ESTIMATION OF CAPITAL COSTS FOR ESTABLISHING COAL MINES IN SOUTH AFRICA

Moshe Mohutsiwa

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 2015

DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the degree of Master of Science to the University of the Witwatersrand, Johannesburg.

(Signature of Candidate)

-------------------------- day of -------------------------- year --------------------------

ABSTRACT

Coal is one of the most abundant mineral resources in South Africa and it is predominantly used in electricity generation in the country. Of all the mineral resources in South Africa, development of coal resources attracted most of the financial investment between 2010 and 2013. Development of mining projects requires estimation of capital and operating costs in the early stages of the project's life. Estimation of costs is an essential exercise that assists on deciding the future of mining projects.

Despite all the investment in the South African coal mining sector, there is still little consistency in unit capital costs invested/required to develop coal mining projects. Lack of research within the area of coal mining projects' costs is attributable to a lack of publicly available information. Research in this area will enable investors and operators in the coal mining sector to be able to assess financial viability early in the project life.

This study reviewed coal mining projects across the world, looking at publicly available capital costs. The study further recognised similarities between the South African and Indian coal mining sectors thereby enabling the research to leverage data from the Indian coal mining sector to estimate capital costs in South Africa. The parametric estimating technique was used to estimate capital costs in this study.

Finally, six formulae were initially developed to estimate the capital costs of establishing coal operations in South Africa. The six formulae were then reduced to three formulae by eliminating outliers. The formulae can be used to estimate capital costs to an error of magnitude error level of -30% to +50%. An estimation formula for underground longwall operation was not developed due to an insufficient number of underground longwall operations in both South Africa and India. In conclusion, this study

recommends further research to develop more formulae which can be used to estimate capital costs more accurately.

DEDICATION

This research report is dedicated to my family, my wife Samu Mohutsiwa and my son Kgosi Tshiamo for their support and encouragement in both my career and studies.

ACKNOWLEDGEMENTS

I wish to extend my grateful thanks to all those who assisted me in the preparation of this research, particularly:

- Prof Cuthbert Musingwini, my supervisor and mentor, for guidance, supervision and always speaking wisdom in my life
- The Anglo American capital projects team for allowing me to use their data, in particular Vusi Maseko, Ian Hall and William Chicks
- Ajay Lala, (Research Analyst at McKinsey&Company) for all the problem solving and brain storming sessions made possible by him sacrificing some of his evenings.
- My Mohutsiwa family, Papa, Mama, Goitsemang, Puni, Lolo, Puleng and Papi, thank you for always supporting and believing in me.
- To my wife Samu (MaMshengu) for allowing me to pursue a master's degree and being so understanding.
- Lastly to God, I would not have made it without you.

TABLE OF CONTENTS

CONTENTS **Page**

LIST OF TABLES

List of Figures

LIST OF ABBREVIATIONS

ACC:	Average Cost of Capital
ANOVA:	Analysis of Variance
AUD:	Australian Dollars
CFE:	Capacity Factored Estimates
CLT:	Coal to Liquid
CPI:	Consumer Price Index
DMR:	Department of Mineral Resources
EIA:	U.S Energy Information Administration
Eskom:	Electricity Supply Commission
FS	Feasibility Study
ISPA:	International Society of Parametric Analysts
LOM:	Life of Mine
Mtpa:	Million tonnes per annum
PFS	Pre-Feasibility Study
RMG:	Raw Materials Group
ROM:	Run of Mine
RBCT:	Richards Bay Coal Terminal
SACMA:	South African Colliery Managers Association
USD:	United States Dollars

1. INTRODUCTION

1.1. Chapter overview

This chapter begins by discussing the mining overview, focusing on the five stages in the life of mine. The chapter continues by looking at the types of surface and underground mining methods. The context of South African coal sector is then discussed, focusing on the history and the current status of the coal sector in South Africa. The role of the South African coal market within the global coal market is also discussed. The influence of different mining methods on capital and operating costs, including the breakdown of the costs were then discussed. The chapter concludes by discussing the purpose and the context of this study, the problem statement and the delimitation of this study.

