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/m³)	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.

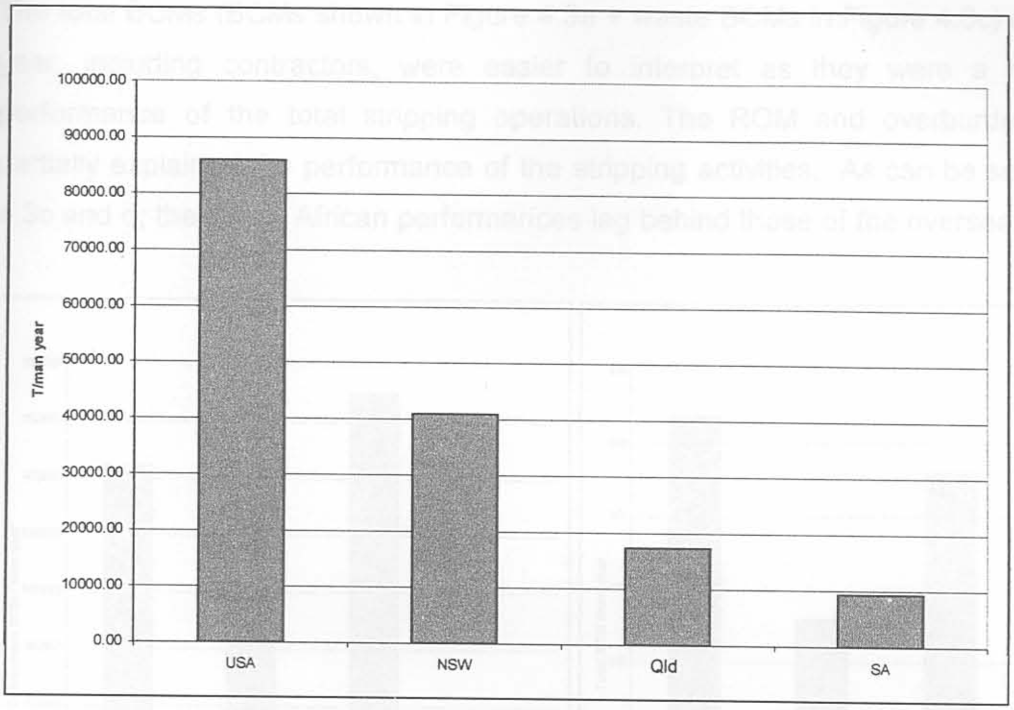

Figure 4.3a: ROM tons per man-year, including contractors

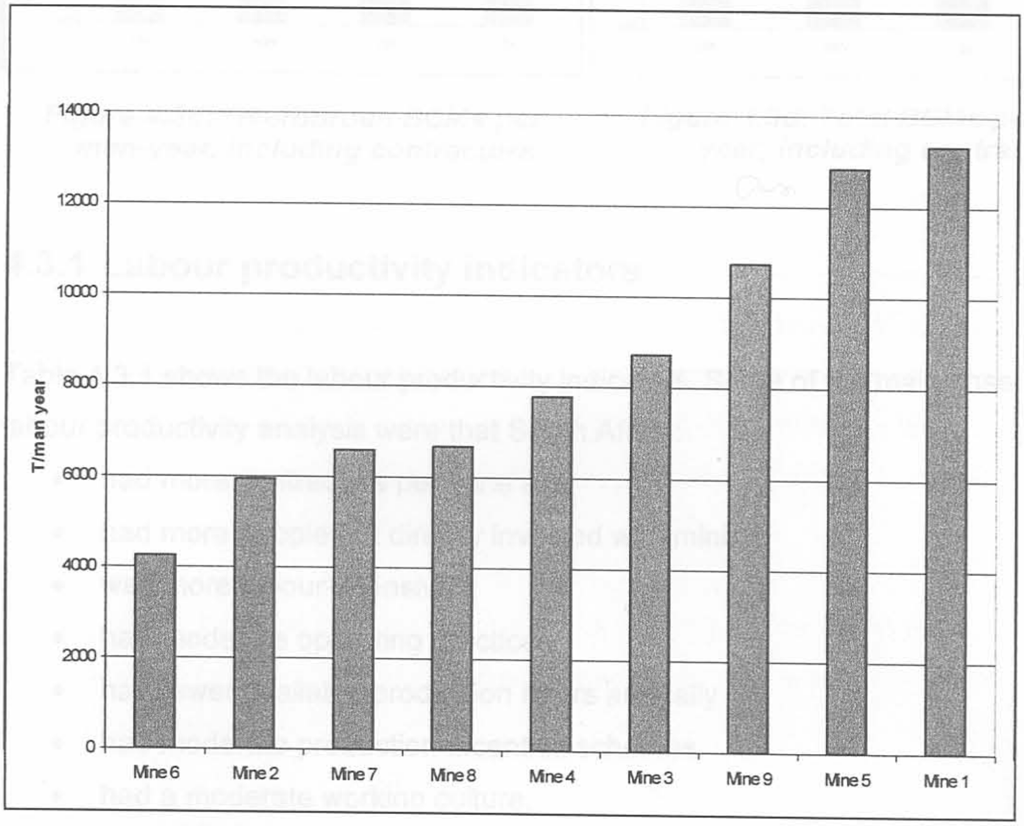

Figure 4.3b: South African ROM tons per man-year, including contractors

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.

