


Figure 10. Forecast total roundwood demand for two GDP growth scenarios (LHA, 1993)

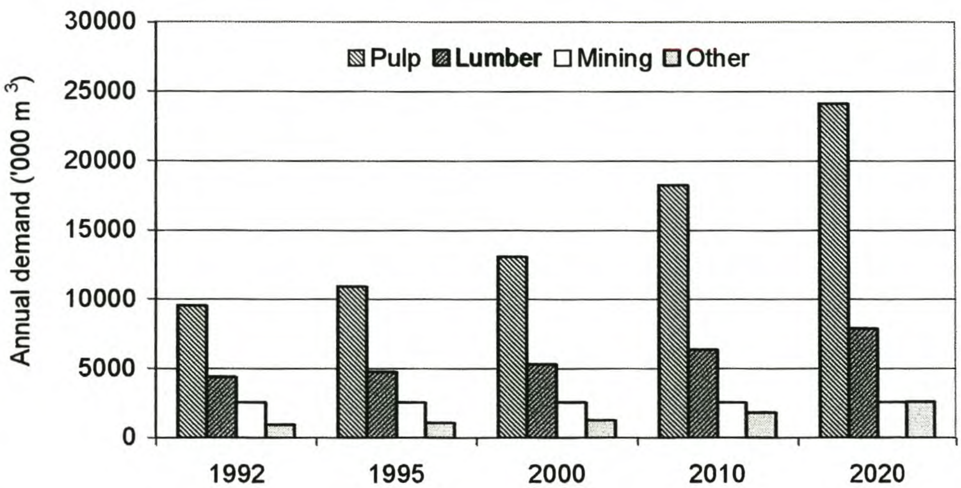


Figure 11. Forecast demand for four commodities based on 2,5% annual GDP growth (LHA, 1993)

2.2.4. Timber harvesting

2.2.4.1. Forest technical survey

The first Forest Technical Survey (FTS) for South Africa (Brink, 1989) was followed by two surveys (i.e., 1993 and 1997), of which only the latter is officially available (Brink, 1998). When comparing the 1988 and 1997 surveys, it is important to keep the following issues in mind:

- Data excludes plantation holdings smaller than 200 ha (i.e., small-growers and farm foresters). This represents 5% of the total South African afforested area (Brink, 1998).
- Operations of the Department of Water Affairs and Forestry (DWAF) and the former homelands, not included in the 1988 data, were included during the 1997 survey (Brink, 1998).
- The surveyed annual cut increased to 18 million m^3 (1997) from 14.5 million m^3 (1988).

Table 2 shows the annual cut (%) by species and plantation business unit size for 1988 and 1997. The significance of the large growers (i.e., greater than 10 000 ha plantation units) is clear, increasing from 60% to 75% of the combined soft- and hardwood produced.

Table 2. Annual cut (%) by species and plantation unit size (ha) (Brink, 1989 and 1998)

Area (ha)	1988			1997		
	Softwood	Hardwood	Total	Softwood	Hardwood	Total
200-499	1%	1%	2%	1%	2%	3%
500-999	1%	2%	3%	1%	1%	2%
1000-1999	2%	2%	4%	2%	1%	3%
2000-4999	10%	6%	16%	4%	2%	6%
5000-9999	7%	6%	12%	7%	4%	11%
>10000	28%	34%	63%	31%	44%	75%
Total	50%	50%	100%	46%	54%	100%
Annual cut (m^3)	14 518 899			18 078 224		

Between 1988 and 1997, South African forestry saw a strong move to the outsourcing of forest operations (Figure 12).

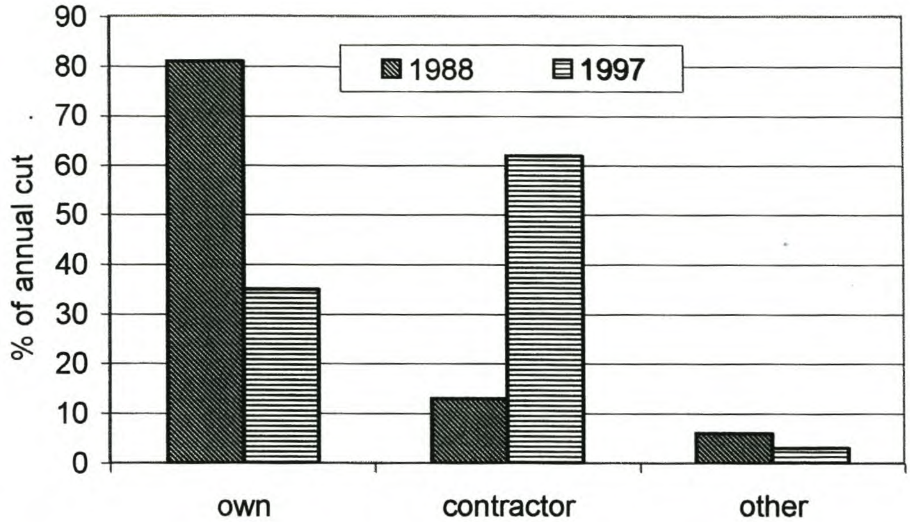


Figure 12. Own operations vs. contractor operations as a percentage of the annual cut (Brink, 1989 and 1998)

There appears to be a significant trend towards longer employment periods (>24 months), with female employees comprising 46% of the total labour force (Figure 13).

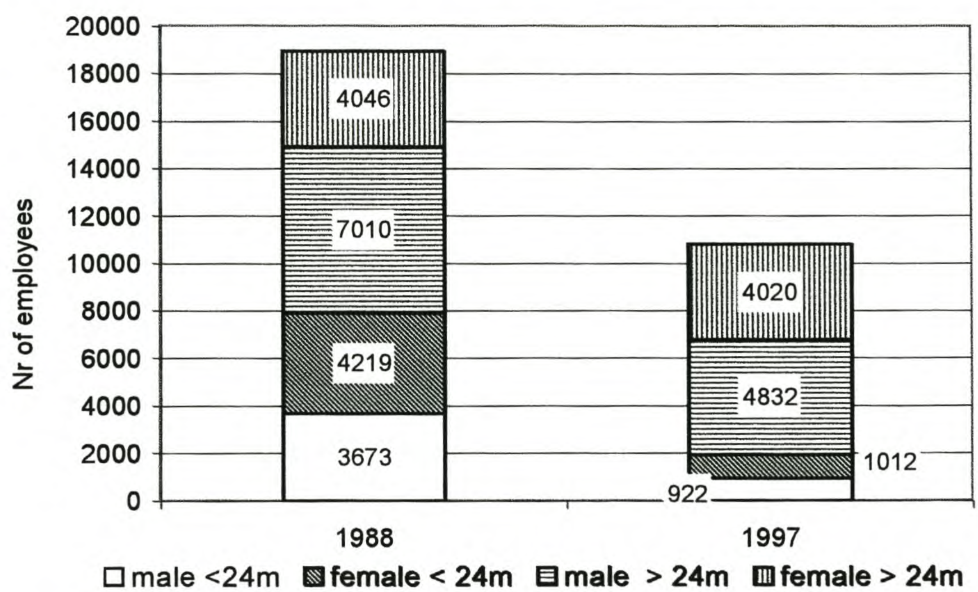


Figure 13. Harvesting employee composition by gender and employment period (Brink, 1989 and 1998)

When put into perspective the longer employment period is probably a result of the downsizing of operations through retrenchment and/or natural attrition from 19 000 to

11 000 employees in harvesting operations. Considering the increased annual cut this relates to a productivity improvement from 764 m^3/worker-year to 1 643 m^3/worker-year. As a large employer in the rural areas where single parent households abound, the gender equity indicates a positive contribution by forestry.

Figure 14 reviews the trend in harvesting methods by species, with a marginal reduction in South Africa in the predominance of cut-to-length, specifically in hardwoods, and a marginal increase in full tree operations.

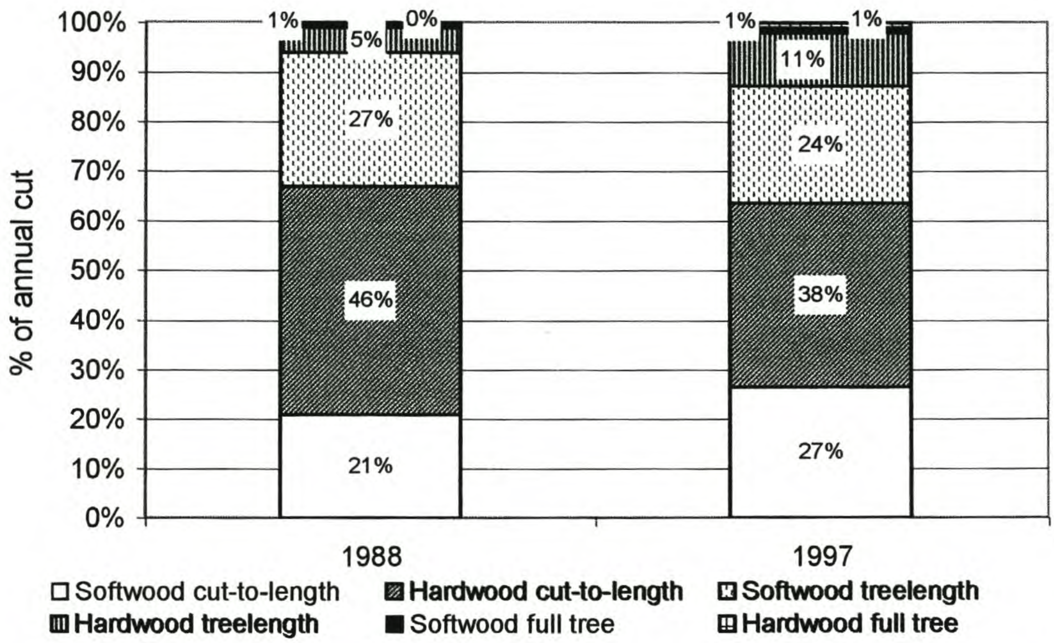


Figure 14. Harvesting methods by softwood (SW) and hardwood (HW) (Brink, 1989 and 1998)

In both surveys motor-manual debranching still predominates (48% of annual cut), followed by hatchets, axes and a small movement to mechanised debranching (Brink, 1989 and 1998).

Manual debarking still predominates with 61% of the total annual cut. This amounts to 94% of the annual hardwood cut and 22% of the annual softwood cut. Many past attempts to mechanise or semi-mechanise debarking resulted in poor debarking quality, stem damage and/or excessive cost. This has resulted in an actual decrease in mechanised debarking.

The most significant indicator is probably an overview of the extraction methods for the period 1988 to 1997 (Figure 15). Keeping in mind that the 1988 survey excluded DWAF, the strong prevalence of "lower" or more basic technology (Figure 16) significantly reflects the current status with regard to contract period, harvesting rates and labour cost. The significant increase in mechanised systems can largely be attributed to SAFCOL's sawtimber operations.

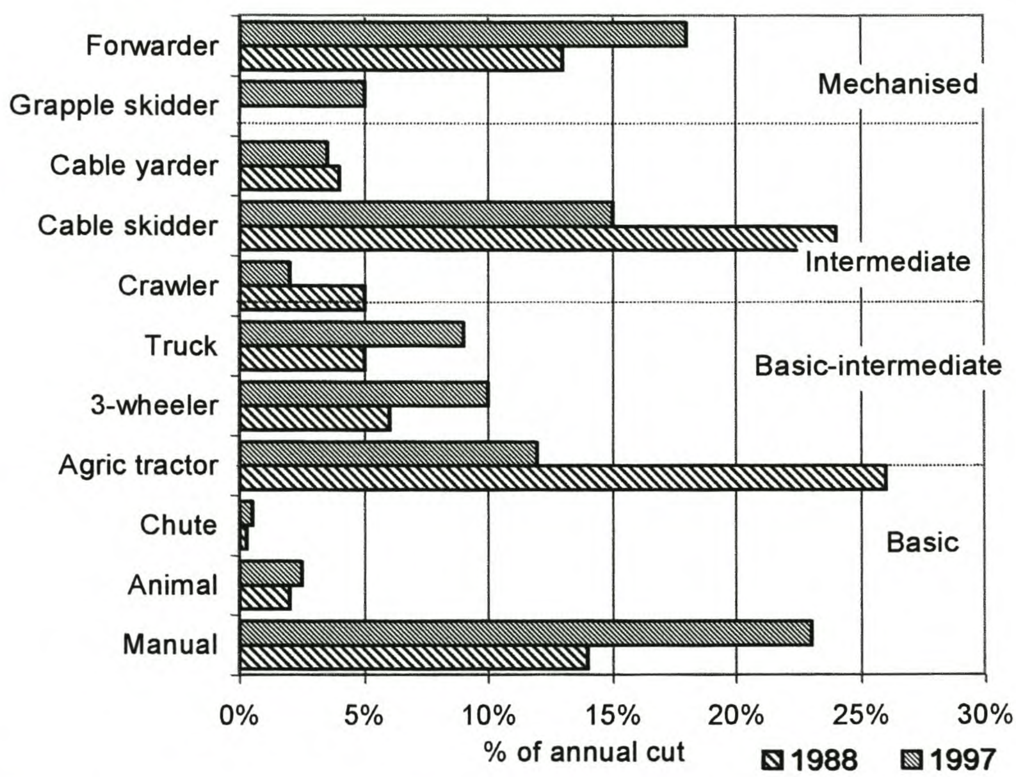


Figure 15. Extraction methods (Brink, 1989 and 1998)

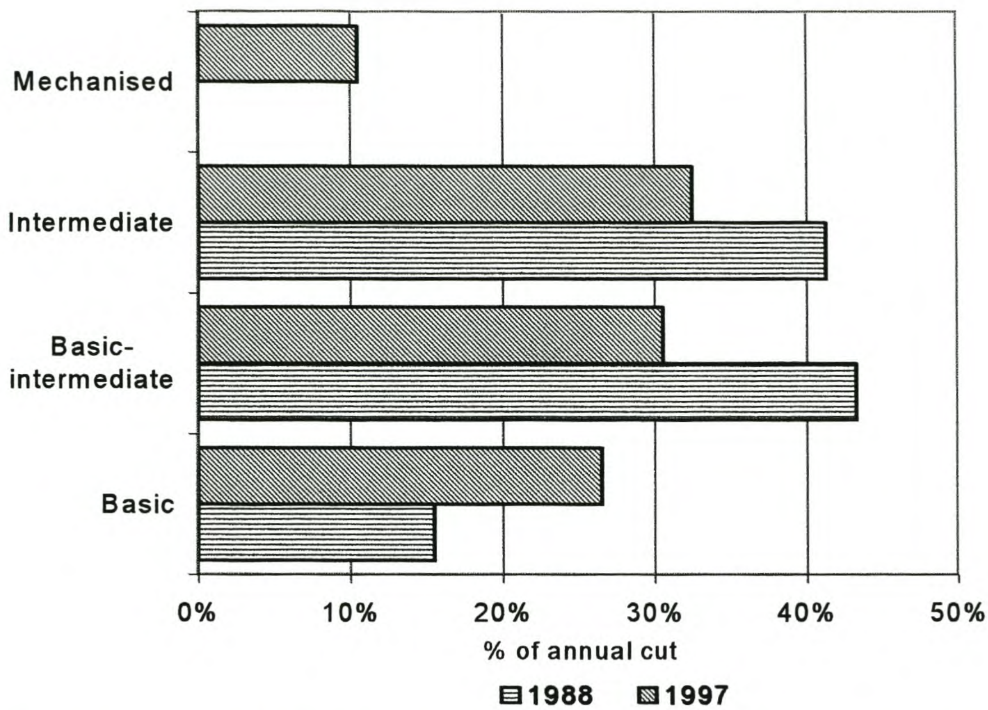


Figure 16. Spread of technological levels in timber extraction (Grobbelaar, 1999)

2.2.4.2. Small-scale harvesting survey

From a survey of 26 "small-scale" timber harvesting contractors working for NCT Forestry Co-operative Limited in the Kwazulu-Natal province (FESA 1996), 92% of respondents worked with *Eucalyptus* spp, 31% *Pinus* spp, 19% *Acacia* spp and 4% *Casuarina* spp. Figure 17 shows the activities they engage in, with available equipment shown in figure 18.

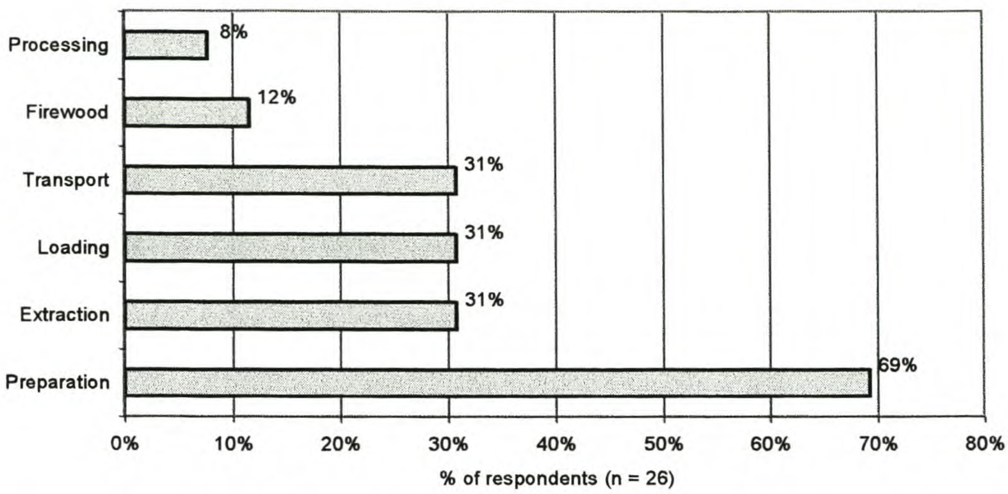


Figure 17. Small-scale contractor survey: timber activities (FESA 1996)

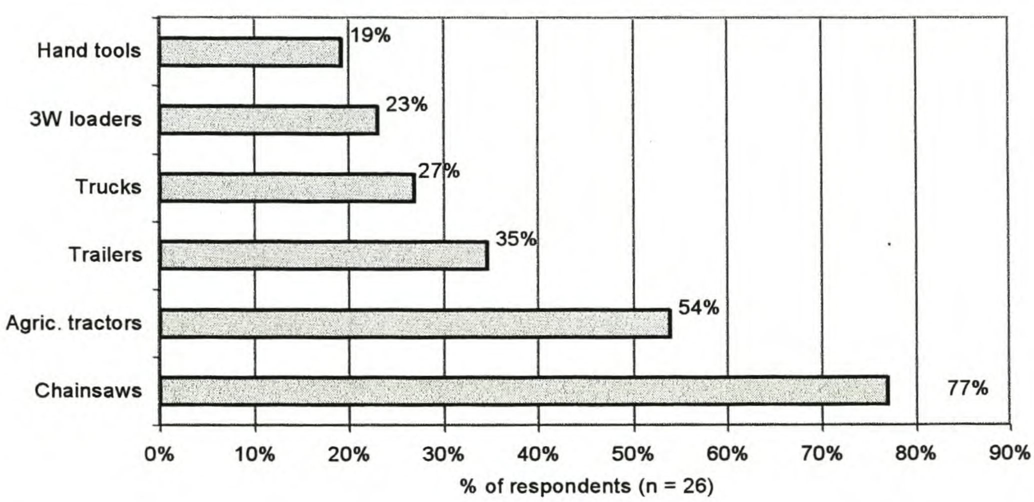


Figure 18. Small-scale harvesting contractor survey: equipment (FESA 1996)

These "small-scale" contractors are especially found in the Kwazul-Natal and southeastern Mpumalanga provinces, jointly responsible for almost 60% of the total plantation area in South Africa. With woodlot harvesting operations still extensively using hand tools and draught animals (Grobbelaar, 1998a), it can thus be assumed that low capital, labour intensive operations predominate amongst "small-scale" harvesting operations in most provinces.

2.3. Sustainable development and the concept of Appropriate Technology (AT)

Dunster (1996) defines sustainable development as development meeting the needs of present generations without compromising the ability of future generations to meet their own needs: i.e., meeting the basic needs of all and providing the opportunity to fulfil their aspirations for a better life. It is a process of change where resource exploitation, resource renewability, investment direction, technological development and institutional needs are made consistent between present and future needs.

Schuhmacher (1974) argues that modern man, through his scientific and technical power, built a production system that ravishes nature and a society that mutilates people, while believing that everything will fall in place if there is more wealth. The resulting problem is man's tendency never to be satisfied with his material status, hence the threat against sustainability (Evans, 1979).

As long as 80% of the world population is subject to rural poverty and stagnation, no amount of stimulation of international trade can have a real impact on the problems of world poverty (McRobie, 1981).

Science and technology need to concentrate on methods and equipment that are cheap enough to be accessible to all, suitable for small-scale applications, and are compatible with the creative need of people (Schuhmacher, 1974).

Considering globalisation and rampant unemployment, any attempt towards sustainable development will need the co-operation of the four major partners in any industry in finding common ground to build their strengths on: i.e., government, company management, employees and communities.

2.3.1. National forestry values and environmental guidelines

Over the past decade various international initiatives attempted to define guidelines supporting the ideal of sustainable development. Undoubtedly the most prominent was the United Nations Conference on the Environment and Development (UNCED) held in Rio de Janeiro in 1992. Various documents that can influence forest policy were produced (Dykstra, 1995): i.e., the Rio declaration, the Forest principles, the International Framework Convention on Climate Change, the International Framework Convention on Biological Diversity, and Agenda 21. UNCED recommendations relevant to this study are (Dykstra, 1995):

- All production and consumption decisions should include true resource and environmental costs.
- Focus on the development of environmentally sound, economically practical and technically efficient harvesting and processing techniques.
- Motivation of sustainable forest practice and greater profit share by society.
- Participation of local communities in forestry activities.

According to the Worldwide Fund for Nature (WWF, 1996) forest resources and associated lands need to be managed in accordance with the social, economic, ecological, cultural and spiritual needs of present and future generations.

