A CRITICAL EVALUATION OF THE PRODUCTIVITY OF SOUTH AFRICAN SURFACE COAL MINES

by

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SUMMARY

During 1998, the general oversupply of coal continued with a 3,7 % decrease in world coal demand and an increase in production. This resulted in the continuation of the downward trend in world coal prices which started in 1996, with coal prices dropping by another 13,8 %. With no market improvements foreseeable in the immediate future, the South African surface coal mining industry will come under severe pressure to improve its labour and capital productivity levels and to reduce its operating costs in order to maintain its competitive edge.

The current state of the South African economy will also not make these improvements an easy task. With the labour sector putting more pressure on government to protect job opportunities in an industry that has long been known as one of the greatest providers of employment in South Africa, low economic growth rates and an ever-increasing trend towards globalisation, the surface coal mines will be hard-pressed to remain competitive and economically sustainable well into the 21st century.

As part of the Coaltech 2020 research initiative into the sustainable exploitation of the Witbank coalfield, this study focused on the different overburden stripping techniques used in South African surface coal mines and evaluated their efficiencies in terms of capital invested, labour productivity, production outputs, operational expenditures and other productivity measures.

These results were used to benchmark each individual South African surface coal mine with every other mine and with selected international mines in order to identify the critical performance areas that need to be improved upon in order to make South African surface coal mines more competitive in the international market environment.

On average, the South African surface coal mining industry recorded a lower overburden stripping productivity performance as determined from the analysis of a survey of mines in the Powder River Basin, United States of America, and in New South Wales and Queensland, Australia. The low productivity performance was mainly due to moderate labour and capital productivity performance levels.

Having identified the critical performance areas that need to be improved upon in order to make South African surface coal mines sustainable and competitive well into the 21st century, it is recommended that:

- Labour productivity be improved to be in line with the best international standards
- Capital productivity be improved to be in line with the best international standards
- The basis of this study be expanded to include all the surface mines in South Africa, thus enlarging the database and allowing cross-pollination of standards to improve productivity
- Newly planned surface mines be measured using the findings of this report to establish better mining investment guidelines for mine planners
- South African surface coal mines be re-evaluated on a yearly basis in order to set the standards for management to continuously improve their operations.

DIE KRITIESE EVALUERING VAN DIE SUID-AFRIKAANSE OOPGROEFSTEENKOOLMYNE SE PRODUKTIWITEIT

deur

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Graad: **M. Ing. (Mynbou)**

SAMEVATTING

Gedurende 1998 het die internationale oorvoorsiening van steenkool verhoog hoofsaaklik weens stygings in steenkoolproduksie, met ‘n gepaardgaande verlaging van 3,7 % in die steenkoolaanvraag. Dit het die afwaartse druk op steenkoolpryse, wat in 1996 ontstaan het, ‘n verdere hupstoot gegee en val steenkool pryse met ‘n verdere 13,8 %. Met geen onmiddelike verbetering in die internationale markstoestande binne die afsienbare toekoms nie, gaan die Suid-Afrikaanse oopgroefsteenkoolbedryf onder geweldige druk te staan kom om sy arbeids- en kapitaalproduktiwiteite te verbeter en terselfdertyd bedryfskostes te sny net om sy voortbestaan te kan verseker.

Die huidige toestand van die Suid-Afrikaanse ekonomie gaan dit geen maklike taak maak nie; met die arbeidsektor wat groter druk op die regering plaas vir die beskerming van arbeidsgeleenthede in ‘n bedryf wat vir jare bekendgestaan het as een van die grootste arbeidsektore in Suid-Afrika, laer ekonomiese groeikoerse, en ‘n kontinue globaliseringsdryf, gaan die Suid-Afrikaanse oopgroefsteenkoolbedryf dit moeilik vind om onder hierdie omstandighede kompeterend en suksesvol te bly.

As deel van die Coaltech 2020 navorsingsinisiatief, wat die volgehoue voortbestaan van die Witbanksteenkoolveld ondersoek, het hierdie verhandeling gefokus op die Suid-Afrikaanse oopgroefsteenkoolbedryf se prestasies ten opsigte van kapitaal geïnvesteer, arbeidsproduktiwiteit, produksie-uitset, bedryfskoste en ander produktiwiteitsmeetpunte en was dit dienooreenkomstig geëvalueer.

Die resultate van die studie is gebruik om die individuele Suid-Afrikaanse oopgroefsteenkoolmyne intern met mekaar, asook met ‘n paar internasionale myne, te

vergelyk, om die kritiese areas vir verbetering uit te lig, wat Suid-Afrikaanse myne instaat sal stel om hul meer kompeterend te maak op die internasionale arena.

Gemiddeld was die Suid-Afrikaanse myne se deklaagstropingsproduktiwiteit laer as die van geselekteerde myne in die Powder River Basin, Verenigde State van Amerika en New South Wales en Queensland in Australië. Die laer prestasie kan hoofsaaklik toegeskryf word aan die ondergemiddelde prestasies op arbeids- en kapitaalproduktiwiteit-vlakke.

Na die identifiseering van daardie kritiese meetpunte wat verbeter moet word om te verseker dat die Suid-Afrikaanse steenkoolbedryf kompeterend en mededingend gaan bly in die 21ste eeu, is die volgende aanbevelings gemaak:

- Arbeidsproduktiwiteit moet verhoog word om in lyn te kom met internasionale standaarde.
- Kapitaalproduktiwiteit moet verhoog word om in lyn te kom met internasionale standaarde.
- Die invloedsfeer van die studie moet vergroot word om alle Suid-Afrikaanse oopgroefmyne in te sluit, om sodoende die kruisbestuiwing van standaarde te bewerkstellig en tot verbeterde prestasie aanleiding te gee.
- Die bevindinge van die verslag moet met nuutbeplande oopgroefmyne vergelyk word om beter kapitaalinvestingsriglyne vir mynboubeplanners daar te stel.
- Die Suid-Afrikaanse oopgroefsteenkoolbedryf moet op 'n jaarlikse basis herevalueer word met die doel om bestuur by te staan met die standaarde benodig vir aaneenlopende verbeterings.

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Abbreviations

CAPEX	Capital expenditure
ERM	Exposure Rate Measurements
GPS	Global Positioning System
IT	Information Technology
KPI	Key Performance Indicators
NSW	New South Wales (Australia)
OEM	Original equipment suppliers
OPEX	Operating expenditure
PFP	Partial Factor Productivity
PRB	Powder River Basin
QLD	Queensland (Australia)
ROM	Run-of-mine
TPF	Total Productivity Factor
USA	United States of America

Symbols

h	hour
km	kilometre
m^3	cubic metre
Rm	rand million
t	ton

Nomenclature/Definitions

BCM: Bank cubic metre

Blast gain: Material moved by chemical energy and never touched by any other equipment. It must be deswelled or expressed as a percentage.

Blasting: The activity of harnessing chemical energy in the form of explosives to fracture or break the in situ rock into a manageable size fragmentation

Bucket factor: Ratio between the available bucket capacity and the amount of the available bucket capacity that is filled with material during one pass, expressed as a percentage

Bush clearing: The activity of removing all groundcover vegetation prior to mining, including the removal of tree stumps and roots

Coal exposure rate: Linear advance over the cut width of the pit, measured in square metres

Coal removal: The activity of removing the coal in order to expose the parting or interburden in multi-seam operations

Digging availability: Operational and mechanical availability of the dragline to dig

Digging index: Effective utilisation of each cubic metre of bucket capacity, measured over every passing hour

Doze-over gain: Blasted material that is dozed to its final resting position (expressed as BCM)

Drilling: The activity of creating a shot hole by means of rotary and/or percussion drilling equipment

Hards: Material that requires chemical energy to break in order for it to be handled by standard mining equipment.

Haul distances: The distance that haul trucks travel from the shovel loading point to the dump site

Highwall control: The activity of controlling the highwall stability by means of chemical or mechanical energy

LCM: Loose cubic metre

Parting removal: The activity of removing the parting or interburden in order to expose the underlying coal seam in multi-seam operations

Powder factor: Mass of explosives used per BCM rock blasted

Pre-stripping: The activity of removing blasted material that cannot be accommodated by the primary stripping tool

Primary stripping:	The activity of removing blasted material in order to expose coal
Rehabilitation:	The activity of levelling and/or profiling before revegetating the spoil material
Rehandle:	Material that is handled by the same equipment for a second time
Softs:	Material that can be freely dug or can be removed by mechanical means without the use of chemical energy
Subsoil removal:	The activity of removing all soft material other than topsoil
Swell factor:	Percentage increase in volume when in situ rock is subjected to mechanical or chemical energy
TCM:	Total cubic metres for equipment only (LCM + rehandle)
Topsoil stripping:	The activity of removing topsoil as per the definition of topsoil contained in the Minerals Act, 1991
Total BCMs:	Sum of coal and waste BCMs mined
Truck spotting time:	Time (in seconds) taken from when a haul truck arrives at the loading shovel until it has positioned itself at the shovel ready for loading

1. Introduction

1.1 Background

During 1998, the current international oversupply of coal continued with a 3,7% decrease in world coal demand and an increase in production in the USA (5,9%), Australia (1,2%), South Africa (2,8%) and Indonesia (8,3%) (Minerals Bureau, 1999). This resulted in the continuation of the downward trend in world coal prices which started in 1996, with coal prices dropping by another US$5,8 (13,8%) (Minerals Bureau, 1999). With no market improvements foreseeable in the immediate future, the South African surface coal mining industry will come under severe pressure to improve its labour and capital productivity levels and its operating costs in order to maintain its competitive edge.

The current state of the South African economy will also not make these improvements an easy task. With the labour sector putting more pressure on government to protect job opportunities in an industry that has long been known as one of the greatest providers of employment in South Africa, low economic growth rates and an ever-increasing trend towards globalisation (Runge, 1998), the surface coal mines will be hard-pressed to remain competitive and economically sustainable (O'Conye & Thomas, 1993) well into the 21st century. As part of the Coaltech 2020 research initiative into the sustainable exploitation of the Witbank coalfield, this study focused on the different overburden stripping techniques used in South African surface coal mines and evaluated their efficiencies in terms of capital invested, labour productivity, production outputs, operational expenditures and other productivity measures.

1.2 Geology

South Africa's coal deposits occur in three geologically separate, though closely related, environments within the Karoo Sequence. One is the Volksrust formation and the Lower Beaufort Group with coalfields such as:

- Springbok Flats
- Waterberg
- Limpopo
- Pafuri
- Soutpansberg

Figure 1.1: South African coalfields

The second, the Vryheid Formation, is by far the most important from a coal-bearing point of view as it underlies traditional coal mining areas such as:

- Witbank
- Highveld
- Ermelo
- KwaZulu-Natal coalfields.

The third is the Molteno Formation, which contains the Molteno Indwe coalfield. The latter is of minor economic importance due to its thin seams and high ash content (Minerals Bureau, 1999).

South Africa has 18 principal coalfields spread over an area of 700 km from north to south and 500 km from west to east (Minerals Bureau, 1998), as illustrated in Figure 1.1 (Pinheiro, 1999). Coal mining activities take place primarily within the province of Mpumalanga, which produces 83,8% of the country's total output. Approximately 44% of South Africa's coal is mined underground by bord-and-pillar methods which are almost entirely mechanised, 0,9% by longwalling, 10,6% by pillar recovery (stooping) and 44,5% by opencast mining methods. (Minerals Bureau, 1999).

The general occurrence of the coal seams in the Witbank coalfield is of a shallow nature and favourable stripping ratios can be found over large areas. Surface mining methods are therefore an ideal option for most of the available mineable reserves. For this reason there are a large number of opencast mining operations in this region, ranging in size from relatively small contractor-based operations to large multi-dragline mines.

Because of its significance, surface mining was one the of six technology areas identified under the Coaltech 2020 collaborative research programme that required specific research to be undertaken, hence this study.

1.3 Problem statement and objectives

The cost-effectiveness of removing overburden from the underlying coal seams ("overburden stripping") holds the key to the success of any surface mining operation. Overburden stripping techniques differ from one mining operation to another, depending on the size of the operation, the prevailing geological conditions and the type of mining equipment selected.

The primary objectives of this study were to identify the various mining techniques used on South African coal mines and to evaluate their efficiencies in terms of capital invested, labour productivities, production outputs, operational efficiencies and/or any other measurable items that could be identified. These results were used to benchmark individual South African operations with each other and with selected overseas mines in order to identify the critical performance areas that need to be improved upon in order to make South African operations more competitive in the international market environment.

1.4 Outline of the study

Section 1 provides the background, problem statement and the objectives of this thesis. The research methodology is outlined in Section 2 which also discusses the benchmarking process that formed the basis for the data collection and evaluation.

A brief description of the data collection process is given in Section 3. The data analysis and the results are discussed in Section 4 and Section 5 contains the conclusions. Possible recommendations for improving the productivity levels of the South African surface coal mining industry are presented in Section 6.

2. Research methodology

2.1 Introduction

This study formed part of the Coaltech 2020 research initiative into the sustainable exploitation of the Witbank coalfield. Coaltech 2020's objective is to develop technology and apply research findings that will enable the South African coal industry to remain competitive and sustainable well into the 21st century.

After the Coaltech Management Committee had approved Task 3.14.1, *Evaluation of stripping techniques*, in March 1999, the study on which this thesis is based started in April 1999 with an international literature survey. In May 1999 an industry workshop was held during which the scope, objectives, rules and guidelines for the project were evaluated and approved. The workshop was also used to identify the various stripping activities with associated mining methods. This workshop ensured that the scope and direction of the study would address the real issues with which the industry is faced.

The information required on actual stripping operations was very sensitive and not readily available in the public domain. It was decided to follow the internationally accepted benchmarking protocol for information gathering. On the basis of the benchmarking guidelines and code of conduct, ground rules were established for constructing the benchmarking checklist and partners. Coaltech's confidentiality agreement was signed, agreed to and made data collection from the mines possible.

Once approval of the evaluation (benchmarking) checklist and the benchmarking partners had been obtained and the confidentiality agreement had been signed, the South African survey commenced. This was followed by an international survey.

The benchmarking checklist was sent to each surface coal mine two weeks before the mine visit. The completed benchmarking checklist and any additional productivity-related information were collected during the site visit. The local site visits were followed by international site visits to the USA and Australia.

The data collected were analysed and evaluated to determine South Africa's current stripping practices and performance levels. The international survey was used to establish the best-practice scenario against which the South African surface coal mining industry was evaluated. By evaluating the mining methods, labour practices and equipment utilisation in this way, it was possible to draw conclusions and make recommendations from the analyses of the available data. Future stripping trends and techniques were also determined.

2.1.1 Literature survey

The aim of the literature survey was to:

- Identify the stripping activities and mining methods that would form the basic structure of the checklist
- Identify mining supply companies that would be able to provide information relevant to the evaluation and identification of available methods and international benchmark sites
- Determine future mining methods and equipment trends.

2.2 The benchmarking process

To evaluate the stripping activities, a comprehensive analysis of the mines' stripping performances was required. For this purpose an extensive amount of information on actual stripping operations was required, which was very sensitive and not readily available in the public domain.

Benchmarking was chosen as the process that would be used to collect information for the study. In essence, the process involves performing a comparative study of specific processes in an industry that are considered to hold some potential for improvement. In *The Benchmarking Book* (Spendolini, 1992), Michael Spendolini summarises this practice as follows:

> *"Benchmarking is a continuous, systematic process for evaluating the products, services and work processes of organisations that are recognised as representing best practices for the purpose of organisational improvement".*

An internal benchmarking approach was first used to collect and compare mine performance data on the South African surface coal mining industry in order to establish the '*South African scenario'*. The competitive benchmarking approach was then used to compare the South African scenario against international competition.

Two benchmarking activities were carried out on strategic and operational levels. On the strategic level, the level of investment, level of automation and strong functional areas were analysed and compared. On the operational level, the mining operations, cost performances, production processes and service levels were analysed and compared.

The benchmarking process followed can thus best be described as addressing various sub-sets of strip mining activities: subsoil removal, pre-stripping, primary stripping, parting and coal removal. Various productivity measures were used to evaluate these activities.

These measures do not focus only on obtaining comparative performance statistics. In fact, according to Dr Robert Camp (BENSA, 1999), the pioneer and international benchmarking *guru*, finding benchmarks is only about 10 to 15% of the effort involved in a benchmarking study; 85 to 90 % of the effort must go into finding and studying practices that will deliver exceptional performance. Once the differences between these exceptional practices and processes and those of a mine's own organisation have been established, the mine can adapt these practices creatively and implement them.

Benchmarking identified the managerial focus areas and opportunities for improving the productivity and ultimately the economic sustainability of the South African surface coal mining industry. It also fostered organisational learning, broadened the organisations' experience base, assisted in employee development and stimulated teamwork.

According to Wiebmer (1999) the winning mines will be ones which manage their operations so that they stay in the bottom third of the lowest quarter of the cost curve compared with their competitors. This desire to measure where mines stand on the cost curve is driving an intense amount of benchmarking activity in the industry. This has led to some fairly consistent world-class standards by which operations can measure themselves.

2.2.1 What to benchmark

The study identified, compared and evaluated the best stripping operations available. The internationally accepted method for measuring productivity was used as the main measuring or evaluation criterion.

Productivity is a measure of the physical output produced through the use of a given quantity of inputs. Mines use a range of inputs including labour, machines, fuel, materials and services. If a mine is not using its inputs as efficiently as possible, then there is scope to lower costs and increase profitability through productivity improvements. This may come about through the use of better-quality inputs, including a better-trained workforce, the adoption of technological advances, the removal of restrictive work practices and other forms of waste, and better management through a more efficient organisational and institutional structure.

2.2.1.1 Productivity measures

In practice, productivity is measured by expressing output as a ratio of inputs used. There are two types of productivity measure: the total productivity factor (TPF) and the partial factor productivity (PFP) (Tasman, 1997). TPF measures the total output relative to all the inputs used. Output can be increased by using more inputs, making better use of the current level of inputs, through technological improvements and by exploiting economies of scale. The TPF index measures the impact of all the factors affecting growth in output other than changes in input levels. The PFP measures one or more outputs relative to one particular input (for example, labour productivity is the ratio of output to labour input).

Partial productivity measures are widely used as they are simple to calculate. It is now widely accepted that TPF is a robust measure of the overall performance of an organisation.

2.2.1.2 Expected deliverables

From the industry workshop and literature survey, an initial expected TPF and various PFP measures were established.

The checklist constructed aimed at capturing the information required to report on the expected outputs or deliverables of this study.

The initial indication was that the output data would consist of the following partial productivity factors:

- Variations in productivity within mine categories
- Variations in stripping costs between mines
- Variations in capital costs between mines
- Efficiency of the labour force
- Efficiency of equipment utilisation
- Efficiency of each stripping activity
- Efficiency of stripping equipment or associated mining methods.

2.2.2 Analyse the process

Before the actual benchmarking process started, ground rules were established and the currently available international performance levels were determined.

2.2.3 Set ground rules

Each mine is known to have its own units of measure. Standardised units of measure were created as a means of measuring the different strip-mining operations, both local and international. In order to determine what to measure, performance measures were created. Using the known performance measures, the units of measure were finalised and the evaluation checklist was constructed. (Appendix 2 details the units of measure and assumptions used for this study.)

This research did not examine the revenue-generating capabilities of a surface coal mining operation but rather looked at the effectiveness of removing the overburden in order to expose the underlying coal seams. The main process is the removal of overburden and coal material by means of surface mining methods, or stripping activities as they are more commonly known. The data obtained for the different stripping methods were evaluated and compared in terms of 'exposure rate measurements' (ERM) and TPF. The ERM seems to be a unique stripping evaluation method.

Although the Coaltech 2020 Management Team developed its own code of conduct and confidentiality clause, this study also operated according to Benchmarking South Africa's Code of Conduct (see Appendix 3). This provided a structure and an international standard by which the benchmarking study was conducted.

2.2.4 Current performance levels

This is the first collaborative evaluation study of overburden removal in South Africa. In fact, this is the first study that the author is aware of for benchmarking strip mining activities. It was not surprising then that very little literature was found that could contribute to this study. The available literature reports on the evaluation of some primary stripping methods, but nowhere was the total overburden stripping activity evaluated.

Almost all the productivity and efficiency results published discuss the performance of the whole mining operation in terms of run-of-mine (ROM) coal or saleable coal tons. This reporting is in line with the core business of the coal mines. Measuring the efficiency of overburden removal was not the main purpose of publishing the results and therefore each mine generally used its own measuring or reporting system.

In October 1997 the Industry Commission of Australia contracted Tasman Asia Pacific to undertake a benchmarking study of the productivity performance of Australia's black coal mines (Industry Commission (Australia), 1998). Tasman benchmarked Australia's black coal industry against best-practice world coal mines and best-practice Australian metalliferous mines. They benchmarked 44 separate mining operations in 1996, and 22 truck-and-shovel and 13 dragline operations in the first nine months of 1997 (Tasman, 1997). See Section 3 for more detail.

2.3 Benchmarking partners

Most of the South African surface coal mines were already part of the study through the Coaltech 2020 initiative.

The international surface coal mines were identified according to benchmarking criteria, i.e. throughput, unit cost, quality and relative productivity performance.

The Coaltech 2020 Management Team, consisting of members from Anglo Coal, Ingwe, Eskom, Iscor and Duiker, provided information on their own South African mining operations. The industry project members and the manufacturers of surface mining equipment assisted with information-gathering on mines in the USA, Asia, Europe and Australia.