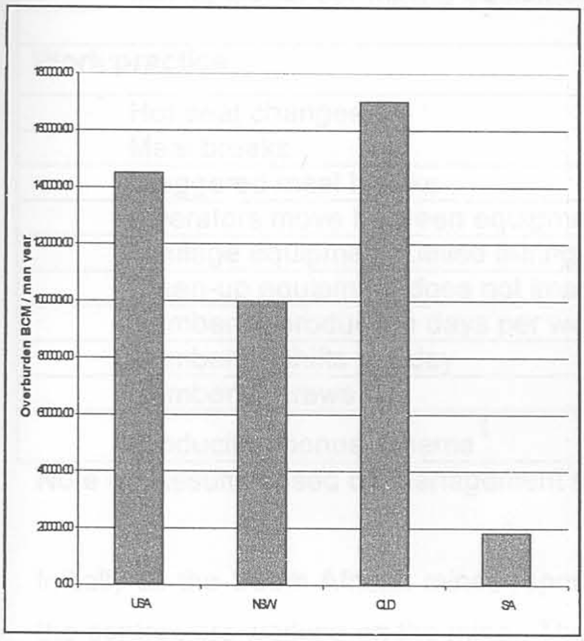

Figure 4.3c: Overburden BCMs per man-year, including contractors

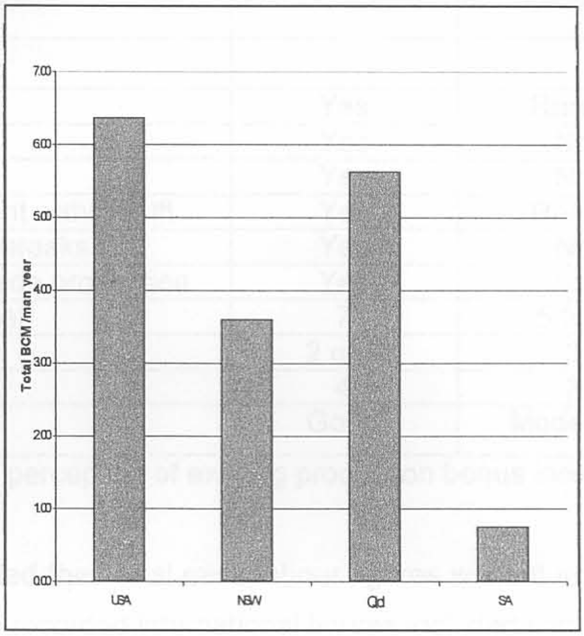

Figure 4.3d: Total BCMs per man-year, including contractors

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.

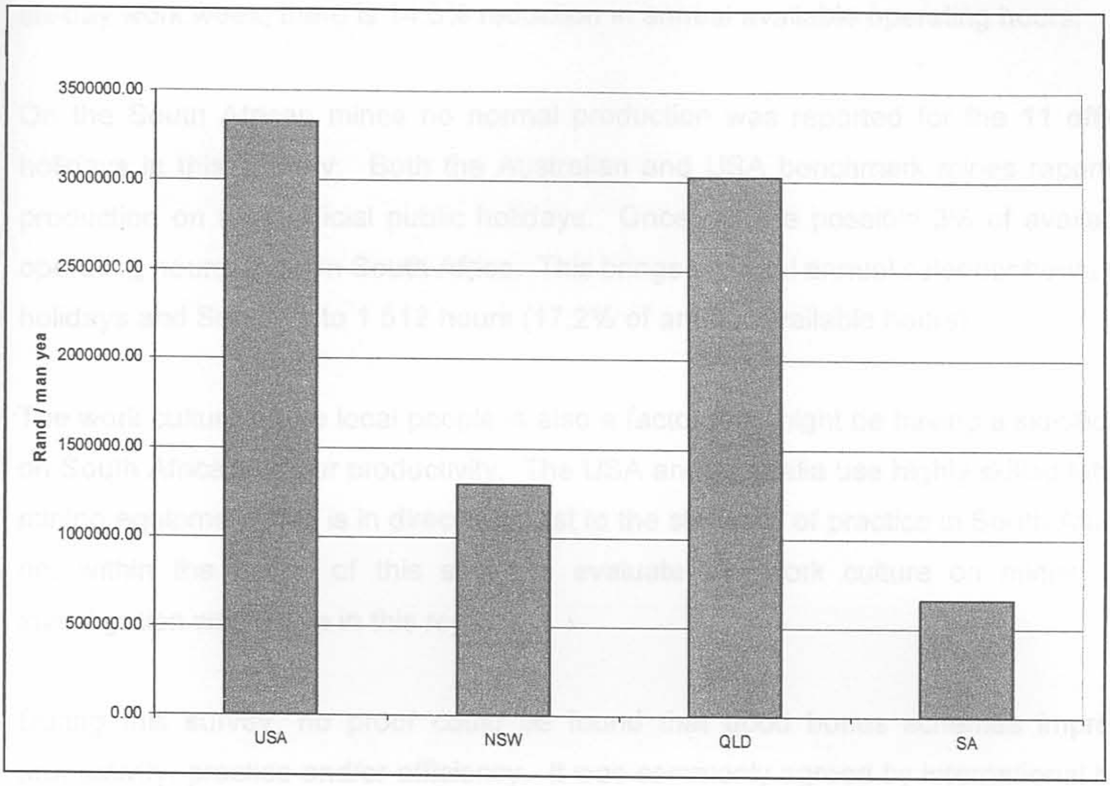

Figure 4.3.1: Mining CAPEX per mine employee, including contractors

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.