With the UNCED drawing the attention of all industries towards the environment and development, the Forest Stewardship Council (FSC) (WWF, 1996) and ISO 14000 (SCC, 2000) developed environmental management standards. In forestry this promotes the environmentally responsible, socially beneficial and economically viable management of natural forests, partially replanted forests and plantations. The FSC public awareness focus areas include the incorporation of full management and production costs into the price of forest products, promotion of best use of forest resources, reduced waste and damage, and avoidance of over-consumption and over-harvesting (WWF, 1996).

Since the UNCED, the South African Forestry Industry saw the publication of a number of relevant documents: e.g., *Guidelines for Environmental Conservation Management in Commercial Forests in South Africa* (FIEC, 1995), *Harvesting Code of Practice* (Engelbrecht, 1995), *Guidelines for Forest Engineering Practices in South Africa* (FESA, 1999) and the *National Forestry Action Programme (NFAP)* (DWAF, 1997).

2.3.2. Appropriate forest technology

2.3.2.1. Definition of AT

AT had its origin in the work of Schumacher (1978) with numerous authors subsequently displaying different interpretations. Unfortunately, there is no single widely-accepted definition available (Dudley, 1993). To most authors AT is synonymous with employment creation (labour intensive) and environmentally sound methods. Dunster (1996) defines AT as low impact technology that is ecologically balanced, thermodynamically sound, locally controlled, knowledge-rich, labour-intensive, and designed as if humans and nature matter. Meth (1990) is more careful, describing AT as labour intensive in labour surplus economies constrained by the issues of political economy, productivity and international competition.

Various authors have a functional approach to AT: i.e., the technology that serves the intended purpose (Hermelin, 1985); the right, suitable or fitting technology (McLeod, 1985); and the technology that is most appropriate to getting the job done (Hindle, 1994).

Sedlak (1987) defines AT as a combination of humans and machines optimally meeting the economic and social needs. Heinrich (1986) tends to be more holistic in considering economic, social and environmental considerations within a framework of sustainable development.

Many of the above approaches create the impression that technology can be grouped, without qualification, in two classes: i.e., appropriate technology and inappropriate technology. However, AT requires a wider definition that relates the technology to a specific situation (Francis, 1988); e.g., the definition of Willoughby (1990 *ex* Dudley, 1993) that AT is technology fitting the psychosocial and biophysical context prevailing in a particular location and period.

The more holistic definition of AT proposed by the author of this thesis argues that it is a spectrum of basic, intermediate, and highly mechanised technologies, evaluated and selected for a specific situation based on a range of criteria that support economic, social and environmental values. In real terms this means that depending on the economic, environmental and social values of a specific situation, the same technology can be appropriate, less appropriate or inappropriate.

Due to its influence on the long-term sustainability of a harvesting operation, the external and internal environment (figure 19) within which it functions need to be considered in the evaluation of AT.

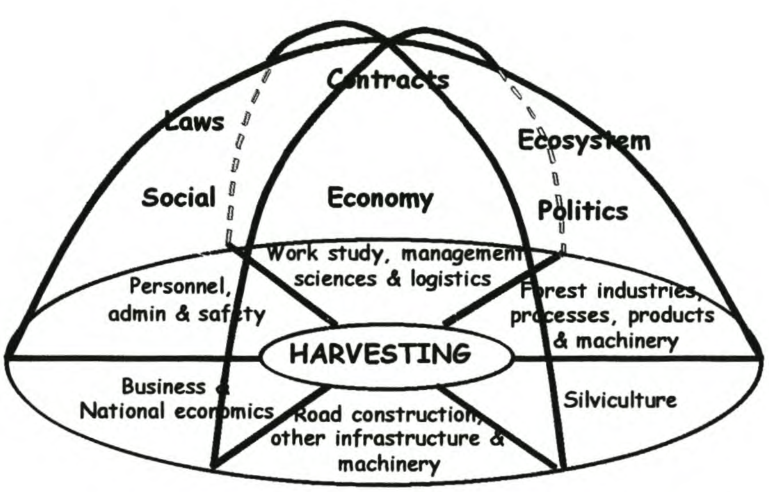


Figure 19. The timber harvesting operating environment (Hoefle, 1974)

2.3.2.2. The levels of AT

Heinrich (1987) defines three technological levels: i.e., basic technology, intermediate technology and highly mechanised technology. Because of the wide range of harvesting equipment involved in the intermediate technology (FAO, 1988), Grobbelaar (1999) proposes an additional level between basic technology and intermediate technology: i.e., basic-intermediate technology. The four technological levels are:

- Basic technology. Technology where manual labour input predominates, using relatively cheap handtools and simple equipment, making use of local skills and materials. Very often this technology is aimed at providing tools to reduce the physical stress of the manual operation (FAO 1982, and FAO 1989): e.g., felling levers, logging tongs and hand sulkie.
- Basic-intermediate technology. Technology that reduces manual labour, increasing the labour productivity through the introduction of machines and equipment (FAO, 1982): e.g., chainsaws, agricultural tractors with skidding bar, and agricultural tractor and general purpose trailer.
- Intermediate technology. This is basically an extension of the basic-intermediate technology with application of dedicated forestry equipment: e.g., agricultural tractor with dedicated forestry attachments (skidding winch, skidding grapple and bogie axle trailer), cable skidder, and standard cable yarders.
- Highly mechanised technology. Technology using more powerful, specialised and high production machines (Johansson, 1997): e.g., harvesters, feller-bunchers, purpose-built forwarders, grapple skidders, clambunk skidders and agricultural tractors with harvesting or processing head. This technology requires more specialised skills and training of the machine operator.

By considering harvesting systems as stages along the technological development trajectory, Heinimann (1999) differentiates between five stages: i.e., biomechanical (motor-manual), mechanical, partially automated systems for single cognitive tasks, automated systems for rule-based cognitive tasks and automated systems for intelligent behaviour (next generation).

The performance limits of basic technology are set by the equipment, while that of advanced technology were set by the operator during the 1970's and 1980's (Singleton *ex* Silversides, 1974). The modern automated machines require little operator input and performance limits are therefore again limited by machine capability.

Although it tends to be easier to mechanise a large commercial operation, the technological level is not entirely dependent on the size of the operation. A large commercial harvesting operation in South Africa can successfully operate on the intermediate technology level, while a Scandinavian farm-forestry (small-scale) operation might effectively utilise a processing attachment on an agricultural tractor (mechanisation).

2.3.2.3. The evaluation of AT

The appropriateness of a technology is generally governed by the climate, organisation, income levels, available skills and social reasons, and should not be distorted by so-called "back-to-earth" technology (Frances, 1988).

AT can be evaluated using the five evaluation criteria for harvesting systems (Brink, 1995):

- Technically possible. Determine whether the identified technological alternatives are possible considering the physical and technical limitations of a specific forestry operation (e.g., terrain and available expertise).
- Economically feasible. Determine the relative economic feasibility of each technological alternative using different operational indicators.
- Socially acceptable. Determine the relative social acceptability of each technological alternative.

- Environmentally agreeable. Assess the impact on the environment (e.g., soil damage) (Smith, 1998).
- Silviculturally agreeable. Assess the impact on the silvicultural activities and practices (e.g., slash management, fire hazard, and forest health and hygiene).

According to Burrus (1993) the technological choice, timing of its implementation, as well as the management of change, are critical to ensure successful application of selected technology.

Developing countries should mechanise with great caution (Sundberg, 1974), rather focussing on optimum use of resources adapted to socio-economic conditions. This can however display great variation resulting in technology ranging from fully manual to fully mechanised.

3. THE AT DECISION METHODOLOGY

A decision is the conclusion of a process by which a choice is made between two or more alternative courses of action for the purpose of attaining the predetermined goals (Turban, 1994). Decisions can be made individually or collectively, with management science principles (i.e., tools and techniques) providing insight and understanding of decision problems (Ragsdale, 1998). Decision analysis, with the aid of these tools and techniques, structure the decision problems into a general framework for analysis and problem-solving (Thierauf *et al.*, 1985).

Considering the apparent conflict in objectives of the economic, social and environmental goals, the proposed methodology needs to be simple to emulate, be objective, review the process holistically (as a system), and ensure consistency between different projects (Solberg, 1988). It should assist in finding local solutions to local problems, and make use of local, national and international information and experiences.

3.1 The systems approach

According to Turban (1994) a system is a collection of people, resources, concepts and procedures intended to serve a certain goal. The *hierarchy of systems* determines that all systems form sub-systems of a larger system, with the result that any decision in one segment of a system (organisation) may significantly influence other segments of the system. Where possible the organisation should be viewed holistically (i.e., the systems approach).

All systems have five distinct parts (Turban, 1994): i.e., inputs, processes, outputs, operating environment and a feedback mechanism (Figure 20).

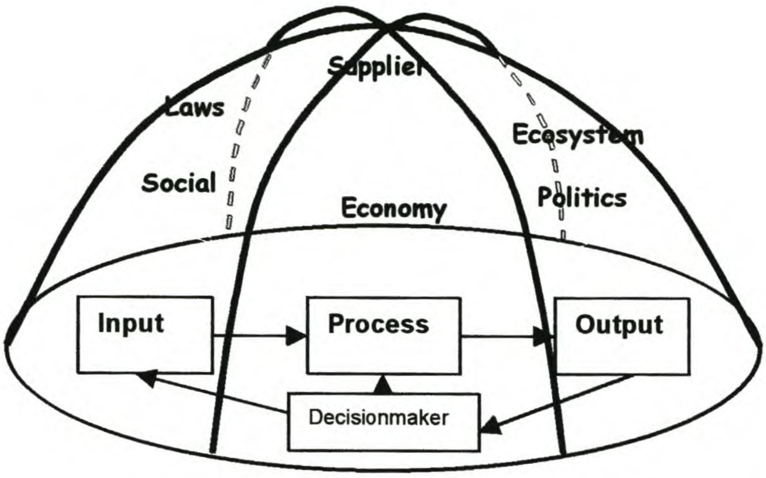


Figure 20. The system and its environment (adapted from Hoefle, 1974; Turban, 1994)

3.2. The basic decision-making process

According to Bird (1992) the process of decision-making is often mistaken for the process of problem-solving. Problem-solving precedes decision-making and requires the collection and analysis of information to enable a sound decision-making process.

The basic decision-making process entails problem diagnosis, identification of alternatives, evaluation of alternatives, selection of suitable alternative, and implementation of the solution (Bird, 1992). An important step, often neglected and following on from the actual implementation, is the control: i.e., on-going monitoring of the succes of the implementation.

3.3. Management science techniques

Management science (MS) techniques can be used in the problem-solving process as well as decision-making. Figure 21 attempts to group the different techniques (algorithms) according to the availability of relevant information regarding the independent variables (X_i), and functional relationship between dependent (Y) and independent variables (X_i) (Pulkki, 1984 and Ragsdale, 1998).

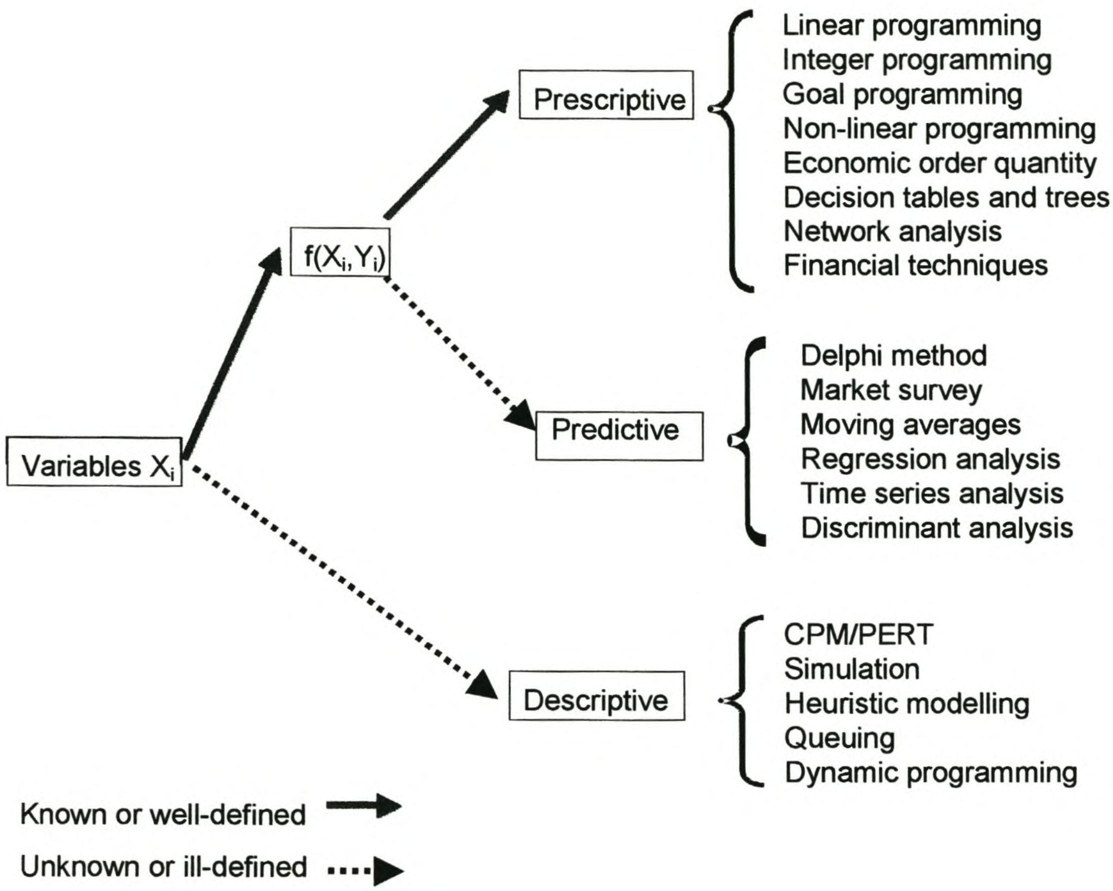


Figure 21. Categories and characteristics of modeling techniques (adapted from Ragsdale, 1998)

The following presents a brief overview of the more common techniques shown in figure 21.

3.3.1. Prescriptive techniques

This is a broad group of techniques that attempts to maximise a goal subject to a clear set of constraints. Techniques in this group include:

3.3.1.1. Linear programming (LP)

This is the simplest mathematical programming technique and can give valuable information when input information is reliable and abundant (Pulkki, 1984). In a comparison of standard LP, parametric LP, goal programming, and integer programming, Mikkonen (1983 ex Pulkki, 1984) found that standard LP and goal programming was the most suitable tools in forest harvesting system selection. Standard LP was however found to be only fairly suitable due to its assumption of a linear world, single objectives and perfect certainty. In the optimisation process LP allocates fractional amounts which can be impractical in practice (Pulkki, 1984). Some special cases of LP include the transportation model, network minimisation and the shortest route problem (Pulkki, 1984).

3.3.1.2. Integer programming (IP)

This is a modification of standard linear programming (Turban, 1994) and is useful for solving problems that require some or all the decision variables to be integer values (Ragsdale, 1998). Turban (1984) mentions a number of differences between LP and IP: i.e., the cost of indivisability, solution method, number of solutions, LP codes and optimal solutions. Some special cases of IP includes the branch and bound procedure, Gomory cutting plane method, and zero-one model (Pulkki, 1984 and Turban, 1994).

3.3.1.3. Goal programming (GP)

This is a relatively young, developing theory with increasing applications. It is a modified approach to LP, applicable to problems with multiple goals. The GP model attempts to find the most satisfactory solution subject to the relative importance of a number of goals (Turban, 1994). Where LP techniques have one primary objective to optimise subject to a number of inflexible constraints, GP aims at satisfying a number of objectives, each with its own flexible target (Ragsdale, 1994). The different objectives in a GP problem can have different dimensions.

3.3.1.4. Economic order quantity (EOQ)

This is used to determine the best inventory level and time to reorder merchandise, and forms part of the oldest management science techniques. Turban (1994) mentions seven different inventory systems, the majority of which make use of the elementary economic order quantity (EOQ) model. These models will not be further discussed.

3.3.1.5. Decision tables and trees

Decision tables arrange quantitative data for systematic analysis of the problem when selecting an alternative (Turban, 1994). It usually consist of four elements: i.e., alternatives, states of nature (or events), probabilities of states of nature, and payoffs (outcome of certain alternative and specific state of nature).

Three classes of managerial problems can be solved using decision tables: i.e., decisions under certainty, decisions under risk and decisions under uncertainty. The probability of the risk or uncertainty inherent in a specific problem can be assessed objectively through historical occurrences or experimentation, or subjectively through the decision-maker's belief in the likelihood of a specific outcome. For decisions under certainty the most appropriate alternative is the one yielding the highest or lowest payoff (depending on the goal objective) for a specific criterion. In the case of decisions under risk or uncertainty a probability weighted average payoff is calculated, with the lowest or highest payoff (depending on goal objective) indicating the most appropriate alternative.

Hoefle (1974) presented a multi-dimensional approach to the decision table technique using utilities to convert payoffs of different measurement units to a common unit. Decision trees are graphical expositions of decision tables that also enable a multi-period decision process (Turban, 1994).

3.3.1.6. Network analysis

Network analysis techniques have proven useful in solving a wide range of problems in the forest industry involving multiple periods, and fixed and variable cost e.g., alternative harvesting systems, alternative destinations, alternative road standards, minimum cost and maximum value (Sessions, undated). Although network analysis is mostly used as a prescriptive modeling technique (figure 22), it can also be used as a descriptive modeling technique.

3.3.1.7. Financial techniques

Although not strictly management science techniques, a number of very useful financial analysis techniques are available to determine economic viability (Gup, 1980). These techniques can be categorised according to its consideration of the time value of money (Uys, 1998): i.e.,

- techniques ignoring the time value of money e.g. payback period and return on investment (ROI), and
- techniques accounting for the time value of money (discounted cashflow techniques) e.g. net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR).

According to Clutter *et al* (1983) a financial investment criterion should fully reflect the magnitude and timing of cash flows, highlighting net present value (NPV), internal rate of return (IRR) and benefit-cost ratio (BCR) (profitability index) as the three most common discounted cash flow criteria. Although some argument exists concerning the proper definition of benefit-cost ratio (Clutter *et al*, 1983), its freedom of dimension is seen as a distinct advantage. Gup (1980) and Stair (1984) regards NPV as the discounted cash flow technique with the fewest shortcomings.

In an evaluation of different equipment replacement models (Adam, 1986) found that the simplicity of using the payback period offsets its other shortcomings (e.g., not considering the time-value of money), and recommends using it with NPV.

Gup (1980) supports the use of more than one financial analysis technique in decision-making. In this study a basic five-year cash flow will be compiled for each case study, with NPV, ROI and payback period used as financial analysis techniques.

3.3.2. Predictive techniques

These forecasting techniques are used in MS to predict the logical relationship of a model and the value of its input data. Turban (1994) distinguishes between four groups of forecasting methods: i.e., judgment methods (e.g., expert opinion, delphi method, and historical analogy), counting methods (e.g., market surveys), time series methods (e.g., moving average and exponential smoothing), and association methods (e.g., regression analysis, econocentric models, and input-output models). The availability of historical data, money and time, and the required accuracy influence the method selection. This study will briefly address the following:

3.3.2.1. Delphi method

This technique makes maximum use of the judgmental skills of a group of people while largely excluding personal bias in the interaction between members of the group (Bird, 1992). The intention is to allow the benefits of multiple opinions while avoiding the negative aspects of dominant behaviour, “groupthink”, and the resistance to change one’s mind (Turban, 1994).

3.3.2.2. Market survey

Public attitudes and behaviour can be surveyed by making use of telephone surveys, mail questionnaires, consumer panels, and test markets (Turban, 1994).

3.3.2.3. Moving averages

In analysing historical data the moving averages method allows the averaging of data for a specific period rather than a simple average, ignoring older data that can distort the analysis e.g., seasonality of data (Turban, 1994).

3.3.2.4. Regression analysis

Regression analysis is a statistical method (Harstela, 1993) for modeling a function that defines the "best-fit" relationship between the dependent (Y) and independent (X) variables in order to predict the value for the dependent variable given values for the independent values (Ragsdale, 1994).

3.3.3. Descriptive techniques

This group of techniques is used where the input variables are unknown or ill-defined. Techniques in this group include:

3.3.3.1. CPM/PERT

In essence these techniques are also network models, applied as project-scheduling techniques. The program evaluation review technique (PERT) and the critical path method (CPM) are the most common models in this application (Turban, 1994).

3.3.3.2. Queuing theory

With increasing psychological, economical, and technical interdependence in society, waiting lines or queues become more important. A queuing system consists of a customer source, an arrival process, service process, and a queue. Queuing analysis aims at determining the appropriate service level by determining the optimum queue as the break-even between the cost of providing a service and the cost of waiting (Turban, 1994).

3.3.3.3. Simulation models

Simulation modeling is a technique that uses random numbers and probability distribution to generate input data to imitate the functioning of a system over time (Pulkki, 1984). It is a very flexible method that is widely applicable to forestry problems. The cost of simulating wood harvesting systems is justifiable, rarely exceeding 1% of the total system cost (Henriksen, 1983 *ex* Pulkki, 1984). However it is subject to statistical error, requires great programming skill (Pulkki, 1984), and is usually applied in problems that are too complex for analytical models (Turban, 1994). Examples of simulation models include Monte Carlo, business games and corporate planning.

Benefits of simulation include consideration of the problem in terms of a total system, providing good insight into the simulated problem, and avoid sub-optimisation.

3.3.3.4. Heuristic programming (HP)

Heuristic programming can prove useful when a mathematical formulation is too complex, or its required computation impractically long. This technique implements rules-of-thumb (heuristics) (Turban, 1994): e.g., labour overhead cost is 40% of the direct labour cost, in searching for satisfactory solutions. Heuristics search intelligently from one solution point to another in order to determine a number of feasible solutions, selecting the one giving the best possible result (i.e., no further improvements to the model objective is possible).

Of all the managment science techniques HP is the closest to traditional problem solving. There is no set procedure and the methodology largely depends on the problem to be solved. Heuristics can be used in conjunction with other management science techniques (Pulkki, 1984): e.g., linear programming.