2.3.1 South African survey

From the 12 possible South African surface mines identified, a total of nine data sets were received. Checklists were received for evaluation from two truck-and-shovel operations, and eight strip mines submitted their dragline and stripping information.

Table 2.3.1 outlines the number of mines per mining house that participated in the benchmarking exercise and the number of mines not surveyed.

Table 2.3.1

Potential participating South African mining operations

Mining house	Surface mines per mining house planned to be surveyed			Data not received
	Truck and shovel	Dragline	Total	
Ingwe	0	4	4	2
Anglo Coal	0	4	4	0
Iscor	2	0	2	1
Duiker	1	1	2	0
Total	**3**	**9**	**12**	**3**

2.3.2 International survey

Table 2.3.2 outlines the mines per country identified and surveyed during the international survey. The USA mines were chosen for their good overall productivity standards, the New South Wales mines for their good truck-and-shovel operations and the Queensland mines for their outstanding dragline performances.

Table 2.3.2

Participating international surface coal mines

Country	Truck and shovel	Dragline	Total	Usable information
PRB, USA[1]	1	2	3	2
NSW, Aus[2]	3	0	3	2
QLD, Aus[3]	0	3	3	2
Total	**4**	**5**	**9**	**6**

1. PRB – Powder River Basin, United States of America
2. NSW – New South Wales, Australia
3. QLD – Queensland, Australia

The mining information of one NSW and one Queensland mine could not be used for the evaluation process. The data and relative productivity performances of these mines were insignificant and could not be used as a best practice.

The mines used as benchmarks are internationally known for their high mining productivity performances (Australian Coal, 1999). One mine surveyed in NSW was judged as the most productive mine in Australia during 1998 (Tasman, 1998).

3. Data collection

3.1 Introduction

In this part of the project, the available data for South Africa and the world were collected and evaluated to:

- Identify the stripping class activities and mining methods that formed the basic structure of the checklist
- Identify mining supply companies that could provide information on the evaluation and identification of available methods and international benchmark sites
- Determine future mining methods and equipment trends.

3.2 Previous research work

In 1998 the Industry Commission of Australia expressed the opinion that the Australia coal producers must use their workforces and capital more efficiently than in the past (Tasman, 1998). In April 1998 the Commission released Australia's first draft report on the benchmarking study, undertaken by Tasman Asia Pacific, into the productivity performance of Australia's black coal mines. As stated before in Sub-section 2.2.4, Tasman benchmarked Australia's black coal industry against best-practice world coal mines and best-practice Australian metalliferous mines. In 1996, 44 mining operations were benchmarked and in 1997, 22 truck-and-shovel and 13 dragline operations.

The coal mines surveyed by Tasman (Tasman, 1997) in the United States included a number of mines that had been nominated by industry experts as best-practice operations, as well as mines that were affiliates of Australian mining companies. Responses were received from 20 Australian coal mines, eight United States coal mines and four Australian metalliferous mines.

The coal production from the responding Australian coal mines is equal to nearly 40% of Australia's raw coal production.

Tasman's benchmarking is based on TPF measures (which measure total output relative to all inputs used) and supported by partial productivity measures to identify the drivers of productivity differences between mines. This is in contrast to the coal exposure rate per time unit used in this benchmarking study. As in Tasman's study, this benchmarking analysis focused on the main components of the mining process. However, it does not cover all mine inputs nor does it cover development work (e.g. setting up mine offices, developing access roads). The items excluded are washeries and mine overheads, basically all the maintenance activities and some materials used in production.

3.3 Truck-and-shovel benchmark

Truck-and-shovel mines remove both overburden and coal primarily by means of trucks and shovels. Tasman's benchmarking results indicated that in 1996 to 1997, the total productivity factors of the participating NSW and Queensland truck-and-shovel coal operations were, on average, well below best practice (Figure 3.3a).

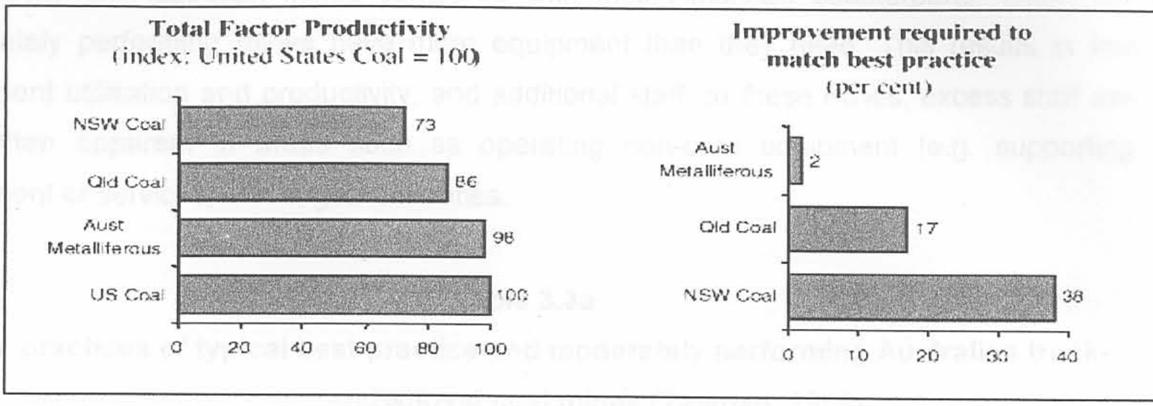

Figure 3.3a: Total factor productivity of truck-and-shovel operations, (Tasman, 1998).

To match the best-practice productivity levels of United States coal mines, NSW and Queensland coal mines needed to increase their productivity by 38 and 17% respectively. Increases in average productivity of 35 and 14% respectively were required for these mines to match the average productivity of the Australian metalliferous mines covered by the survey. As a whole, the Australian coal mines in the sample needed to increase productivity by about 30% to match the performance of the United States coal mines and Australian metalliferous mines.

Geological conditions, such as thinner coal seams and a greater number of them in the NSW mine category, were just one of a number of factors influencing the productivity outcomes. The main factors adversely affecting productivity were over-staffing, over-capitalisation of equipment and poor work practices. These were reflected in relatively low labour and truck productivity in the NSW and Queensland coal mines. Labour and truck productivity both needed to increase by around 70% in the NSW coal mines to match the performance of the United States coal mines. Queensland coal mines needed a corresponding 40% increase on average.

Tables 3.3a and 3.3b outline the key characteristics of the 'frontier' and moderately performing Australian truck-and-shovel operations. These characteristics indicate ways for the poorer-performing mines to improve their efficiency and unit operating costs.

Table 3.3a indicates that over-staffing and over-capitalisation are common causes of lower productivity on Australian mines compared with their American counterparts. Often the moderately performing mines have more equipment than they need. This results in low equipment utilisation and productivity, and additional staff. In these mines, excess staff are also often apparent in areas such as operating non-core equipment (e.g. supporting equipment or services) and in general duties.

Table 3.3a

Work practices of typical best-practice and moderately performing Australian truck-and-shovel coal mines (Tasman, 1998).

	Best practice operation	Moderately performing mine
Total productivity	100	60
Resource levels		
Staffing levels: ratio of labour hours worked to equipment hours worked	1,5	2,1
Work time in shifts: time excludes leaving and joining shifts, meal and other breaks (%)	92	85
Utilisation of truck fleet: hours operated as a percentage of total available hours	45	40
Utilisation of major digging equipment: hours operated as a percentage of total available hours	50	40
Work practices		
Hot-seat changes	Yes	Yes
Meal breaks in the field	Yes	No
Staggered meal breaks	Yes	No
Operators move between equipment within shifts	Yes	Rarely
Haulage equipment fuelled during breaks	Yes	No
Clean-up equipment does not impede production	Yes	No

Work practices are more efficient in the high-performing mines in the sample, resulting in a higher or improved productivity. In efficient mines, staff use effective hot-seat changes, take meal breaks on machines, stagger meal breaks to ensure that core equipment continues to operate, move between units of equipment within shifts where necessary, fuel haulage equipment during breaks and ensure that clean-up equipment does not impede production.

Generally, the poorer-performing mines in the sample implement only a few of these good practices.

Table 3.3b

Key attributes of typical best-practice and moderately performing Australian truck-and-shovel coal mines (Tasman, 1998).

	Best-practice mine	Moderately performing mine
Efficient truck-loading practices: incidence of double-sided or other efficient truck-loading method (%)	>50	0
Stopping time of trucks under shovels (seconds)	35	65
Truck loads per shovel per eight-hour shift	185	135
Industrial disputes: days lost per thousand hours worked	0	20
Safety: lost time injuries per million man-hours	20	50

Highly productive truck-and-shovel operations often use shovel techniques such as double-sided loading of trucks. Double-sided loading imposes an extra dimension of care to maintain safety standards. It allows substantially more excavation time per shift and improves truck productivity. For example, based on this sample, stopping times for trucks at shovels are often around 35 seconds with double-sided loading, compared with 65 seconds with single-sided loading.

The better-performing mines invariably had fewer industrial disputes and also seemed to have a better safety record.

3.3.1 International trends for trucks and shovels

The competitive nature of opencast mining forces mine operators to adhere to one simple bottom-line mentality: moving the largest amount of material for the least amount of money. The growth in the capacity of trucks and shovels during the last 15 years has enabled mines to achieve these goals.

The trend for the last 15 years in the surface mining business has been simply towards larger and larger. Wiseda (now owned by Liebherr Mining Equipment) was the first company to introduce a 220-ton haul truck during 1984 at the Black Thunder mine. Dresser (now Komatsu Mining Systems) followed suit shortly thereafter, and Caterpillar (CAT) introduced its 220-ton hauler in 1991 (Fisher, 1999).

The capacity of loading tools has caught up with and surpassed that of the 220-ton haulers. The P&H 4100 is capable of loading a 290-ton truck in four passes. The new P&H 4100XPB will be able to load a 330-ton haul truck in three to four passes (Caterpillar, 1999).

Komatsu Mining Systems (KMS) launched the 290-ton 930E haul truck at MINExpo '96 in Las Vegas, Nevada, USA, and production went into high gear during 1997 and 1998. Although KMS have sold only three 930Es in the coal industry, they have sold almost 100 in the hard rock mining industry, thus setting the standard for the development of the new ultra-heavy off-highway trucks (Fisher, 1999).

Liebherr Mining Equipment Co. (Liebherr) introduced the 330-ton T282 during October 1998. "This is the first truck in this size range and is a two-axle, six-tire configuration, using proven structural and mechanical concepts," said Bill Lewis, Liebherr's Vice President Engineering (Fisher, 1999).

CAT recently announced its intention to build the 360-ton CAT 797 haul truck. With a more conservative bent, Pete Holman, CAT's Sales Manager - Corporate Mining Group, said to Fisher (Fisher, 1999), "CAT takes a total systems approach, and we do what makes the most sense to create a more cost-effective mining system."

For a long time the hard rock mining industry led the way with large truck-and-shovel fleets and was followed by the oil sand operations in North America (Caterpillar Inc, 1999; *et al*). It is only recently that the USA coalfields have started upgrading their truck-and-shovel fleets. The Australian and Indonesian coal mines are also preparing to follow the USA trend and will soon start upgrading to large equipment. The Douglas pillar project introduced Caterpillar's proven 793s with Demag's 655 face shovel into the South African coal industry in 1999. The motivation for larger trucks and shovels was to take advantage of the economies of scale offered by the new larger equipment, as can be seen from Figure 3.3.1a, but it was clear that South Africa was not following this trend vigorously (Komatso Mining Systems, 1999 & Gove *et al.*, 1994).

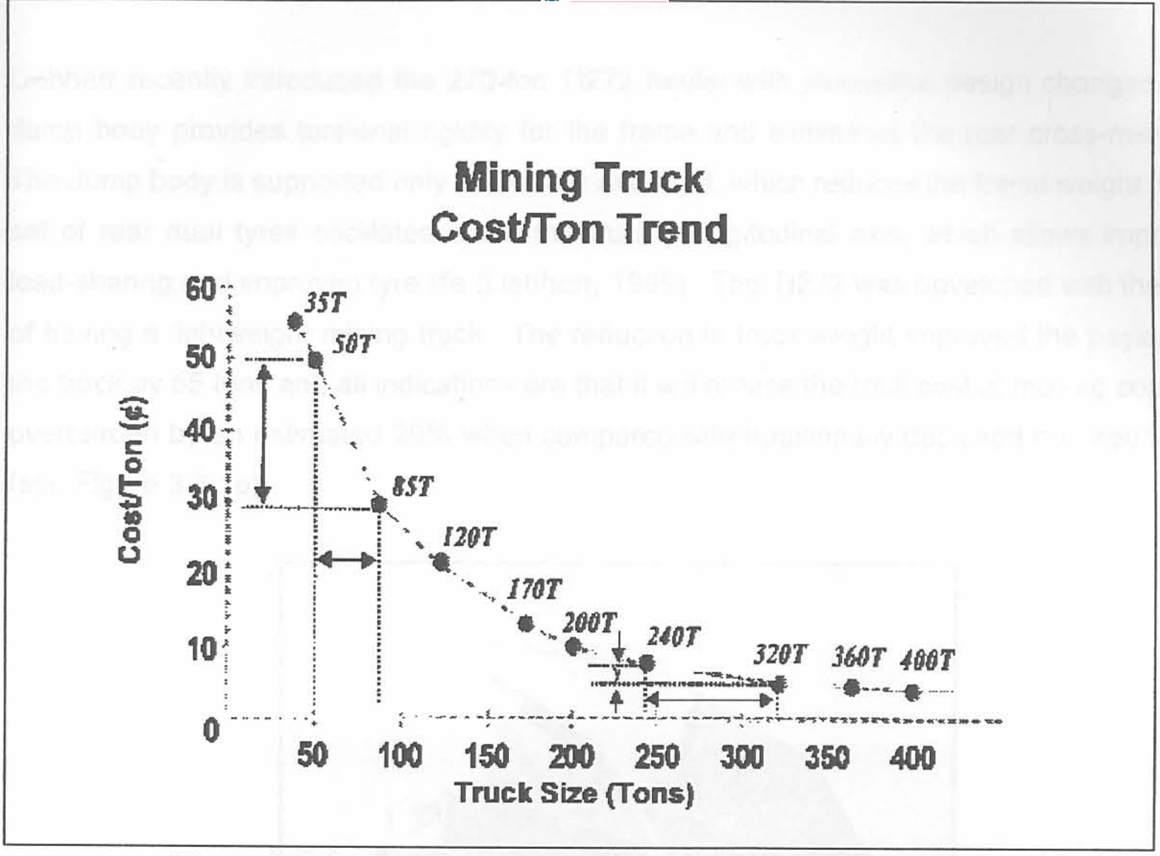

Figure 3.3.1a: Truck size cost (Komatso Mining Systems, 1999)

According to Fisher (1999), truck selection is site-specific. Mines that have large quantities of material to move can use the larger trucks better and more efficiently. The projected life-time of a project, however, is critical to justifying the investment. Site infrastructure, the size of the loading equipment, the size of the maintenance facilities and the haulage roads also play an important role when considering upgrading to larger trucks and shovels. The 300-ton haulers will be more than 20% wider than the 220-ton trucks. The weight and braking of these heavy haulers have an impact as deep as 5 m below the surface and therefore the dynamics of haulage road design must change accordingly.

The rate of increase in truck and shovel sizes cannot continue forever as tyre and horsepower limitations are already slowing down the next generation of trucks and shovels (Lightfoot, 1999 & Ellis, 1994). The increase in research and development, building and transportation costs associated with the larger trucks and shovels will put pressure on the economic viability of this larger equipment (Holman, 1994). Figure 3.3.1a gives an indication of one original equipment manufacturer's (OEM) estimates of the economies of scale associated with larger haul trucks.

Liebherr recently introduced the 270-ton TI272 hauler with innovative design changes. The dump body provides torsional rigidity for the frame and eliminates the rear cross-member. The dump body is supported only at the rear and front, which reduces the frame weight. Each set of rear dual tyres oscillates about the truck's longitudinal axis, which allows improved load-sharing and improved tyre life (Liebherr, 1999). The TI272 was developed with the idea of having a lightweight mining truck. The reduction in truck weight improved the payload of the truck by 55 tons and all indications are that it will reduce the total cost of moving coal and overburden by an estimated 20% when compared with traditionally designed haulage trucks (see Figure 3.3.1b).

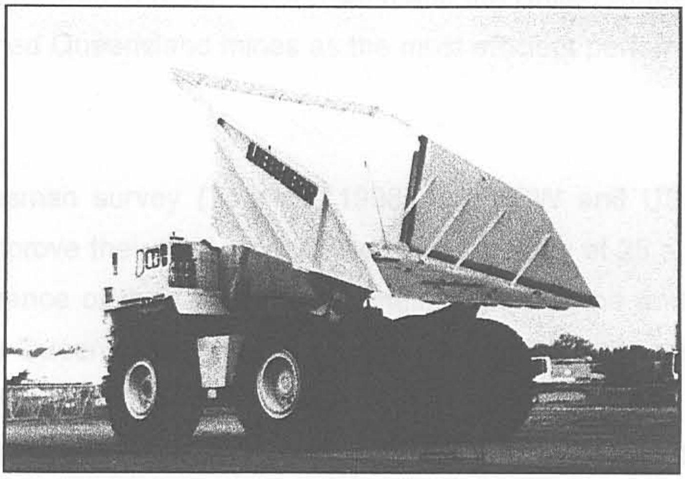

Figure 3.3.1b: Liebherr's TI 272 (Liebherr, 1999)

During the past ten years there has been a significant improvement in truck design. The life of major components such as engines and drive trains has increased from 7 000 hours to 12 000 hours. Computer-assisted diagnostics are standard on all large trucks. One microprocessor can monitor more than 90 vital factors controlling the truck's operation. These systems allow continuous statistical data recording, which improves truck availability and lowers operating cost. Most OEMs agree that, with appropriate rebuilds, a mine can get up to 100 000 hours out of a haul truck (or 12 to 15 years). Availability is also improving. Availabilities of 7 000 to 8 000 operating hours per year are routinely achieved whereas ten years ago, 4 000 hours was accepted (Ellis, 1994). These improvements in truck design and diagnostics are expected to continue in future and will further reduce the cost of moving material (Caterpillar, 1999; Lightfoot, 1999).

The trucks of the future will depend heavily on innovative designs, such as Liebherr's TI272, and to what extent Global Positioning Systems (GPS) (Schaidle, 1994) and Information

Technology (IT) will revolutionise the surface mining industry, (Kral, 1997). There is already talk of autonomous trucks and the continuous growth in environmental pressures is reshaping the business environment, but for the time being preventative maintenance, improved availability and the drive for higher productivity will remain the mainstays of coal mining operations (Caterpillar, 1999).

3.4 Dragline benchmarks

Tasman's estimates (Tasman, 1998) of dragline productivity focused on overburden removal in 13 strip coal mines located in NSW, Queensland and the United States. The results of this benchmarking identified Queensland mines as the most efficient performers in 1996 to 1997 (Figure 3.4).

According to the Tasman survey (Tasman, 1998), the NSW and USA producers in the sample needed to improve their total productivity by an average of 25 and 19% respectively to equal the performance of the Queensland mines. High dragline and labour productivity helped the sample of Queensland mines to achieve this best-practice result. Several factors contributed to the observed differences in productivity, including:

- high dragline-capacity utilisation, coupled with the operational efficiency of draglines in Queensland mines
- low dragline operational productivity in NSW mines
- low blasting requirements in Queensland mines due to the geology of the overburden.

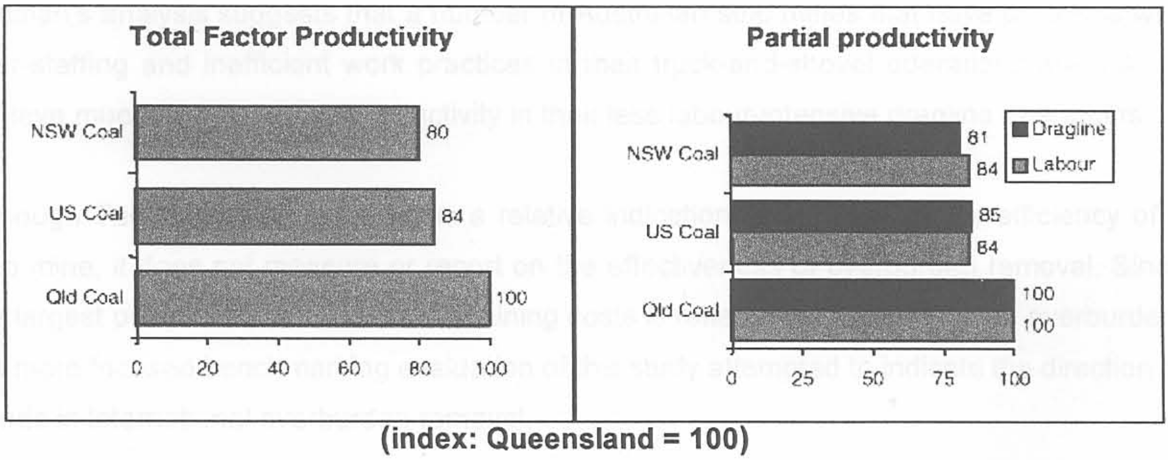

Figure 3.4: Total factor productivity and key partial productivity of dragline operations (Tasman, 1998).

Table 3.4 shows that the Queensland mine category achieved the highest operational efficiency with 47 full dragline bucket equivalents per hour, compared with 44 in the United States mines category and only 37 for mines included in the NSW category. The mines in the NSW category were not making effective use of their relatively large draglines. The main reason could be related to the average number of swings per hour. It appears that a number of these NSW mines achieved high dragline bucket factors.