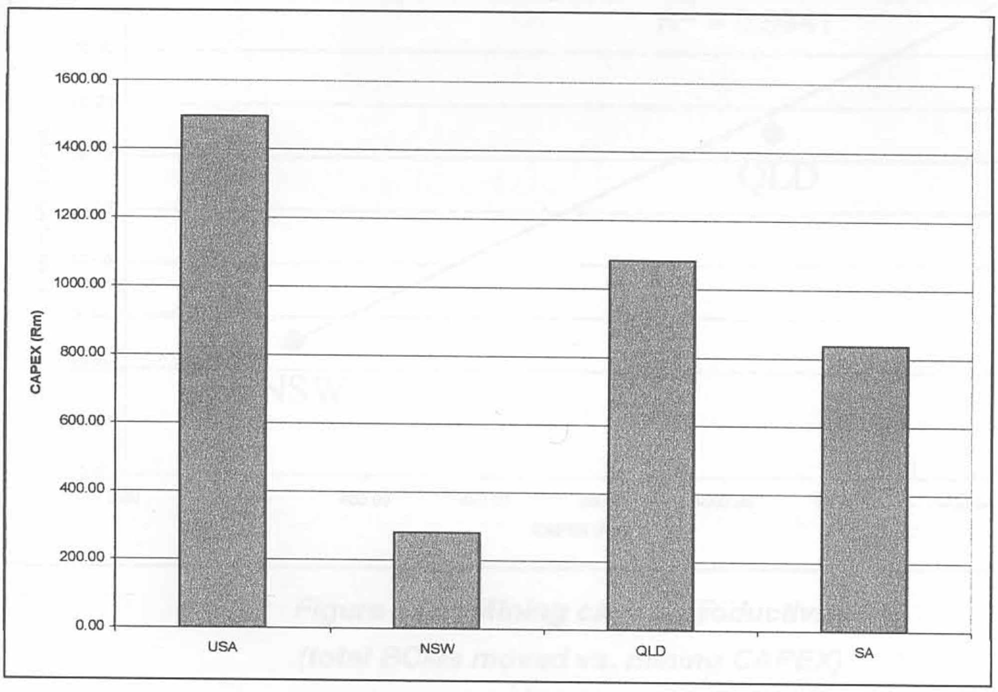

Figure 4.5a: Average mining capital invested on a benchmark mine

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.

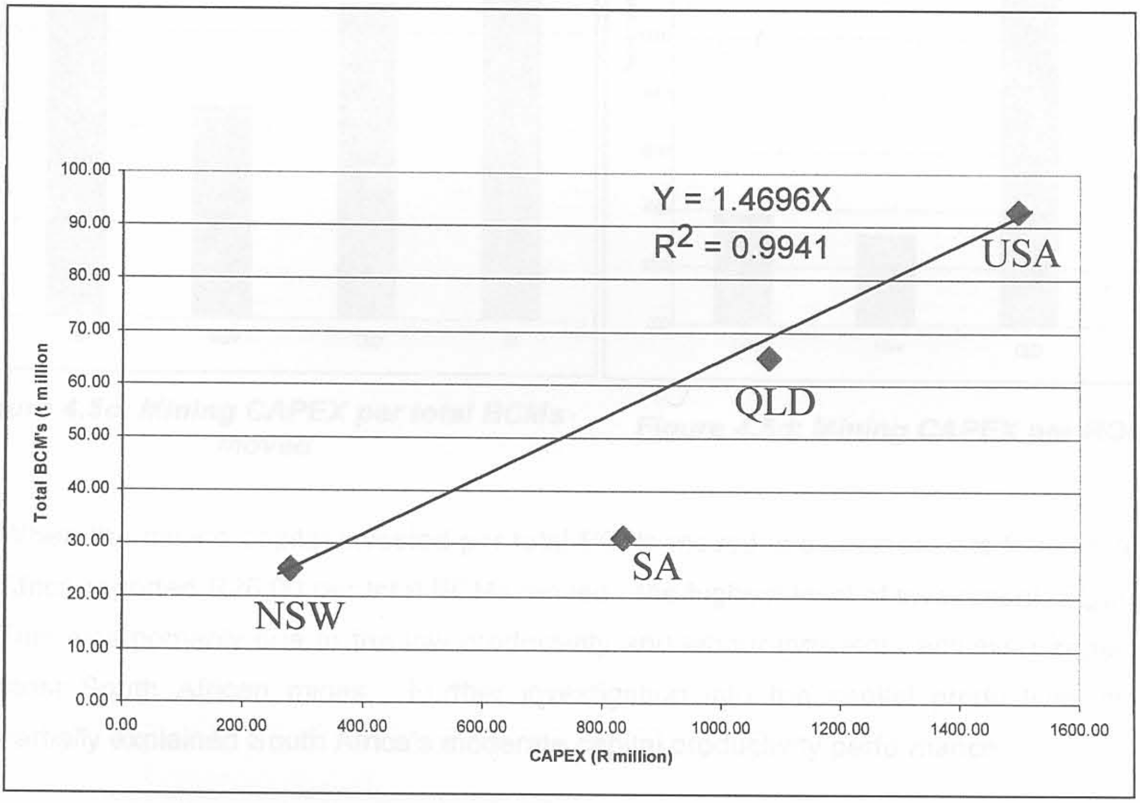

Figure 4.5b: Mining capital productivity (total BCMs moved vs. mining CAPEX)