Advantages of HP are its flexibility, fast derivation of a solution and simplicity. Possible disadvantages include potential contradiction of other heuristics applied in the problem, and no optimal solution (Turban, 1994).

3.3.3.5. Dynamic programming (DP)

This technique finds an optimal solution through breaking the problem down into decision stages (Thierauf *et al.*, 1985). The procedure solves one stage at a time, producing a set of optimal solutions that is then used as the input to the next stage. Compared to linear programming this technique can span time intervals (Thierauf *et al.*, 1985). According to Turban (1994) the application of DP is limited by its tailor-made formulation for each new problem and the quadrupling of required computation with doubling in problem size.

3.3.4. Other techniques

Other possibly useful techniques not included in the previous three categories are:

3.3.4.1. Game theory

This technique involves decision-making under conflict, involving two or more decision-makers trying to maximise their overall welfare at the expense of the others (Turban, 1994). Some real-life game theory problems include marketing strategies, military conflicts, negotiations and potential takeovers.

3.3.4.2. Decision support systems (DSS)

DSS are interactive computer-based support systems that are flexible and user-friendly, reducing the gap between technology and management. DSS couples the intellectual resources of individuals with the capabilities of computers to improve the quality of management decisions when dealing with semi-structured problems requiring sound management judgment (Turban, 1994). It does not attempt to automate the manager's decision process, but operates as an analytical support tool. It is a philosophy surrounding a new decision-making approach rather than a well-defined methodology.

Some of the characteristics of a DSS are fast analysis yielding satisfactory results, and the involvement of teamwork in data collection and modeling (Pulkki, 1988). The system cost needs to be in relation to its benefits. A DSS is capable of executing what-if analysis, developing new insight by the user. Through providing pertinent management information, management efficiency can be improved.

A DSS consists of a database, a model base and a user-system interface, and can use any or a combination of the previously mentioned MS techniques (Turban, 1994). The system should be developed progressively in modules tailored to the situational needs, with involvement of the end-user (Pulkki, 1988).

In this study a number of separate building blocks or modules (e.g., machine cost calculation, system analysis, growth models, productivity tables and cycle time model) will be used to determine the input to the decision model. The decision-maker's involvement in the process ensures active management judgement, supported by a structured methodology.

3.3.4.3. Expert systems (ES)

ES imitate the reasoning process of experts in solving specific problems. It is intended for the transfer of expertise from the expert to a computer with subsequent transfer of knowledge and advice from the computer to other people (non-experts). These will not be discussed further.

4. The proposed AT selection process

The basic AT selection process (Figure 22) developed by the author of the thesis is a combination of the decision-making process (Adam, 1986) and the management science process (Turban, 1994).

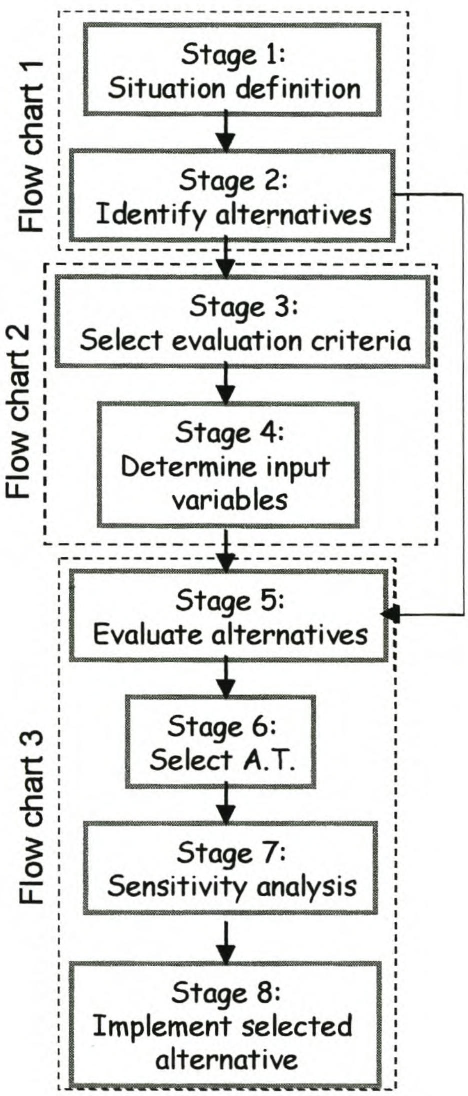


Figure 22. The basic AT selection process

The first two stages of the decision process are shown in the flow chart in figure 23.

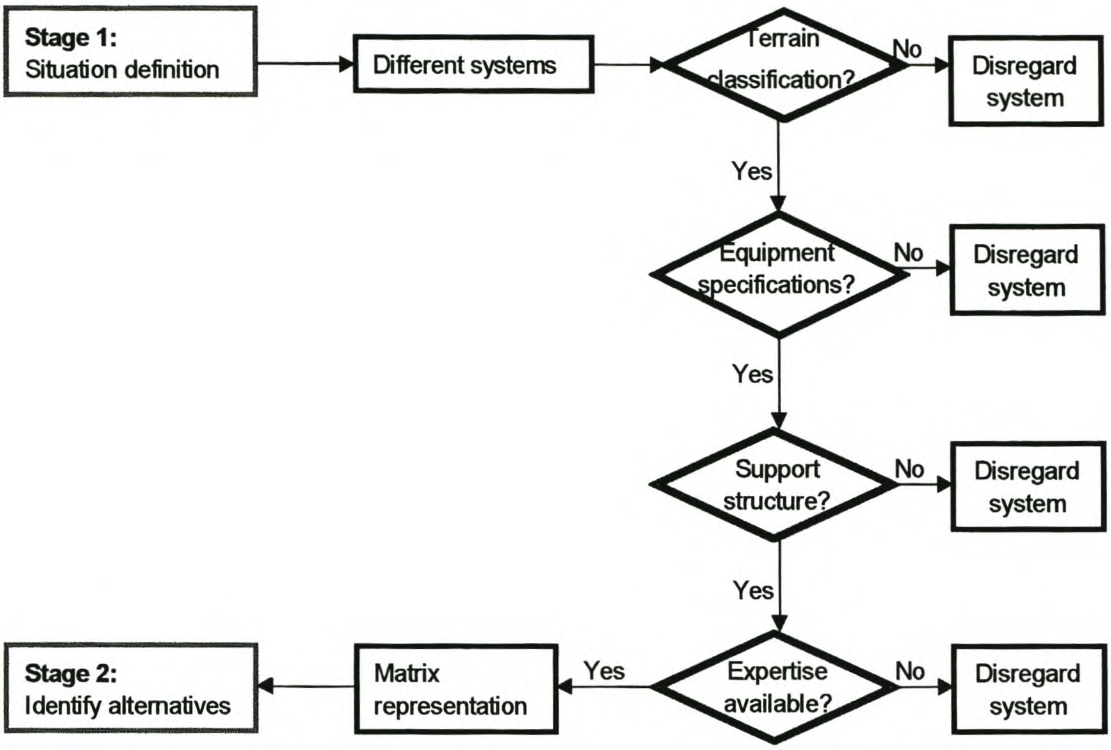


Figure 23. Flow chart 1 (stages 1 and 2)

The proposed appropriate forestry technology selection process consists of the following stages:

4.1. Stage 1 – Situation definition

Understand the specific situation in which the selected AT will need to operate. A comprehensive situation checklist (Warkotsch, 1987) highlights the relevant technical, economic, environmental and social issues.

4.2. Stage 2 – Identify alternatives

To avoid bias on the side of the decision-maker, it is important to ensure that all relevant technological alternatives are included in the analysis. Subliminal pre-analysis will exclude obvious impossible alternatives, although care should be taken to always remain objective

Assessing the technical feasibility of possible alternatives within the context of the situation analysis will determine the potential suitability of each system. If any one or more of these sub-criteria exclude an alternative, that alternative will not be further evaluated. This stage assesses the technical and physical feasibility of the alternative harvesting systems by means of the following criteria:

4.2.1. National Terrain Classification

The descriptive terrain classification (Musto, 1994) (i.e., slope class, ground condition and ground roughness) is compared with a functional terrain classification (i.e., guidelines to equipment suitable to the terrain), to determine the potential suitability of the alternative methods.

4.2.2. Equipment specifications

The manufacturer's specifications of the system equipment (i.e., nominal power, rimpull, cable drum and load capability) are assessed in conjunction with physical stand conditions (i.e., gradient, tree size and road spacing) to determine its technical possibility. Useful planning aids include *SkidPC* (OSU, 1987), *LoggerPC* (OSU, 1992), and *Logtran* (CSIR, 1991).

4.2.3. Support structure

This criterion determines whether a sufficient technical support back-up (i.e., spare parts and technical expertise) is available to ensure optimum availability and utilisation of equipment.

4.2.4. Available expertise

This criterion evaluates the access of the company or operation to the expertise required for efficient application and management of the technology involved in the system equipment.

4.2.5. Matrix representation

A matrix representation (figure 24) is compiled for each of the alternative systems that successively passed each of the previous criteria. Supported by a brief description of the process involved in each system, this matrix allows clear communication to all stakeholders.

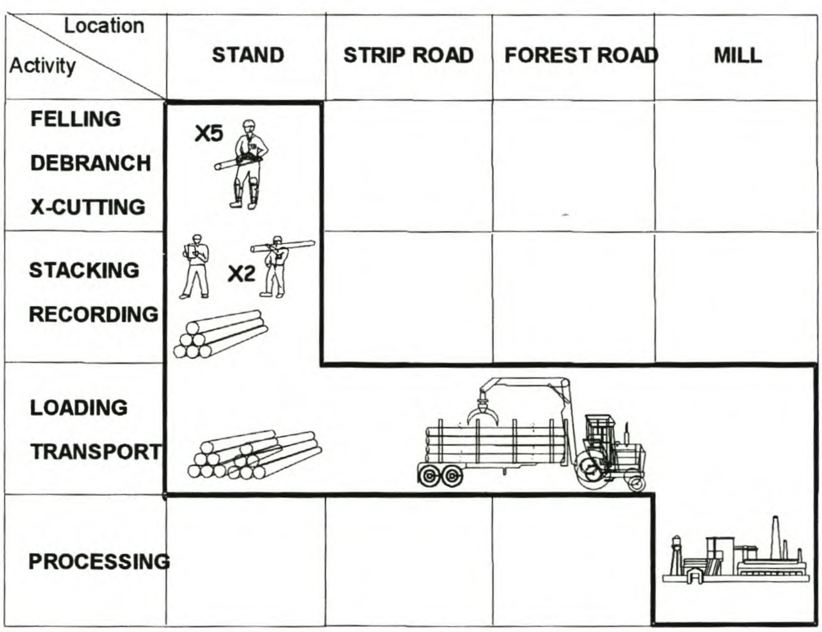


Figure 24. A matrix presentation of a timber harvesting and transport operation

4.3. Stage 3 - Select the evaluation criteria and identify the relevant variables

Stages 3 and 4 of the decision process are shown in the flow chart in figure 25.

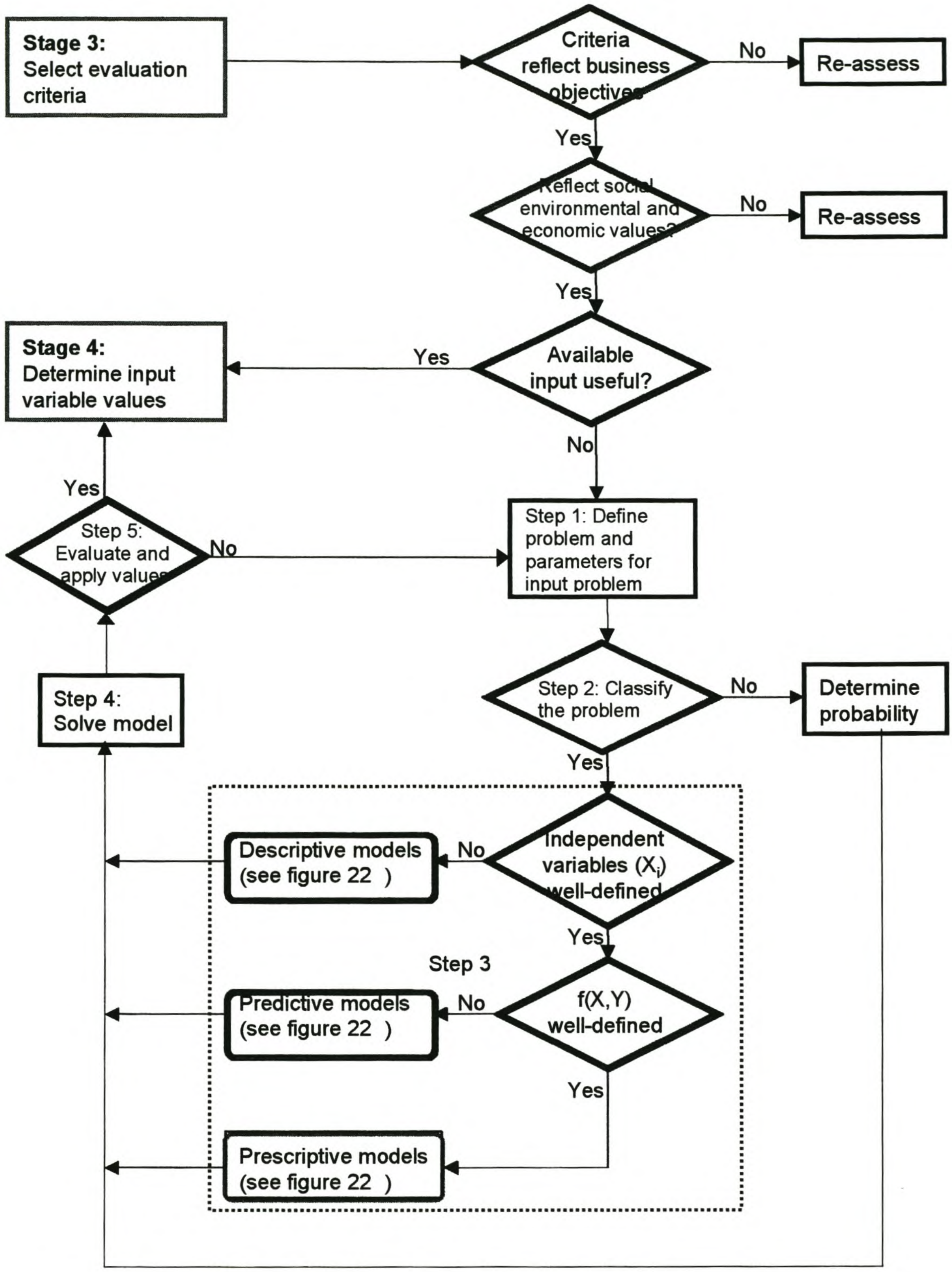


Figure 25. Flow chart 2 (stages 3 and 4)

To support sustainable development the evaluation criteria need to reflect the national development objectives (Solberg, 1988). This study proposes the use of the following evaluation criteria and sub-criteria to objectively evaluate forestry technology appropriate to sustainable development.

4.3.1. Economic viability

Solberg (1988) refers to economic viability as production efficiency; the ratio of output goods or services to the quantity of production inputs (e.g., R/m^3 or R/hr).

In assessing the economic viability of a technological alternative, two points of view need to be considered: i.e., national economics and business economics. The former is involved with issues influencing society in general, such as occupational safety standards, import dependence, employment creation, disposable income, and foreign and local investment. The latter is largely concerned with the profitability of an individual business through lowest cost, best sales price and highest productivity. Towards the ideal of sustainable development it is important for these two viewpoints to support each other.

Macro-economic policies (e.g., tariff structure, tax incentives, credit policies and minimum wage legislation) influence the AT choice through creating a fertile environment for the implementation of technology promoting the sustainable development (Bhalla, 1979).

The neo-liberal economic theory promotes economic policy geared to maximise market operation and minimise state intervention (Kaplinsky, 1990). AT can play a significant role in the development of private entrepreneurship.

For this study the selected sub-criteria and indicators for economic viability are:

- Profitability (R/m^3 of roundwood produced). The main objective of any business is to maximise profit. Profit is influenced by the balance between product sales price, product mix, production volume and cost (Tucker, 1981). Profitability will be expressed in R/m^3 of roundwood produced to allow for roundwood operations as well as integrated operations (roundwood production combined with value-adding processes).

- Cost per production unit (R/m^3). The sales price of the product at point-of-sale is largely determined by market forces over which the individual timber harvesting and transport business seldom has a major influence. It is clear from the simple profit equation $Profit\ (R/m^3) = Sales(R/m^3) - Cost(R/m^3)$ that with little control over sales price, cost management is the only opportunity for increasing profit. Production cost, together with profit, gives a fairly good idea of the potential financial soundness of the operation. In this study the intention will be to minimise the cost.

- Net Present Value (NPV). The NPV is calculated from a five-year cashflow compiled for each individual system to be evaluated. Applying the same discounted cashflow format to all the alternative systems, the objective is to determine the relative profitability within each case study rather than the absolute profitability of each system. In this study the intention will be to maximise the NPV.

- Payback period (years). In this study the intention is to minimise the period (years) required to recover the initial financial investment.

- Capital investment. The sustainable operation of any timber harvesting and transport operation requires initial capital investment, followed by periodic capital expenditures for equipment maintenance, upgrade and replacement. In any timber harvesting and transport operation this fixed cost becomes a liability and potential risk, requiring full utilisation of the assets and minimisation of capital cost per unit of production. This risk is especially relevant in out-sourced operations, where the lack of long-term contracts, and short-term to medium-term production cutbacks, can affect a business's ability to meet equipment repayments. Another possible perspective on capital expenditure is the question of expenditure on imported goods (net capital outflow from local economy) versus local expenditure creating domestic growth. This should however be seen in the light of the small local timber industry and its ability to support a local manufacturing industry. Solberg (1988) makes use of a "risk" criterion to evaluate the flexibility of the technological alternatives to change and failure. In this study the aim is to minimise capital investment in order to reduce the risk.

- Return on investment (ROI). Return on investment (ROI) is also known as the return on total assets. It is a measurement of the productivity of assets (Gup, 1980) and is calculated as the earnings before interest and tax, divided by the total assets. A disadvantage of this method is different methods of its calculation, with resulting difficulty in comparing results (Uys, 1998). This study aims at maximising the ROI.

- Break-even throughput. Break-even throughput provides management with simple facts regarding the business's profit structure (Tucker, 1981). The break-even point is the point or sales level where production cost equals income. It can also be used as an indicator of risk in that the lower the break-even throughput, the lower the financial risk to the business. In a contract management situation this knowledge will help in making effective short-term decisions during periods of production cutbacks and market slumps, to ensure the survival of a corps of competent timber contractors. For the purposes of this study the objective is to minimise the break-even throughput measured in daily m^3 of timber produced.

- Fixed daily cost. The fixed portion of the daily cost includes the costs of equipment ownership (capital investment), labour and overheads. It is unrelated to production and is therefore a liability and risk. In reality the fixed daily cost will also include the variable cost involved in recovering the above-mentioned cost. In this study the aim is to minimise the "fixed" cost elements.

4.3.2. Social acceptability

Without due consideration of the human being, sustainable development in the forestry industry is impossible. This includes forestry employees, general public and communities surrounding the forestry enterprise. This criterion, with its set of sub-criteria and operational indicators, aims at maximising the social benefit.

- Employment. Forestry is largely a rural industry, often operating in areas where few other employment opportunities exist.

  The human being in an enterprise is impacted by the internal and external forces (figure 26), thus affecting productivity (Klatt *et al.*, 1985).

Figure 26. The internal and external forces impacting on productivity

According to the needs theories (Klatt *et al.*, 1985), motivation is the drive to reduce a tension caused by an unsatisfied need. According to Maslow's Hierarchy of Needs, the individual generally attempts to satisfy the lower-level needs (i.e., physiological and security) first, after which the satisfaction of higher-level needs will become strong motivators. Herzberg's theory of satisfiers and dissatisfiers led to the concept of job enrichment (Klatt *et al.*, 1985). According to McClelland (*ex* Klatt *et al.*, 1985) high achievement motivation is a prerequisite for economic development. Solberg (1988) highlights the promotion of self-esteem through the recognition of being involved in worthwhile activities. Consistent with needs theories, the expectancy theories indicate that motivation results from the individual's belief that certain performance will result in organisational reward and inner satisfaction.

In the light of the seriousness of the South African employment situation, and the complications thereof to our society, the study's aim is to maximise the number of direct employment opportunities, not only meeting lower-level needs but also ensuring consideration of higher-level needs. The operational indicator for employment is person-years.

- Occupational health and safety. As the first of two criteria evaluating the working environment, this study will subjectively evaluate the occupational health, safety and ergonomic hazards. The objective is to minimise the occupational health, safety and ergonomic hazard.

  Alternatives are subjectively ranked in ascending order of potential health, safety and ergonomic hazard. With detailed occupational safety records the disabling injury rate associated with specific systems and/or equipment can be used. In all alternatives it is assumed that basic personal protective equipment is provided and used, vehicles and machines are supplied with basic protective equipment, and the labour force is properly trained to operate equipment and follow safety rules.

- Human energy expenditure (MJ/m^3). This is the second of the two criteria associated with the working environment, and is used to quantify physical stress. The physical working capacity of a human being determines the amount of physical work a worker is able to exert without overloading him/herself (Staudt, 1993). This is measured as oxygen consumption, energy expenditure or heart rate. In all three methods the result is expressed as energy expenditure per time unit (kJ/min). For the purposes of this study the results of Durnin and Passmore (1967) and Christensen (1953) were used to model the energy expenditure of the forest worker. The objective will be to minimise the individual's effort.

The renewable human energy is obtained through nutrition. For the purposes of this study the energy requirements for basic metabolism and leisure will be disregarded in that it is not solely work related. The energy requirements of machines are non-renewable, being dependent on fossil fuel, and will be further discussed under the Environment.

- Independency (capital imports R/m^3). According to Solberg (1988) independency is the ability of a project to operate independently from imported goods. Closely associated with the sub-criterion "capital investment", the import portion of the capital cost of specialised equipment is expressed per m^3 of timber harvested. The objective is to minimise the imported capital dependence.