Based on Tasman's sample, labour productivity in Queensland dragline operations exceeded that in NSW and the United States mines by about 20%. Much of this difference stemmed from the greater operational efficiency of the Queensland draglines and fewer staff being required for drilling and blasting activities.

Table 3.4

Productivity performance of dragline operations (Tasman, 1998)

	Dragline output per hour (BCM)	Bucket factor (%)	Swings per hour (number)	Bucket capacity (LCM)	Equivalent dragline bucketfuls (number/h)
Queensland coal	1 901	92	51	41	47
United States coal	2 074	88	50	47	44
NSW coal	1 910	95	39	51	37

Tasman's analysis suggests that a number of Australian strip mines that have problems with over-staffing and inefficient work practices in their truck-and-shovel operations are able to achieve much higher relative productivity in their less labour-intensive dragline operations.

Although Tasman's TPF factor gives a relative indication of the productivity efficiency of a strip mine, it does not measure or report on the effectiveness of overburden removal. Since the largest portion of a surface mine's mining costs is reflected in the removal of overburden, the more focused benchmarking evaluation of this study attempted to indicate the direction or trends in international overburden removal.

3.4.1 International trends

Large walking draglines were found to be the primary method for moving overburden in the South African coal strip mines (SAIMM, 1987). Despite the dragline's cost advantages and the growing overburden-removal requirements at most mines, the USA coal industry's demand for new walking draglines diminished substantially in the 1990s. In fact, the last new machine commissioned was the Bucyrus International (B-I) 2570WS at Thunder Basin Coal's Black Thunder Mine in 1993 (Gilewicz, 1999). The last dragline commissioned in South Africa was a Marion 8200S at Sasol's Syferfontein Mine in June 1997.

Since the start-up of the B-I 2570 at Black Thunder, at least six used machines have been decommissioned, relocated and put into service; in mid-1999, three more machines were relocated and put into service (Gilewicz, 1999).

Even among these giants, the trend is towards the use of larger machines, with nearly 75% of America's total dragline capacity falling in the 61 m^3 and larger range (Gilewicz, 1999). Since machines are matched to mines' total overburden requirements, digging depths and other size-related characteristics, the dominance of larger machines reflects a shift towards larger mines.

The capital cost of large walking draglines, along with the relative inflexibility of their application, combine to make individual purchases a major investment decision for even the largest coal mine operators (Fair *et al.*, 1997). Traditionally, dragline machines were destined for a mine where they would work for decades until retired, but changing market conditions have forced the premature closing of many operations.

3.4.2 Mining deeper from surface

In order for mines to mine deeper with the current technology used at surface coal mines, the productivity must be improved with the currently available resources (Herbar, 1991). Once the productivity limit has been reached, technical improvements will produce further improvements in operating cost and consequently in the depth of mining (Ross, undated).

Since draglines are the cheapest method of moving overburden on South African surface coal mines, they work under very strict operating conditions. More and more overburden material will have to be moved which will be impractical for the draglines currently operating on the coal mines in the Witbank coalfield.

The developments in the oil sands industry and the Powder River Basin could be used to give some insight into the possibilities of future operating techniques for the South African surface coal industry.

Two of the main economic advantages of the truck-and-shovel system for a new mine application are the lower capital cost and high service factors. Comparative data for dragline and truck-and-shovel systems are summarised in Table 3.4.2. The capital costs of support equipment for each system have not been included. The capital cost per annual ton of capacity for the dragline is more than double that of a truck-and-shovel system.

Table 3.4.2

Economic comparison of draglines vs. truck-and-shovel operations in the oil sands in Canada (Caterpillar, 1999)

Mining system	Capacity tons/year (1 000's)	Capital cost (US$ 1 000's)	Capital cost per ton (US$ 1000's)	Service factor %	Operating hours per year
Dragline	25 400	138 000	5,43	51	4 500
Truck-and-shovel	25 400	60 000	2,36	66	5 800

There are a large number of technical advantages associated with the truck-and-shovel mining system (Hartung & Rosenburg, 1998), with the importance of each advantage being dependent on the geology of the ore body proposed for development. Some of these advantages can have a major impact on both capital cost and operating costs (Popowich and Clarke, 1993). The main technical benefits as compared with existing strip mining techniques are listed below:

- Flexible mine plans
- Reduced working area per ton of capacity
- Delayed overburden stripping
- Less technical support needed
- Ease of linking the mining system to new transportation or extraction technologies

- Interchangeability of trucks and shovels on overburden stripping and coaling equipment
- Reduced rehabilitation efforts and cost.

3.4.3 Application of truck-and-shovel technology

The future of the surface coal mining industry is dependent on the cost-effective exploitation of new and current coal reserves. In particular, existing operations will require the development of off-site reserves to replace or expand existing capacity. This can be accomplished by linking truck-and-shovel mining with remote extraction (Ingle, 1992).

Truck-and-shovel mining offers excellent opportunities to add value and increase the opportunity for economic development of the coal reserves (Fair *et al.*, 1997). In this respect the main conclusions are summarised below:

- Existing mines that adopt truck-and-shovel technology will have lower operating costs in the future
- Truck-and-shovel technology will continue to improve in the future when the next generation of larger shovels and trucks is developed
- It will be possible to exploit small and remote coal reserves economically with truck-and shovel mining plus new extraction technology.

3.5 Data collection

In order to lend credibility to the benchmarking process, it was necessary to agree at the outset that this data collection should be free from any personal and manual manipulation. It was decided that the results of the 1997/98 financial year would be used as the baseline since mine and group management had already approved those results.

The physical collection of data was initiated by using a comprehensive questionnaire or checklist. The checklist was required to capture the information on each mine. See Appendix 4 for the checklist template.

Mining industry suppliers were also asked to assist with this study. A supplier-specific questionnaire was used to obtain relevant information from the industry suppliers (see Appendix 5).

The checklist was also used to capture the geological characteristics of each surveyed surface coal mine, i.e. factors such as the seam thickness, hardness and specific gravity of rocks which affect the explosive requirements and the digging and loading components of the mining cycle (Wayland & Chenne,1996). These data were required to determine the effects that mine-specific geology had on each mine's performance.

3.6 Comment on previous research work

Very little literature was found that could contribute to this study. The available literature reports on the evaluation of some primary stripping methods, but nowhere is the whole overburden stripping activity evaluated.

Tasman's results (Tasman, 1998) on the black coal mine benchmarking exercise indicates a very mixed productivity performance by Australian black coal mines. In each mining technology examined (truck-and-shovel and draglines), Australia can boast a number of mines that are at or very close to world best-practice performance levels. The Americans were found to be the leaders in truck-and-shovel productivity.

Queensland's dragline operations were identified as best practice, operating at productivity levels of around 20 to 25% higher than similar mines in the United States and NSW. This productivity performance was achieved consistently in the Queensland operations and appeared to be due to good engineering, management and labour practices.

The quality and usefulness of the productivity comparisons is dependent on the selection of benchmarking partners whose operations are reasonably similar and on co-operation between them over time to ensure consistency of terminology, classification and measurement (Moolman *et al.*, 1999). Some of the better-performing Australian and American mines will be very useful benchmarking partners for comparison with their South African counterparts.

4. Analysis and discussion of the results

4.1 Characteristics of the benchmarking sites

The geological characteristics of the mines surveyed are presented in Table 4.1. South African overburden material appears to be the most competent and the hardest of the international sites surveyed. Australian overburden material appears to be of average hardness but softer than the South African overburden. Drilling and blasting on the international benchmark mines appears to be easier than in South Africa. However, South Africa reported the lowest overburden powder factor. This was as a result of the higher bench heights (Table 4.1) and bigger blast holes. The average diameter of the overburden blast holes drilled on South African mines was 200 to 250 mm, compared with USA, NSW and Queensland averages of 170, 120 and 200 mm respectively. (The smaller the blast hole, the smaller the burden and spacing, and the bigger the powder factor.)

Table 4.1

Characterisation of geological conditions on mines surveyed

	Number of coal seams	Average thickness of seams (m)	Overburden powder factor (kg/m^3)	Stripping ratio (BCM/ROM ton)	Overburden thickness (m)	Number of overburden benches[2]
SA	3	4,7	0,46	2,19	33	1
NSW[1]	8	3	0,50	2,45	10,4	1
QLD	4	9	0,53	9,8	70	5
USA	2	25	0,59	1,69	45	3

1. Coal seams dipping on average 42°.
2. Number of individually blasted benches within overburden.

The Queensland and NSW coal mines appear to have the most difficult mining conditions with thin, multiple, deep and dipping coal seams, yet NSW possesses the most productive coal mine. The South African surface coal mines appear to have the second most difficult mining conditions. The coal seams are horizontal and on average thicker and not as deep as those of the Australian mines, but the harder overburden affects the productivity performance of the local mines.

The highly productive USA surface coal mines in the Powder River Basin area appear to enjoy favourable mining conditions with thick horizontal coal seams underlying a combination of clay, sand and shale overburden. Their stripping ratios are the most favourable among the mines surveyed. They also do not need to beneficiate their ROM coal.

The variations in operating factors (Louw, 2000), such as borehole diameter, burden and spacing, face height, type of formation, minimum required pit width and ratios of wall height to pit width, also affected blasting performances on mines. The mining equipment linked to the different blasting factors, such as the type of explosives, designed powder or energy factor, energy distribution, drill pattern and timing delay, made blasting on each surveyed mine unique with, as expected, mixed blasting results.

The recorded percentage of primary overburden BCMs cast-blasted to final position for South African mines was:

- 15 to 25% for benches lower that 25 m
- 32 to 38% for 25-m benches
- 38 to 45% for 30-m benches.

The international mines reported cast-blast results of 15 to 45%. Only one mine was evaluating the potential of cast-blasting as a primary stripping method. This mine reported casts of up to 45% but refused to elaborate on their cast-blasting project.

Very few mines planned and scheduled cast-blasting as the primary method of moving overburden. Those that did appeared to believe in the production and cost benefits to be gained from cast-blasting. The rest of the mines had various reasons for not using cast-blasting despite its potential benefits but, in general, they all agreed that cast-blasting had great potential as a stripping method.

4.2 Productivity performance evaluation

Overburden removal involved broad functions and two physical outputs, namely coal and waste. These outputs were only obtained after a set of inputs had been obtained and utilised. The inputs used and the outputs obtained were evaluated as follows:

- **Inputs**
    - Labour
    - Capital invested in mining equipment
    - Operating expenditure
- **Outputs**
    - Coal exposure rate
    - Total BCMs mined
    - Overburden BCMs mined
    - ROM coal tons mined.

Total BCMs were used to evaluate a mine's overall stripping productivity performance as data on each stripping activity were difficult to obtain and required manual manipulation.

4.3 Labour

The internationally accepted standard means of measuring labour productivity on coal mines is to calculate the average coal tons removed per man-year. For this productivity analysis, labour included mine labour and contractors working on a mine. The USA achieved the highest ROM tons per man-year, including contractors, of all the participating benchmark mines (Figure 4.3a). The South African standard was nearly nine times lower than the USA benchmark as reflected in Figure 4.3a. Figure 4.3b shows the performances of the individual South African mines.

The South African ROM tons per man-year, excluding contractors, are summarised in Appendix 1: Figure 1.

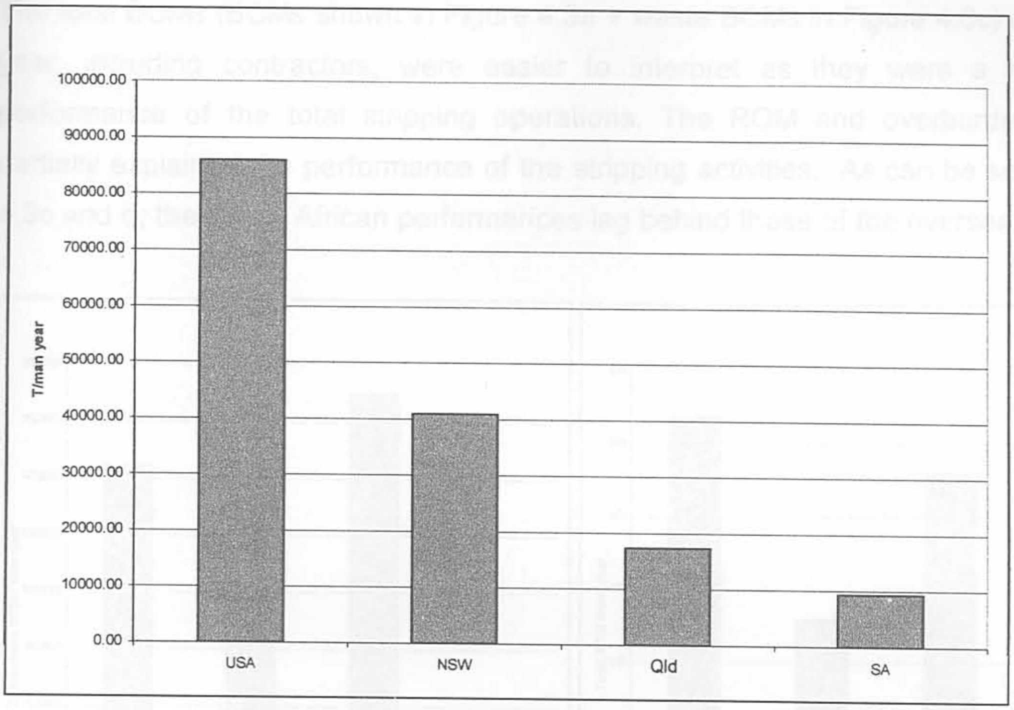

Figure 4.3a: ROM tons per man-year, including contractors

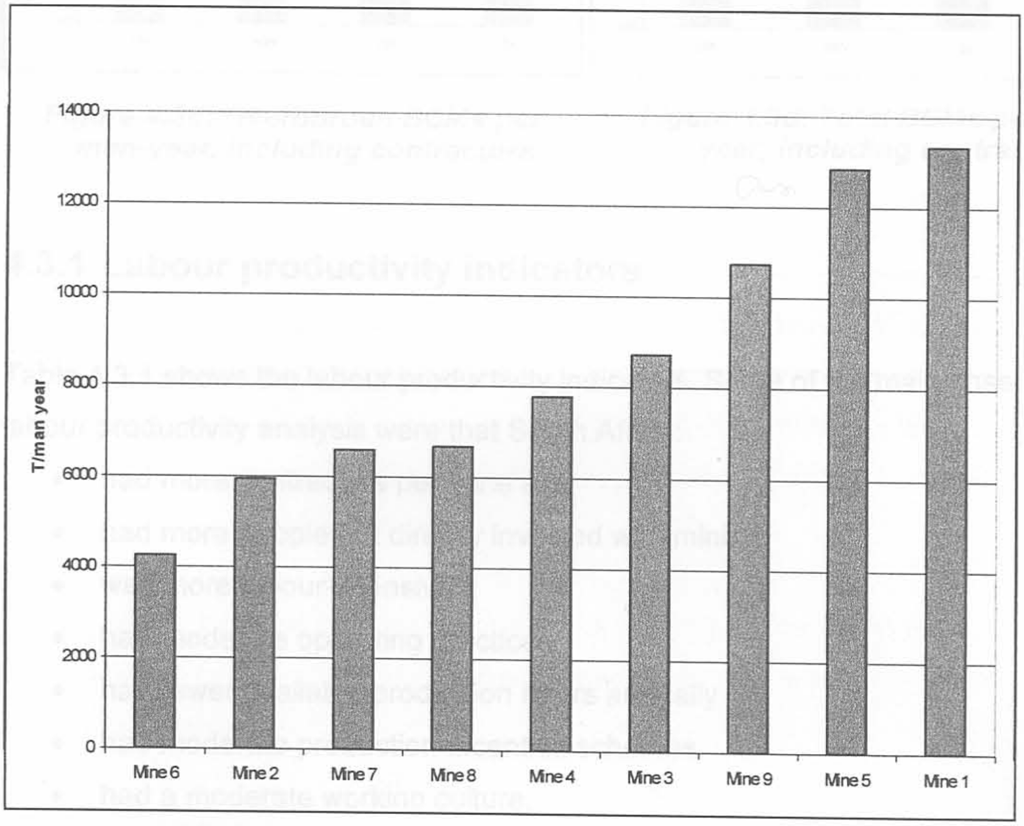

Figure 4.3b: South African ROM tons per man-year, including contractors

The total BCMs (BCMs shown in Figure 4.3a + waste BCMs in Figure 4.3c) moved per man-year, including contractors, were easier to interpret as they were a measure of the performance of the total stripping operations. The ROM and overburden analysis only partially explained the performance of the stripping activities. As can be seen from Figures 4.3c and d, the South African performances lag behind those of the overseas operations.

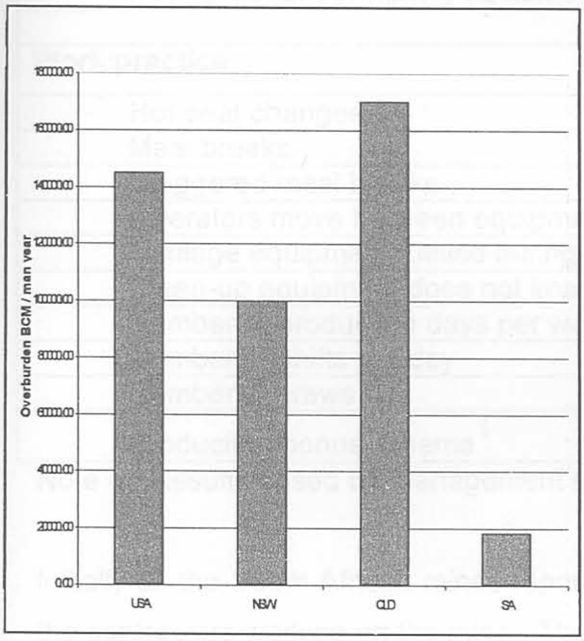

Figure 4.3c: Overburden BCMs per man-year, including contractors

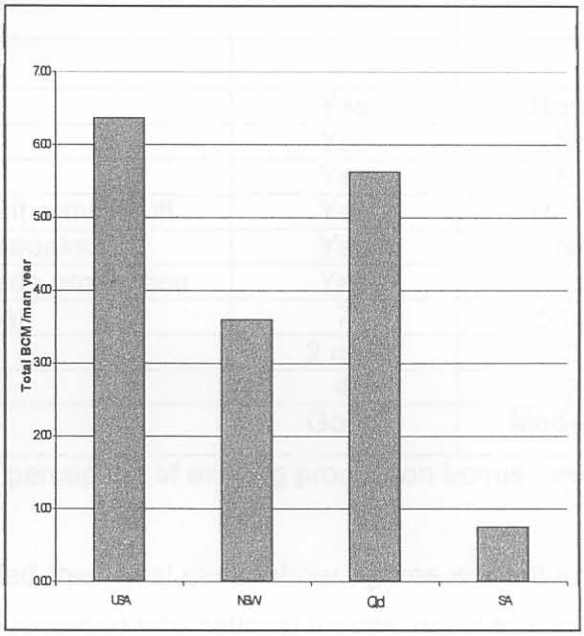

Figure 4.3d: Total BCMs per man-year, including contractors

4.3.1 Labour productivity indicators

Table 4.3.1 shows the labour productivity indicators. Some of the main observations from this labour productivity analysis were that South Africa:

- had more contractors per mine site
- had more people not directly involved with mining
- was more labour-intensive
- had moderate operating practices
- had fewer available production hours annually
- had moderate production-incentive schemes
- had a moderate working culture.

Table 4.3.1

General labour productivity indicators

Productivity measures	International benchmark	SA standard
Labour		
Percentage of contractors working on mine	10 (estimate)	29,8
Total labour per mining equipment unit	6,93	18,82
Mining labour per mining equipment unit	3,71	5,81
Work practice		
Hot-seat changes	Yes	Rarely
Meal breaks	Yes	No
Staggered meal breaks	Yes	No
Operators move between equipment within shift	Yes	Rarely
Haulage equipment fuelled during breaks	Yes	No
Clean-up equipment does not impede production	Yes	Yes
Number of production days per week	7	5 to 7
Number of shifts per day	2 or 3	3
Number of crews	4	3
Production bonus scheme[1]	Good	Moderate

Note 1: Results based on management's perception of existing production bonus incentives.

Initially all the South African mines reported their total mine labour figures without including the contractors working on the mine. The recorded international figures included contractors and therefore the numbers of contractors working on South African operations were also obtained and included in the labour productivity analysis.

It also appeared that most of the international contractors were directly involved with mining or equipment maintenance, unlike in South Africa. The remote Queensland mines, like most South African mines, appeared to have a greater socio-economic responsibility and thus a larger non-mining labour component and infrastructure than the NSW and USA benchmark mines. (See Appendix 1: Figure 2 for the contractors as a percentage of mine employees working on South African mines.)

Very few of the total number of contractors working on the South African mines were directly involved in mining or mining maintenance. Those who worked in mining during the survey were contracted to:

- move topsoil and subsoils
- undertake rehabilitation
- supply explosives.

The international benchmark operations used contractors for the same activities, but they also sub-contracted the maintenance of mining equipment to the original equipment suppliers. It appeared that most overseas equipment operators assisted with general maintenance and fuelling of equipment.

Further investigation into the labour composition of the mines surveyed revealed that a relatively high percentage of the total labour force on the USA and NSW mines worked directly in mining. The difference between the number of mining labour (workmen) per mining equipment unit and the total mine labour per mining equipment unit gave an indication of the number of people not directly involved with the mining operation. The larger number of people not working directly in mining reduced the labour productivity performance level of the South African surface coal mining industry.