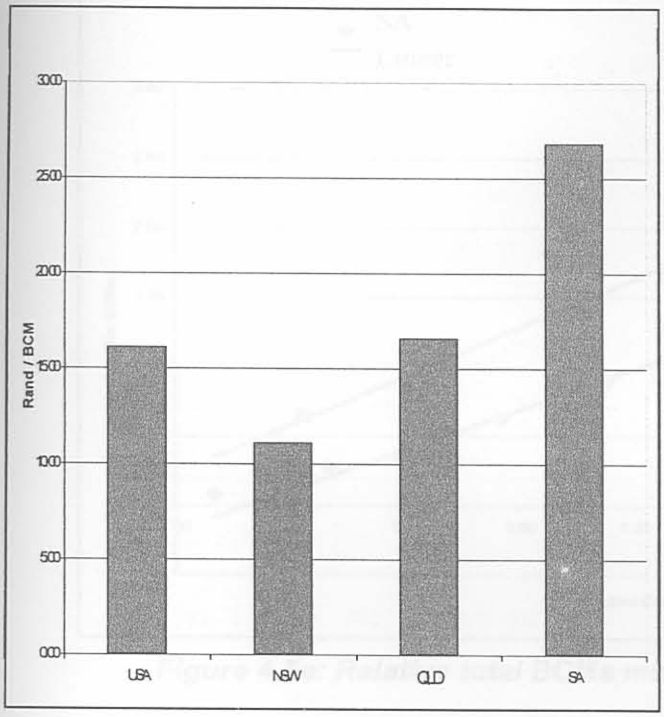

Figure 4.5c: Mining CAPEX per total BCMs moved

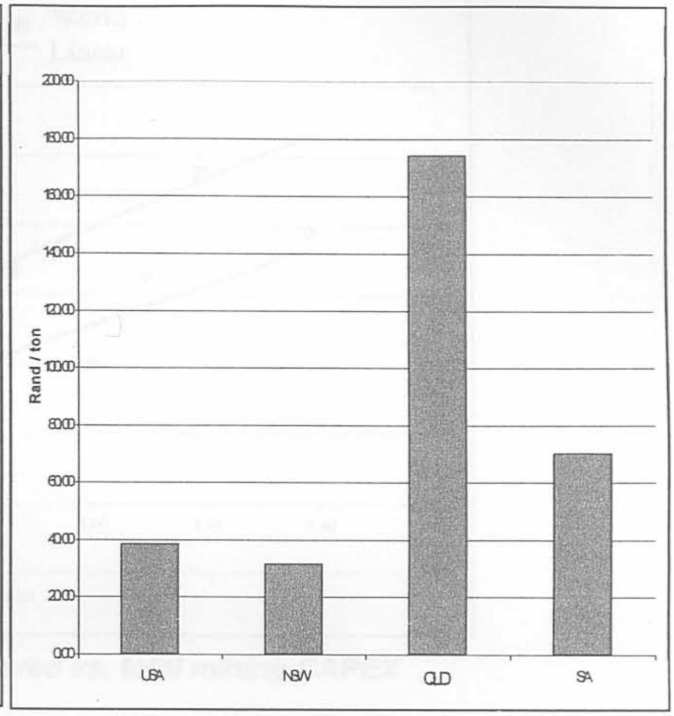

Figure 4.5d: Mining CAPEX per ROM tons

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.