  According to Solberg (1988) financial self-reliance of projects in less-industrialised countries is a necessary condition for survival. In the South African context the change in exchange rate from R2.86/$US (1992) to R6.14/$US (1999) means a 115% increase in the cost of capital equipment due just to currency change. This has major implications on operational cost. With an inflation rate of 6.3% per annum (CSS, 1999), most companies intend keeping cost increase at or below this value. This is almost impossible due to the recent exchange rate changes affecting the cost of imported equipment.

  Equipment importation can result in a net outflow of capital that could otherwise create wealth locally through forward and backward linkages. It should however be born in mind that the local industry is too small to effectively support a specialised equipment manufacturing operation, necessitating the possible import of certain types of equipment: e.g., harvesters and processors.

- Integration. Solberg (1988) considers integration to reflect the degree that a specific alternative is integrated with the existing technological, economic and social structure of the country. Some questions to consider are:
  - Will the technological alternative disrupt the existing social life?
  - Does the technological alternative effectively promote social participation?
  - How does it fit into existing organisational and managerial requirements?

  Regarding future development Rweyemamu (1976) raises three questions:
  - Does the technological alternative stimulate new and wanted skills, and capabilities?
  - Does it promote technological autonomy or continued dependency?
  - Does it comply with regional and national resource management?

  The alternatives are subjectively ranked in descending order of integration i.e., most integrated alternative being ranked 1 and least integrated ranked *x* for *x* number of alternatives. The objective in this study is to have the highest level of integration.

- Investment per working position. Although the social ideal would be to maximise the investment to create employment, the minimisation of cost per working place can potentially result in more employment opportunities. The value is calculated as total capital investment divided by man-years employed annually, with the objective in this study to minimise the investment per working position.

- Average annual disposable income. Disposable income is an important factor to the healthy development of an economy. Income available after meeting basic needs of food and shelter can increase the need for other products (e.g., furniture and automobiles), resulting in further employment opportunities in local and regional businesses. From an economic and social perspective the objective is to maximise the average annual disposable income of families.

- Annual disposable income. The average annual disposable income is an indicator of individual household wealth and the total annual disposable income reflects the buying power available to a region. However, you have to be careful when using average and total annual disposable income. For example, 100 people employed at an average disposable income of R10 000 per annum has the same average annual disposable income and total annual disposable income as a technology alternative employing 50 people earning R20 000 per annum, with 50 people receiving R0 per annum. Clearly from the point of view of further wealth and employment creation through backward and forward linkages, the former is preferred. The objective is to maximise the total annual disposable income to benefit the maximum number of persons.

4.3.3. Environmental agreeability.

For the purposes of the study the harvesting site damage impact rating developed by Smith (1998) will be used. This makes use of three indicators: i.e., soil compaction, erosion and soil organic matter loss. For these three indicators the percentage of the area affected is specified. Other sub-criteria involve slash management and non-renewable energy consumption. The objective of the decision process will be to minimise the impact of the indicators.

- Compaction. According to Smith (1998) the main effects of compaction on soil involves water retention and infiltration rate, soil strength, soil aeration and nutrient uptake. The specific South African threat results from harvesting during all seasons and heavy axle loads with no snow blanket to minimise the impact. The increased surface water flow due to reduced infiltration can contribute to erosion.

- Organic matter loss. Soil disturbance includes displacement of topsoil and litter, rutting and smearing of the surface, mounding and hollows, and soil deformation (Smith, 1998). Independently or in conjunction with compaction it results in organic matter loss, de-nitrification, reduced infiltration, disrupted rooting environment, stream and wetland damage, increased run-off, and poor soil aeration. Organic matter is the main barrier preventing erosion and its maintenance needs to be carefully considered to prevent erosion and the loss of a nutrient source.

- Erosion. As a result of compaction and/or organic matter loss, erosion results in on-site and off-site impacts. On-site impacts include soil loss, nutrient loss, productivity loss and permanent resource loss. Off-site impacts include reduced water quality through increased sedimentation, water temperature and algae growth and loss of oxygen.

- Slash management. Slash management (i.e., broadcasting, brushpiling or removal) is largely a compromise between specific silvicultural prescriptions and harvesting system constraints. For example, silviculture requires broadcasting of slash but animal extraction requires brushpiling to prevent injury to the animals. This results in additional cost to broadcast the brushpiled slash.

  This study will consider whether or not the technological alternative or harvesting system requires additional cost to manage the slash in conformance to silvicultural prescriptions. Ideally the system alternative should support the silvilcultural prescription without additional cost.

- Non-renewable energy expenditure (MJ/m^3). As an indicator of non-renewable energy expenditure, the nominal power (kW) of individual equipment is converted to energy (MJ), and expressed as expenditure per m^3 of roundwood produced. The objective of the decision process will be to minimise the expenditure of non-renewable energy.

Due to the potential conflicting social, economic and environmental interests, the criteria for each should first be evaluated independent of each other: i.e., evaluate social criteria without influences by economic and environmental criteria, and *vice versa*.

4.4. Stage 4 - Determine the input variables for decision criteria

Real management science problems often involve the use of more than one technique or a combination of techniques to solve a problem (Hoefle 1974; Turban 1994): e.g., heuristic programming and linear programming (Pulkki, 1984). In this study the following modeling techniques are used.

4.4.1. Heuristic programming

Many of the independent variables relating to the alternative systems are unknown or ill defined: e.g., equipment cost, required resources and cash flow information. A detailed systems analysis is done for each alternative within the operating environment defined for each case study.

4.4.2. Regression analysis

Although no regression analysis is done in this study, some of the input variables are derived from regression analysis of past studies by various authors. Examples used include time study results (Dunn, 1992; Richardson, 1992; van Daele, 1999), energy expenditure (Durnin and Passmore, 1967; Christensen, 1953), tree volume models (Pienaar and Kotze, 1999), soil damage (Smith, 1998) and vehicle performance (Marchio 1995).

4.4.3. Decision tables

The input variables obtained through using a range of techniques, as mentioned above, will be structured into a decision table or matrix for final evaluation and selection of AT. Decision tables allow all criteria to be measured in one measurement unit (Solberg, 1988).

If the required data is available proceed to stage five. In the absence of useful data the following five steps in the management science process can assist in solving the problem (Turban, 1994):

- *Step 1 – Define the required input variable*

- *Step 2 – Classify the problem*

  Conceptualise the problem and determine the expected certainty of the outcome considering the available knowledge:
  - Complete information is available indicating **certainty** of outcome for each alternative course of action. This is also called a deterministic decision situation, and is normally of short time horizon.
  - Where two or more possible outcomes exist for an alternative, the decision is subject to **risk**, with actual outcome depending on the occurring state of nature. This is also called a probabilistic or stochastic decision situation.
  - Where the decision-maker does not know and cannot estimate the probability of occurrence of a specific state of nature, the decision is subject to **uncertainty**.

- *Step 3 – Formulate and construct the decision model*

  Based on the degree of abstraction, Turban (1994) classifies models in three groups: i.e., iconic, analog and mathematical. Iconic and analog are the least abstract and involve simulation and decision support systems. Most management science models are mathematical. The different modeling techniques were reviewed in chapter 3.3. The new model needs to be evaluated before application. This evaluation involves understanding of the underlying rationale; determining its usefulness in the specific situation and confidence in its predictions (Pulkki, 1988).

- *Step 4 – Solve the model*

  The solution depends on the decision-maker's choice of a solution approach (Turban, 1994): i.e., optimal (normative) solution, sub-optimal solution or satisfactory (satisficing) solution.

- *Step 5 – Evaluate and apply modeled values*

  Sensitivity analysis can be applied to verify the accuracy of information by determining the effect of changes in the independent variables on the values of the dependent variables. Feasible modeled data are used as input to stage five.

4.5. Stage 5 - Evaluate the alternatives (framework)

For the purpose of evaluating the alternatives the author designed a spreadsheet model to investigate the appropriate technology based on the input variables, weighted for specified scenarios.

In the evaluation of technological alternatives, the complexity of the decision process require consideration of the relative costs and benefits of one system as opposed to a more or less complex system. Some issues to consider are data collection, the available technical expertise and equipment, and the degree of understanding of interest groups. The benefits to consider are the potential significance of conflicting interests and subjective preferences, adequate reflection of resource value by the market price, importance of time and understanding of interest groups (Solberg, 1988). These cost and benefit factors are a function of the agreed development objectives.

Stages 5 to 8 of the decision process are shown in the flow chart in figure 27.

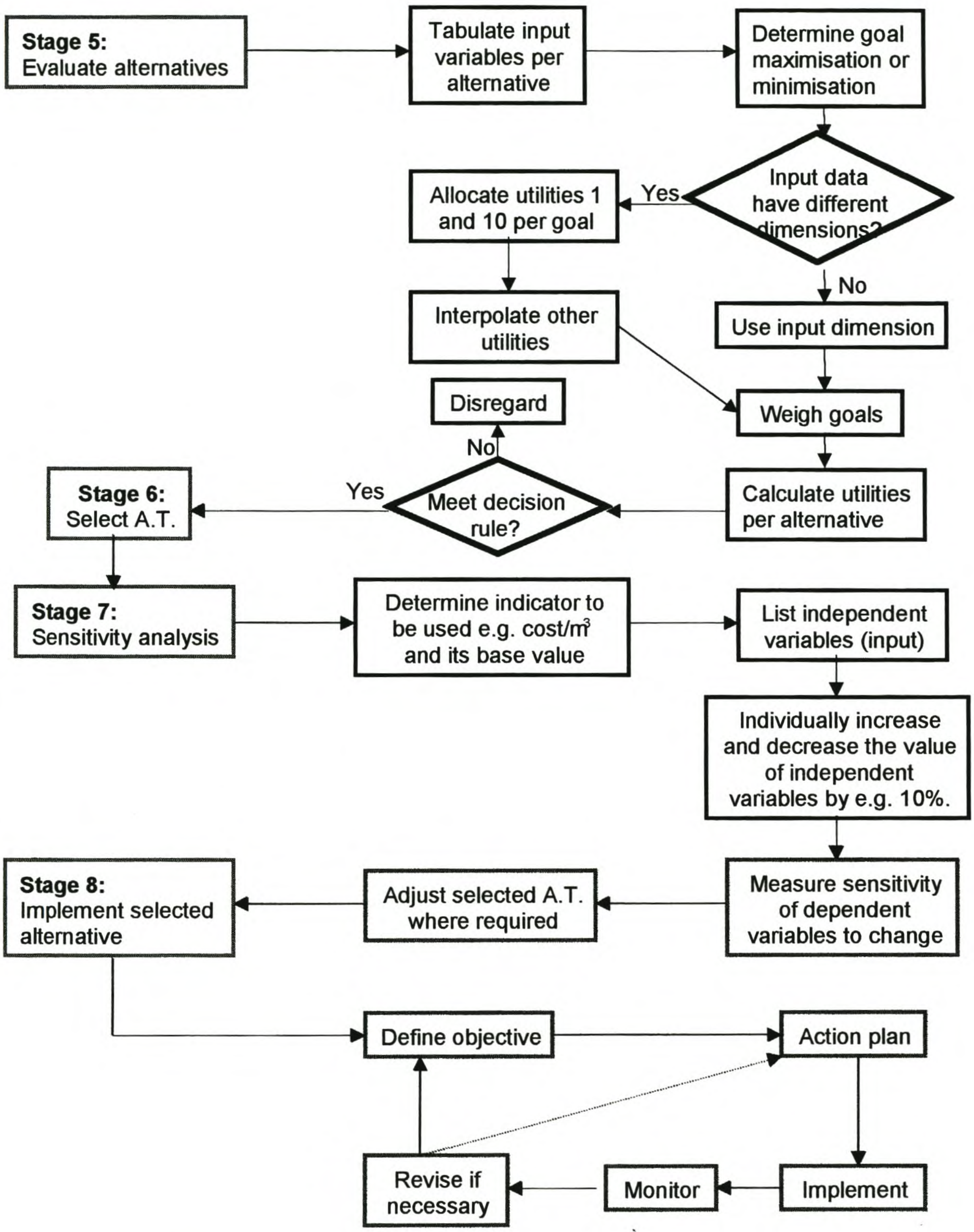


Figure 27. Flow chart 3 (stages 5 to 8)

Considering the literature survey of modeling techniques (chapter 3.3) this study found decision tables to be a very appropriate technique to formulate the decision problem. Further investigation highlighted the application of utility theory to convert different units of measurement to a common dimension: i.e., utility.

The values or input variables in stage four have different units of measurement. By determining the objective of each criterion (maximise or minimise) the utilities 1 and 10 are allocated: e.g., if the objective is minimisation, the highest value will be allocated the utility 1 and the lowest 10. Values between 1 and 10 are then interpolated for the other input values.

In order for the decision model to rank the alternatives in appropriate order, the planner needs to weight the criteria on two levels: i.e., each sub-criterion within a main criterion, as well as main criteria against each other. The application of weighting to each criterion as agreed by the decision-makers, converts the utility values to weight-corrected values. All weight-corrected values per alternative are added to obtain a single utility value for each alternative.

The decision-makers can agree in advance on the weighting that best support the values of the enterprise. By entering these weights the model will rank the alternatives according to their appropriateness to the specific scenario depicted by the weighting. The model also allows objective evaluation of the 232 scenarios based on the weights applied to the three main criteria (appendix 3). These scenarios are defined by weighting the main criteria in combinations of 5% intervals from 0 to 100%, with one additional scenario weighting the three main criteria equally: i.e., 33.3% each. The frequency of occurrence of each ranking combination as well as the percentage of the 232 scenarios that an alternative ranked in a specific position, can be determined. The minimum and maximum values of each criterion for each ranking combination are depicted in a histogram to highlight the relative importance of the values to the specific ranking order. This process provides an opportunity for making informed decisions regarding the most AT for each situation or case study.

An important aspect of the decision process is the objective evaluation of the individual main criteria: i.e., evaluate economic feasibility purely from an economic point of view, social acceptability purely from a socio-economic point of view, and likewise environmental agreeability purely from an environmental point of view.

Ideally the selection of AT that meets national developmental objectives within a specific country or industry, will require cooperation between the relevant government departments, private business, organised labour and local communities. Solberg (1988) highlighted this by stating that the choice of AT is not purely a technical or economical exercise, but needs to consider the political (social) aspect.

The evaluation process/methodology should be designed to be applicable to industrial as well as social forestry, and large as well as small-scale operations. For specific differences weighting can be used to emphasise the core aspects.

4.6. Stage 6 - Select the most appropriate alternative

Based on the defined decision rule (i.e., whether the alternative with lowest or highest utility value is the most AT), the single utility values for each alternative are compared and the most appropriate alternative selected.

4.7. Stage 7 - Sensitivity analysis

From the final ranking for a specific scenario or range of scenarios in the previous step, the most suitable technology or system can be determined. The decision-makers need to decide what indicator will be used as the basis of the sensitivity analysis (e.g., profit per m^3 and cost per m^3). All independent variables are listed and individually increased and decreased by an agreed percentage (e.g., 10%) (Williams and Nader, 1993). The resulting impact on the selected indicator is noted for each independent variable adjusted. The potential impacts on the most appropriate alternative are ranked in order from highest to lowest, allowing the alternative to be further refined by focussing on the greatest potential impacts.

4.8. Stage 8 - Implement the selected alternative.

It is often more difficult to implement the solution to a problem than to find the solution to the problem (Turban, 1994). There are numerous reasons for a carefully selected problem solution to disappear into oblivion during the implementation stage. These include a lack of clear responsibility, absence of an implementation plan, insufficient funds allocated and passive resistance by covert opponents (Bird, 1992).

According to Bird (1992) successful implementation follows the following basic steps:

4.8.1. Define the implementation objective

The characteristics of a good objective include relevance, attainability, clarity and understandability, consistency with other organisational objectives, and measurability.

4.8.2. Construct a plan of action

A good action plan will restate the objective and at least include who is overall in charge, a timetable of action steps and milestones, the responsible person for each action, how progress will be monitored, and budget and cash-flow.

4.8.3. Communication

Good communication of the implementation objective, and action plan, and monitored progress is fundamental to the successful implementation of the action plan. Poor communication is very often the cause of opposition during the implementation phase, therefore "if in doubt, tell them".

4.8.4. Action

Commence the implementation of the selected AT alternative according to the action plan.

4.8.5. Monitor progress

A good monitoring system will provide timely, and sufficiently comprehensive and precise information to assess progress. It also assists in predicting future events, help diagnose any obstacles encountered, and indicate possible need for revision of the plan, objective or both.

4.8.6. Revise the plan or objective

Do not hesitate to revise the objective or plan if major adjustments become apparent during implementation. This will often include a contingency plan included in the original action plan. Communicate the detail and consequences of the revised action.

5. CASE STUDIES

5.1 Eastern Cape Province, Butterworth community woodlots

5.1.1. Stage 1 - Situation definition

5.1.1.1. Location and structure data

Figure 28 shows the location of the Butterworth woodlots in the Eastern Cape province of South Africa. The 29 woodlots range in size from 6 ha to 320 ha, with a total area of 3 177 ha.

Figure 28. Geographic location of the Butterworth Community Woodlots

Howard (1998) estimates a potential MAI of 30 m^3/ha/a (high potential), 20-25 m^3/ha/a (moderate potential) and <15 m^3/ha/a for low potential sites. The yield of the existing coppice-regenerated stock is estimated at a weighted average MAI of 6.5 m^3/ha/a, resulting in a clearfelling volume (wattle and gum) of 39 m^3/ha over a rotation of six years. The sustainable annual cut without stock improvement is 21 000 m^3/a. The roads are generally in a poor condition, with road area covering 10 to 12% of the planted area.

5.1.1.2. Work Object

Eucalyptus spp form 91% of the planted area, with general neglect resulting in large variability of tree size and coppice stems per stump. The average tree size at rotation age is 0.05 m^3. The timber is mainly prepared and transported as tree-length, with less than 5% of the harvesting volume crosscut on roadside to 2.1m for treatment plants.

5.1.1.3. Environmental influences

The altitude ranges from sea level to 1 200 m above mean sea level (AMSL). Generally, the area poses few terrain constraints, with ground roughness class 1 to 2, approximately 70% of the area constituting slope classes 1 and 2, with the rest mainly slope classes 3 and 4. Based on soil information (Shone, 1985) the ground condition class ranges between 124 to 135 (dry – moist – wet conditions), based on a clay content of between 16 and 50%. The area receives above average summer rainfall (815 mm/a) (Shone, 1985). During the wet season the subsistence farmers cultivate their land; timber harvesting and extraction taking place in the dry season (April to September). The mean summer temperature ranges from 18 to 24°C and winter temperature from 0 to 18°C. Hot, dry bergwinds are characteristic of the late winter, preceding a cold front, and can cause devastating fires. The two main natural vegetation types are coastal tropical forests consisting of open thornveld and extensive forests, and grassveld on the central plateau.

5.1.1.4. Market

The woodlots mainly attend to the subsistence needs of the immediate communities for building and fencing material, and firewood. There is a good market for treated and untreated building and fencing poles. A few small pole treatment plants situated close to the woodlots dip-treat timber with inconsistent quality.

To obtain a cutting permit, the customer specifies the number of 7.2 m poles required. After paying cash, the permit is issued and compartment for cutting indicated. All stems (±7.2 m) are sold standing at R1.60 per stem (DWAF, 1998). The coppice reduction in all woodlots is done by labour of the Department of Water Affairs and Forestry, leaving the removed coppice for waste. These are prepared and collected by customers and sold in bundles of 12 laths at 75 cents per bundle. It is used as smaller fencing and building material.

Firewood is being collected as "head loads" or vehicle loads. Head loads are provided free of charge and entail women collecting firewood from harvesting and coppice reduction waste. This firewood is bundled for carrying on their heads. At Mabululu this activity takes place at least twice a week to provide firewood to one household and the walking distance is up to 10 km per load. Firewood other than head loads is prepared after all utilisable poles have been removed from a compartment. The customers are then allowed to cut and remove the remaining timber at R12 per m^3.

5.1.1.5. Labour

The Eastern Cape province is experiencing a high unemployment rate at 41% (CSS, 1998). The Butterworth woodlots offer much needed rural employment to 272 employees involved in fire protection, silviculture and administration. Subsistence farming is the main alternative livelihood for most families. 89% of the rural communities can be regarded as illiterate, with general forestry skills level is low due to very little formal training offered. The Department of Water Affairs and Forestry offers a minimum wage of R1 824/month, with salaries and wages constituting 92% of the 1997/8 budget. Because of the subsistence nature of harvesting woodlots, the labour normally consist of the farmer, as well as family members and friends, and not a formal labour force.

5.1.1.6. Harvesting system

In most instances only stems of utilisable size are removed, leaving the stragglers on the stump. Stump size and height can pose a problem for extraction other than manual or animal. The system matrix BW_Sys A in appendix 1.1 illustrates the current harvesting system. Felling of trees are mainly done by bow saw, with manual tree-length (small trees) extraction and stacking at roadside. The oxen loads consist of 7.2 m poles manually stacked in the shape of an inverted V, with butt-ends overlapping. A choker-chain is then put around the overlap and hitched to the team of oxen. The 7.2 m stems are converted to shortwood at the customer's homestead.

5.1.1.7. Working environment

Through the utilisation of labour intensive systems the renewable energy requirement (human and animal energy expenditure) is high as opposed to non-existent use of fossil fuels. The mental stress, potentially high in labour intensive operations, will be low as a result of the cutting of timber as needed. However the collection of firewood (head loads) twice a week can be regarded as strenuous considering the multiple responsibilities on the women. Noise, CO emission and vibration are largely non-existent due to the predominant use of animals and manual labour. The accident risk can be potentially high due to the absence of protective clothing and lack of formal skills training. However the lack of production targets, small tree size and use of hand tools limits the occurrence and severity of accidents, although extended involvement could lead to muscle strain and back problems.