By expressing the total amount of capital invested per person working on a mine, one can determine whether the operation is labour or capital-intensive. The international benchmark operations appeared to be more capital-intensive and South African ones more labour-intensive (Figure 4.3.1). (See Appendix 1: Figure 3 for the South African scenario.)

The USA and NSW benchmark mines used relatively large pieces of equipment (requiring relatively less labour to operate). A 320-t truck operator in the USA produced 1.6 BCM units for every 1 (one) BCM unit produced by a 200-t truck operator in South Africa, all other things being equal. The use of larger pieces of equipment on the international mines resulted in the need for fewer mining and relief operators. This partially explains the low mining labour per mining equipment unit reported for the international mines.

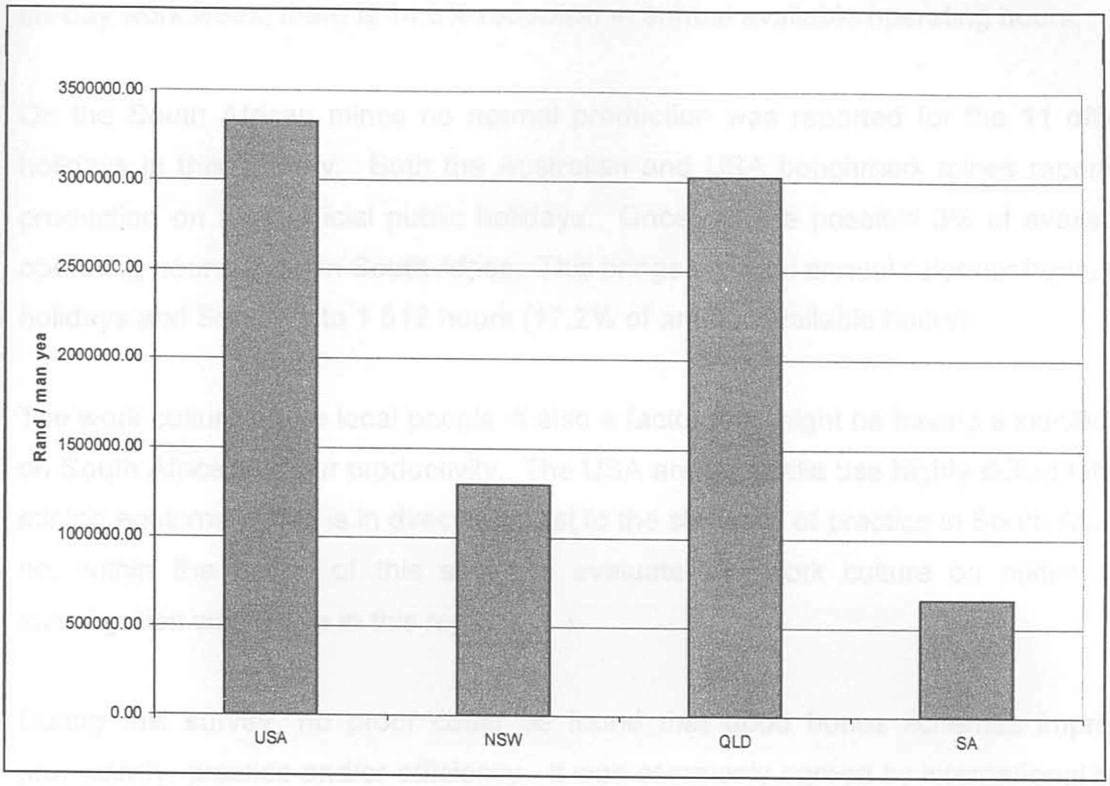

Figure 4.3.1: Mining CAPEX per mine employee, including contractors

It did not appear that South Africa employed more labour on ancillary equipment than the international benchmark mines as the ratio of ancillary equipment to total mining equipment was basically the same for the South African and international benchmark mines, as indicated in Table 4.5.1 (page 40).

Work practices in the international benchmark operations appeared to be more efficient, resulting in a higher productivity performance. In the international mines, staff used effective hot-seat changes, took meal breaks on machines or staggered meal breaks, and moved between pieces of equipment to ensure that the core equipment continued to operate. Operators also fuelled the equipment between breaks and ensured that clean-up equipment did not impede production. Only some of the South African operations were found to be implementing a few of these work practices in order to improve operational efficiency.

All the international best-practice mines worked on a four-crew, two to three shifts per day, full calendar principle (365 days x 24 h per day = 8 760 h). Of all the mines surveyed in South Africa, only three coal mines worked on a full calendar year. The rest of the South African operations worked a six-day or 11-shift fortnight. For every day a mine is not operating, there is a 0,27% drop in annual available operating hours. If a mine only works a six-day work week, there is 14,3% reduction in annual available operating hours.

On the South African mines no normal production was reported for the 11 official public holidays in this country. Both the Australian and USA benchmark mines reported normal production on their official public holidays. Once more a possible 3% of available annual operating hours is lost in South Africa. This brings the total annual calendar hours lost due to holidays and Sundays to 1 512 hours (17,2% of annual available hours).

The work culture of the local people is also a factor that might be having a significant impact on South Africa's labour productivity. The USA and Australia use highly skilled labour on the mining equipment; this is in direct contrast to the standard of practice in South Africa. As it is not within the scope of this study to evaluate the work culture on mines, no further investigation was made in this regard.

During this survey, no proof could be found that good bonus schemes improve labour productivity, practice and/or efficiency. It was commonly agreed by international benchmark mining operations that they had effective bonus schemes in place and used them as an incentive to foster better labour productivity, practice and efficiency. In contrast, the South African mines agreed that their bonus schemes were not good and did not serve their purpose as an incentive to improve labour productivity, practice and/or efficiency.

4.4 Coal exposure rate

As defined by the project team, coal exposure rate per annum was planned as the prime productivity measurement. However, the coal exposure rate analysis did not produce meaningful and measurable results and therefore the project team decided not to use these results as a productivity measure.

In this analysis the tons mined from the two thick coal seams in the USA benchmark mines were reduced to a single surface area as per definition. This negatively affected the performance of the USA mines. The Australian and most of the South African surface coal mines, which opened multiple coal seams per unit of pit length, benefited from this productivity measurement. The results obtained were confusing, difficult to interpret and deemed to be impractical by the project team.

4.5 Capital invested

The USA, followed by Queensland, had the most mining capital invested in their mining operations (Figure 4.5a). One USA mine, all the Queensland mines and most of the South African mines had draglines with truck-and-shovel fleets for moving overburden and coal. The NSW mines, two South African mines and one USA mine were the only mines using only truck-and-shovel operations.

The capital invested on each of the South African mines surveyed is summarised in Appendix 1: Figure 4.

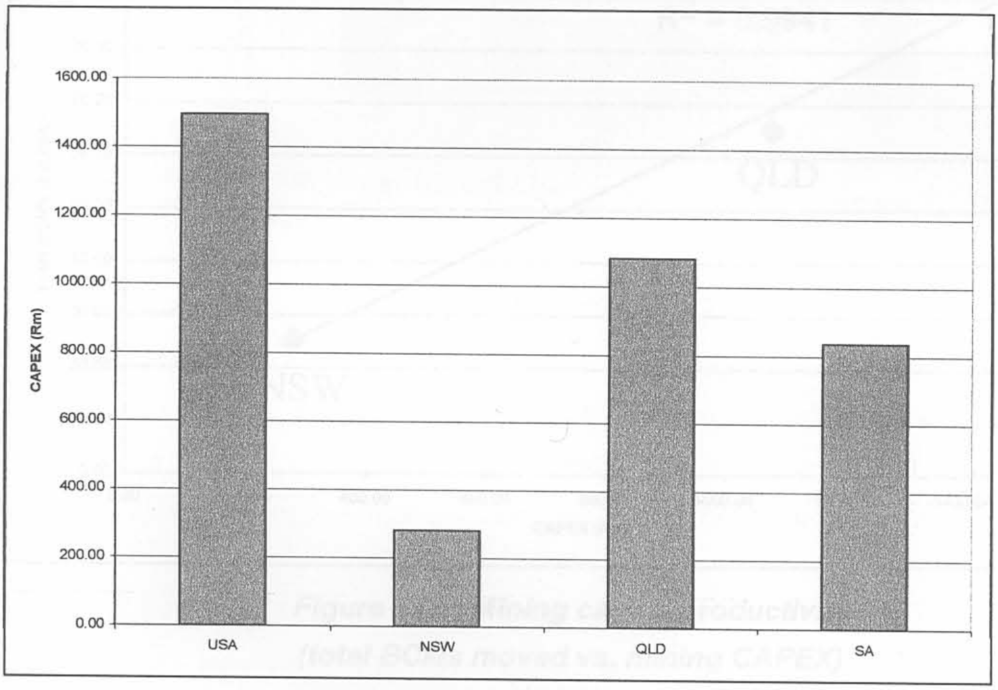

Figure 4.5a: Average mining capital invested on a benchmark mine

On average, the international benchmark mines produced 1,47 total BCM units for every unit of mining capital invested (Pretorius, 2000). The South African mines achieved only 1 (one) total BCM unit for every unit of mining capital invested (see Figures 4.5b, 4.5e and 4.5f for all the South African mine results). The capital productivity of the international benchmark mines formed a linear relationship, with the South African operations substantially lower, also in a linear relationship (Figure 4.5e). The South African mines did not move the same number of BCMs per unit of mining capital invested as the international benchmark operations.

Mining capital invested and the total digging capacity available appeared to have a direct relationship (Figure 4.5g). It also appeared that there was no significant difference between the capital invested on dragline and truck-and-shovel mines (Figure 4.5g).

From Figure 4.5f it is also clear that the international benchmark mines moved more BCMs per cubic metre of digging capacity deployed per mine than the South African mines.

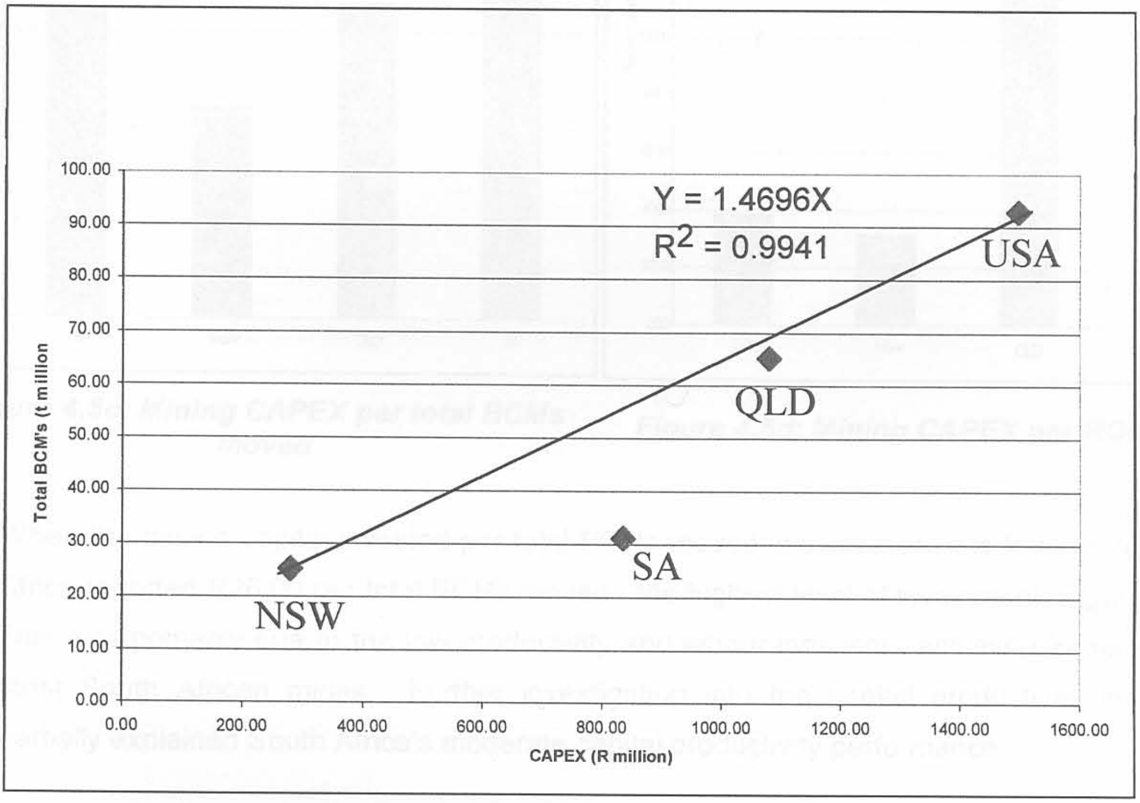

Figure 4.5b: Mining capital productivity (total BCMs moved vs. mining CAPEX)

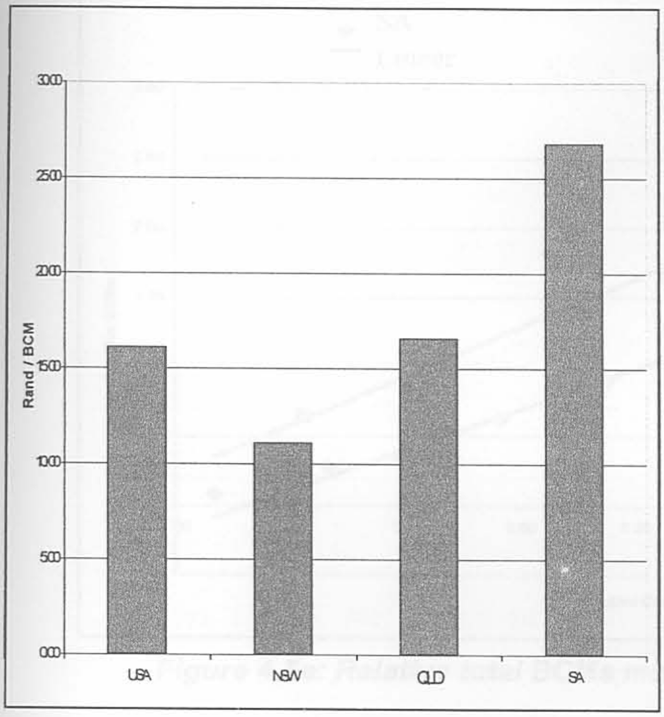

Figure 4.5c: Mining CAPEX per total BCMs moved

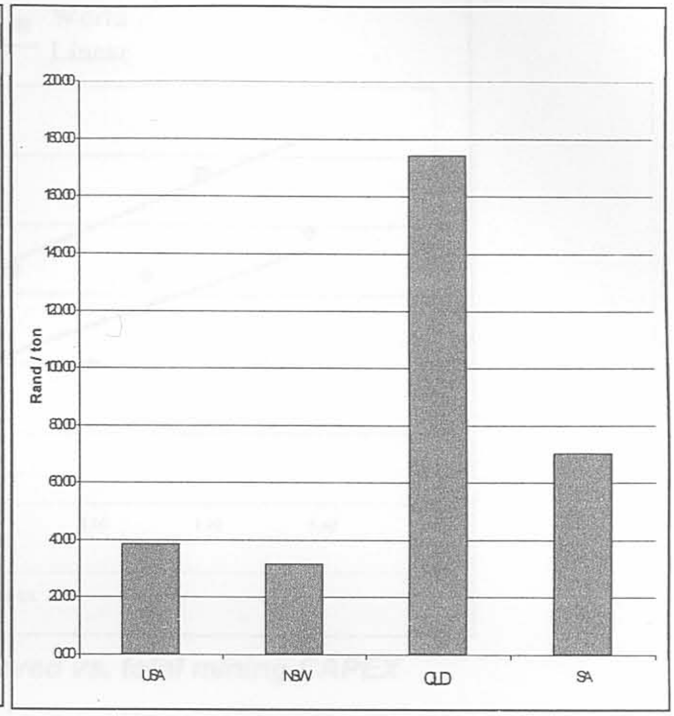

Figure 4.5d: Mining CAPEX per ROM tons

When the mining capital invested per total BCMs moved is examined, it is found that South Africa reported R26,00 per total BCMs moved - the highest level of investment (Figure 4.5c). This was primarily due to the low productivity and labour indicators achieved in general on most South African mines. Further investigation into the capital productivity indicators partially explained South Africa's moderate capital productivity performance.

When the mining capital invested per ROM coal ton is examined, it is found that Queensland, with R174,00, has the highest level of investment (Figure 4.5d). The high stripping ratios were the main reason for the high level of mining capital required. The South African operations appeared to be on the expensive side when compared with the NSW operations that had similar stripping ratios. However, the NSW operations were entirely truck-and-shovel operations.

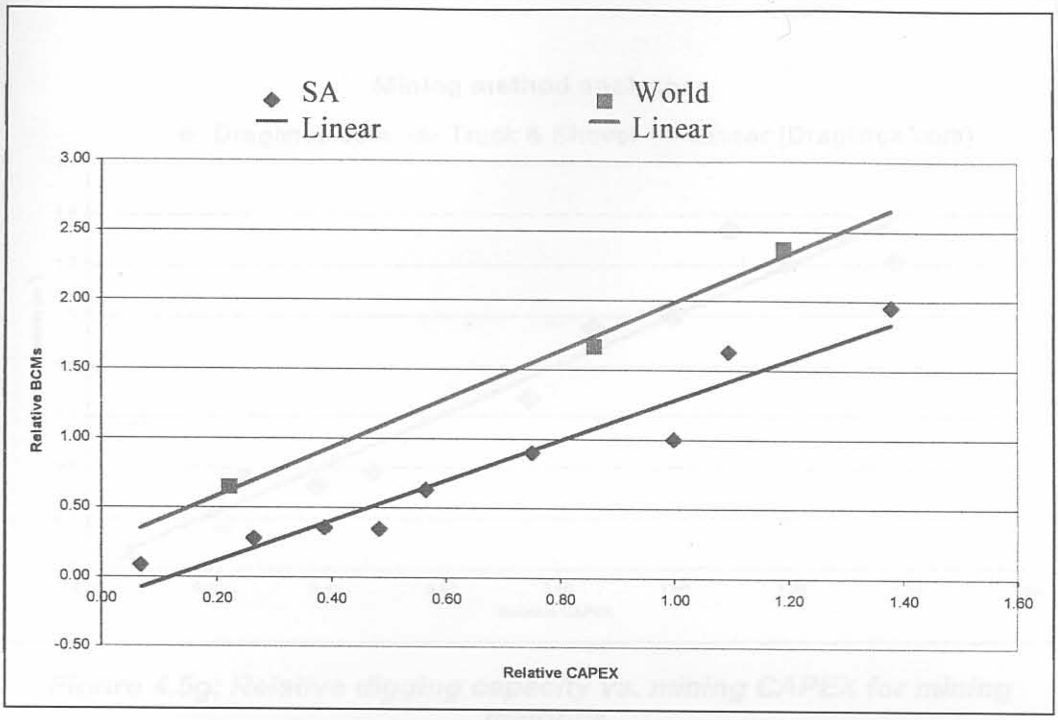

Figure 4.5e: Relative total BCMs moved vs. total mining CAPEX

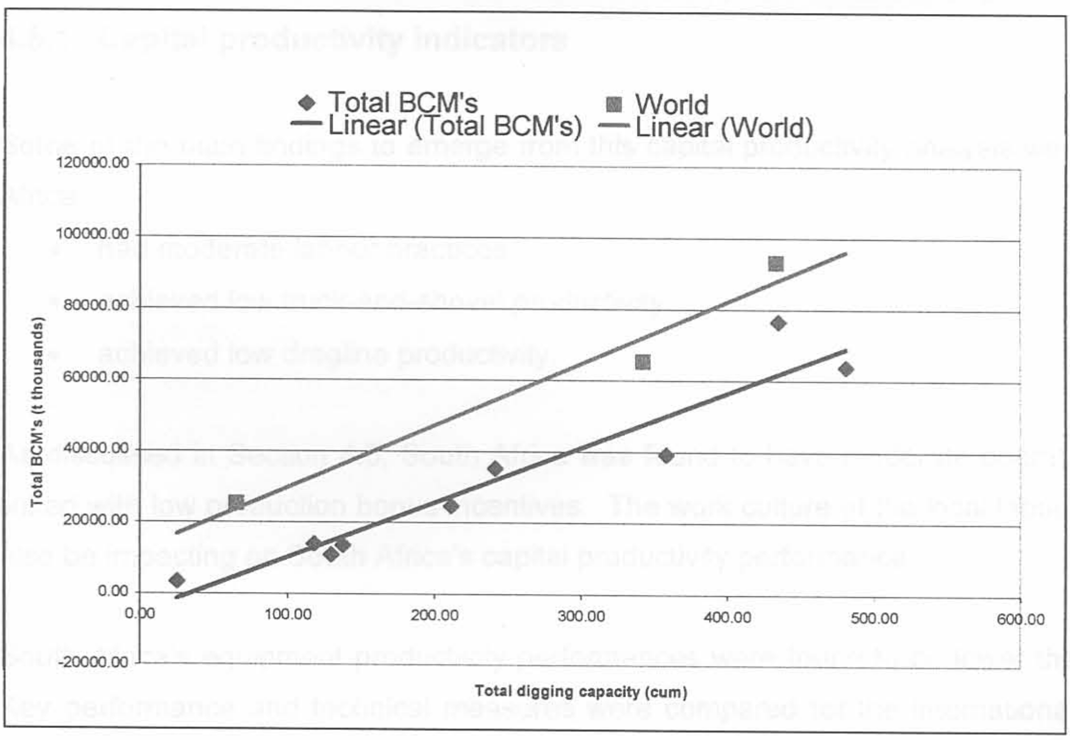

Figure 4.5f: Total BCMs moved vs. total digging capacity

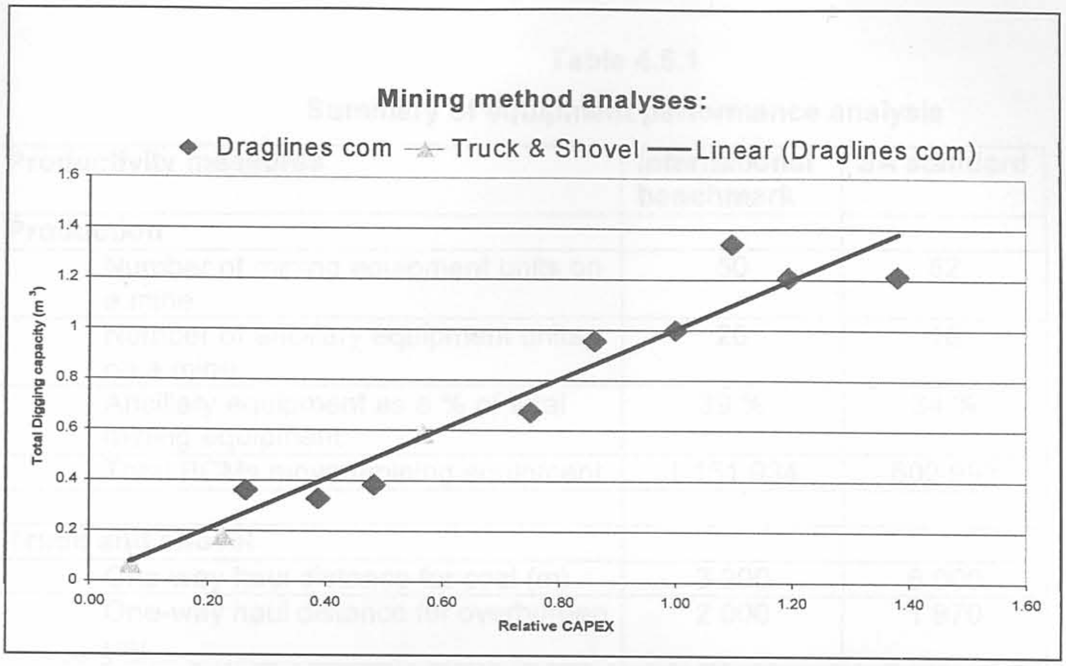

Figure 4.5g: Relative digging capacity vs. mining CAPEX for mining methods

4.5.1 Capital productivity indicators

Some of the main findings to emerge from this capital productivity analysis were that South Africa:

- had moderate labour practices
- achieved low truck-and-shovel productivity
- achieved low dragline productivity.