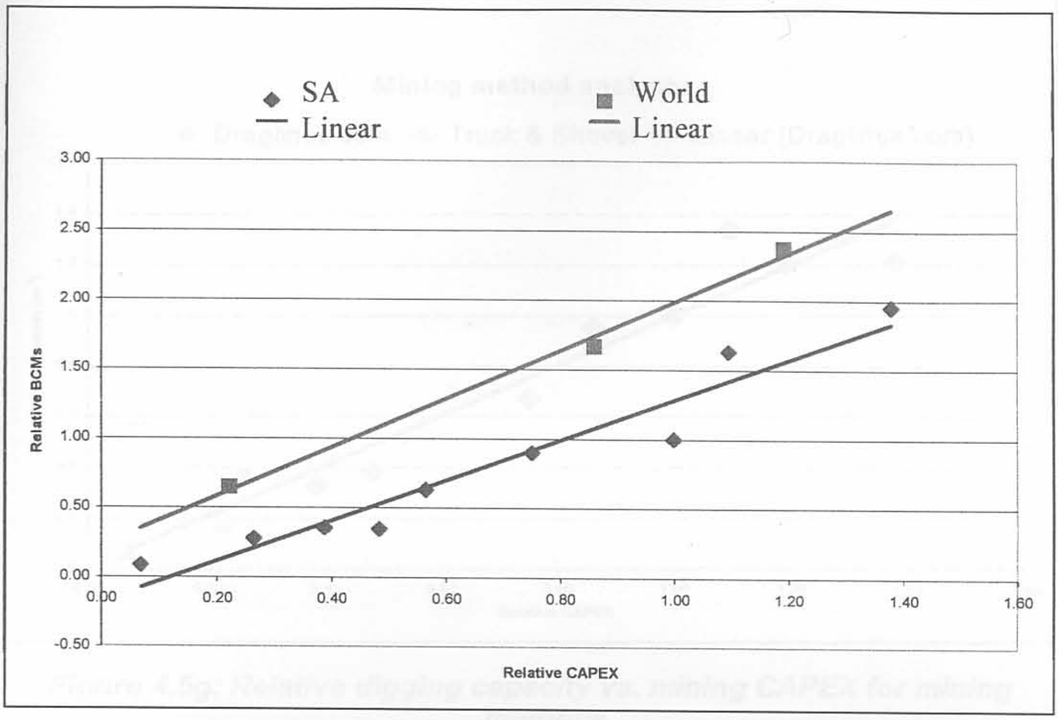

Figure 4.5e: Relative total BCMs moved vs. total mining CAPEX

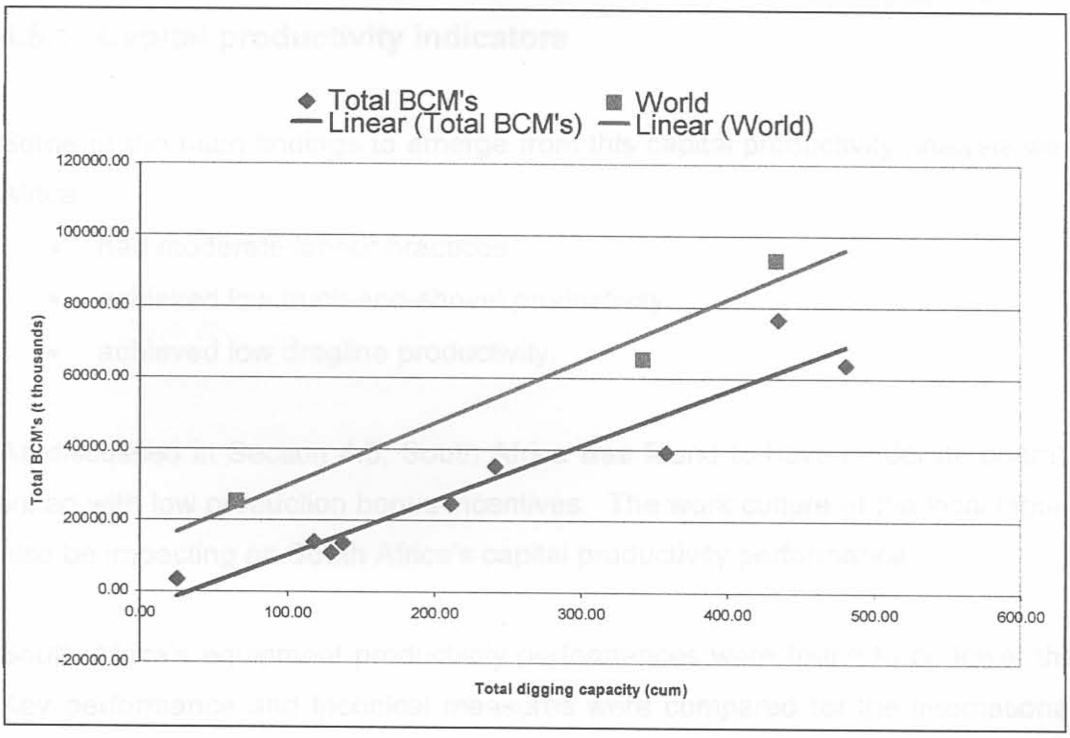

Figure 4.5f: Total BCMs moved vs. total digging capacity

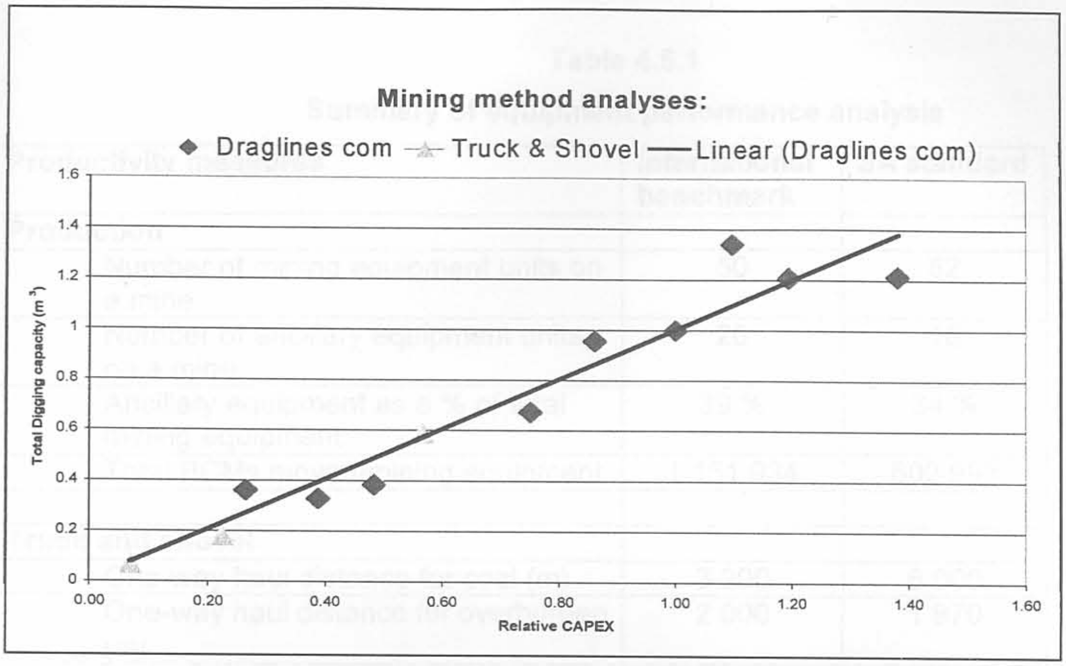

Figure 4.5g: Relative digging capacity vs. mining CAPEX for mining methods

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.)