5.1.1.8. Effect of harvesting systems

The systems currently employed have minimal impact on the soil and stand. During transport the method of choking poles impact on the road surface through creating a V-shaped road surface. Considering the above average rainfall and the absence of road drainage because of the V-shaped road surface, dramatic erosion results from this practice. This is one of the main areas for possible improvement. The whole operation could be improved to the advantage of all stakeholders through effective planning and provision of value-adding opportunities.

5.1.2. Stage 2 - Identification of possible technological alternatives

During the pre-analysis phase terrain conditions, average extraction lead distance and equipment specifications are considered within constraints of the situation analysis. Basic system knowledge is used to define possible appropriate technological alternatives according to its technical feasibility. The four basic alternative systems are (appendix 1.1):

5.1.2.1. Butterworth woodlot system A (BW_sys A)

This is the current system in use.

5.1.2.2. Butterworth woodlot system B (BW_sys B)

This system is basically the same as BW_sys A except for the use of an oxen-drawn sulkie to partially suspend the load and reduce road damage.

5.1.2.3. Butterworth woodlot system C (BW_sys C)

Similar to the previous two systems, the team of oxen is replaced by an agricultural tractor with skidding bar to partially suspend the load.

5.1.2.4. Butterworth woodlot system D (BW_sys D)

Manual felling, debranching, and in-field crosscutting, with manual loading of agricultural tractor and trailer for transport of cut-to-length timber to homestead.

5.1.3. Stage 3 and 4 - Select evaluation criteria and analyse alternatives

For this study the evaluation criteria as discussed in chapter 3.4.3 are used. During stage 3 the decision-makers agree on the relative weights of the criteria and sub-criteria, or apply the range of scenarios indicated in appendix 3. For the purpose of this study the sub-criteria per main criteria carry equal weighting. The input variables for the decision criteria for each alternative are determined according to the proposed methodology.

5.1.3.1. Economic feasibility

The assessment of the economic feasibility of the four technological alternatives, using a detailed systems analysis and simple discounted cash flow, resulted in the values shown in table 3. These values are used as input to the decision matrix in appendix 2.1. Alternatives A and B makes use of oxen owned by the subsistence farmers. Because harvesting is seasonal and subsistent of nature, the investment value of the oxen is assumed to be 50% of the total opportunity cost of all oxen involved. System C and D assume that the equipment will be dedicated to the harvesting of the total annual cut.

Table 3. Economic input values for system evaluation as obtained through systems analysis and discounted cash flow

Economic sub-criteria	BW_Sys A	BW_Sys B	BW_Sys C	BW_Sys D
Profit (R/$m^3_{roundwood}$)	5.30	15.50	31.69	43.41
Cost (R/$m^3_{roundwood}$)	80.95	70.74	54.56	42.84
NPV (R)	3 579	833 922	2 008 066	2 754 962
Payback period (yrs)	3.24	0.65	0.18	0.17
Investment (R)	204 000	119 000	135 000	180 000
ROI (%)	31	155	558	573
*BE daily tp (m^3)	60	36	16	13
Fixed cost (R/day)	814	799	616	658

* Break-even daily throughput measured in m^3

5.1.3.2. Social acceptability

Table 4. Social input values for system evaluation as obtained through systems analysis

Social sub-criteria	BW_SysA	BW_SysB	BW_SysC	BW_SysD
Direct employment (man-yr)	88	68	44	46
Health and safety	4	3	2	1
Human energy (MJ/m^3)	32,0	24,7	16,0	16,7
Independency	0,00	0,00	0,00	0,00
Integration	1	2	3	4
Investment/employee	4,636	3,500	3,068	3,913
*Ave disp R/a	1,645	1,645	1,645	1,645
**Tot disp R/a	144,760	111,860	72,380	75,670

* Average annual disposable income

** Total annual disposable income

The assessment of the social acceptability of the four technological alternatives resulted in the values shown in table 4. These values are used as input to the decision matrix in appendix 2.1.

5.1.3.3. Environmental agreeability

The assessment of the environmental agreeability of the four technological alternatives, using research results of Smith (1998), energy expenditure model, and subjective assessment resulted in the values shown in table 5. These values are used as input to the decision matrix in appendix 2.1.

Table 5. Environmental input values for system evaluation as obtained through systems analysis and equipment risk assessment (Smith, 1998)

Environmental sub-criteria	BW_SysA	BW_SysB	BW_SysC	BW_SysD
Compaction	L	L	M	M
Organic matter loss	L	L	M	M
Erosion	M	M	M	M
% of area impacted	50	50	25	25
Slash management	N	N	N	N
*NRE (MJ/m^3)	0	0	30,2	30,2

* Non-renewable energy obtained from fossil fuel

5.1.4. Stage 5 and 6 - Evaluate alternatives and select AT

The results of the above analysis are used as input to the decision matrix (appendix 2). Normally the weighting for sub-criteria and main criteria will be applied as agreed by decision-makers, resulting in a specific ranking of alternatives applicable to the specific scenario as defined by the agreed weighting.

From the evaluation of the 232 scenarios the frequency of occurrence of different ranking options[2] is shown in table 6, with table 7 showing the ranking position of individual alternatives in the 232 different scenarios as a percentage of the total number of scenarios. Alternatives grouped in brackets in a ranking option indicates an equal ranking position within that ranking option.

Table 6. Occurrence of ranking options for the 232 scenarios evaluated (including labour cost)

Ranking 1 2 3 4	Frequency	% of total
(AB) (CD)	1	0.4
B D A C	6	2.6
D B C A	8	3.4
B D C A	11	4.7
B A D C	63	27.2
D C B A	**143**	**61.6**
Total	232	100

Table 7. The percentage of scenarios that alternatives ranked in specific position (including labour cost)

		Alternatives				Total
		A	B	C	D	
Ranking	1	0.2%	35%		**65%**	100%
	2	27%	4%	62%	7%	100%
	3	3%	62%	8%	27%	100%
	4	70%		30%	0.2%	100%
Total		100%	100%	100%	100%	

From both tables 6 and 7 the most common ranking order of the alternative systems for the 232 different scenarios appear to be DCBA, with alternative D being the most appropriate alternative in 65% of the simulated scenarios. By determining the maximum

[2] Most appropriate alternative ranked 1, and least appropriate ranked 4.

and minimium values for each scenario, a value range can be approximated for each ranking order. This value range (figure 29), specific to the input data used, highlights the relative importance of the different main criteria on the ranking order.

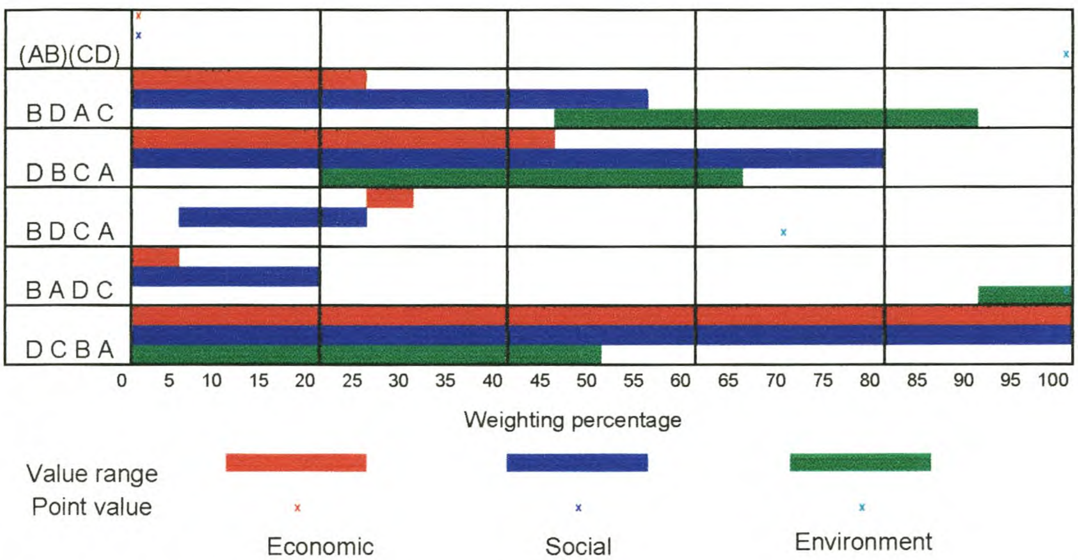


Figure 29. The impact of the value range on the ranking combinations (including labour cost)

5.1.5. Stage 7 - Sensitivity analysis

The sensitivity analysis is done on the most appropriate alternative: i.e., the alternative that ranks first in the highest percentage of evaluated scenarios namely alternative D. The potential impacts on alternative D is shown in table 8 in sequence of importance.

Table 8. Potential impacts on selected AT (including labour cost)

Input variables	Change R/m^3			Change %	
	-10%	0%	+10%	-10%	+10%
Labour numbers (#)	40.30	42.84	45.94	-5.9%	7.2%
Labour cost (R/manday)	40.04	42.84	45.63	-6.5%	6.5%
PMH/shift (hrs)	40.92	42.84	44.82	-4.5%	4.6%
Overheads (R)	42.33	42.84	43.35	-1.2%	1.2%
Fuel & lubricant cost (R)	42.34	42.84	43.34	-1.2%	1.2%
Fuel consumption (l/hr)	42.34	42.84	43.34	-1.2%	1.2%
Daily throughput (tons)	43.35	42.84	42.37	1.2%	-1.1%
Capital cost (R)	42.49	42.84	43.19	-0.8%	0.8%
Useful life of equipment (hrs)	43.09	42.84	42.63	0.6%	-0.5%
Tyre life (hrs)	43.01	42.84	42.70	0.4%	-0.3%
Tyre cost (R)	42.71	42.84	42.97	-0.3%	0.3%
Repair & maintenance (%)	42.71	42.84	42.97	-0.3%	0.3%
Interest rate (%)	42.76	42.84	42.91	-0.2%	0.2%
Licencing & insurance (%)	42.81	42.84	42.86	-0.1%	0.0%
Residual value (R)	42.84	42.84	42.84	0.0%	0.0%

Labour numbers and labour cost have the greatest potential impact on the operational cost with a 10% increase in labour numbers and labour cost resulting respectively in a 7.2% and 6.5% increase in the total cost. When excluding the labour cost consistent with the current subsistence woodlot harvesting, and repeating stages 5 and 6, alternative B becomes the most appropriate alternative (table 9).

Table 9. The percentage of scenarios that alternatives ranked in specific position (excluding labour cost)

		Alternative				Total
		A	B	C	D	
Ranking	1	0.2%	**52%**		48%	100%
	2	28%	5%	43%	25%	100%
	3	2%	43%	28%	27%	100%
	4	71%		29%	0.4%	100%
Total		100%	100%	100%	100%	

A sensitivity analysis (stage 7) of alternative B resulted in the potential impacts (table 10) in sequence of importance.

Table 10. The impact of the value range on the ranking combinations (excluding labour cost)

Input variables	Change R/m^3			Change %	
	-10%	0%	+10%	-10%	+10%
Overheads (R)	12.47	12.96	13.45	-3.8%	3.8%
Daily throughput (tons)	13.45	12.96	12.51	3.8%	-3.5%
Tyre life (hrs)	13.25	12.96	12.73	2.2%	-1.8%
Tyre cost (R)	12.71	12.96	13.21	-1.9%	1.9%
Capital cost (R)	12.78	12.96	13.14	-1.4%	1.4%
PMH/shift (hrs)	13.14	12.96	12.81	1.4%	-1.2%
Interest rate (%)	12.86	12.96	13.06	-0.8%	0.8%
Useful life of equipment (hrs)	13.01	12.96	12.92	0.4%	-0.3%
Licencing & insurance (%)	12.93	12.96	12.99	-0.2%	0.2%
Repair & maintenance (%)	12.94	12.96	12.98	-0.2%	0.2%
Labour cost (R/manday)	12.96	12.96	12.96	0.0%	0.0%
Fuel & lubricant cost (R)	12.96	12.96	12.96	0.0%	0.0%
Fuel consumption (l/hr)	12.96	12.96	12.96	0.0%	0.0%
Labour numbers (#)	12.96	12.96	12.96	0.0%	0.0%
Residual value (R)	12.96	12.96	12.96	0.0%	0.0%

5.1.6. Stage 8 – Implement selected alternative

Although findings during the implementation stage can influence the final system selected, this stage will not be further discussed in this study.

5.1.7. Discussion of results

The selection of the AT in this situation is greatly influenced by the labour cost as shown by the two alternative ranking orders.

The inclusion of labour cost according to DWAF minimum wages shows a preference for less labour-intensive alternatives (i.e., ranking order DCBA). This is largely due to the unrealistically high minimum wage compared to normal unskilled forestry wages and low achieved productivity.

When excluding the labour cost to closer simulate the current situation of subsistence harvesting the appropriate ranking order shows a preference for less capital intensive alternatives (i.e., ranking order BDCA). Making use of cattle available on the homestead, alternative B is the most AT for this situation. The higher potential productivity and reduced environmental impact (soil disturbance) through using a skidding sulkie allowed adaptation of the existing system (BW_Sys A, 4^{th} position in ranking order) into the most appropriate system (BW_Sys B).

The appropriateness of alternative B in the medium to long term will be dependent on the availability of people willing to assist in this type of work. With the Eastern Cape burdened with the highest unemployment in South Africa, economic development, education and urbanisation will affect the numbers of young healthy workers willing to be involved in this work.

In the event of rural economic development offering opportunities to skilled people in the rural areas, an assortment of small business can develop. With the individual's time becoming more valuable, small businesses will develop to fill niche areas. While subsistence farmers are self-sufficient (independent) for basic needs (e.g., food, shelter, and energy), future regional economic development will promote interdependence. The subsequent development of small businesses will prevent complete self-sufficiency, developing specialised small business (e.g., timber merchants) to supply in the household timber needs and basic timber processing. Improved equipment utilisation and productivity will make dedicated forestry equipment a feasible alternative.

This case study illustrates the conflicts between increased employment and higher wages. As mentioned before, sustainable development in South Africa requires the cooperation of government, company management, employees (including organised labour) and communities. Unless trade unions and their members acknowledge and support the reality that more jobs at higher wages (with no productivity gains) are a pipe dream, the results of this case study will be a window to the future of employment in South Africa. However, employers should guard against exploiting people, ensuring they are paid a reasonable wage.

5.2. Northern Cape Province, Small-scale integrated harvesting and processing

5.2.1. Stage 1 - Situation analysis

5.2.1.1. Location and structure data

In the Northern Cape province a total of 1.2 million hectares are invaded by *Prosopis spp.* This exotic species mainly affects the low-lying alluvial plains, with the Orange River catchment being the most affected (Versfeld *et al.*, 1998). The project forms part of the National Working for Water programme, in conjunction with a local entrepreneur. The pilot project (case study) involves an area of 60 km radius around the town of Prieska (Figure 30). This area with a weighted average lead distance of 43 km will supply 15 000 m^3 of timber annually for seven years. Based on biomass models (le Maitre *et al.*, 1996), assuming a 50% stand density, and allowing for mixed-aged stands, the above-ground biomass is estimated at 20 m^3/ha. The existing farm and district roads are in a good condition, although sparse. As no future rotations are envisaged, no additional roads will be constructed. Thus extended in-field travel is required due to the low road density, allowing an average extraction distance below 50 m.

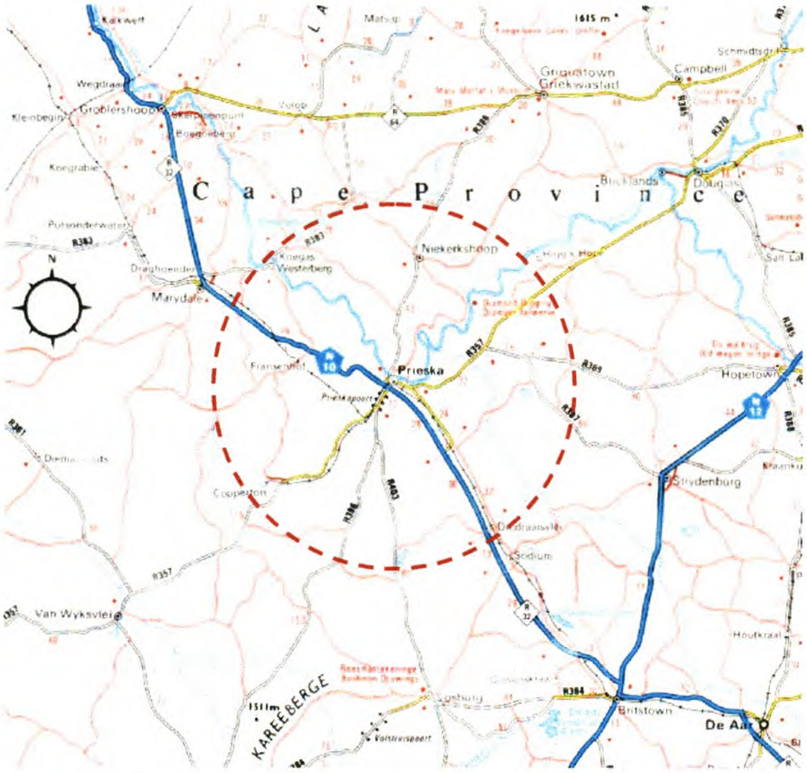


Figure 30. Geographic location of Working for Water pilot area

5.2.1.2. Work Object

Prosopis spp. are the second most prolific invader in South Africa after *Acacia cyclops* (Versfeld *et al.,* 1998). The tree size ranges from mature trees (height of ±13 m, with short trunk up to 45 cm diameter) to shrub-size with prolific young regrowth (www1, 1999). The trees are very branchy, and often confused with some indigenous *Acacia spp.* because of its nodal thorns. The percentage distribution of the above-ground biomass of the *Prosopis* tree falls in three broad diameter classes (Stoltsz, 1999): i.e., 24% with diameter greater than 8 cm; and 38% with diameter between 4 and 8 cm, and 38% with diameter smaller than 4 cm.

5.2.1.3. Environmental influences

Most of the Northern Cape Province is situated between 1 000 to 1 400 m above mean sea level. The terrain is generally flat, with no large obstacles and the soils are highly erodable with relatively low clay content. The observed terrain classification for the pilot area ranges between 323.1.1 to 432.1.1.

The Northern Cape is arid with MAP between 100 and 520mm (Rutherford *et al.*, 1985). Aggravated by the low MAP, the alien species' water-use in the Northern Cape province is the highest of all alien species in the country (Versfeld *et al.*, 1998), with root systems up to three times the height of the above-ground biomass. Erosion is not a serious problem due to the low Mean Annual Runoff to MAP ratio of 5% (Görgens and Hughes, 1984).

Eradication of *Prosopis spp* through stump treatment of cut stumps is most effective during the period September to June. *Prosopis spp* generally proliferates in over-grazed areas, stunting the recovery of the natural vegetation. The dependence of vegetation rehabilitation on rainfall makes it critical to minimise damage to the natural vegetation. The positive impact of effective eradication is greater than the possible short-term negative impacts.

5.2.1.4. Market

The basic daily harvest of 60 m^3 of roundwood will supply a number of potentially lucrative niche markets with possible export opportunities (Appendix 1.2.6).

This case study aims at fully utilising the available timber in the following range of products:

- Fine wood, parquet and strip flooring. The highly desirable wood attributes found in *Prosopis spp* (www1, 1999) open a lucrative market for the manufacture and export of parquet and strip flooring, exterior doors, cabinets and other furniture. With skilled craftsmen a small cottage furniture industry can be established allowing full utilisation of the high quality timber. The average sales price free-on-rail (FOR) for the sawn boards is estimated at R1 000/m^3.

- Smoke chips. The *Prosopis spp* chips, especially heartwood chips, show significant potential for domestic and industrial smoking of meat and fish. With a favourable exchange rate for exports and high cost of imported smoke chips, opportunities exist for developing a local replacement with export potential. The sales price (FOR) is estimated at R1 200/m^3.
- Energy. With an annual urban and rural firewood consumption of 11 million m^3, the commercial supply of firewood and charcoal will be investigated for specifically the Northern Cape province and the western part of the Orange Free State. An opportunity exists for support from a local petroleum company to supply kilns, packaging material and a market for locally manufactured charcoal. Although much bulkier than charcoal, firewood is a low risk commodity requiring very little capital investment, yet yielding reasonably high prices. Future export opportunities could be possible. The sales prices (FOR) for charcoal and firewood is estimated at R450/m^3 and R280/m^3 respectively.
- Soil productivity. A huge potential market exists for mulch and compost in gardens and farms to improve water-holding capacity and fertility of the soil and reduce moisture loss through evaporation. By chipping all biomass smaller than 4cm diameter, as well as waste from other product lines, a market can be created in soil productivity improvement. The wood waste can be composted through addition of urea, or through mixing with municipal household sewage waste. Successful utilisation of sewage waste, avoiding industrial sewage waste, can help solve the municipal problem of solid waste disposal, saving capital otherwise required to expand the sewage plants. The sales prices (FOR) for mulch and compost are estimated at R300/m^3 and R350/m^3, respectively.
- Other. Tests have shown that the seed pods can successfully be mixed with mulched river reed, a problem in Northern Cape wetlands, to offer a good quality livestock feed for local use. Stock farmers in the area have already shown interest in a cost-effective livestock feed. To prevent seed germination, the seeds will be mechanically cracked. *Prosopis spp* also have medicinal and human nutritional value (www1, 1999). These products will not be further considered in this study.

5.2.1.5. Labour

The Prieska district has an approximate 70% unemployment. The current National Working for Water programme employs previously unemployed local people to clear infested land in collaboration with landowners. Opportunities exist for establishing other related small enterprises that can offer long term sustainability after the eradication program: e.g., small-scale agriculture through community vegetable gardens, aquaculture, ecotourism and indigenous cutflower production.

Generally the workers are semi-literate to illiterate. Some skills training has been provided through the national Working for Water project. The pilot project intends to empower people through training and shareholding.

The current productivity standard (fell, stack and stump treatment) is 1,8ha/day per 10-person crew. The current labour cost amounts to R167/ha, with basic wages of R30/day. The pilot project proposes to base remuneration on productivity, with a quarterly dividend or bonus of approximately 30% supplementing a daily wage of between R30 and R35.