As discussed in Section 4.3, South Africa was found to have moderate operating practices linked with low production bonus incentives. The work culture of the local labour force could also be impacting on South Africa's capital productivity performance.

South Africa's equipment productivity performances were found to be lower than expected. Key performance and technical measures were compared for the international benchmark operations and the standard South African surface coal mining operation. Table 4.5.1 gives a summary of these partial performance indicators.

Table 4.5.1

Summary of equipment performance analysis

Productivity measures	**International benchmark**	**SA standard**
Production		
Number of mining equipment units on a mine	50	52
Number of ancillary equipment units on a mine	20	18
Ancillary equipment as a % of total mining equipment	39 %	34 %
Total BCMs moved/mining equipment	1 151 934	602 993
Truck and shovel		
One-way haul distance for coal (m)	3 200	6 000
One-way haul distance for overburden (m)	2 000	1 970
Main loading method	Single sided	Single sided
Truck spotting time (seconds)	30	90
Shovel swing time per load (seconds)	30	35
Truck utilisation (% of annual hours)	78	62
Shovel utilisation (% of annual hours)	76	60
Draglines		
Number of swings per hour	51	46
Cut width	55-60	55
Pit lengths	3 500	3 450
Utilisation (% of annual hours)	79	73

The low truck-and-shovel productivity performance can be attributed to:

- Moderate truck-and-shovel utilisation – number of annual hours in which trucks and shovels were producing
- Longer haulage distances
- Longer truck spotting times
- Smaller equipment used.

A marginal difference was reported in the number of pieces of mining and ancillary equipment deployed on the mines surveyed. It must be noted that the USA mines reported 65 mining equipment units per mine and the NSW mines only 28 mining equipment units per mine. These mines had on average three primary mining equipment units for every ancillary unit respectively. (See Appendix 1: Figure 5 for the South African scenario.)

The international benchmark for total BCMs moved per mining equipment unit was almost double the result reported for South Africa (Table 4.5.1 and Figure 4.5.1a). Once more South Africa's poor capital productivity performance is highlighted. (See Appendix 1: Figure 7 for the BCMs moved per mining equipment unit on South African mines.)

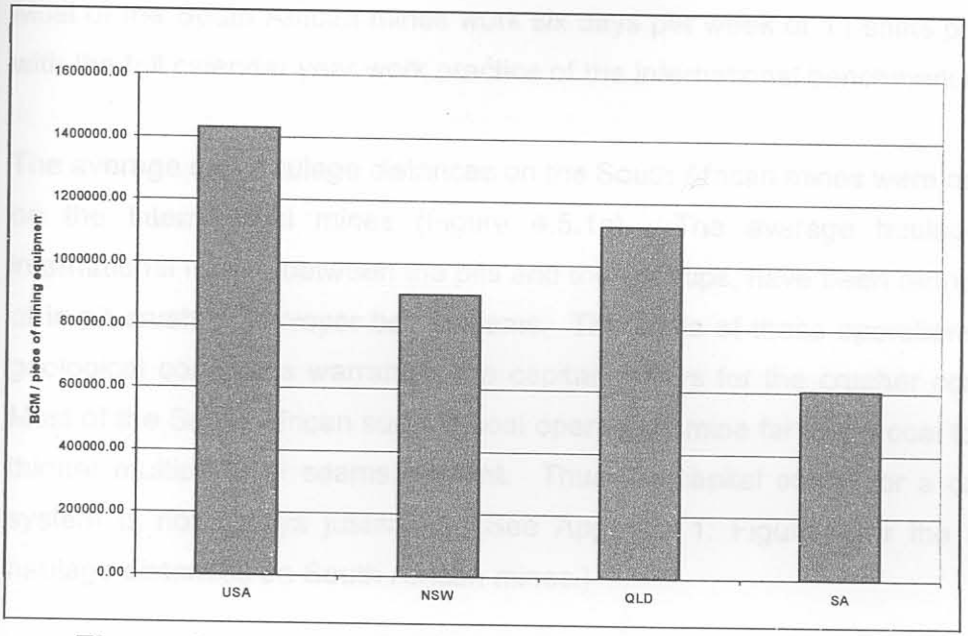

Figure 4.5.1.a:Total BCMs per mining equipment unit

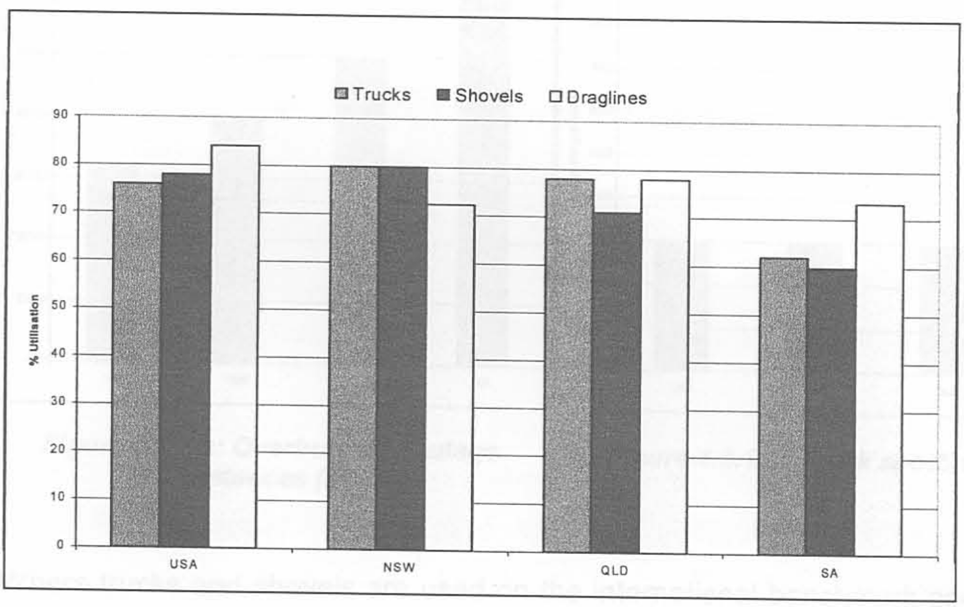

Figure 4.5.1.b: Equipment utilisation

The NSW, USA and Queensland mines reported average truck utilisation data respectively 1,29; 1,22 and 1,26 times higher than the South African coal mines' average. Shovel utilisation data for NSW, the USA and Queensland were on average respectively 1,34; 1,31 and 1,19 times higher than the South Africa coal mines' average (Figure 4.5.1.b).

Most of the South African mines work six days per week or 11 shifts per fortnight compared with the full calendar year work practice of the international benchmark mines.

The average coal haulage distances on the South African mines were nearly twice as long as on the international mines (Figure 4.5.1c). The average haulage distances on the international mines, between the pits and the coal tips, have been reduced by the installation of in-pit crusher conveyor belt systems. The scale of these operations and the favourable geological conditions warranted the capital outlays for the crusher conveyor belt systems. Most of the South African surface coal operations mine far fewer coal tons per pit due to the thinner multiple coal seams present. Thus the capital outlay for a crusher conveyor belt system is not always justifiable. (See Appendix 1: Figure 8 for the average overburden haulage distances on South African mines.)

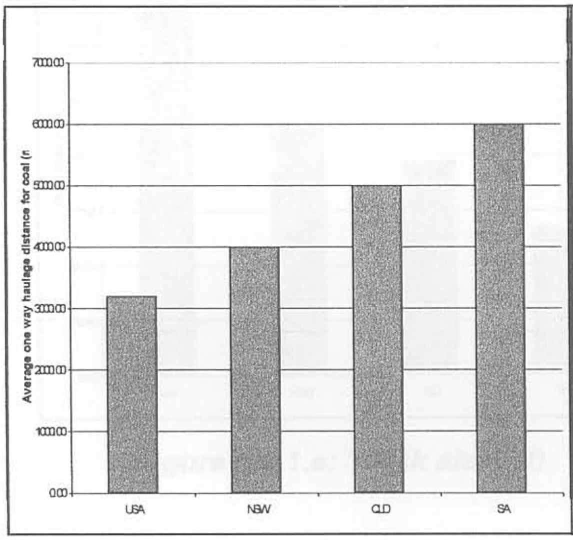

Figure 4.5.1.c: Overburden Haulage distances (m)

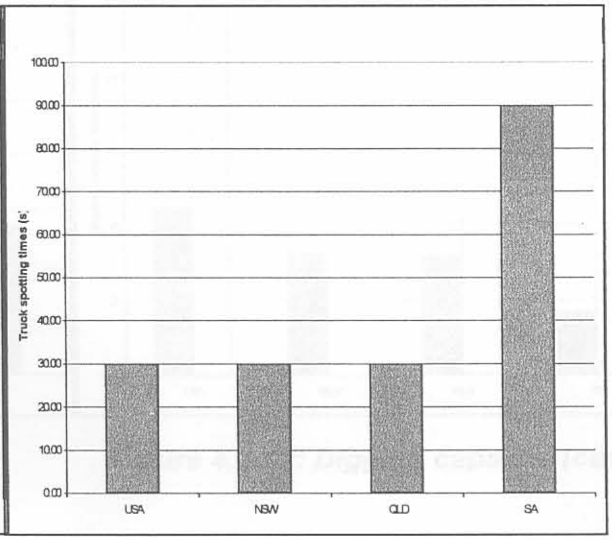

Figure 4.5.1.d: Truck spotting times (s)

Where trucks and shovels are used on the international benchmark operations as the main method of moving overburden, the mining layout is designed to keep haulage distances shorter than 2 400 m. Where trucks and shovels are used with draglines for pre-stripping and parting removal, cross-pit bridges are constructed to keep haulage distances as short as possible. This practice is used on the Queensland benchmark operations where cross-pit bridges are spaced between 1 000 and 1 500 m apart.

Truck spotting times on the South African mines were, on average, 30 seconds higher than on the benchmark operations (Figure 4.5.1d). The shovel swing times and truck loading methods are basically the same. (See Appendix 1: Figure 11 for the South African scenario.)

Mine haul trucks used on South African mines appear to be two truck-size generations behind the USA and one generation behind NSW and Queensland (Figure 4.5.1e). The largest trucks operating on the South African surface coal mines are 200-t haul trucks. (See Appendix 1: Figure 9 for the truck sizes on South African mines.) The largest trucks operating in Queensland and NSW were 220 – 240-t trucks. The USA operates 320-t trucks and is testing the new 360-t trucks. The smallest production truck operating on the international benchmark mines was a 153-t rear dumper used for coal haulage. The smallest truck operating on the overburden was a 190-t truck.

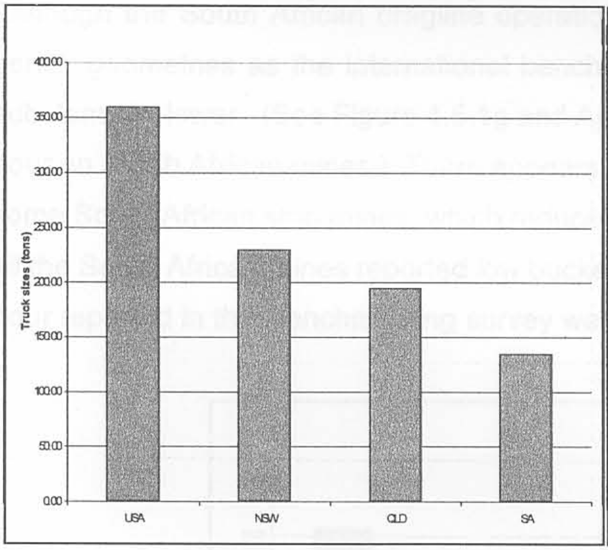

Figure 4.5.1.e: Truck sizes (t)

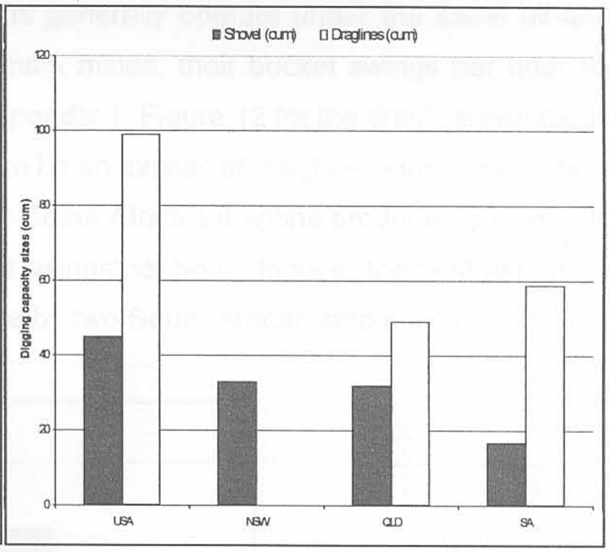

Figure 4.5.1.f: Digging capacity (cum)

The shovels used on South African mines appear to be three shovel-size generations behind the USA (Figure 4.5.1f). The largest shovel operating on any South African surface coal mine is a 25-m^3 hydraulic shovel. (See Appendix 1: Figure 10 for the sizes of shovels and draglines operating on South African mines.) NSW and Queensland are using 33-m^3 shovels. The USA is already implementing 90 metric ton shovels (51,2 m^3). This new generation of shovels was introduced into the USA at the end of 1999. South Africa is only one shovel generation behind the Australian benchmark mines which still operate 28-m^3 shovels.

The South African draglines were generally found to achieve a low productivity performance level when compared with overseas operations, although some individual mines achieved outstanding dragline productivity performance levels. The overall moderate dragline productivity performance can be attributed to:

- Digging capacity (m^3)
- Equipment utilisation.

The largest international dragline surveyed was a Marion 8750 fitted with a 99-m^3 bucket operating in the USA (Figure 4.5.1f). The Australian benchmark mines had larger draglines in operation than South Africa, but with similar bucket sizes. The smaller buckets were dictated by the configurations of pit width and bench height.

Although the South African dragline operations generally operate under the same pit-and-bench geometries as the international benchmark mines, their bucket swings per hour are substantially lower. (See Figure 4.5.1g and Appendix 1: Figure 12 for the dragline swings per hour on South African mines.) There appears to be an excess of dragline digging capacity on some South African strip mines, which reduces South Africa's dragline productivity level. Not all the South African mines reported low bucket swings per hour. Indeed, the best swings per hour reported in this benchmarking survey were by two South African strip mines.

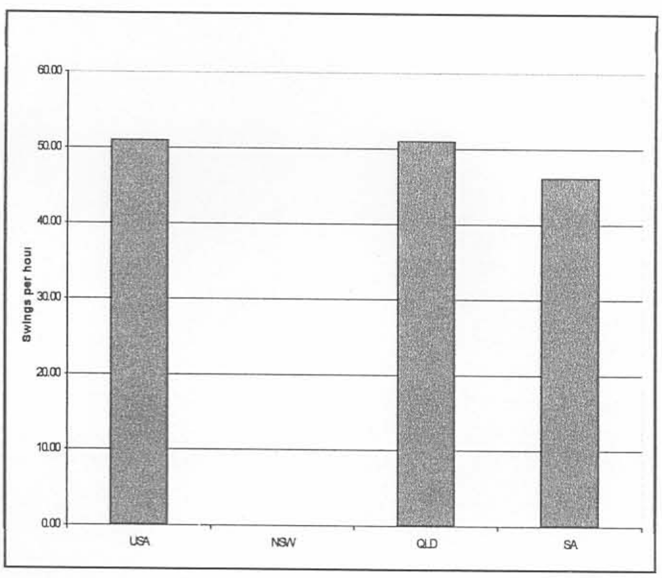

Figure 4.5.1.g: Dragline swings

The average South African dragline utilisation was on par with that of NSW but lower than the Queensland and USA reported utilisation (Figure 4.5.1.b). However, some individual South African dragline operations were found to be outperforming the international benchmark mines and were once more setting a world-class performance standard (see Appendix 1: Figure 6).

4.6 Operating expenditure

Mines found it difficult to report on the operating expenditure as requested in the benchmarking checklist because their financial systems did not provide for stripping activity-based costing. The mines were then requested to provide a mining operating expenditure (OPEX) per ROM coal delivered to the tip (Figure 4.6a).

However, the mining OPEX per ROM coal was not meaningful. The mining cost data were therefore recalculated and a mining cost per total BCM moved was produced (Figure 4.6b).

Due to the difficulty in obtaining the mining operating expenditure and the amount of manual manipulation required, the project team decided to exclude these data from the evaluation process.