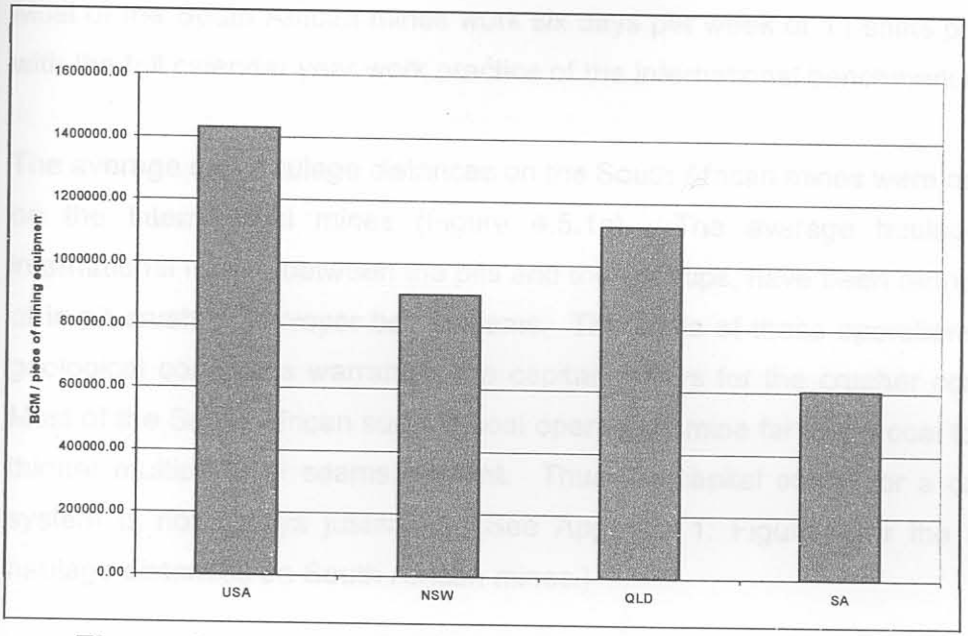

Figure 4.5.1.a:Total BCMs per mining equipment unit

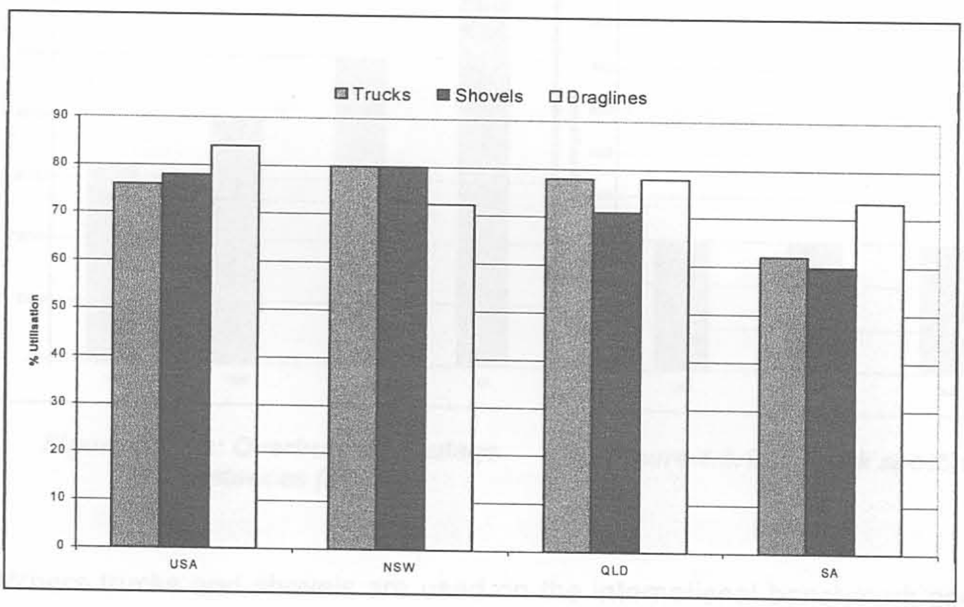

Figure 4.5.1.b: Equipment utilisation

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.)

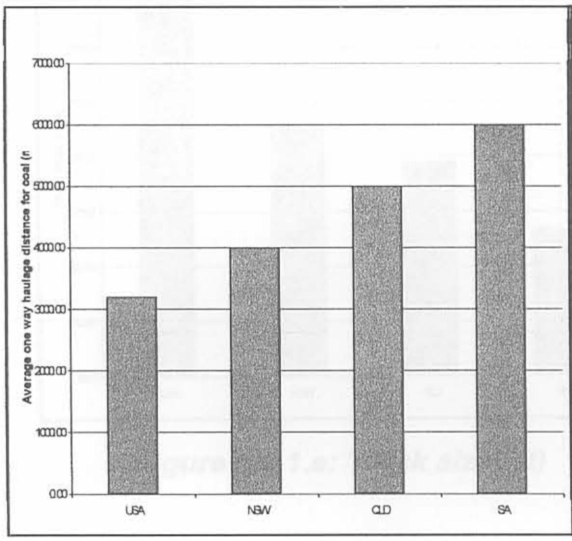

Figure 4.5.1.c: Overburden Haulage distances (m)

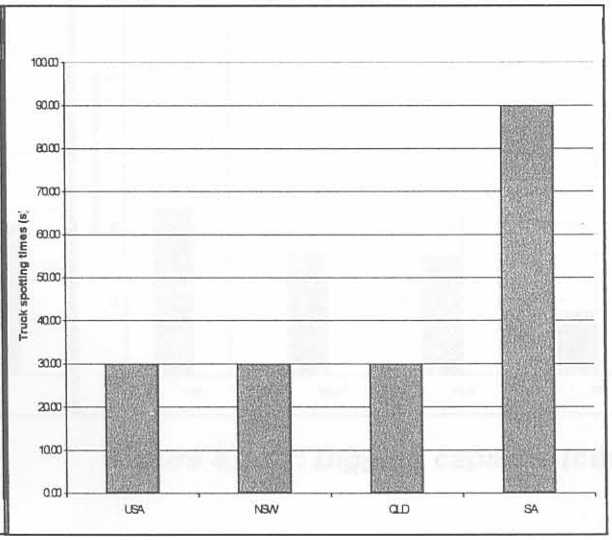

Figure 4.5.1.d: Truck spotting times (s)

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.