5.2.1.6. Harvesting system

Currently the trees are felled, biomass stacked and burnt, and stumps treated with a Tordon and diesel mixture to prevent re-growth. A process of follow-up is done to detect and eradicate young seedlings and live stumps.

Where ad hoc collection and making of domestic firewood is done, the *Prosopis* trees are felled and crosscut by chainsaw (R60/day), with manual labour accumulating and stacking timber. The residual stumps are killed by treating it with a Tordon and diesel mixture at a cost of R425/day.

The efficiency of this project will have to be measured by indicators of profit rather than labour productivity. The social and environmental benefits are numerous: i.e., water production, natural vegetation rehabilitation and social empowerment. The manual nature of the operation will dictate that night shifts are almost impossible. With pressure on optimal utilisation of expensive capital equipment, this project will pose the opportunity for appropriate equipment selection to keep capital low and employment at a maximum while ensuring cost-effective operations. The advantages of value-adding can help to off-set the constraints on utilisation. The current operation does not require large capital expenditure other than a truck for labour transport. Although some areas might be marginal, requiring eradication with little opportunity for cost-effective value-adding, this is not considered to be a major problem.

5.2.1.7. Working environment

The minimum temperature for the coldest month ranges between 0 and -9°C, with frost occurring between 30 and 180 days per annum. In summer the temperatures can rise to over 40°C. The Northern Cape climate can be considered very stressful to manual labour with an average daily energy expenditure of approximately 21.8 MJ/man-day (Pancel, 1993). The minimum personal protective equipment of overall, protective shoes and gloves are supplied. Due to the noise and dust from the operation of chainsaws, chippers, and bandsaws respiratory and hearing protection are also required. The potentially high accident risk can be minimised through continuous training and supervision. With 70% of the annual daylight hours experiencing bright sunshine (Rutherford and Westfall, 1986), the working time is 9.25 hr/day for five days per week, allowing sufficient rest period to minimise accidents. Some activities will require multiple shifts (e.g., charcoal). Sufficient fresh water and supplementary nutrition (e.g., *mageu*) should be considered for this harsh environment.

5.2.1.8. Effect of harvesting systems

The current manual and motor-manual operations have a low impact on the soil. Any changes to the process can be kept to a low impact level through careful planning. Currently the operation is regarded as a social cost for water production. The extent of the alien plant problem for all of South Africa indicates that an annual budget of R600 million per annum over 20 years, would be required to rectify the problem. During 1998/99 the programme had a budget of R261 million with an anticipated budget for 1999/2000 of R300 million (WFW, 1998). The Northern Cape province alone would require an estimated total of R870 million over 20 years to alleviate the infestation problem (Versfeld *et al.*, 1998). The budget shortfall highlights the need to seriously consider the economic value of the eradication program: i.e., maximised utilisation of available fibre and development of secondary industries. It is believed that this pilot project will prove that this net cost can be turned into a net profit, benefitting all communities.

5.2.2. Stage 2 - Identification of possible technological alternatives

During the pre-analysis phase, terrain conditions, average extraction lead distance, and equipment specifications are considered within the constraints of the situation analysis. Basic system knowledge is used to define possible appropriate technological alternatives according to its technical possibility. The four basic alternative systems are (appendix 1.2):

5.2.2.1. Northern Cape Prosopis *system A (NC_Sys A)*

Motor-manual felling, debranching and crosscutting, manual extraction, stacking and loading, and primary and secondary transport by agricultural tractor and trailer combination. Biomass with diameter <4 cm will be chipped in-field with a Jensen chipper, and manually loaded onto tractor-drawn trailer. The biomass greater than 4 cm will be cut to maximum possible length, manually loaded on top of chipped material, and further centrally processed in Prieska. Sawmilling will be done with a small Woodmizer bandmill, with selected pieces separately chipped as smoking chips. The charcoal kiln will be converted from fuel storage tanks supplied by a petroleum company. Firewood and compost will be prepared manually. The latter will involve the manual handling of stockpiled chipped material in rows to a height of 1.2 m.

5.2.2.2. *Northern Cape* Prosopis *system B (NC_Sys B)*

This system is similar to NC_Sys B, but the single trailer per tractor is replaced by a system of shuttle trailers to reduce double-handling, and improve utilisation of tractors. The biomass smaller than 4 cm is chipped directly into the trailer.

5.2.2.3. *Northern Cape* Prosopis *system C (NC_Sys C)*

This system is similar to NC_Sys B, but the system of shuttle trailers is replaced with a truck (GVM > 25000kg) and multiple (shuttle) roll-on/off containers. The biomass smaller than 4 cm is chipped directly into the bin.

5.2.2.4. *Northern Cape* Prosopis *system D (NC_Sys D)*

All above-ground biomass will be chipped/mulched in-field with a large crane-fed Morbark tub-grinder into containers similar to NC_Sys C. The tub-grinder will be centrally positioned to optimise the fibre processed between moving location.

5.2.2.5. *Northern Cape* Prosopis *system E (NC_Sys E)*

Similar to NC_Sys D except that 60% of the above-ground biomass (>4 cm) will be converted to firewood and the rest chipped/mulched with a small Jensen hand-fed chipper.

5.2.3. Stage 3 and 4 – Select evaluation criteria and analyse alternatives

During stage three the decision-makers agree on the relative weights to be applied to each criterion and sub-criterion, or apply the defined scenarios in appendix 3. The input variables for the decision criteria for each alternative are determined according to the proposed methodology.

5.2.3.1. Economic feasibility

A detailed integrated systems analysis and simple discounted cash flow were done for each identified technological alternative to determine input values for evaluation of the economic sub-criteria and operational indicators (Table 11).

Table 11. Economic input values for system evaluation as obtained through systems analysis and discounted cash flow

Economic sub-criteria	NC_Sys A	NC_Sys B	NC_Sys C	NC_Sys D	NC_Sys E
Profit (R/$m^3_{roundwood}$)	59.22	48.67	80.33	79.70	124.81
Cost (R/$m^3_{roundwood}$)	166.44	176.99	145.33	149.05	111.09
NPV (R)	1 469 897	558 003	2 433 948	2 020 641	4 422 224
Payback period (yrs)	1.35	2.39	0.93	1.31	0.53
Investment (R)	1 203 475	1 743 115	1 121 980	1 570 475	1 000 680
ROI (%)	74	42	107	76	187
*BE daily tp (m^3)	30	36	25	15	10
Fixed cost (R/day)	3 075	3 624	2 931	2 589	1 898

* Break-even daily throughput measured in m^3

In this case study the sum of the profit and cost for alternatives D and E varies from alternatives A, B and C because of the different combinations of products and its relative sales prices.

5.2.3.2. Social acceptability

The assessment of the social acceptability of the five technological alternatives resulted in the values shown in table 12. These values are used as input to the decision matrix.

Table 12. Social input values for system evaluation as obtained through systems analysis

Social sub-criteria	NC_Sys A	NC_Sys B	NC_Sys C	NC_Sys D	NC_Sys E
Employment	85	84	81	52	62
Health and safety	4	4	3	1	2
Human E (MJ/m^3)	31.6	31.6	30.2	16.4	23.3
Independency	4.01	5.81	3.74	12.56	2.00
Integration	2	3	3	4	1
Investment/employee	14 159	20 751	13 852	30 201	16 140
*Ave disp R/a	12 698	12 170	14 025	16 685	18 721
**Tot disp R/a	1 079 303	1 022 265	1 136 048	867 600	1 160 720

* Average annual disposable income

** Total annual disposable income

5.2.3.3. Environmental agreeability

An assessment of the five alternative systems regarding its agreeability to the environmental and silvicultural sub-criteria as previously discussed resulted in the values presented in Table 13.

Table 13. Environmental input values for system evaluation as obtained through systems analysis and equipment risk assessment (Smith, 1998)

Environmental sub-criteria	NC_Sys A	NC_Sys B	NC_Sys C	NC_Sys D	NC_Sys E
Compaction	M	M	H	H	H
Organic matter loss	L	L	L	L	L
Erosion	L	L	L	L	L
% of area impacted	25	25	25	25	25
Slash management	N	N	N	N	N
*NRE (MJ/m^3)	131.5	131.5	131.1	196.8	132.6

* Non-renewable energy obtained from fossil fuel

5.2.4. Stage 5 and 6 - Evaluate the alternatives and select the AT

The results of the above analysis are used as input to the evaluation matrix (appendix 2.2).

The 232 different scenarios resulted in 11 alternative ranking orders, with the frequency of occurrence of each shown in table 14. Table 15 shows the ranking position of individual alternatives as a percentage of the 232 scenarios.

Table 14. Occurrence of ranking options for 232 scenarios evaluated

Ranking 1 2 3 4 5	Frequency	% of total
(AB) C E D	1	0.4
E C (AD) B	1	0.4
A E C B D	2	0.8
A B C E D	5	2.2
E A B C D	5	2.2
A E B C D	6	2.6
A B E C D	17	7.3
E A C B D	19	8.2
E C A B D	47	20.3
E C A D B	62	26.7
E C D A B	**67**	**28.9**
Total	232	100

Table 15. The percentage of scenarios that alternatives ranked in specific position

		Alternatives					Total
		A	B	C	D	E	
Ranking	1	13%	0.2%			**87%**	100%
	2	11%	10%	76%		3%	100%
	3	47%	5%	12%	29%	7%	100%
	4	29%	29%	12%	27%	3%	100%
	5		56%		44%		100%
Total		100%	100%	100%	100%	100%	

From the above AT evaluation, the most common ranking order is ECDAB (67 of 232 scenarios), with alternative E (NC_Sys E) ranking as the most AT in 87% of the scenarios. The value range for the three main criteria is shown in figure 31.

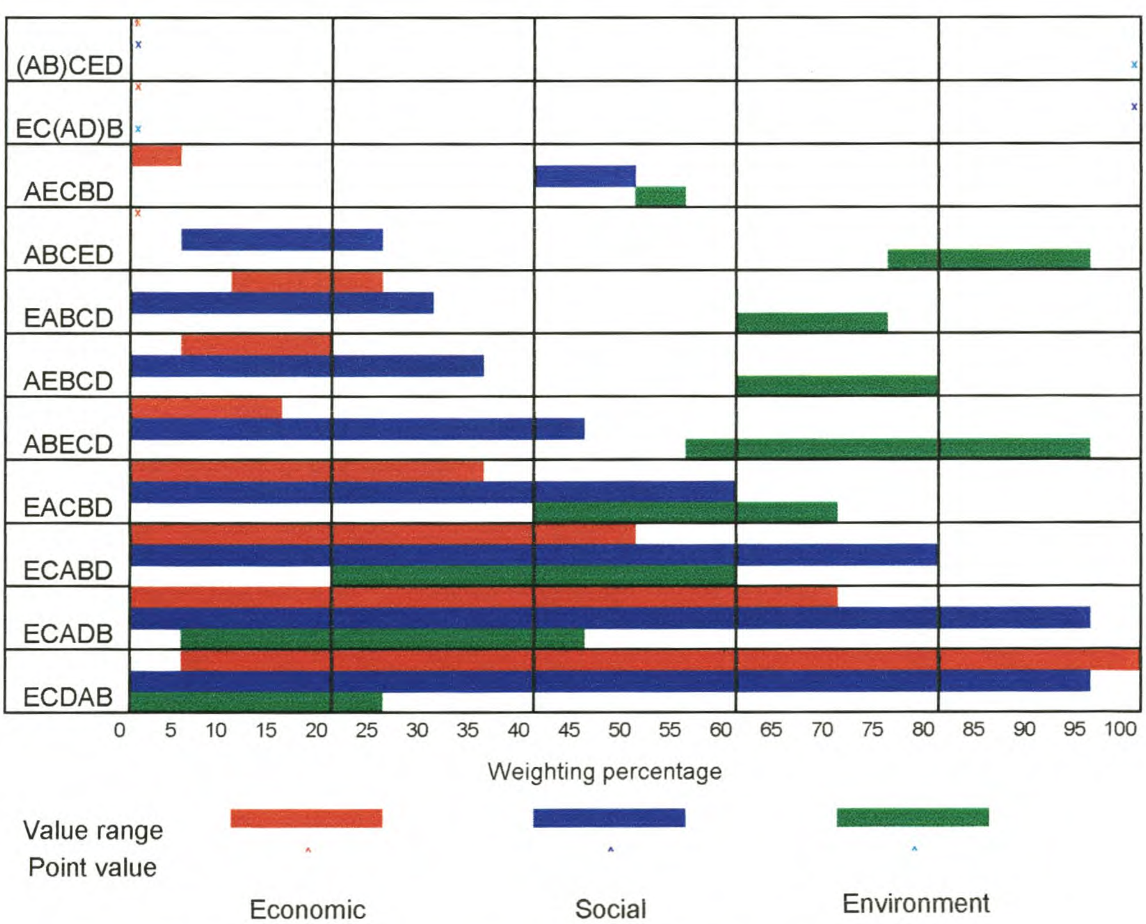


Figure 31. Impact of the value range on the ranking combinations

5.2.5. Stage 7 - Sensitivity analysis

To determine the greatest potential impacts on the most appropriate technological alternative, the input variables to System E were individually increased and decreased by 10%. For each input variable the percentage impact on the bottom-line cost per m^3 was noted. The potential impacts ranked in order from greatest to smallest are shown in table 16.

Table 16. Potential impacts on cost efficiency of operation

Input variables	Change R/m^3			Change %	
	-10%	0%	+10%	-10%	+10%
Daily throughput (m^3)	115.00	111.09	107.95	3.5%	-2.8%
Capital cost (R)	108.70	111.09	113.49	-2.2%	2.2%
Labour cost (R/man-day)	108.84	111.09	113.34	-2.0%	2.0%
Labour numbers (#)	109.05	111.09	113.59	-1.8%	2.3%
Useful life of equipment (hrs)	112.97	111.09	109.56	1.7%	-1.4%
Overheads (R)	109.91	111.09	112.28	-1.1%	1.1%
Repair & maintenance (%)	110.26	111.09	111.92	-0.7%	0.7%
Fuel consumption (l/hr)	111.58	111.09	111.73	0.4%	0.6%
Fuel & lubricant cost (R)	110.45	111.09	111.73	-0.6%	0.6%
Interest rate (%)	110.59	111.09	111.60	-0.5%	0.5%
PMH/shift (hrs)	111.08	111.09	111.54	0.0%	0.4%
Tyre cost (R)	110.80	111.09	111.38	-0.3%	0.3%
Tyre life (hrs)	111.44	111.09	110.81	0.3%	-0.3%
Licencing & insurance (%)	110.91	111.09	111.28	-0.2%	0.2%
Residual value (R)	111.15	111.09	111.03	0.1%	-0.1%

To analyse individual activities a similar sensitivity analysis can be done for each, providing more detail on potential impacts.

5.2.6. Stage 8 – Implement selected alternative

This will not be further discussed in this study.

5.2.7. Discussion of results

In essence this project aims at adding value to the existing Working for Water invader eradication program, creating employment and wealth locally rather than exporting low-value timber from the area. From the socio-economic overtone of the project it is important to keep the break-even throughput as low as possible considering marginal areas and allowing flexibility within changing markets.

The Northern Cape is a vast area comprising more than 12 million ha, with little available detail for planning purposes, requiring the need for assumptions. The preliminary assessment of the Council for Scientific and Industrial Research (CSIR) (Versfeld *et al.*, 1998) highlights the complexity of clearly defining the parameters of such a project.

The greatest potential impact on the cost (R per m^3) of the AT for the Northern Cape *Prosopis* project is daily throughput. If an additional 6 m^3 per day can be produced and sold, the potential cost saving is 2.8% with an annual profit increase of R239 025 or 12.8%. Through the sharing of profits, each worker will earn an additional R1 160 per annum.

There appears to be definite opportunities for turning the costly eradication process into a profitable community-based operation. The real benefits of this project lie in the value-adding secondary industries, with a potential in the Northern Cape of turning an annual net cost of R75 million of taxpayers money into a community enterprise with an annual net profit of R13 million. Apart from becoming an economically feasible operation, the integrated approach will effectively eradicate the alien infestation, provide much needed employment and allow wealth creation in the region.

This case study illustrates the potential for employment and wealth creation involved in adding value to a low value resource. This project can be the hub for various other smaller industries in the rural Northern Cape province, offering further employment opportunities with resulting increased disposable income for the local economy. By initiating similar projects across South Africa small business with community involvement, can effect gigantic results for sustainable development of this country. Small, applied in the right context, can indeed be beautiful (Schuhmacher, 1974).

5.3. Mpumalanga Province, Commercial forestry

5.3.1. Stage 1 – Situation analysis

5.3.1.1. Location and structure data

The timber plantations of the Mondi Hazyview Area are situated on the important Sabie River Catchment between the town of Hazyview (east) and the escarpment below the town of Graskop (west) (Figure 32).

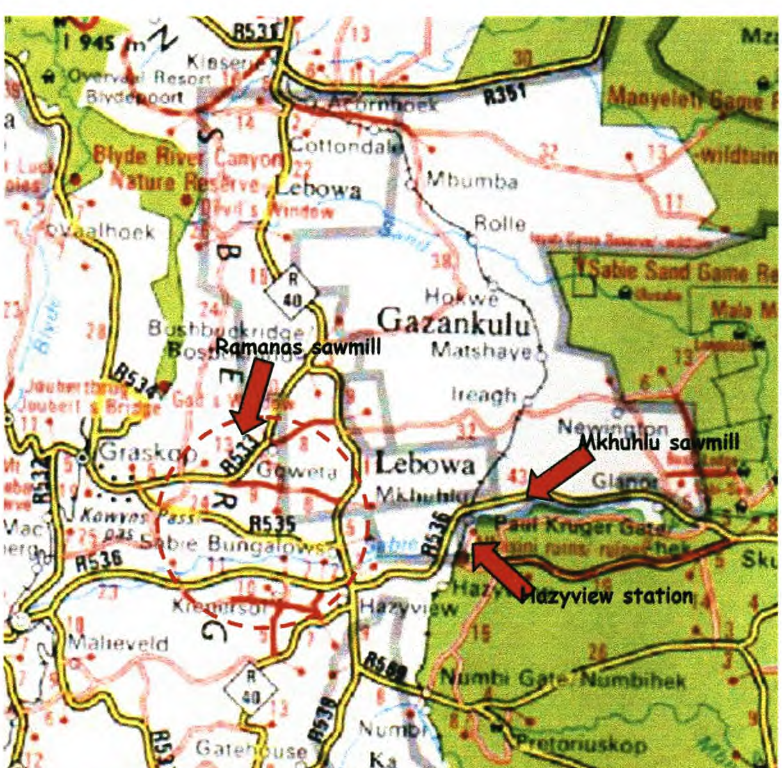


Figure 32. Geographical location of Mondi Forest's Hazyview Area

An area of 10 863 ha out of a total 17 670 ha have been afforested to *Eucalyptus spp* (9 380 ha) and *Pinus spp* (1 483 ha). The Mean Annual Increment (MAI) of the hardwood plantations range between 8.2 and 28.4 m^3/ha/a, with weighted average of 14 m^3/ha/a resulting in a weighted average yield of 110 m^3/ha on a weighted average rotation age of 8.3 years (Mondi, 1997). A planted area of 5 499ha is managed for mining timber and pulpwood with a sustainable harvest of 76 944 m^3/a. The existing roads are generally in a reasonable condition, although the high rainfall would require sufficient drainage. The 452 km of forest road result in an average extraction lead distance of 60 m.

5.3.1.2. Work Object

Of the total planted area 86% is planted to *Eucalyptus* spp, with an average tree size of 0.13 m^3/tree at rotation age. The timber is mainly converted in-field to shortwood (2.3m), with specific customer length and diameter specifications for the special pole operations. The quality specifications are dependent on the specific market, with higher standards on special poles and mining timber than on pulpwood.

5.3.1.3. Environmental influences

The Hazyview Area is situated between 900 and 1 500 m above mean sea level (AMSL). There are few obstacles (ground roughness 1), with varying ground conditions (Ground Condition 323 to 135), and gradient below 35% in 85% of the area (Slope Condition 1 to 4). The Hazyview area has a sub-tropical climate with summer rainfall of 800 to 1 300 mm/a (Mondi, 1997). The average day temperatures range between 22°C (winter) and 30°C (summer) on the Bergvliet Estate (Mondi, 1997). The timber plantations were established on old banana plantations and through clearing of natural vegetation. In marginal growing areas the natural vegetation is re-establishing at the cost of the timber plantations. Mondi is actively involved in initiatives to manage the Sabie River catchment through conserving riverine areas for water production

5.3.1.4. Market

Mondi Forests North is currently in the process of a strategic review which might greatly impact on its future markets: i.e., the possible conversion from mining timber to sawtimber rotations. Subject to the present state of uncertainty, this case study will concentrate on the existing situation. The Hazyview area supplies the following products:

- Pine and Gum saw timber supplied to Mondi Ramanas sawmill and a number of other small-scale sawmills. The Ramanas sawmill is situated off the main road between Graskop and Bushbuckridge, with planned future expansions to increase the capacity from 160 to 500 m^3/day.
- Gum mining timber supplied to Mhkuhlu mining timber mill. Due to the poor mining timber market the mill will probably close. Based on stand quality mining timber compartments will probably be managed for sawtimber, special poles and pulpwood. Some *Eucalyptus* compartments will be replanted to *Pinus spp*.
- Gum special poles are sold to treatment plants, offering the best returns. A possible future scenario involves selling timber standing.
- In the mining timber industry pulpwood has traditionally been a by-product. Based on the long distance from the Mondi pulpmill in Richard's Bay this situation will probably continue.

For the purposes of the study the non-sawtimber commodity price is assumed to be R150.00 per m^3 delivered to mill.

5.3.1.5. Labour

Mondi Forests North is in the process of outsourcing all forestry operations. The current harvesting contractor employs 82 people to harvest 180 m^3 of mining timber, pulpwood and special poles per day, and 30 people to harvest 300 m^3 of sawtimber per day. Generally the workers are semi-literate to illiterate. On-the-job training is provided for specialised skills: e.g., chainsaw operation. The productivity of 2.2 m^3/manday complies with established gum harvesting productivity standards, with possible room for productivity gains (Richardson, 1993). The average man-day cost is R36.70.