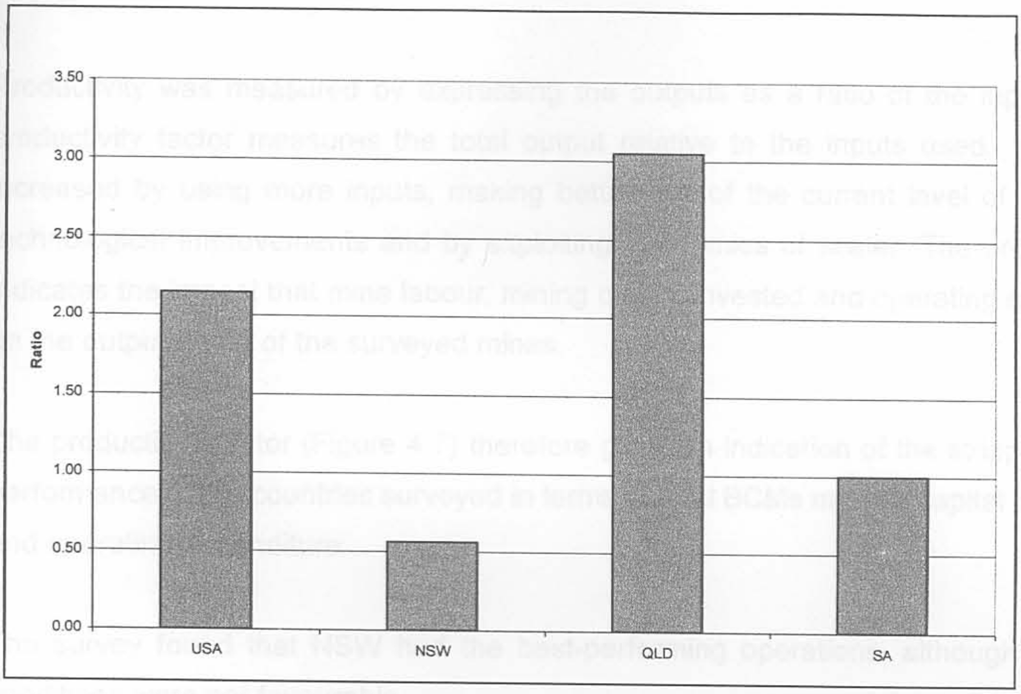

Figure 4.6a: Mining operating expenditure per ROM ton

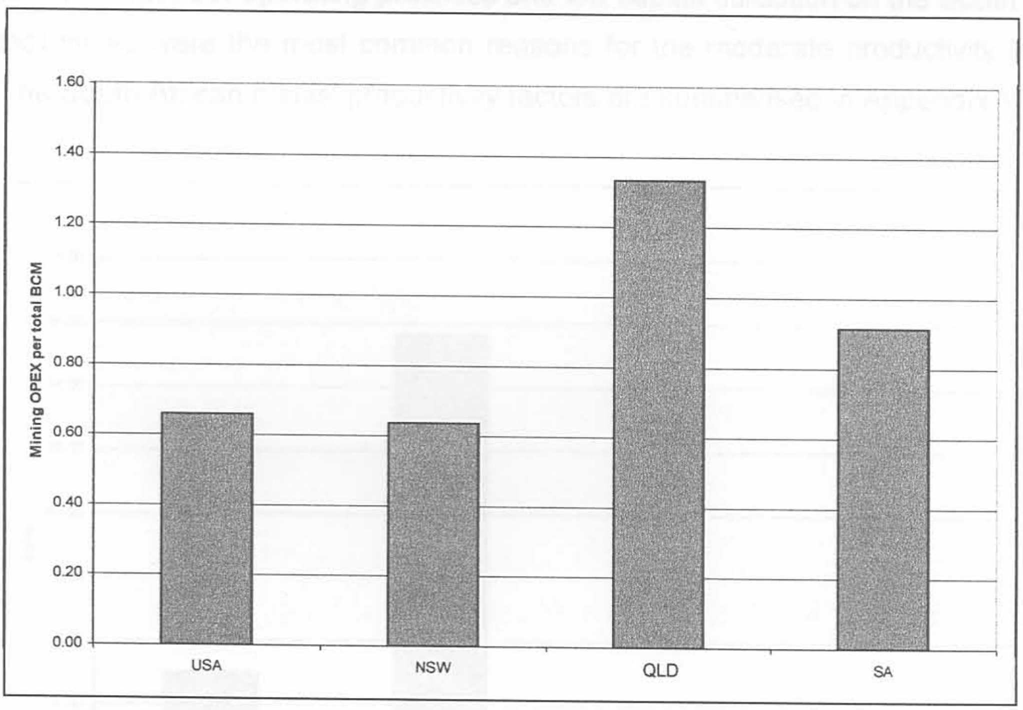

Figure 4.6b: Mining operating expenditure per total BCM moved

4.7 Productivity factor

Productivity was measured by expressing the outputs as a ratio of the inputs used. The productivity factor measures the total output relative to the inputs used. Output can be increased by using more inputs, making better use of the current level of inputs, through technological improvements and by exploiting economies of scale. The productivity factor indicates the impact that mine labour, mining capital invested and operating expenditure had on the output (tons) of the surveyed mines.

The productivity factor (Figure 4.7) therefore gives an indication of the stripping productivity performance of the countries surveyed in terms of total BCMs moved, capital invested, labour and operating expenditure.

The survey found that NSW had the best-performing operations, although the geological conditions were not favourable.

Overstaffing, poor operating practices and low capital utilisation on the South African surface coal mines were the most common reasons for the moderate productivity levels achieved. (The South African mines' productivity factors are summarised in Appendix 1: Figure 6.)

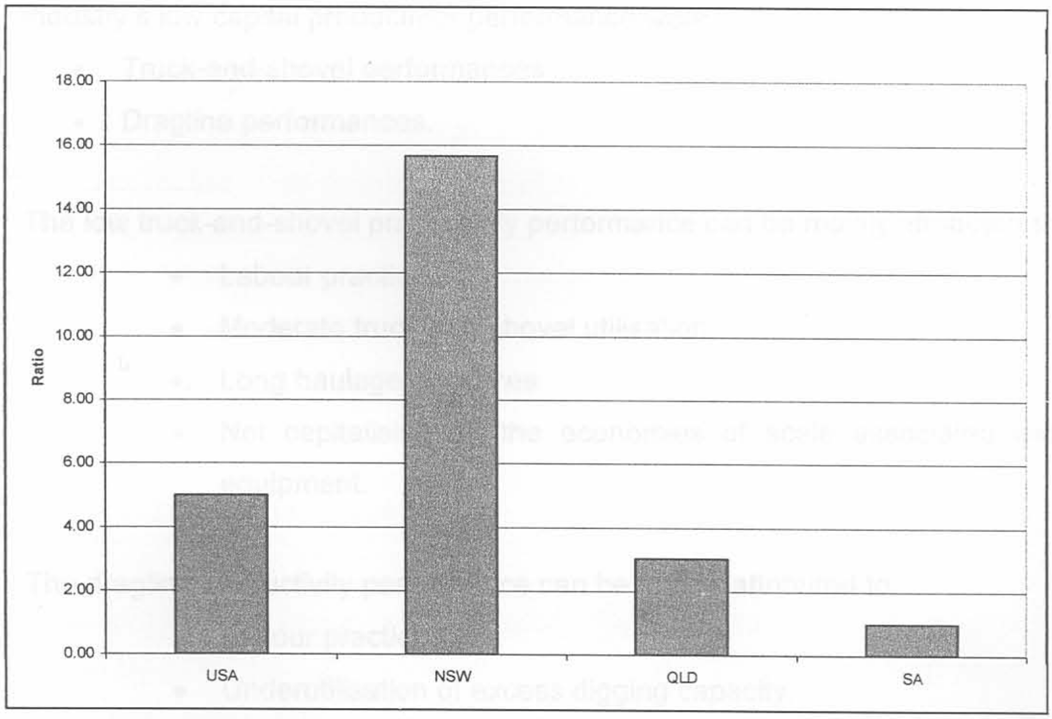

Figure 4.7: Productivity factors for mining countries surveyed

5. Conclusions

The South African surface coal mining industry recorded the lowest stripping productivity performance when compared with the survey results from the mines in the USA, NSW and Queensland. This below-benchmark productivity performance was mainly the result of low labour and capital productivity performance levels.

The labour productivity indicators contributing to the South African surface coal mining industry's low labour productivity performance were:

- Large percentage of contractors employed on local mines, but not directly involved in mining operations
- Work practices
- Labour-intensive mining operations
- Large percentage of mine labour not directly involved with mining, i.e. support staff (due to the socio-economic responsibilities of South African mines)
- Work culture of local work force
- Moderate production incentive schemes.

The capital productivity indicators contributing to the South African surface coal mining industry's low capital productivity performance were:

- Truck-and-shovel performances
- Dragline performances.

The low truck-and-shovel productivity performance can be mainly attributed to:

- Labour practices
- Moderate truck-and-shovel utilisation
- Long haulage distances
- Not capitalising on the economies of scale associated with large mining equipment.

The dragline productivity performance can be mainly attributed to:

- Labour practices
- Underutilisation of excess digging capacity.

However, some individual South African dragline operations were found to be outperforming the international benchmark mines and were setting a world-class performance standard. Key performance indicators, implemented by management to track the performance of the draglines, assisted these mines in achieving world-class standards.

Very few mines planned and scheduled cast-blasting as the primary method of moving overburden. In general, mine management agreed that cast-blasting had great potential as a cost-effective stripping method and that it was not being fully utilised on most mines.

Due to the difficulty in obtaining the operating expenditure from the mines and the amount of subjective manual manipulation required, these results were not used for evaluation purposes. Coal exposure rate analysis was also not considered an appropriate productivity performance measure due to the difficulty in interpreting those results.

6 Recommendations

The recommendations made below are aimed at assisting the South African surface coal mining industry and Coaltech 2020 in achieving the higher productivity objectives.

6.1 Improve labour productivity

With profit margins becoming marginal, the future value of coal is locked up in volume and costs. Those mines that manage to increase coal output at marginal cost levels through mergers, acquisitions and re-engineering will benefit. Other labour-improvement initiatives, such as restructuring of the organisation, mechanisation of mining-related processes and outsourcing of non-core activities, could also improve labour productivity performances.

6.2 Improve capital productivity

6.2.1 Labour practices.

Investigating and implementing a production performance management scheme that will foster improved labour productivity, practices and efficiency without sacrificing mine health and safety could also improve labour productivity and ultimately capital productivity.

6.2.2 Equipment utilisation

In order to improve equipment utilisation, it is recommended that mines:

- Work on a **full calendar year**, thus reducing unproductive time to an absolute minimum. Some South African dragline operations are already setting the standards in this regard.
- Either fully utilise or permanently remove **excess mining equipment** and digging capacity from the mines. This will lead to better utilisation of the available mining equipment.

6.2.3 Mine planning (haulage distances)

Mine planning and production decisions should aim at optimising the current stripping activities and practices by:

- Optimising truck haulage distances to tips and dump sites.

6.2.4 Economies of scale

When current mining equipment is due for replacement, the mine must consider the latest proven technologies in mining equipment. In particular, the latest generations of trucks and shovels will improve the economies of scale of the mining operations. For example, the tons hauled per truck cycle on South African mines could be improved by up to 80% if local mines were to replace their existing truck fleets with the latest 360-t haulers. However, it is important to have an optimal truck-and-shovel match as a sub-optimal match will influence the truck loading times and ultimately the capital productivity of surface mining operations.

6.2.5 Key Performance indicators

Key Performance Indicators (KPIs) can be of great help to management in managing and improving a mine's productivity performance. KPIs for the measurement and management of material transportation, i.e. truck spotting times, dragline swings per hour, truck loading times, loading and hauling, and dumping parameters, could be implemented, tracked and monitored against the international benchmark on a regular basis.

6.2.6 Cast-blasting

Very few mines planned and scheduled cast-blasting as the primary method of moving overburden. In general, mine management agreed that cast-blasting had great potential as a cost-effective stripping method and that it was not being fully utilised on most surface mines. The possible benefits of cast-blasting should be established for every overburden blast. South African explosive suppliers provide this service to their customers free of charge.

6.3 Measure results against newly planned surface coal mines

As this study outlines the capital and labour investments on international best-practice operations, it is recommended that the findings of this study be used to measure the capital and labour investment on newly planned surface coal mines. The outcome could be used to update and improve the study results and the plans of the new mines.

6.4 Extend the survey to other surface mining operations

By extending this benchmark study to other surface mining operations, the exceptional best practices at these surface mines could be documented and transferred to South Africa's surface coal mines to further improve their current productivity performance.

6.5 Re-evaluate the South African coal surface mines on a yearly basis

The findings of this study reflect the productivity performance of South Africa's surface coal mines at a certain point in time. Due to the external and internal changes affecting the industry, its productivity performance will certainly change. In order to remain competitive and sustainable, it is important to know what the impact of these changes will be or has been on the industry. By monitoring the impacts of these changes, management could use the information collected for decision-making to achieve best practices.

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Appendix 1

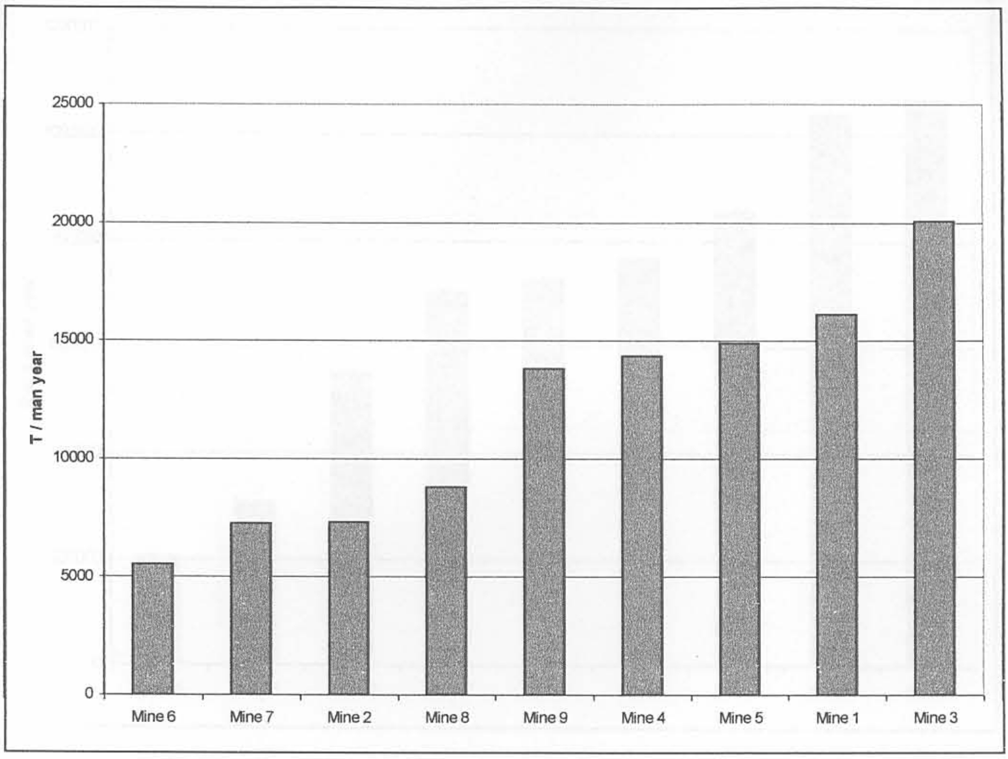


Figure 1: South African ROM tons per man-year, excluding contractors

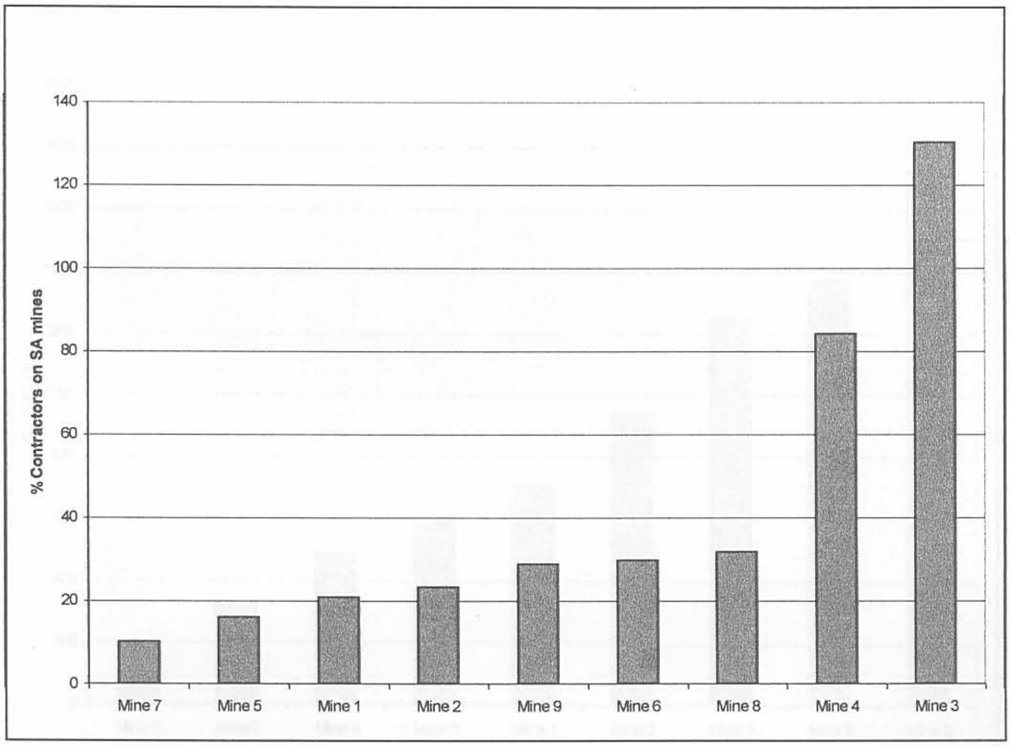


Figure 2: Contractors as a % of mine employees working on South African mines

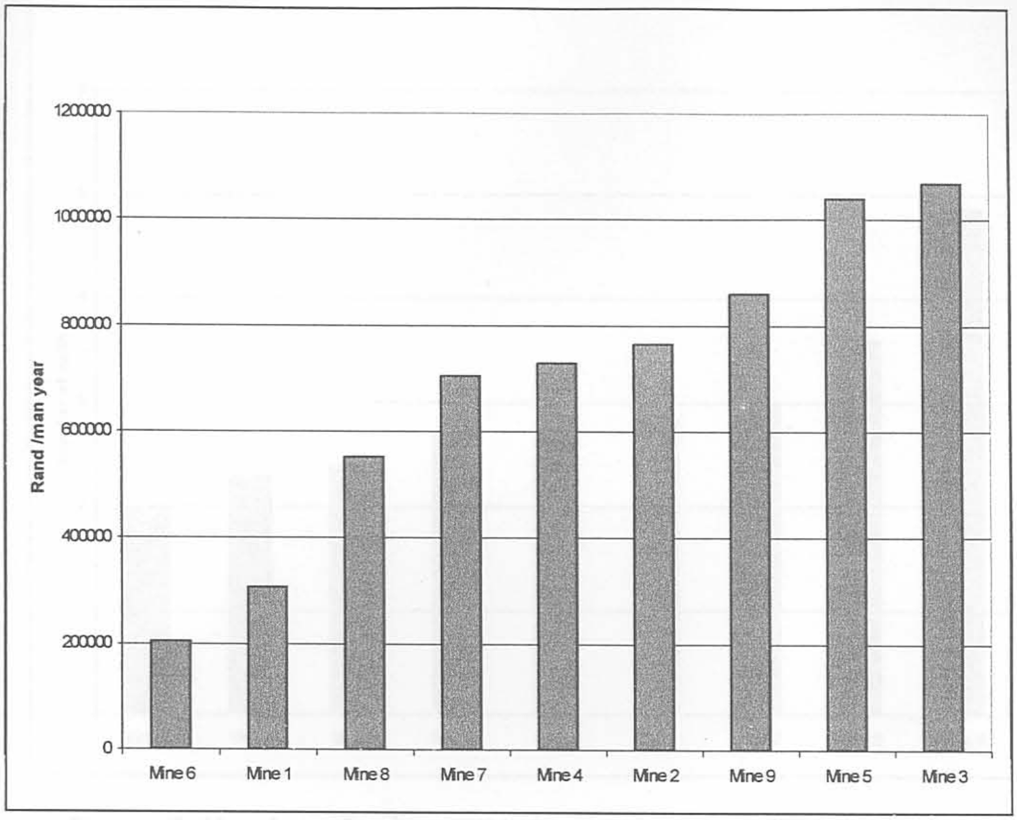


Figure 3: South African mining CAPEX per mine employee, including contractors

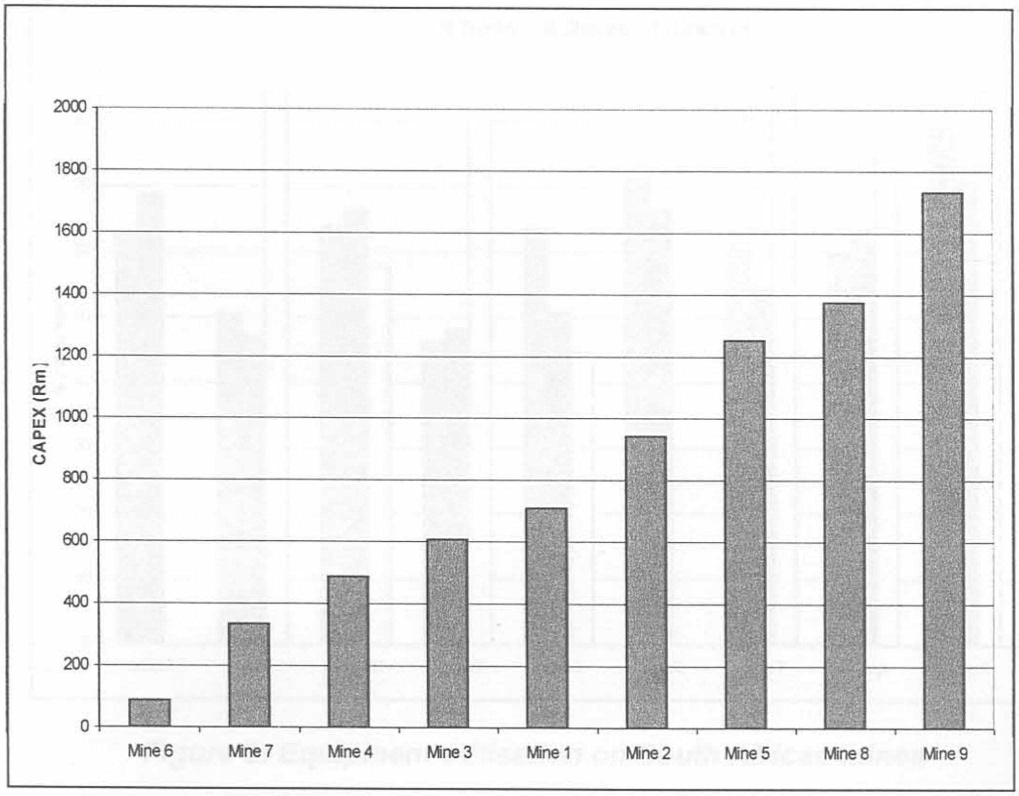


Figure 4: Capital invested on South African mines

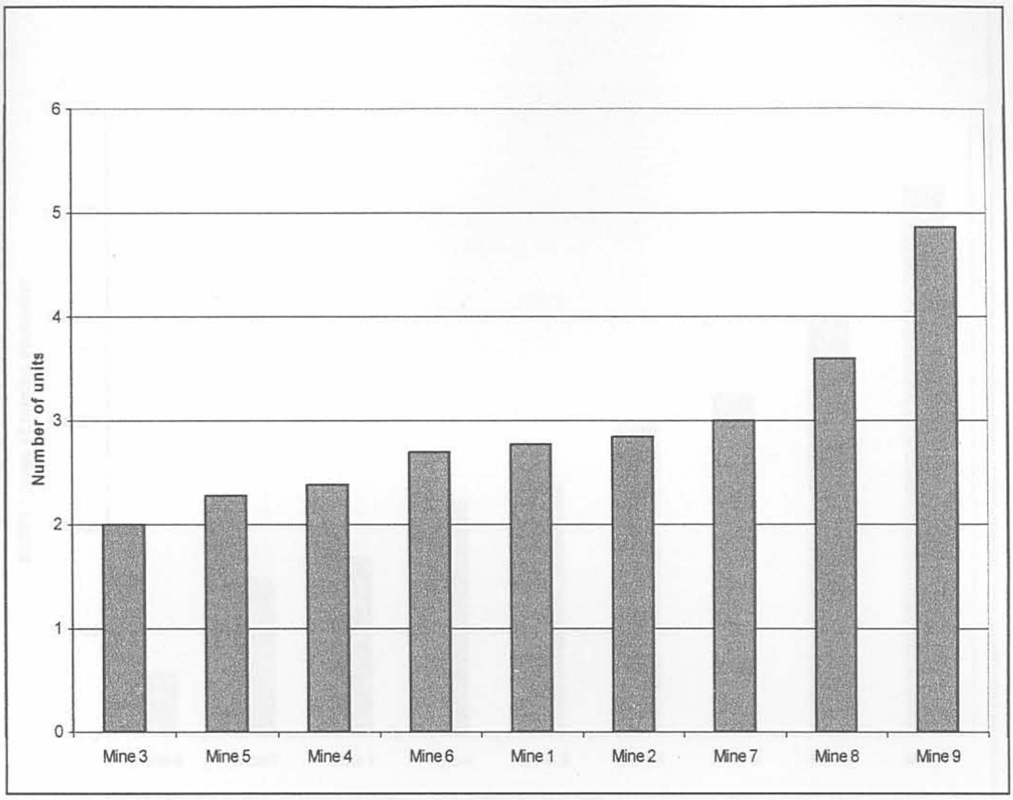


Figure 5: Number of primary equipment units per ancillary unit on South African mines