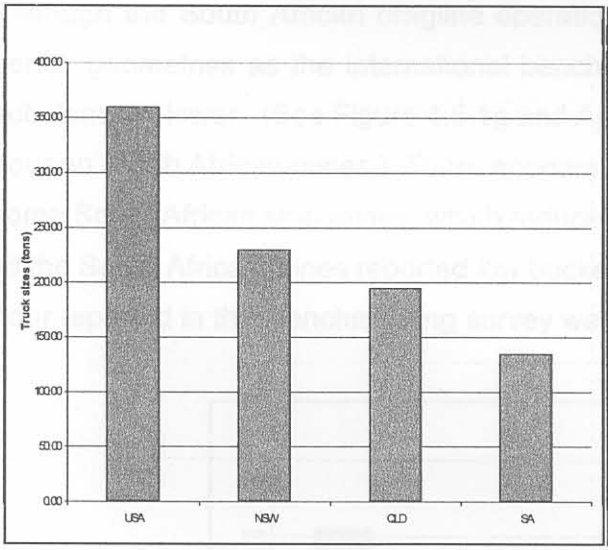

Figure 4.5.1.e: Truck sizes (t)

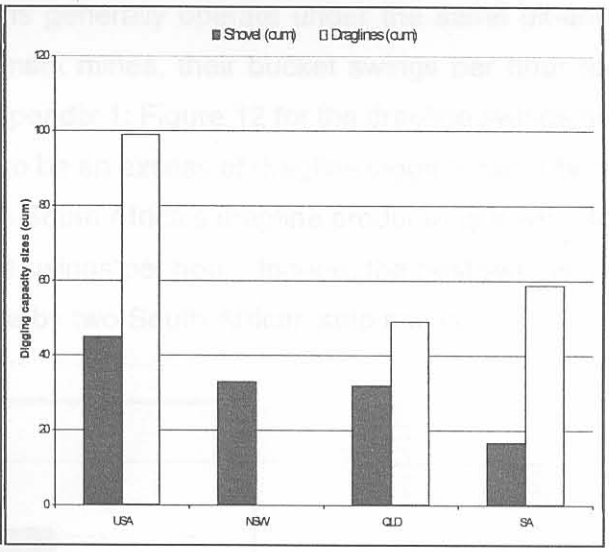

Figure 4.5.1.f: Digging capacity (cum)

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.

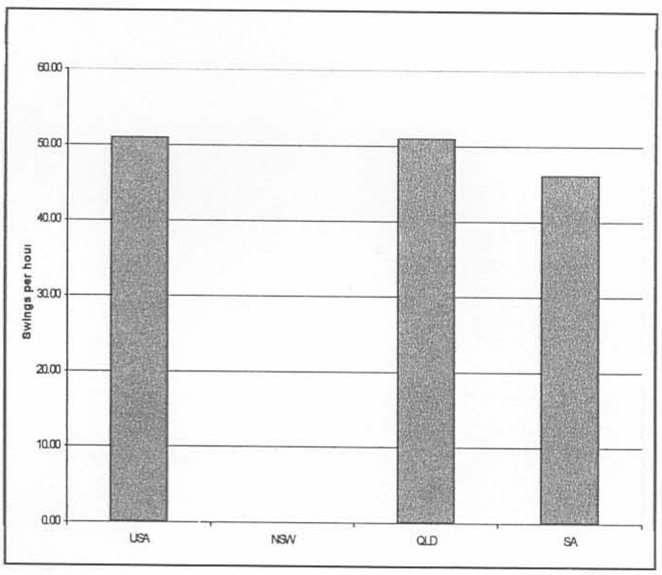

Figure 4.5.1.g: Dragline swings

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.