5.3.1.6. Harvesting system

Ground skidding accounts for 85 to 90% of the harvested volume, with cable yarding for 10 to 15%. The harvesting system for clearfelling of *Eucalyptus* mining timber involves motor-manual felling, debranching and crosscutting of trees with assistant, manual debarking and stacking of two-m^3 bundles for extraction by 100 kW cable skidder. The cable yarding system involves the same felling and preparation, with extraction by a Bell modified highlead. In both systems a Bell three-wheel loader stacks and loads the timber for secondary transport to railway station and sawmill. In difficult areas not suitable for the above two systems, a PVC chute system and manual extraction are employed. The working methods need to minimise the damage to the cambium of the stumps to ensure maximised future coppice yields. The current small-size timber operation requires a capital investment of R2 038 378 from stump to mill. The equipment availability exceeds 90% on a single shift, with the extraction of two-m^3 bundles resulting in potential under-utilisation of the cable skidder.

This study will exclude the sawtimber operation, and only investigate the hardwood mining timber, pulpwood and special pole operation.

5.3.1.7. Working environment

In the warm and humid Mpumalanga climate, manual and motor-manual labour is considered to be very stressful with an average daily energy expenditure of approximately 21.8 MJ/man-day (Pancel, 1993). Basic personal protective equipment (i.e., overall, protective shoes and gloves) are supplied to all labour, including hearing protection for machine operators. The labour intensity of the operation presents an accident risk, requiring continuous training and good supervision to minimise the hazard. The scheduled working time of 9.25 hrs/day, 5 days per week, allows sufficient rest period to minimise accidents caused by exhaustion. In an attempt to improve the working environment, the awareness is created to spread the workload over the daily working hours rather than going home when the task is completed.

5.3.1.8. Effect of harvesting systems

The current system has a moderate impact on the soil and stand. Careful planning and supervision can help keep the impact low. The felling, preparation and extraction to roadside landing costs R40.07/m^3, with transport to mill or railway station costing an additional R12.87/m^3.

5.3.2. Stage 2 - Identification of possible technological alternatives

During the pre-analysis phase terrain conditions, average extraction lead distance, and equipment specifications are considered within the constraints of the situation analysis. Basic system knowledge is used to define possible appropriate technological alternatives according to its technical possibility. The six alternative harvesting systems that will be further investigated are (appendix 1.3):

5.3.2.1. Commercial hardwood system A (CH_Sys A)

Motor-manual felling, debranching and crosscutting, manual debarking, stacking and loading, and forwarding by tractor and trailer to landing. Off-loading of forwarding equipment and loading of secondary transport with three-wheel loader. Secondary transport by rigid truck and drawbar trailer.

5.3.2.2. Commercial hardwood system B (CH_Sys B)

Mechanised felling, debranching, debarking, crosscutting, and roughlining by Timberjack 1270 single grip harvester. Loading, forwarding, and off-loading at landing by Timberjack 1010 forwarder. Loading and secondary transport by self-loading rigid truck and drawbar trailer.

5.3.2.3. Commercial hardwood system C (CH_Sys C)

Motor-manual felling, debranching and crosscutting, manual debarking and bunching, and loading, forwarding and offloading by self-loading agricultural tractor and trailer. Loading and secondary transport by self-loading rigid truck and drawbar trailer.

5.3.2.4. Commercial hardwood system D (CH_Sys D)

Mechanised felling, debranching, and debarking by excavator-based Waratah harvester. Motor-manual crosscut and manual bunching, with forwarding by self-loading agricultural tractor and trailer. Loading and secondary transport by self-loading rigid truck and drawbar trailer.

5.3.2.5. Commercial hardwood system E (CH_Sys E)

This is the current system used for small-size timber harvesting. Motor-manual felling, debranching, and crosscutting, manual debarking and stacking, with extraction of two-m^3 shortwood bundles to roadside by Timberjack 240 cable skidder. Loading and secondary transport by self-loading rigid truck and drawbar trailer.

5.3.2.6. Commercial hardwood system F (CH_Sys F)

This system involves motor-manual felling, debranching, and crosscutting, manual debarking and roughlining, with shortwood extraction to roadside by "Boomslang" timber conveyor system (Anon 1, 1999). Loading and secondary transport by self-loading rigid truck and drawbar trailer.

5.3.3. Stage 3 and 4 – Select evaluation criteria and analyse alternatives

This study uses the evaluation criteria as discussed in chapter 3.4.3. During stage three the decision-makers must agree on the relative weights to be applied to each criterion and sub-criterion. The input variables for the decision criteria for each alternative are determined according to the proposed methodology.

5.3.3.1. Economic feasibility

A detailed systems analysis and simple discounted cash flow were done for each identified technological alternative to determine input values for evaluation of the following sub-criteria and operational indicators (table 17).

Table 17. Economic input values for system evaluation as obtained through systems analysis and discounted cash flow

Economic sub-criteria	CH_Sys A	CH_Sys B	CH_Sys C	CH_Sys D	CH_Sys E	CH_Sys F
Profit (R/m^3_{rw})	50.73	33.55	66.17	55.68	51.23	63.63
Cost (R/m^3_{rw})	99.27	116.45	83.83	94.32	98.77	86.37
NPV (R)	5 859 086	3 232 338	8 206 847	5 215 470	5 473 039	7 796 694
Payback (yrs)	0.59	1.04	0.4	1.1	0.8	0.43
Investment (R)	1 508 706	4 881 587	1 313 058	3 065 688	2 038 378	1 373 000
ROI (%)	168	96	252	91	126	232
*BE daily tp (m^3)	83	112	55	65	85	62
Fixed cost (R/day)	8 309	8 853	5 214	5 708	7 521	6 163

* Break-even daily throughput measured in m^3

5.3.3.2. Social acceptability

From the detailed integrated systems analysis and simple discounted cash flow and other tools, the six alternatives were assessed regarding the social sub-criteria as previously discussed (table 18).

Table 18. Social input values for system evaluation as obtained through systems analysis, discounted cash flow and personal observation

Social sub-criteria	CH_Sys A	CH_Sys B	CH_Sys C	CH_Sys D	CH_Sys E	CH_Sys F
Employment	98	9	56	12	79	86
Health and safety	6	1	3	2	5	4
Human E (MJ/m^3)	10.7	0.7	5.1	1.3	8.6	9.4
Independency	0	16.83	0	7.33	2.78	0
Integration	2	6	4	5	3	1
Investment/employee	15 395	542 399	27 937	255 474	25 802	15 965
*Ave disp R/a	10 250	34 793	11 270	27 855	11 073	9 990
**Tot disp R/a	1 004 500	313 133	529 690	334 260	874 728	859 140

* Average annual disposable income

** Total annual disposable income

5.3.3.3. Environmental agreeability

An assessment of the six alternative systems regarding its agreeability to the environmental and silvicultural sub-criteria as previously discussed (table 19).

Table 19. Environmental input values for system evaluation as obtained through systems analysis and equipment risk assessment (Smith, 1998)

Environmental sub-criteria	CH_Sys A	CH_Sys B	CH_Sys C	CH_Sys D	CH_Sys E	CH_Sys F
Compaction	M	VH	M	M	M	L
O.M. loss	L	M	L	M	M	L
Erosion	L	M	L	M	M	L
% of area	25	25	25	25	25	25
Slash management	N	Y	Y	Y	N	N
*NRE (MJ/m^3)	94.6	84.6	41.1	90.1	62.2	68.7

* Non-renewable energy obtained from fossil fuel

5.3.4. Stage 5 and 6 - Evaluate the alternatives and select A.T

The results of the above analysis are used as input to the evaluation matrix (appendix 2). For the purposes of the case study all sub-criteria are weighted equally, with variable weights applied to the three main criteria i.e., economic feasibility, environmental agreeability, and social acceptability.

The frequency of occurrence of different ranking options is shown in table 20, with table 21 showing the ranking position of individual alternatives in the 232 different scenarios (appendix 3) as a percentage of the total scenarios.

Table 20. Occurrence of ranking options for the 232 scenarios evaluated

Ranking 1 2 3 4 5 6	Frequency	% of total
C (AD) B F E	1	0.4
C A F D B E	1	0.4
C D A F B E	1	0.4
C F D (AE) B	1	0.4
F (AC) E D B	1	0.4
C A F D E B	2	0.9
C D F A E B	2	0.9
C F D E A B	5	2.3
C F A D E B	35	15.1
C F A E D B	37	15.9
C F D A E B	45	19.4
F C A E D B	**101**	**43.5**
Total	232	100

Table 21. The percentage of scenarios that alternatives ranked in specific position

		Alternatives						Total
		A	B	C	D	E	F	
Ranking	1			**56%**			44%	100%
	2	2%		44%	2%		53%	100%
	3	75%		0.4%	22%		2%	100%
	4	20%	0.4%		16%	62%	0.4%	100%
	5	2%	1%		60%	36%	0.4%	100%
	6		99%			1%		100%
Total		100%	100%	100%	100%	100%	100%	

The 232 different scenarios resulted in 12 ranking options (table 20), with FCAEDB being the most common ranking option. However out of 12 ranking options only two indicated alternative F to be the most appropriate (102 scenarios out of 232 scenarios), leaving 10 ranking options indicating alternative C as the most appropriate (130 scenarios out of 232 scenarios). Therefore alternative C is considered to be the most appropriate on the balance of the scenarios (56%) for the set of input data used.

The value range for the three core values for each ranking option is shown in Figure 33.

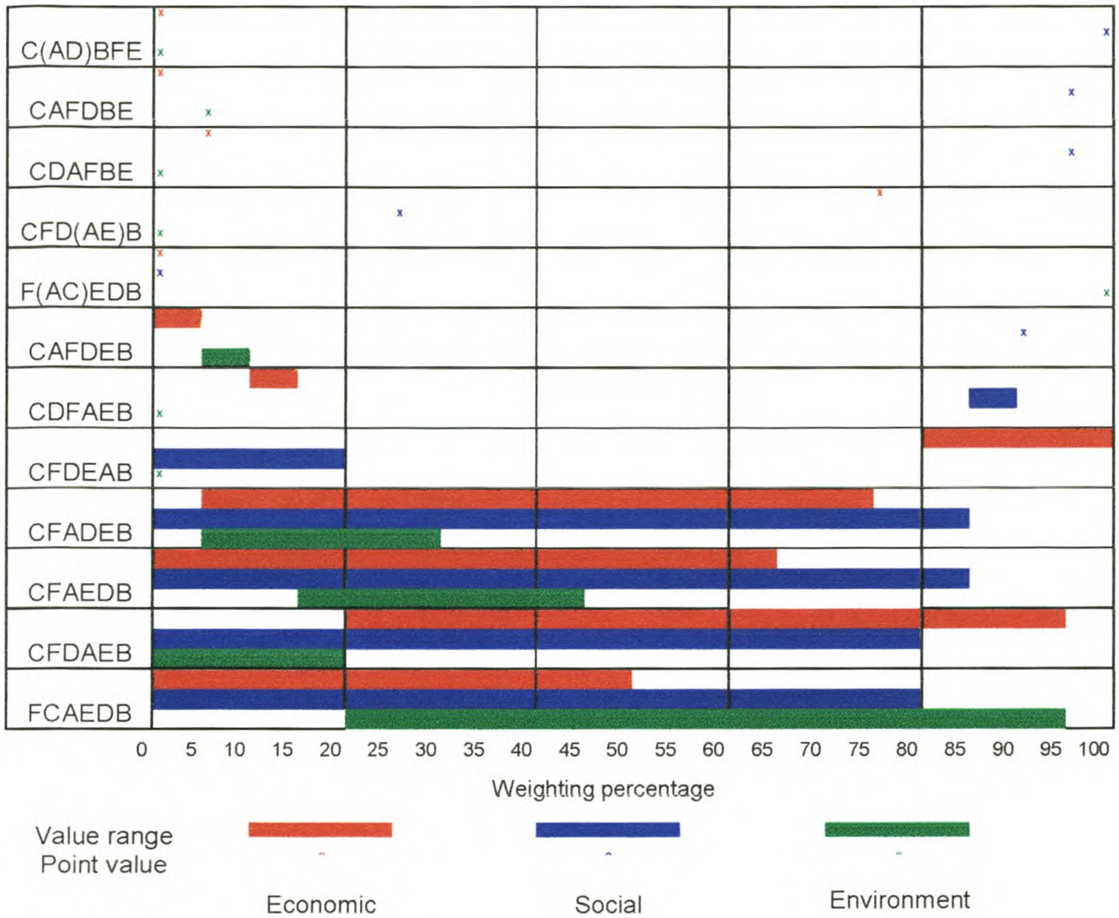


Figure 33. Impact of value range on the ranking combinations

5.3.5. Stage 7 - Sensitivity analysis

For alternative C the input variables were individually increased and decreased by 10%, noting the percentage impact on the bottom-line cost per m^3. The potential impacts, ranked from greatest to smallest, are shown in table 22. The operation can be further optimised by focussing attention on the greatest potential impacts.

Table 22. Potential impacts on cost efficiency of operation

Input variables	Change R/m^3			Change %	
	-10%	0%	+10%	-10%	+10%
Labour numbers	82.54	83.83	85.54	-1.5%	2.0%
Labour cost (R/manday)	82.41	83.83	85.25	-1.7%	1.7%
Capital cost (R)	82.61	83.83	85.05	-1.5%	1.5%
Useful life of equipment (hrs)	84.75	83.83	83.08	1.1%	-0.9%
Fuel consumption (l/hr)	83.34	83.83	84.32	-0.6%	0.6%
Fuel & lubricant cost (R)	83.34	83.83	84.32	-0.6%	0.6%
PMH/shift (hrs)	83.44	83.83	84.22	-0.5%	0.5%
Repair & maintenance (%)	83.46	83.83	84.20	-0.4%	0.4%
Overheads (R)	83.47	83.83	84.18	-0.4%	0.4%
Daily throughput (tons)	84.22	83.83	83.51	0.5%	-0.4%
Tyre life (hrs)	84.17	83.83	83.55	0.4%	-0.3%
Tyre cost (R)	83.54	83.83	84.12	-0.3%	0.3%
Interest rate (%)	83.55	83.83	84.11	-0.3%	0.3%
Licencing & insurance (%)	83.73	83.83	83.93	-0.1%	0.1%
Residual value (R)	83.86	83.83	83.80	0.0%	0.0%

5.3.6. Stage 8 – Implement selected alternative

This stage will not be further discussed in this study.

5.3.7. Discussion of results

In the investigation of the 232 scenarios for the applied input data, only two alternatives featured as most appropriate alternatives i.e., alternative C (130 scenarios) and alternative F (102 scenarios). Where alternative C is the most appropriate in the presence of a strong social or social and economic value, alternative F becomes the most appropriate when the environmental value becomes more significant than the social and economic values (figure 34).

Labour and capital costs have the greatest and second greatest impact on the system selection. This becomes apparent when considering that alternative C, an intermediate technology with relatively low capital cost and less labour intensive than alternative F, is the most appropriate alternative on the balance of the 232 scenarios. The impact of the exchange rate on the capital cost of imported equipment is severe. As a result alternative A (highly labour intensive) is more appropriate (ranked third) than the three mechanised operations featuring fourth, fifth, and sixth, respectively.

6. CONCLUSION

The brief overview of the socio-economic situation highlighted the complexity of South Africa, with both a strong first world component as well as a large third world component. This complex situation sets the scene for exciting opportunities in finding practical solutions that address the three core values i.e., economy, social and environment.

The high unemployment and poverty that affects the quality of life of a large portion of the population can only be addressed through investment and economic development. Unfortunately, the escalation of crime and the potential political instability as a result of the unemployment and poverty, hampers investor confidence and ultimately aggravates the situation through further unemployment, poverty and an exodus of professional South Africans.

As a developing global competitor, the local forest industry needs to ensure its world class status through high quality, improved productivity, reduced cost, maximised timber value, environmental responsibility and excellent customer relations.

As an important sector in the local economy, especially in the rural areas, the industry has definite socio-economic implications. Sustainable development of South Africa requires careful consideration of the economic, social and environmental values. The development of the plantation forest industry in line with the objectives of the NFAP, will ensure that this significant South African industry remains a leader in the future sustainable development of Africa.

For sustainable development in South Africa in general, and forestry in particular, the forest industry needs to:

- Consider forestry's role and influence in the broader South African Industry.

- Be realistic regarding the realities facing South Africa (e.g., unemployment, low exchange rate, environmental impacts, global competition, and productivity).
- Environmentally responsible regarding biodiversity, water quality and quantity, soil conservation, and pollution.
- Get a better understanding of the economic, social, and environmental impacts of our business decisions. Long term stability is as important if not more important than short term profit.
- Accept the objectives and criteria of the NFAP as the national development objectives.
- Objectively find appropriate solutions to the apparent conflicting interests between the core values.

AT can provide the vehicle for achieving sustainable development through careful consideration of the relative impacts of technological alternatives on the evaluation criteria physically possible, economically feasible, environmentally and silviculturally agreeable, and socially acceptable. The harvesting systems currently employed largely reflect the complicated socio-economic situation in South Africa, with technology ranging from basic to highly mechanised. The current trend still appears to be towards lower capital, lower risk systems. This is probably as a result of short-term contracts, high capital cost of imported equipment, high interest rates, harvesting cost versus rates paid, shortage of skilled operators, and a lack of forest engineering expertise.

The AT decision methodology developed in this thesis is based on a number of criteria and sub-criteria attempting to reflect the national development objectives for forestry. The criteria in this study are not an exhaustive list, and might exclude criteria important to specific stakeholders. However, it is seen as a group of criteria of common importance to the four stakeholder groups: i.e., government, labour, communities (public) and private enterprise. It is important to keep in mind that the final ranking of alternatives reflect the AT for the specific situation and not necessarily for the whole industry or sector of the industry.

The methodology proved to be reasonably simple and effective in evaluating different situations using the same criteria and applying weighting to highlight specific values important to a situation. The ability to simulate different scenarios allows for thorough investigation and informed decision-making.

From the study it is clear that technology is appropriate to a specific situation as defined by its economic, social and environmental realities. The aim of this study is not to dictate or specify the most suitable technology for the three case studies, but rather to evaluate and promote a methodology to evaluate alternative technologies within a specified scenario. It is strongly felt that only through the objective and holistic evaluation of the three core values in the process of technological choice, will South African industry be able to embark on the high road to sustainable development.

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Appendix 1: Matrices for alternative harvesting systems

Appendix 1.1: Eastern Cape community woodlots

Appendix 1.1.1

BW_Sys A

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell & debranch				
Extract & stack				
Load & transport				
Secondary processing				

Appendix 1.1.2

BW_Sys B

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell & debranch				
Extract & stack				
Load & transport				
Secondary processing				

Appendix 1.1.3

BW_Sys C

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell & debranch				
Extract & stack				
Load & transport				
Secondary processing				

Appendix 1.1.4

BW_Sys D

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, & crosscut				
Load & transport				
Secondary processing				

Appendix 1.2: Northern Cape integrated harvesting and processing

Appendix 1.2.1

NC_Sys A

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, crosscut				
Extract, sort & stack				
Chip / mulch				
Load & transport chips & roundwood				
Secondary processing				Mulch Compost Sawtimber Charcoal Firewood

Appendix 1.2.2

NC_Sys B

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, crosscut				
Extract, sort & stack				
Chip, load chips & roundwood				
Transport				
Secondary processing				Mulch Compost Sawtimber Charcoal Firewood

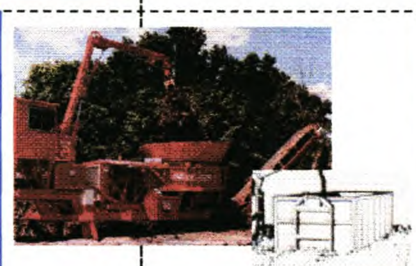
Appendix 1.2.3

NC_Sys C

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, crosscut				
Extract, sort & stack				
Chip, load chips & roundwood				
Transport				
Secondary processing				Mulch Compost Sawtimber Charcoal Firewood

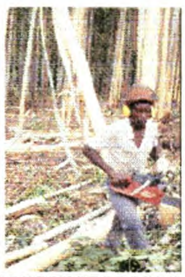
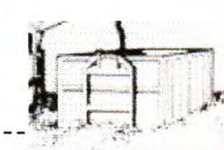
Appendix 1.2.4