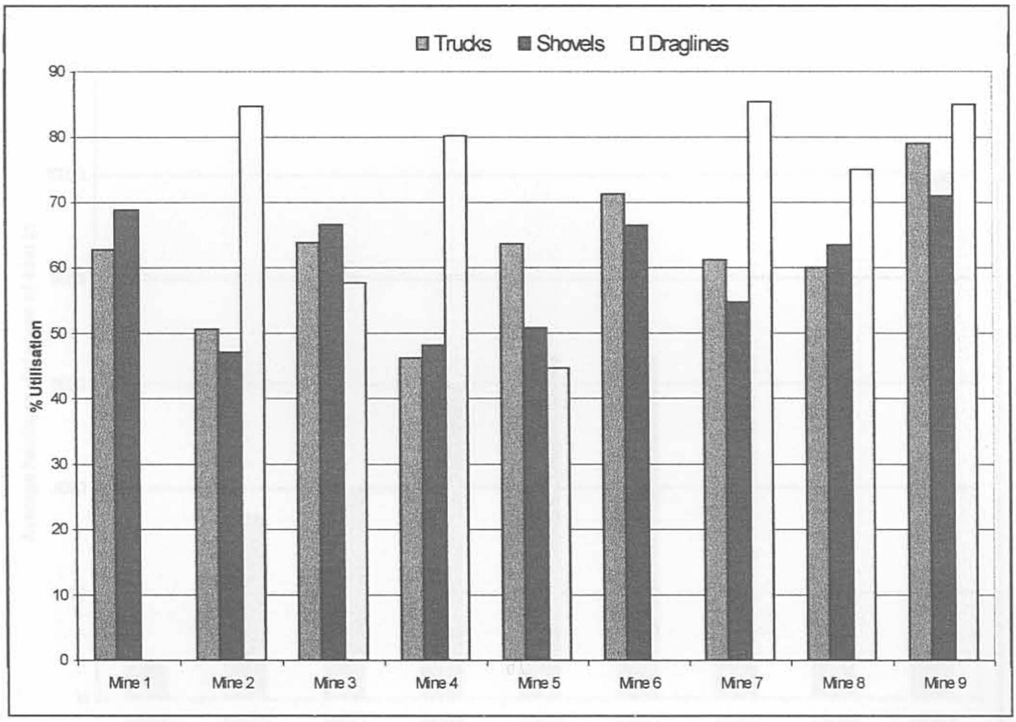


Figure 6: Equipment utilisation on South African mines

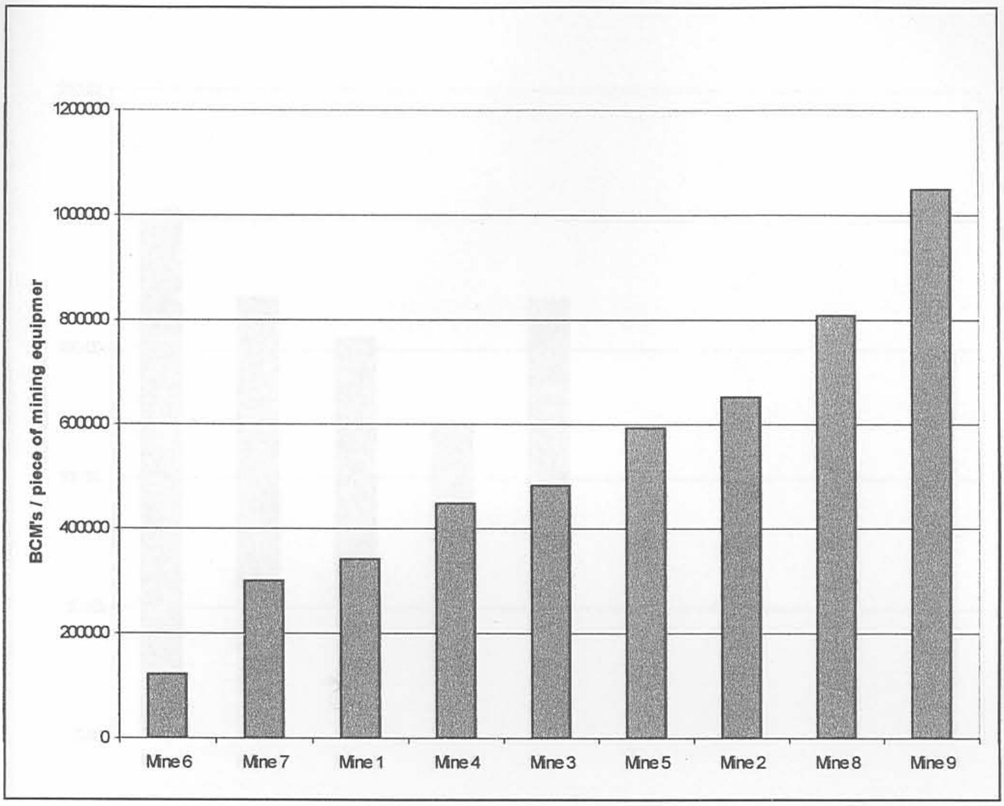


Figure 7: BCMs moved per mining equipment unit on South African mines

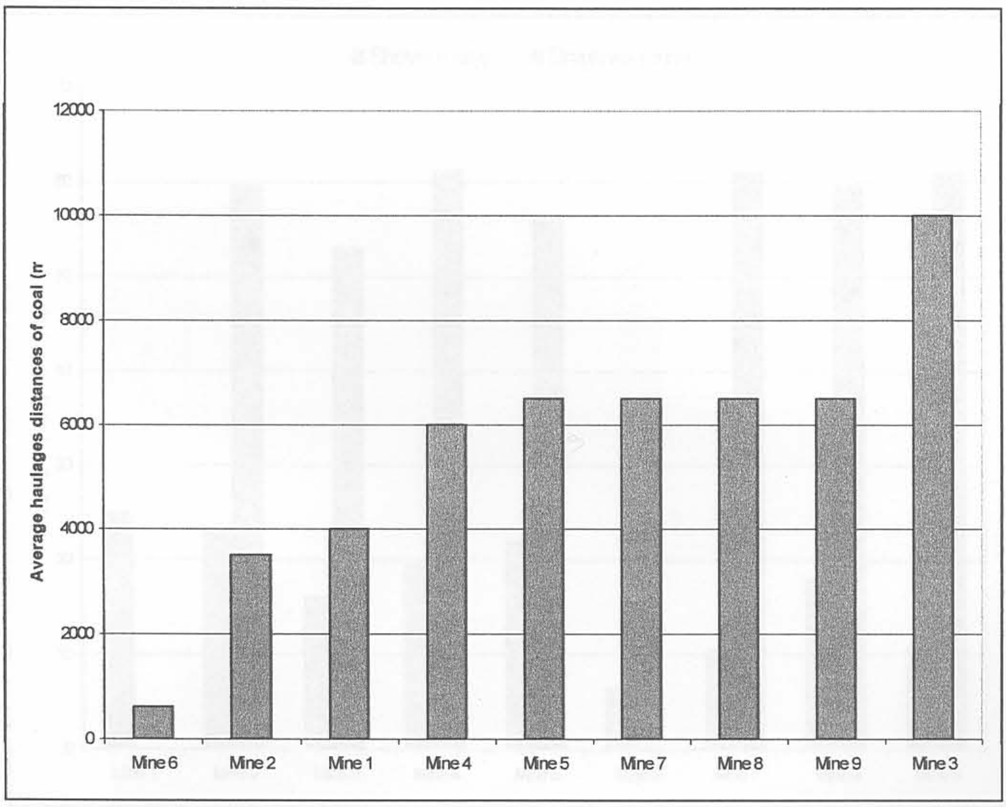


Figure 8: Average overburden haulage distances on South African mines

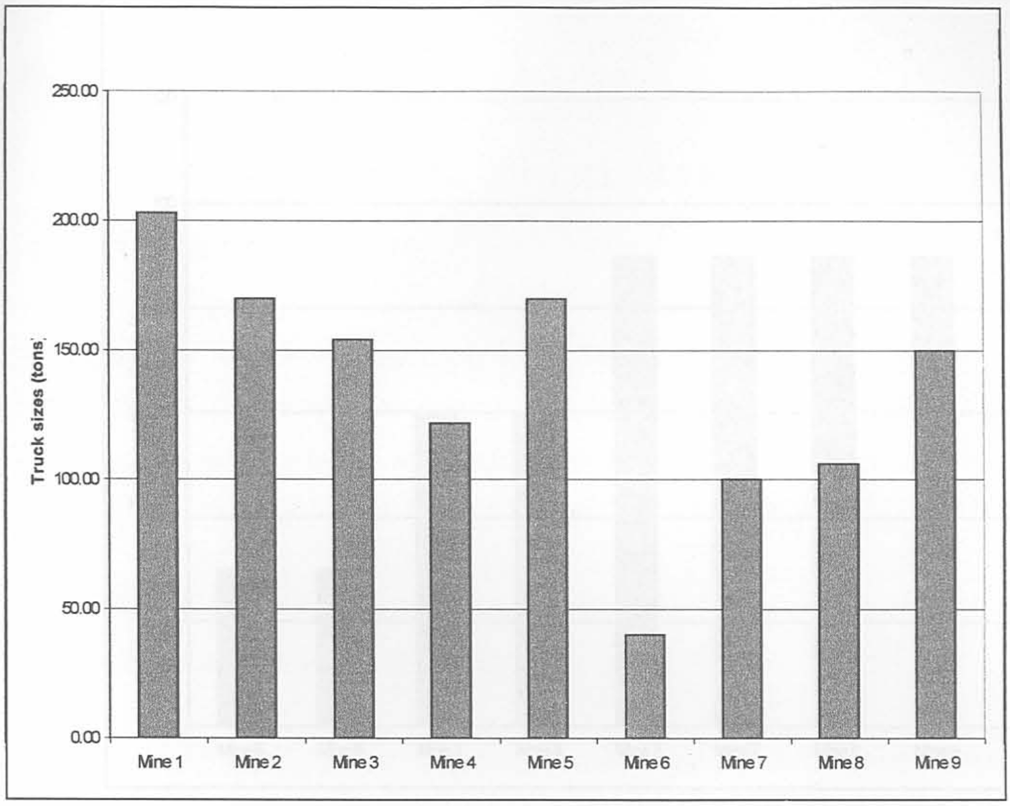


Figure 9: Sizes of haul trucks working on South African mines

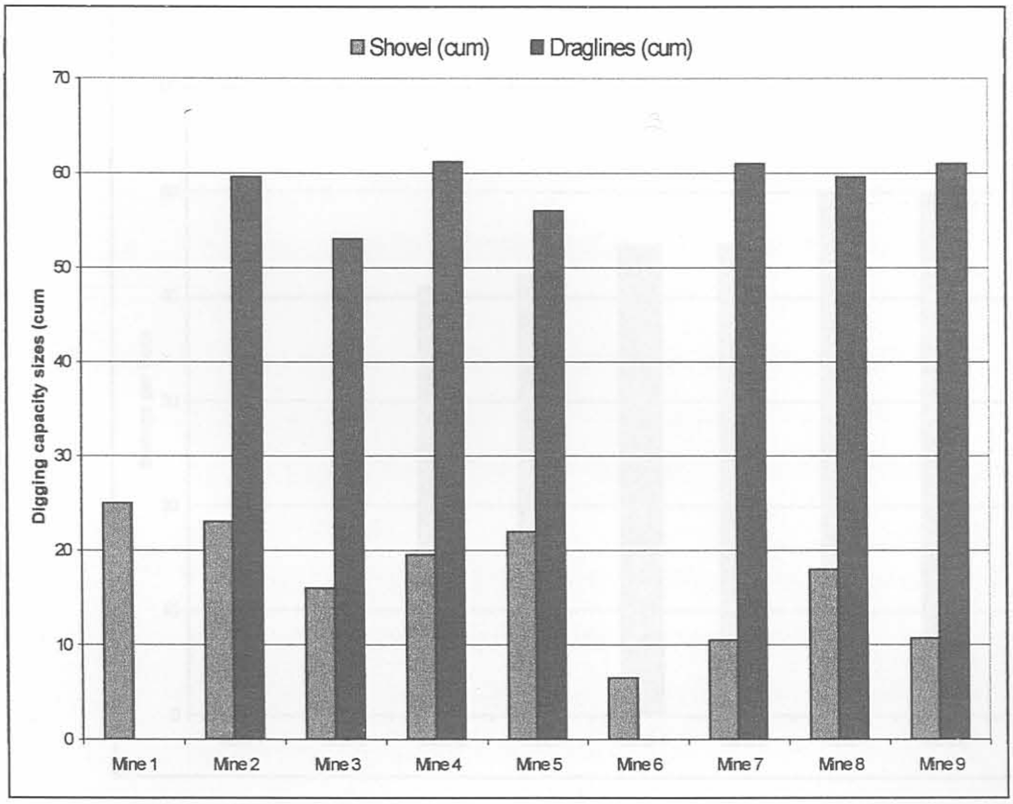


Figure 10: Digging capacity of shovels and draglines on South African mines

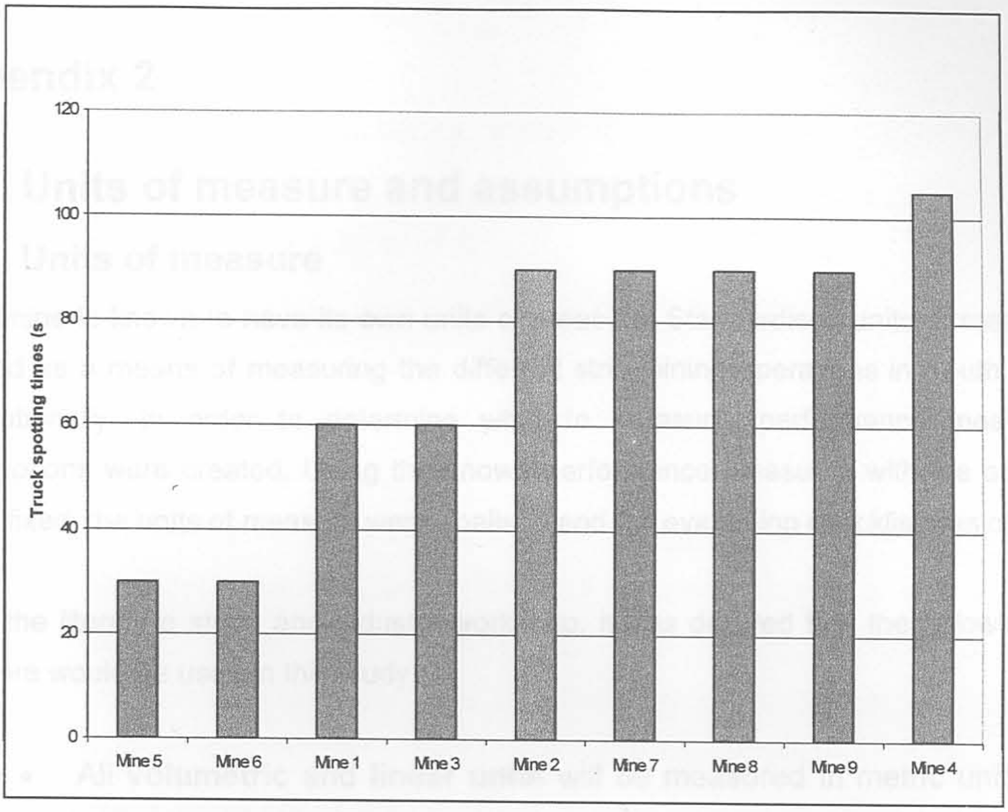


Figure 11: Truck spotting times on South African mines

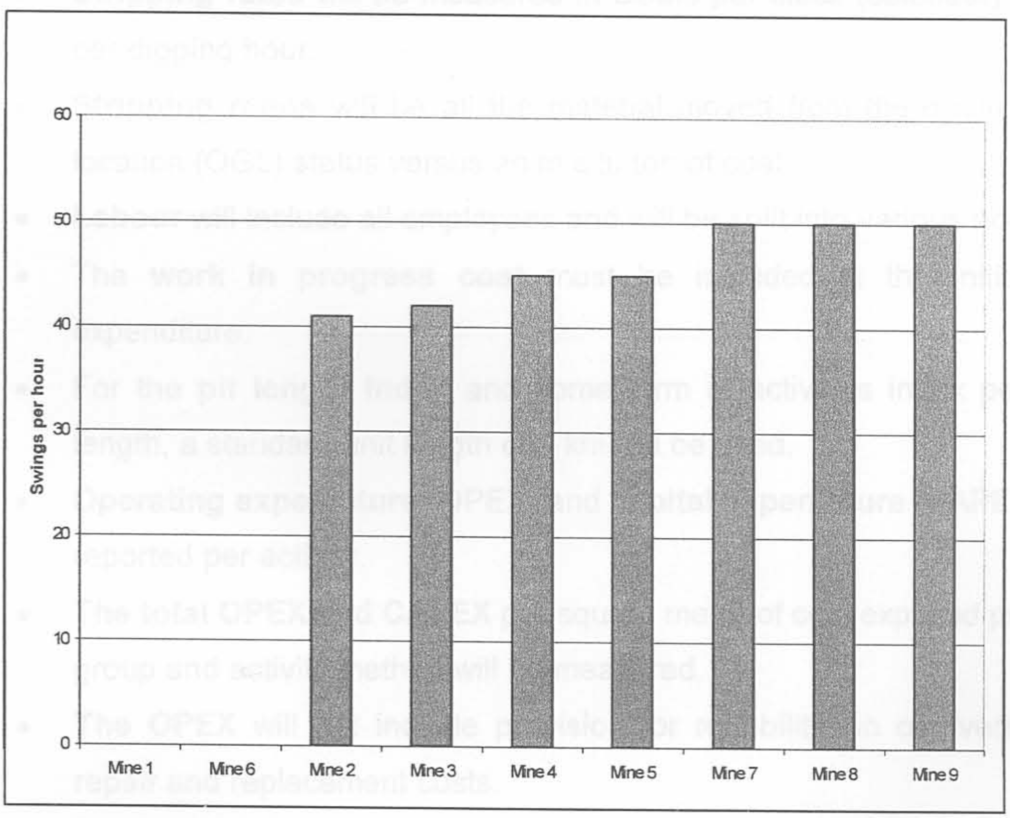


Figure 12: Dragline swings per hour on South African mines

Appendix 2

1. Units of measure and assumptions

1.1 Units of measure

Each mine is known to have its own units of measure. Standardised units of measure were created as a means of measuring the different strip-mining operations in South Africa and internationally. In order to determine what to measure, performance measures and assumptions were created. Using the known performance measures with the assumptions made fixed, the units of measure were finalised and the evaluation checklist was constructed.

From the literature study and industry workshop, it was decided that the following units of measure would be used in this study:

- All **volumetric** and **linear units** will be measured in metric units and not imperial units of measure.
- **Stripping rates** will be measured in BCMs per clock (calendar) hour and per digging hour.
- **Stripping ratios** will be all the material moved from the original ground location (OGL) status versus an in situ ton of coal.
- **Labour** will include all employees and will be split into various activities.
- The **work in progress cost** must be included in the initial capital expenditure.
- For the **pit length index** and some form of activities index per unit pit length, a standard unit length of 1 km will be used.
- **Operating expenditure** (OPEX) and **capital expenditure** (CAPEX) will be reported per activity.
- **The total OPEX and CAPEX** per square metre of coal exposed per activity group and activity method will be measured.
- **The OPEX** will not include provision for rehabilitation or overheads, or repair and replacement costs.