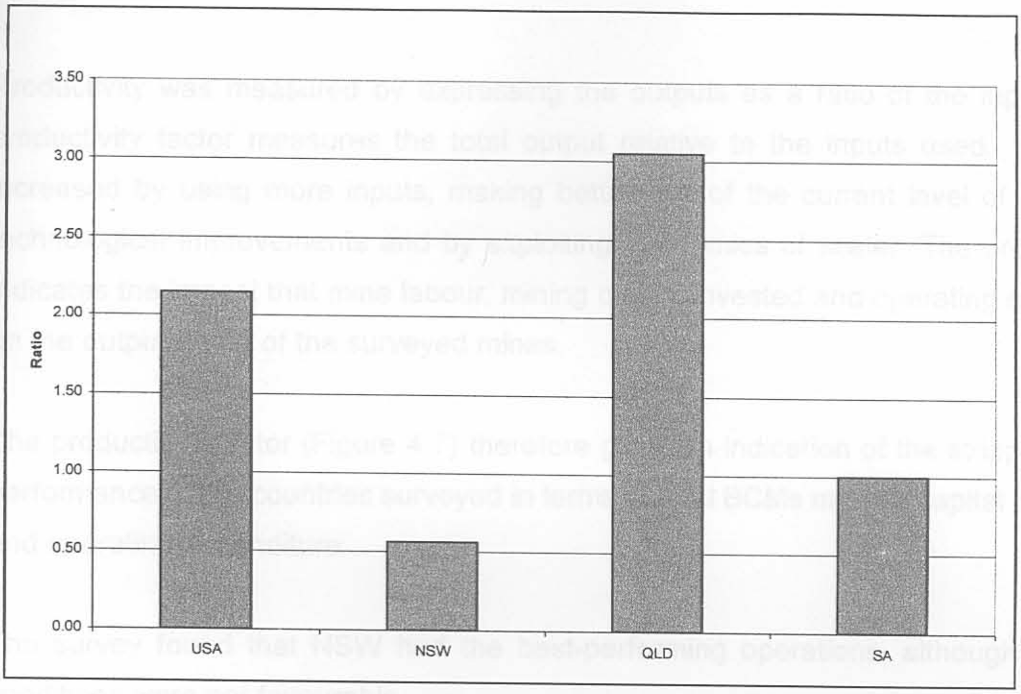

Figure 4.6a: Mining operating expenditure per ROM ton

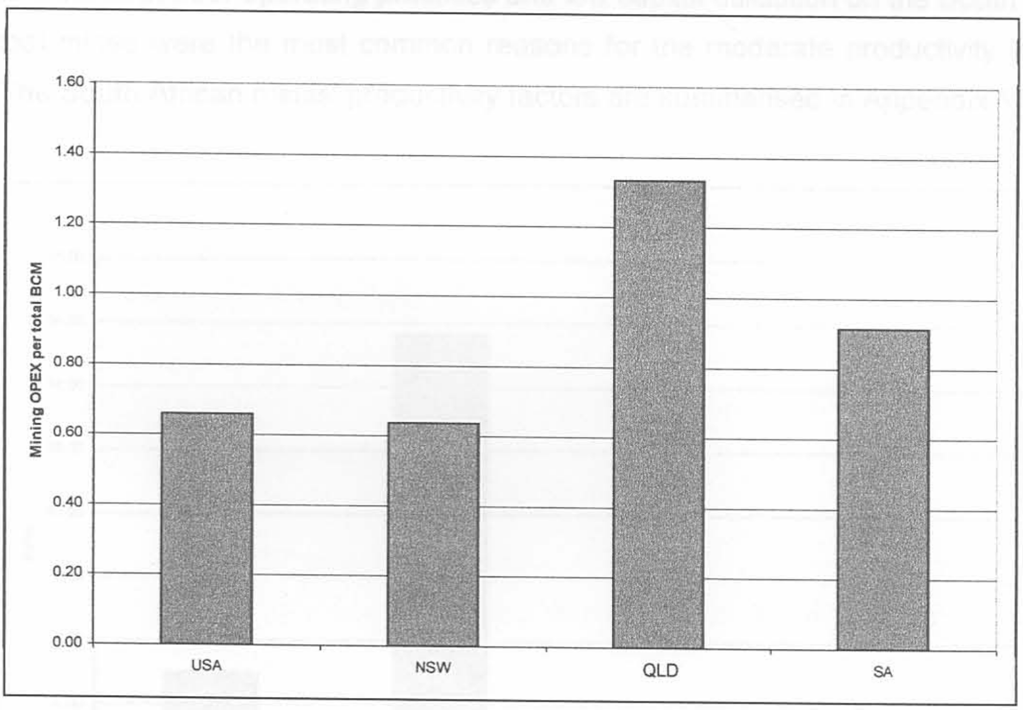

Figure 4.6b: Mining operating expenditure per total BCM moved

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.)

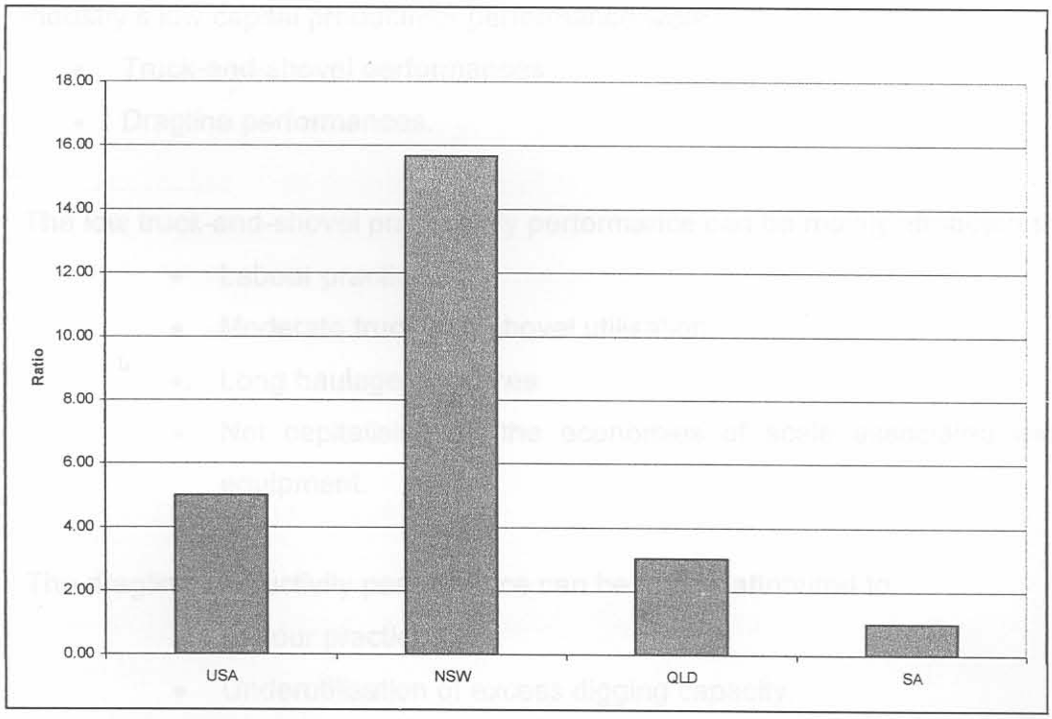

Figure 4.7: Productivity factors for mining countries surveyed