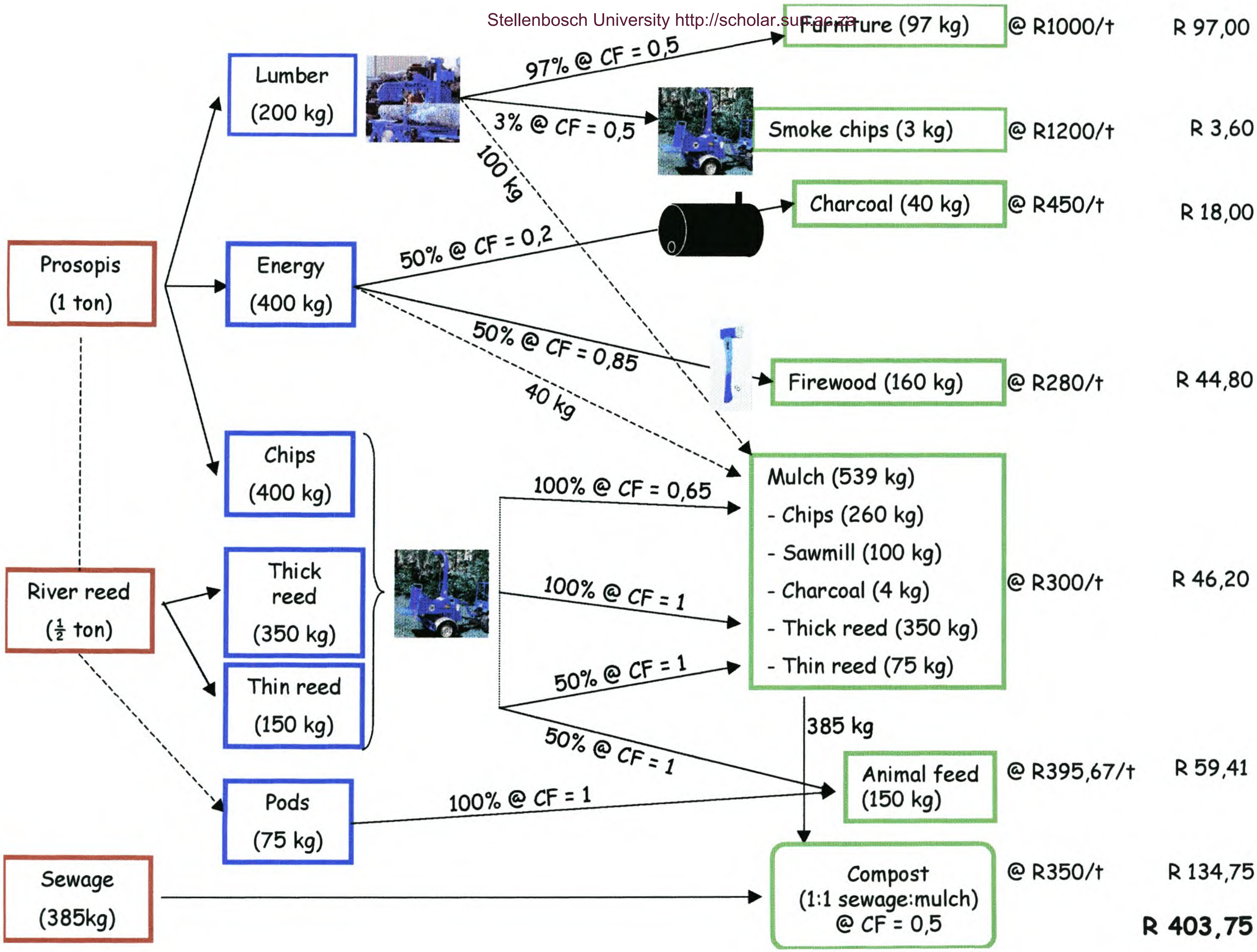
NC_Sys D

Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, crosscut				
Extract, sort & stack				
Chip/ mulch				
Load & transport				
Secondary processing				Mulch Compost

Appendix 1.2.5

NC_Sys E

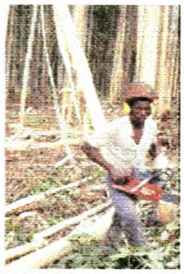
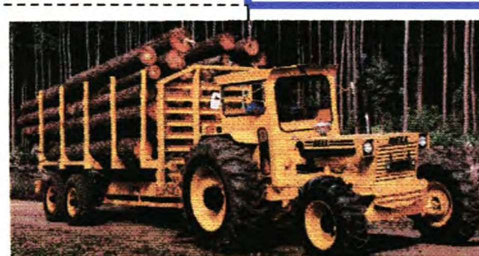
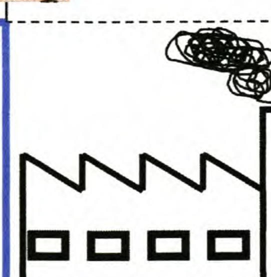
Location / Activity	Stand	Forest rd	Main rd	Plant
Fell, debranch, crosscut				
Extract, sort & stack				
Chip & load				
Load & transport				
Secondary processing				Mulch Compost Firewood


Prosopis
(1 ton)
Lumber
(200 kg)
Energy
(400 kg)
Chips
(400 kg)
River reed
(½ ton)
Thick reed
(350 kg)
Thin reed
(150 kg)
Pods
(75 kg)
Sewage
(385kg)
97% @ CF = 0,5
3% @ CF = 0,5
100 kg
50% @ CF = 0,2
50% @ CF = 0,85
40 kg
100% @ CF = 0,65
100% @ CF = 1
50% @ CF = 1
50% @ CF = 1
100% @ CF = 1
385 kg
Furniture (97 kg)
@ R1000/t
R 97,00
Smoke chips (3 kg)
@ R1200/t
R 3,60
Charcoal (40 kg)
@ R450/t
R 18,00
Firewood (160 kg)
@ R280/t
R 44,80
Mulch (539 kg)
- Chips (260 kg)
- Sawmill (100 kg)
- Charcoal (4 kg)
- Thick reed (350 kg)
- Thin reed (75 kg)
@ R300/t
R 46,20
Animal feed
(150 kg)
@ R395,67/t
R 59,41
Compost
(1:1 sewage:mulch)
@ CF = 0,5
@ R350/t
R 134,75
R 403,75

Appendix 1.3: Mpumalanga commercial gum harvesting operation

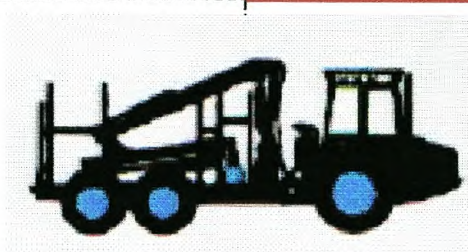
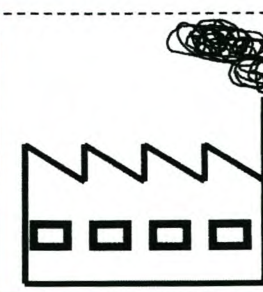
Appendix 1.3.1

CH_Sys A

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debranch, crosscut				
Debark	 			
Loading				
Forward & off-load				
Load & transport				
Secondary processing				

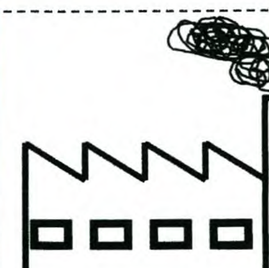
Appendix 1.3.2

CH_Sys B

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debark debranch, crosscut & roughline				
Forward				
Load & transport				
Secondary processing				

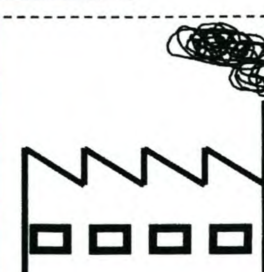
Appendix 1.3.3

CH_Sys C

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debranch, crosscut				
Debark & stack	 			
Forward				
Load & transport				
Secondary processing				

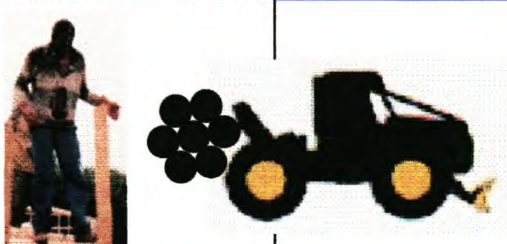
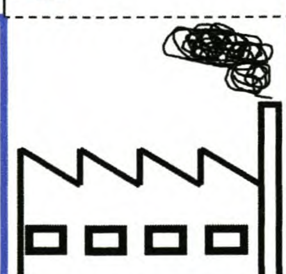
Appendix 1.3.4

CH_Sys D

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debark debranch, & roughline				
Crosscut & bundle				
Forward				
Load & transport				
Secondary processing				

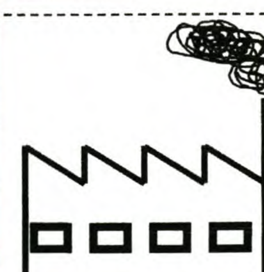
Appendix 1.3.5

CH_Sys E

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debranch, crosscut				
Debark				
Stacking				
Extraction				
Load & transport				
Secondary processing				

Appendix 1.3.6

CH_Sys F

Location / Activity	Stand	Forest rd	Main rd	Plant/rail
Fell, debranch, crosscut				
Debark & roughline	 			
Extract				
Load & transport				
Secondary processing				

Appendix 2: Case study decision tables/matrices

Decision table **Case study 1: Butterworth woodlot situation (including labour cost)**

Criteria	Min/max	Weighting		Alternatives			
				BW_Sys A	BW_Sys B	BW_Sys C	BW_Sys D
Economic		33%	100%	2.13	3.75	7.25	7.75
- Profit/ton$_{roundwood}$	max		13%	5.30	15.50	31.69	43.41
- Cost R/ton$_{roundwood}$	min		13%	80.95	70.75	54.56	42.84
- Net Present Value (R)	max		13%	3,579	833,922	2,008,066	2,754,962
- Payback period (yrs)	max		13%	3.24	0.65	0.18	0.17
- Capital investment (R)	min		13%	204,000	119,000	135,000	180,000
- Return on investment (%)	max		13%	31%	155%	558%	573%
- Breakeven daily throughput (t)	min		13%	60	36	16	13
- Fixed daily cost (R)	min		13%	814	799	616	658
Social		33%	100%	4.38	5.00	5.75	5.88
- Employment	max		13%	88	68	44	46
- Working environment	min		13%	4	3	2	1
- Human energy (renewable) MJ/t	min		13%	32	24.7	16	16.7
- Independency (capital imports) R/ton	min		13%	0.00	0.00	0.00	0.00
- Integration	max		13%	1	2	3	4
- Investment per working position	min		13%	4,636	3,500	3,068	3,913
- Ave annual disposable income	max		13%	1,645	1,645	1,645	1,645
- Total annual disposable income	max		13%	144,760	111,860	72,380	75,670
Environment		33%	100%	6.40	6.40	2.80	2.80
- Compaction	min		20%	L	L	M	M
- Organic matter loss	min		20%	L	L	M	M
- Erosion	min		20%	M	M	M	M
- % area impacted				50%	50%	25%	25%
- Slash management (Y/N)	min		20%	N	N	N	N
- Non-renewable energy MJ/t	min		20%	-	-	30.2	30.2
Total				4.300	5.049	5.266	5.474
Ranking				**4**	**3**	**2**	**1**

Appendix 2.1.

Decision table **Case study 1: Butterworth woodlot situation (excluding labour cost)**

Criteria	Min/max	Weighting		Alternatives			
				BW_Sys A	BW_Sys B	BW_Sys C	BW_Sys D
Economic		33%	100%	2.13	5.50	5.75	5.75
- Profit/ton$_{roundwood}$	max		13%	5.25	9.38	5.15	5.85
- Cost R/ton$_{roundwood}$	min		13%	15.29	11.16	15.39	14.69
- Net Present Value (R)	max		13%	3,579	833,922	2,008,066	2,754,962
- Payback period (yrs)	max		13%	3.24	0.65	0.18	0.17
- Capital investment (R)	min		13%	204,000	119,000	135,000	180,000
- Return on investment (%)	max		13%	31%	155%	558%	573%
- Breakeven daily throughput (t)	min		13%	60	36	16	13
- Fixed daily cost (R)	min		13%	814	799	616	658
Social		33%	100%	4.38	5.63	6.88	7.00
- Employment	max		13%	88	68	44	46
- Working environment	min		13%	4	3	2	1
- Human energy (renewable) MJ/t	min		13%	32	24.7	16	16.7
- Independency (capital imports) R/ton	min		13%	0.00	0.00	0.00	0.00
- Integration	max		13%	1	2	3	4
- Investment per working position	min		13%	4,636	3,500	3,068	3,913
- Ave annual disposable income	max		13%	-	-	-	-
- Total annual disposable income	max		13%	-	-	-	-
Environment		33%	100%	6.40	6.40	2.80	2.80
- Compaction	min		20%	L	L	M	M
- Organic matter loss	min		20%	L	L	M	M
- Erosion	min		20%	M	M	M	M
- % area impacted				50%	50%	25%	25%
- Slash management (Y/N)	min		20%	N	N	N	N
- Non-renewable energy MJ/t	min		20%	-	-	30.2	30.2
Total				4.300	5.841	5.141	5.183
Ranking				**4**	**1**	**3**	**2**

Appendix 2.2.

Decision table **Case study 2: Northern Cape integrated harvesting and processing situation**

Criteria	Min/max	Weighting		Alternatives				
				NC_Sys A	NC_Sys B	NC_Sys C	NC_Sys D	NC_Sys E
Economic		33%	100%	2.88	1.00	5.63	4.13	9.50
- Profit/ton$_{roundwood}$	max		13%	59.22	48.67	80.33	79.70	124.81
- Cost R/ton$_{roundwood}$	min		13%	166.44	176.99	145.33	149.05	111.09
- Net Present Value (R)	max		13%	1,469,897	558,003	2,433,948	2,020,641	4,422,224
- Payback period (yrs)	max		13%	1.35	2	93	1	53
- Capital investment (R)	min		13%	1,203,475	1,743,115	1,121,980	1,570,475	1,000,680
- Return on investment (%)	max		13%	74%	42%	107%	76%	187%
- Breakeven daily throughput (t)	min		13%	30	36	25	15	10
- Fixed daily cost (R)	min		13%	3,075	3,624	2,931	2,589	1,898
Social		33%	100%	5.13	4.50	6.13	5.13	6.63
- Employment	max		13%	85	84	81	52	62
- Working environment	min		13%	4	4	3	1	2
- Human energy (renewable) MJ/t	min		13%	31.6	31.6	30.2	16.4	23.3
- Independency (capital imports) R/ton	min		13%	4.01	5.81	3.74	12.56	2.00
- Integration	max		13%	2	3	3	4	1
- Investment per working position	min		13%	14,159	20,751	13,852	30,201	16,140
- Ave annual disposable income	max		13%	12,698	12,170	14,025	16,685	18,721
- Total annual disposable income	max		13%	1,079,303	1,022,265	1,136,048	867,600	1,160,720
Environment		33%	100%	4.40	4.40	2.80	1.00	2.60
- Compaction	min		20%	M	M	H	H	H
- Organic matter loss	min		20%	L	L	L	L	L
- Erosion	min		20%	L	L	L	L	L
- % area impacted				25%	25%	25%	25%	25%
- Slash management (Y/N)	min		20%	N	N	N	N	N
- Non-renewable energy MJ/t	min		20%	131.5	131.5	131.1	196.8	132.6
Total				4.133	3.300	4.850	3.416	6.241
Ranking				3	5	2	4	1

Appendix 2.3.

Decision table **Case study 3: Mpumalanga Commercial *Eucalyptus* harvesting situation**

Criteria	Min/max	Weighting		Alternatives					
				CH_Sys A	CH_Sys B	CH_Sys C	CH_Sys D	CH_Sys E	CH_Sys F
Economic		33%	100%	4.88	2.00	8.88	6.25	5.00	7.50
- Profit/ton$_{roundwood}$	max		13%	50.73	33.55	66.17	55.68	51.23	63.63
- Cost R/ton$_{roundwood}$	min		13%	99.27	116.45	83.83	94.32	98.77	86.37
- Net Present Value (R)	max		13%	5,859,086	3,232,338	8,206,847	5,215,470	5,473,039	7,796,694
- Payback period (yrs)	max		13%	0.59	1	0	1	1	0
- Capital investment (R)	min		13%	1,508,706	4,881,587	1,313,058	3,065,688	2,038,378	1,373,000
- Return on investment (%)	max		13%	168%	96%	252%	91%	126%	232%
- Breakeven daily throughput (t)	min		13%	83	112	55	65	85	62
- Fixed daily cost (R)	min		13%	8,309	8,853	5,214	5,708	7,521	6,163
Social		33%	100%	5.63	5.50	5.75	5.63	5.25	5.38
- Employment	max		13%	98	9	56	12	79	86
- Working environment	min		13%	6	1	3	2	5	4
- Human energy (renewable) MJ/t	min		13%	10.7	0.7	5.1	1.3	8.6	9.4
- Independency (capital imports) R/ton	min		13%	0.00	16.83	0.00	7.33	2.78	0.00
- Integration	max		13%	2	6	4	5	3	1
- Investment per working position	min		13%	15,395	542,399	27,937	255,474	25,802	15,965
- Ave annual disposable income	max		13%	10,250	34,793	11,270	27,855	11,073	9,990
- Total annual disposable income	max		13%	1,004,500	313,133	529,690	334,260	874,728	859,140
Environment		33%	100%	7.40	1.20	7.40	2.00	4.80	9.00
- Compaction	min		20%	M	VH	M	M	M	L
- Organic matter loss	min		20%	L	M	L	M	M	L
- Erosion	min		20%	L	M	L	M	M	L
- % area impacted				25%	25%	25%	25%	25%	25%
- Slash management (Y/N)	min		20%	N	Y	Y	Y	N	N
- Non-renewable energy MJ/t	min		20%	94.6	84.6	41.1	90.1	62.2	68.7
Total				5.961	2.897	7.334	4.620	5.012	7.284
Ranking				**3**	**6**	**1**	**5**	**4**	**2**

Appendix 2.4.

Appendix 3: Table of 232 simulated scenarios

Econ	Socl	Envi	Econ	Socl	Envi	Econ	Socl	Envi
100%	0%	0%	60%	25%	15%	40%	60%	0%
95%	5%	0%	60%	20%	20%	40%	55%	5%
95%	0%	5%	60%	15%	25%	40%	50%	10%
90%	10%	0%	60%	10%	30%	40%	45%	15%
90%	5%	5%	60%	5%	35%	40%	40%	20%
90%	0%	10%	60%	0%	40%	40%	35%	25%
85%	15%	0%	55%	45%	0%	40%	30%	30%
85%	10%	5%	55%	40%	5%	40%	25%	35%
85%	5%	10%	55%	35%	10%	40%	20%	40%
85%	0%	15%	55%	30%	15%	40%	15%	45%
80%	20%	0%	55%	25%	20%	40%	10%	50%
80%	15%	5%	55%	20%	25%	40%	5%	55%
80%	10%	10%	55%	15%	30%	40%	0%	60%
80%	5%	15%	55%	10%	35%	35%	65%	0%
80%	0%	20%	55%	5%	40%	35%	60%	5%
75%	25%	0%	55%	0%	45%	35%	55%	10%
75%	20%	5%	50%	50%	0%	35%	50%	15%
75%	15%	10%	50%	45%	5%	35%	45%	20%
75%	10%	15%	50%	40%	10%	35%	40%	25%
75%	5%	20%	50%	35%	15%	35%	35%	30%
75%	0%	25%	50%	30%	20%	35%	30%	35%
70%	30%	0%	50%	25%	25%	35%	25%	40%
70%	25%	5%	50%	20%	30%	35%	20%	45%
70%	20%	10%	50%	15%	35%	35%	15%	50%
70%	15%	15%	50%	10%	40%	35%	10%	55%
70%	10%	20%	50%	5%	45%	35%	5%	60%
70%	5%	25%	50%	0%	50%	35%	0%	65%
70%	0%	30%	45%	55%	0%	30%	70%	0%
65%	35%	0%	45%	50%	5%	30%	65%	5%
65%	30%	5%	45%	45%	10%	30%	60%	10%
65%	25%	10%	45%	40%	15%	30%	55%	15%
65%	20%	15%	45%	35%	20%	30%	50%	20%
65%	15%	20%	45%	30%	25%	30%	45%	25%
65%	10%	25%	45%	25%	30%	30%	40%	30%
65%	5%	30%	45%	20%	35%	30%	35%	35%
65%	0%	35%	45%	15%	40%	30%	30%	40%
60%	40%	0%	45%	10%	45%	30%	25%	45%
60%	35%	5%	45%	5%	50%	30%	20%	50%
60%	30%	10%	45%	0%	55%	30%	15%	55%

Econ = Economic; Soci = Social; Envi = Environment

Econ	Socl	Envi	Econ	Socl	Envi	Econ	Socl	Envi
30%	10%	60%	15%	70%	15%	5%	70%	25%
30%	5%	65%	15%	65%	20%	5%	65%	30%
30%	0%	70%	15%	60%	25%	5%	60%	35%
25%	75%	0%	15%	55%	30%	5%	55%	40%
25%	70%	5%	15%	50%	35%	5%	50%	45%
25%	65%	10%	15%	45%	40%	5%	45%	50%
25%	60%	15%	15%	40%	45%	5%	40%	55%
25%	55%	20%	15%	35%	50%	5%	35%	60%
25%	50%	25%	15%	30%	55%	5%	30%	65%
25%	45%	30%	15%	25%	60%	5%	25%	70%
25%	40%	35%	15%	20%	65%	5%	20%	75%
25%	35%	40%	15%	15%	70%	5%	15%	80%
25%	30%	45%	15%	10%	75%	5%	10%	85%
25%	25%	50%	15%	5%	80%	5%	5%	90%
25%	20%	55%	15%	0%	85%	5%	0%	95%
25%	15%	60%	10%	90%	0%	0%	100%	0%
25%	10%	65%	10%	85%	5%	0%	95%	5%
25%	5%	70%	10%	80%	10%	0%	90%	10%
25%	0%	75%	10%	75%	15%	0%	85%	15%
20%	80%	0%	10%	70%	20%	0%	80%	20%
20%	75%	5%	10%	65%	25%	0%	75%	25%
20%	70%	10%	10%	60%	30%	0%	70%	30%
20%	65%	15%	10%	55%	35%	0%	65%	35%
20%	60%	20%	10%	50%	40%	0%	60%	40%
20%	55%	25%	10%	45%	45%	0%	55%	45%
20%	50%	30%	10%	40%	50%	0%	50%	50%
20%	45%	35%	10%	35%	55%	0%	45%	55%
20%	40%	40%	10%	30%	60%	0%	40%	60%
20%	35%	45%	10%	25%	65%	0%	35%	65%
20%	30%	50%	10%	20%	70%	0%	30%	70%
20%	25%	55%	10%	15%	75%	0%	25%	75%
20%	20%	60%	10%	10%	80%	0%	20%	80%
20%	15%	65%	10%	5%	85%	0%	15%	85%
20%	10%	70%	10%	0%	90%	0%	10%	90%
20%	5%	75%	5%	95%	0%	0%	5%	95%
20%	0%	80%	5%	90%	5%	0%	0%	100%
15%	85%	0%	5%	85%	10%	33%	33%	33%
15%	80%	5%	5%	80%	15%			
15%	75%	10%	5%	75%	20%			

Econ = Economic; Soci = Social; Envi = Environment