- **The CAPEX** will include repair and replacement, rehabilitation and overhead costs.
- **The seam dip** must be less than 10^{o}.

1.2 Assumptions made and fixed

For this study the following assumptions were made and fixed:

- Stripping evaluation will be based on the number of square metres of coal exposed per time frame.
- Processing costs must be dealt with as a separate issue.
- The cost curve should reflect OPEX per square metre of coal exposed.
- Direct OPEX should be used. This should exclude provision for rehabilitation and any other off-mine overheads. It must, however, include the provision made for repair and replacement (R&R).
- The capital cost for a stripping activity will be equal to the replacement value of that equipment. Thus the total capital deployed for a stripping activity will be equal to the sum of all the equipment-replacement costs for that activity.

Appendix 3

Benchmarking: Code of Conduct (BENSA, 1999)

1. Principle of ***legality***. Avoid discussions or actions that might lead to or imply an interest in restraint of trade, market or customer allocation schemes, price fixing, dealing arrangements, bid rigging, bribery or misappropriation. Do not discuss costs with competitors if costs are an element of pricing.

> Keep it legal
> Be willing to give what you get
> Respect confidentiality
> Keep information internal
> Use benchmarking contacts
> Don't refer without permission

2. Principle of ***exchange***. Be willing to provide the same level of information that you request in a benchmarking exchange.

3. Principle of ***confidentiality***. Treat benchmarking interchange as confidential to the individuals and organisations involved. Information that is obtained must not be communicated outside the partnering organisations without the prior consent of participating benchmarking partners. The fact that an organisation is participating in a study should not be communicated externally without its permission.

4. Principle of ***use***. Use the information obtained through benchmarking partnering only for the purpose of improving operations within the partnering organisations. External use or communication of a benchmarking partner's name with their data or observed practices requires permission from that partner. Do not, as a consultant or client, extend one organisation's benchmarking findings to another without the first organisation's permission.

5. Principle of ***first party contact***. Initiate contact, whenever possible, through a benchmarking contact designated by the partner organisation.

6. Principle of ***third party contact***. Obtain an organisation's permission before providing its name in response to a contact request.

7. Principle of **preparation**. Demonstrate commitment to the efficiency and effectiveness of the benchmarking process with adequate preparation at each process step, particularly at initial partnering contact.

Appendix 4

4.1 Additional information

Site visit: 1999- General and Truck & Shovel

Table 3.4.1a: Work practices in South African truck-and-shovel coal mines

	Practice
Total productivity	
3 Resource levels	
Staffing levels: ratio of labour hours worked to equipment hours worked	
Work time in shifts: time excluding leaving and joining shifts, meal and other breaks (per cent)	
Utilisation of truck fleet: hours operated as a percentage of total available hours	
Utilisation of major digging equipment: hours operated as a percentage of total available hours	
Work practices	
Hot-seat changes	
Meal breaks in the field	
Staggered meal breaks	
Operators move between equipment within shifts	
Haulage equipment fuelled in breaks	
Clean-up equipment does not impede production	

Table 3.4.1b: Key attributes of South African truck-and-shovel coal mines

	Practice mine
Efficient truck loading practices: incidence of double-sided or other efficient truck loading method (per cent)	
Spotting time of trucks under shovels (seconds)	
Truck loads per shovel per 8-hour shift	
Industrial disputes: days lost per thousand hours worked	
Safety: lost-time injuries per million man-hours	
Reportable per million man-hours	
Dressing station per million man-hours	
Fatalities per million man-hours	
4 General information	
Average round trip (m)	
Bonus scheme (no, bad or good)	

Dragline

Table 2.4.2: Productivity performance of dragline operations

	***Dragline output per hour* (BCM)**	***Bucket factor* (%)**	***Swings per hour* (number)**	***Bucket capacity* (LCM)**	***Equivalent dragline bucketfuls* (number/h)**
Queensland coal	1 901	92	51	41	47

4.2 The stripping activity checklist

Step 1

	Asset register for stripping operation								
	Equipment type, make and name : **Drills**	**Hole size (mm)**	**No. of units**	**Length of drill steel (m)**	**No. of passes per drill hole**		**Design capacity (m/h)**	**Actual operating capacity (m/h)**	**Operating cost (R/h)**
1	e.g. Drill: O&K Drillteck 25 KS	170 mm hole	2	10	1,8		100	80	150
2									
3									
4									
5									
	Trucks	**Size (t)**	**No. of units**	**Dump body size (m^3)**	**Power of truck (kW)**	**Diesel rate (litres/h)**	**Design capacity (m^3/h)**	**Actual operating capacity (m^3/h)**	**Operating cost (R/h)**
1									
2									
3									
4									
5									
	Shovels	**Size (SAE m^3)**	**No. of units**	**Digging force (kW)**	**Brake-out force (kW)**	**Diesel or electric**	**Design capacity in BCM (m^3/h)**	**Actual operating capacity in BCM (m^3/h)**	**Operating cost (R/h)**
1									
2									
3									
4									
5									
	Draglines	**Size**	**No. of units**	**Bucket size (SAE m^3)**	**Boom length (m)**	**Boom angle (°)**	**Design capacity (m^3/h)**	**Actual operating capacity (m^3/h)**	**Operating cost (R/h)**
1									
2									
3									
4									
5									

	Dozers	Size	No. of units	Blade capacity (m²)	Blade type (universal, straight/tilt, angle, etc.)	Blade capacity (SAE m^3)	Design capacity (m^3/h)	Actual operating capacity and doze distance (m^3/h & m)	Operating cost (R/h)
1									
2									
3									
4									
5									
	Ancillary	Size	No. of units	Bucket size	Primary function		Design capacity (units/h)	Actual operating capacity (units/h)	Operating cost (R/h)
1									
2									
3									
4									
5									
6									
7									
8									

Step 2. Drills

	Drilling equipment utilisation on stripping operation							
		% of time spent by equipment type as listed in Step 1 on stripping activity						
		e.g. O&K Drillteck 25 KS						
1	**Stripping activity**	-						
	Bush clearing	-						
	Topsoil removal	-						
	Subsoil removal	-						
	Highwall control	-						
	Blasting	-						
	Pre-stripping	15						
	Primary stripping	60						
	Coaling	5						
	Parting	15						
	Rehabilitation							
	Other	5						
2	**Total time on activity**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3	**Annual hours lost / equipment to:**							
	Shift change							
	Maintenance Planned							
	Maintenance Unplanned							
	Dead headings							
	Pad preparation							
	Relocation of equipment							
	Blasting							
	Other							
4	**Total annual hours lost per equipment**							
5	**Annual additional operating hours**							
	Sundays							
	Holidays							

Step 2. Trucks

	Truck equipment utilisation on stripping operation							
		% of time spent by equipment type as listed in Step 1 on stripping activity						
		e.g. CAT 777 (85t)						
1	**Stripping activity**							
	Bush clearing							
	Topsoil removal	10						
	Subsoil removal	60						
	Highwall control							
	Blasting							
	Pre-stripping							
	Primary stripping							
	Coaling							
	Parting							
	Rehabilitation							
	Other	30						
2	**Total time on activity**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3	**Annual hours lost / equipment to:**							
	Shift change	100						
	Maintenance - planned	1 000						
	Maintenance - unplanned	250						
	Dead headings	0						
	Pad preparation	0						
	Relocation of equipment	0						
	Blasting	500						
	Other	120						
4	**Total annual hours lost per equipment**	1 970						
5	**Annual additional operating hours**							
	Sundays	0						
	Holidays	0						

Step 2. Shovels

	Equipment utilisation on stripping operation							
		% of time spent by equipment type as listed in Step 1 on stripping activity						
		e.g. Cat 994 (20m3)						
1	**Stripping activity**	-						
	Bush clearing	-						
	Topsoil removal	-						
	Subsoil removal	-						
	Highwall control	-						
	Blasting	-						
	Pre-stripping	-						
	Primary stripping	-						
	Coaling	80						
	Parting	15						
	Rehabilitation							
	Other	5						
2	**Total time on activity**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3	**Annual hours lost / equipment to:**							
	Shift change	100						
	Maintenance - planned	1 200						
	Maintenance - unplanned	300						
	Dead headings	0						
	Pad preparation	0						
	Relocation of equipment	0						
	Blasting	1 000						
	Other	100						
4	**Total annual hours lost per equipment**	2 700						
5	**Annual additional operating hours**							
	Sundays	500						
	Holidays	120						

Step 2. Draglines

	Equipment utilisation on stripping operation							
		% of time spent by equipment type as listed in Step 1 on stripping activity						
		e.g. Dragline						
1	**Stripping activity**							
	Bush clearing							
	Topsoil removal							
	Subsoil removal							
	Highwall control							
	Blasting							
	Pre-stripping							
	Primary stripping	100						
	Coaling							
	Parting							
	Rehabilitation							
	Other							
2	**Total time on activity**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3	**Annual hours lost / equipment to:**							
	Shift change	50						
	Maintenance Planned	500						
	Maintenance Unplanned	100						
	Dead headings	70						
	Pad preparation	50						
	Relocation of equipment	150						
	Blasting	200						
	Other	0						
4	**Total annual hours lost per equipment**	1 120						
5	**Annual additional operating hours**							
	Sundays	600						
	Holidays	288						

Step 2. Dozers

	Equipment utilisation on stripping operation							
		% of time spent by equipment type as listed in Step 1 on stripping activity						
		e.g. Dozer						
1	**Stripping activity**							
	Bush clearing	20						
	Topsoil removal	40						
	Subsoil removal							
	Highwall control							
	Blasting							
	Pre-stripping							
	Primary stripping							
	Coaling							
	Parting							
	Rehabilitation	40						
	Other							
2	**Total time on activity**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3	**Annual hours lost / equipment to:**							
	Shift change	200						
	Maintenance - planned	1 000						
	Maintenance - unplanned	500						
	Dead headings	0						
	Pad preparation	0						
	Relocation of equipment	0						
	Blasting	0						
	Other	100						
4	**Total annual hours lost per equipment**	1 800						
5	**Annual additional operating hours**							
	Sundays	0						
	Holidays	0						

Step 2. Ancillary

Equipment utilisation on stripping operation							
	% of time spent by equipment type as listed in Step 1 on stripping activity						
	e.g. Watercar						
1 Stripping activity	-						
Bush clearing	-						
Topsoil removal	-						
Subsoil removal	-						
Highwall control	-						
Blasting	-						
Pre-stripping	-						
Primary stripping							
Coaling	70						
Parting	20						
Rehabilitation							
Other	10						
2 Total time on activity	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
3 Annual hours lost / equipment to:							
Shift change	120						
Maintenance - planned	1 000						
Maintenance - unplanned	200						
Dead headings	0						
Pad preparation	0						
Relocation of equipment	0						
Blasting	0						
Other	50						
4 Total annual hours lost per equipment	1 370						
5 Annual additional operating hours							
Sundays	0						
Holidays	0						

Step 3

	Labour sheet	
1	**Time**	*Annual hours*
	Annual available hours	8 760
	- Annual external hours lost:	
	Sundays	
	Holidays	
	Weather	
	Other	
2	**Annual hours available for production**	
3	**Labour**	**Number of people**
	Total labour component on mine	
	Management	
	Plant labour	
	Human resource labour	
	Plant maintenance labour	
	Mining maintenance labour	
	Admin. labour	
	Services labour	
	Non-mining contractors	
	Other	
	Total labour in mining	
	+ Bush clearing	
	+ Topsoil removal	
	+ Subsoil removal	
	+ Pre-stripping	
	+ Highwall control	
	+ Drilling	
	+ Blasting	
	+ Primary stripping	
	+ Coaling	
	+ Parting	
	+ General labour (pump, road crew, etc.)	
	Mining contractors	

Step 4

	Production sheet							
1	**Production activity**	**Area cleaned / annum (m^2/annum)**	**BCMs moved / annum (m^3)**	**TCMs moved per annum**	**% Rehandle (as % of BCMs moved)**	**% Blast gain (as % of BCMs moved)**	**Powder factor (kg/m^3)**	**Total cost / annum**
	Bush clearing							
	Topsoil removal							
	Subsoil removal							
	Highwall control							
	Blasting							
	Pre-stripping							
	Primary stripping							
	Coaling							
	Parting removal							
	Rehabilitation							
	Survey method							
2	**Total production**							
		Length (m)	**Width (m)**					
3	**Pit 1**							
	2							
	3							
	4							
4	**Total length of pit mined per annum (m)**							

***Please complete a production sheet for each stripping operation.**

Step 5

	Geology sheet					
1	**Coal seam**					
	Name	**Thickness (m)**	**Effective stripping ratio**	**Depth below surface (m)**	**m^2 coal exposed / annum**	**Actual stripping ratio**
	1					
	2					
	3					
	4					
	5					
	6					
2	**Information**	**Material thickness (m)**	**Bench height (m)**	**In situ density(t/ m^3)**	**Compressive strength (MPa)**	**Blasted or free digging**
	Bush clearing					
	Topsoil: Softs					
	Hards		---			
	Subsoils: Softs					
	Hards		---			
	Pre-stripping: Softs					
	Hards		---			
	Primary stripping: Softs					
	Hards		---			
	Coal seam 1					
	Coal seam 2					
	Coal seam 3					
	Coal seam 4					
	Coal seam 5					
	Parting 1					
	Parting 2					
	Parting 3					
	Parting 4					
	Parting 5					

Step 1

This step involves listing the capital equipment needed to do the stripping of overburden, coal and interburden material for the last financial year. This is done by:

1.1 Listing all the equipment involved with the stripping operation. For each piece of equipment:

- Give its full name and description as outlined by the equipment supplier.
- Describe the equipment size in carrying capacity, full size, blade size, etc.
- Describe the bucket size of the dump body, bucket, etc. in volumetric units (m^3) and push blades of dozer in cubic metres (m^3).
- The amount or number of the same units in operation or active in the stripping process.
- Give the design capacity of the equipment as indicated by the equipment supplier in BCM, metres, etc. per operating hour.
- Give the operating capacity of the equipment by obtaining the BCMs moved or metres drilled by the equipment per annum and dividing that by its annual total hours obtained from Step 2.
- Adding all the fixed and variable costs per hour associated with the equipment will result in the total cost per hour. This cost figure should include associated labour, maintenance, fuel and electricity costs and provision for repair and overhaul cost. It should exclude overhead and replacement costs.

Step 2

This step involves listing for each piece of equipment its annual time in hours spent on each stripping activity and annual time in hours lost due to internal stoppages for the last financial year. Each equipment group listed in Step 1 has its own Step 2 form.

2.1 The time spent on each activity is done by:

- Listing each equipment type in the equipment row.

- Determining the percentage of time each item of equipment spends on the associated stripping activity as a percentage of its total operating hours (no time allowed for time losses).

2.2 The sum of the time spent by each item of equipment on each mining activity must be 100%.

2.3 The annual internal hours per equipment type lost to shift change, maintenance - planned, maintenance - unplanned, dead headings, pad preparation, relocation of equipment, blasting and other hours lost is expressed in annual hours and is obtained from the record-keeping system on or of each machine type.

2.5 Adding the equipment operating hours for public holidays and Sundays will give the additional operational hours per annum.

Step 3

This step involves listing the time available for production and the labour component on the mine that was involved in each department for the last financial year.

3.1 The time calculation is done by:

- Using the annual calendar hours (calendar hours = 8 760).
- Deducting the annual external hours lost will result in the annual hours available for production.
- Adding the time in hours lost to Sundays, public holidays and weather conditions will result in the annual external hours lost.

3.2 The labour calculation is done by:

- Listing the labour component for each department on the mine.
- Adding the number of people listed in each department row will result in the total labour on the mine.

- Dividing the mining labour into the number of labour associated with each stripping activity will result in the associated number of people/labour employed per activity.

Step 4

This step involves listing the annual square metres of area cleared, the BCMs moved, the percentage rehandle, the percentage blast gain, the total cost for each mining activity and the powder factor realised by blasting for each associated activity active during the previous financial year.

4.1 The production activity projections are done by:

- Multiplying the width of the cut by the total length of material cleared per annum for each stripping activity will result in the area cleared per annum.
- Multiplying the area cleared per annum by the associated total thickness will result in the BCMs moved per annum for each stripping activity.
- Total cubic metres (TCMs) is the total volume of BCMs moved by the equipment.
- Dividing the BCMs rehandled by the total amount of BCMs moved per annum will result in the percentage of BCMs rehandled.
- Dividing the BCMs moved by blasting by the total amount of BCMs moved per annum will result in the percentage blast gain.
- Dividing the kilograms of explosives used by the associated BCM will result in the powder factor.
- Adding all the total fixed and total variable costs associated with each activity will result in the total cost per annum. This cost figure should include associated labour, maintenance, fuel, electricity costs and provision for repair and overhaul costs. It should exclude overhead and replacement costs.

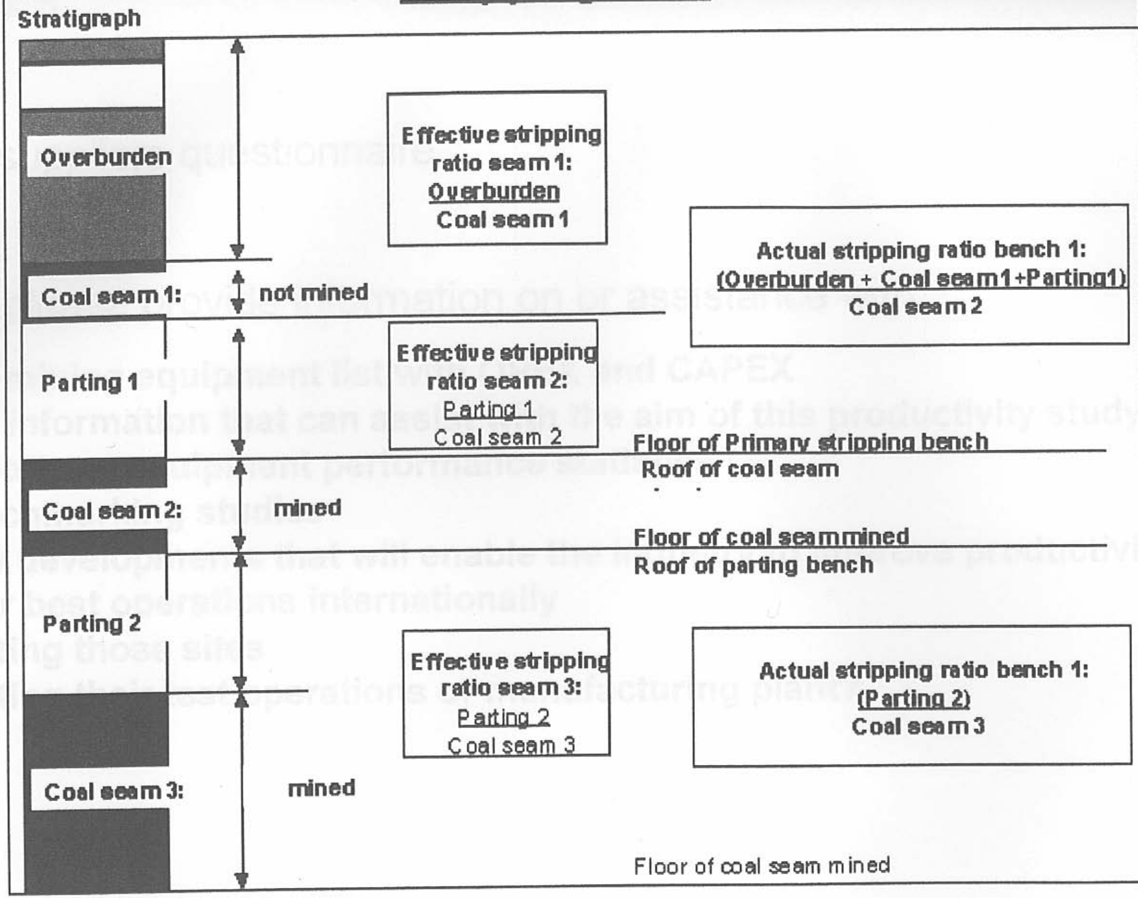
Step 5

This step involves listing the geological conditions present on the mine during the last financial year.

5.1 The information projections for the coal seams are done by:

- Listing all the coal seams present in each stripping operation and listing each one's associated thickness in metres.
- To calculate the effective stripping ratio of each coal seam, see Figure 1. The effective stripping ratio is derived by dividing a coal seam's overlying waste material thickness in metres by the coal seam's thickness in metres.
- Listing the depth from surface to the top of each coal seam for the depth below surface.
- Multiplying the width of the cut by the total length of a coal seam exposed per annum will result in the m^2 of coal exposed/annum.
- To calculate the actual stripping ratio of each coal seam mined, see Figure 1. The actual stripping ratio is derived by dividing the BCMs by the in situ mineable coal tons available in that pit.

Stripping ratio



Appendix 5

Industry suppliers questionnaire.

Can you please provide information on or assistance with:

- **Full mining equipment list with OPEX and CAPEX**
- **Any information that can assist with the aim of this productivity study**
- **Reports or equipment performance statistics**
- **Benchmarking studies**
- **New developments that will enable the industry to improve productivity**
- **Your best operations internationally**
- **Visiting those sites**
- **Visiting their test operations or manufacturing plant?**