1.2. Mining overview

The mining industry plays a critical role within the South African economy. In 2013, the mining industry contributed 4.9% to the South African Gross Domestic Product (GDP) (Statssa, 2014). The mining sector employed 2.8% of the total workforce in South Africa (Statssa, 2014). The GDP and employment contribution of the mining industry to the South African economy is spread across five stages of the mining industry. The five stages in the life of a mine are discussed in the following sections.

1.2.1. Stages in the life of a mine

The mining process can be divided into five stages, namely: prospecting, exploration, development, exploitation/production and reclamation (Hartman and Mutmasky, 2002). Table 1.1 depicts the stages of mining process irrespective of the commodity being mined. Table 1.1 also shows the typical duration and costs per stage.

Table 1.1: Stages in the life of a mine

Stage	Procedure	Duration (years)	Typical Cost (%)
1. Prospecting (Mineral deposit)	Search for ore	1 – 3	0.7%
2. Exploration (Ore body)	Defining the extent and value of ore including PFS and FS	2 – 5	0.9%
3. Development (Prospect)	Opening up ore for production	2 – 5	6%
4. Production/Exploitation (Mine)	Large scale production of ore	2 – 50	90%
5. Reclamation (Real estate)	Restoration of site	1 – 10	2.4%

Source: Hartman and Mutmasky (2002)

Prospecting is the first step in the mining cycle. It is the search for valuable mineral/ore within the ground. Since mineral deposits may be located either at or below the surface of the earth, direct and indirect prospecting methods are used (Hartman and Mutmasky, 2002).

Exploration, the second stage in the mining cycle aims at accurately determining the size and the value of the mineral deposit, including Pre-Feasibility Study (PFS) and Feasibility Study (FS) (Hartman and Mutmasky, 2002). It is during this stage that mining engineers provisionally determine the mining method to use and the cost associated with the method chosen. Once the mining costs have been determined, mining projects are then approved or abandoned with consideration to the mining project's profitability.

The third stage in the mining cycle, ***development,*** is the opening of the ground to access the ore (Hartman and Mutmasky, 2002). Depending on the type of mining method used, the ore can be accessed through sinking a shaft or decline for underground mining, or removing overburden for surface mining. Accessing the ore through underground mining is generally more complex and requires more costs than accessing through surface mining (Bagherpour, 2007). The complexities with accessing underground mines ranges from selecting the right shaft size and position, to selecting the right contactor to sink the shaft since selecting a wrong shaft position or contractor may lead to substantial financial losses and delays in accessing the mineral deposit.

Production/Exploitation is the fourth stage in the mining cycle. This stage is associated with the removal of ore from the ground (Hartman and Mutmasky, 2002). In most cases, development will continue while production is taking place. During production, revenue will be generated from selling the mineral.

The fifth stage in the mining cycle, ***reclamation*****,** deals with the clearing and restoration of the mine site. This stage includes removal of plant and buildings, reclamation of waste and tailing dumps and monitoring of discharges. In some cases, shafts may be sealed and trees are re-planted (Hartman and Mutmasky, 2002).

As mentioned under the production stage above, traditional production methods fall into two broad categories based on the location of the ore: surface and underground (Hartman and Mutmasky, 2002). Geological conditions such as the dip, shape, and strength of the mineral play a key role in selecting the mining method. Over and above stated factors, environmental impacts and safety are also critical in deciding which mining method can be used because without consideration of these two factors, a mining company would always opt for the cheapest mining method.

According to the Raw Materials Group (RMG), 42% of South African coal mines are surface operations and 42% underground operations while the remaining 16% are a combination of both surface and underground mining operations (Raw Materials Group, 2014). Brief descriptions of the mining methods used in coal mines are discussed in the next sections.

1.3. Surface mining

In coal mining, surface mining methods are characterised by the use of large, capital intensive and efficient mining equipment. Surface mining methods are popular for the high productivity, low operating cost and good safety conditions (Hartman and Mutmasky, 2002). Figure 1.1 illustrates the classification of ore reserves and the selection of a suitable surface mining method.

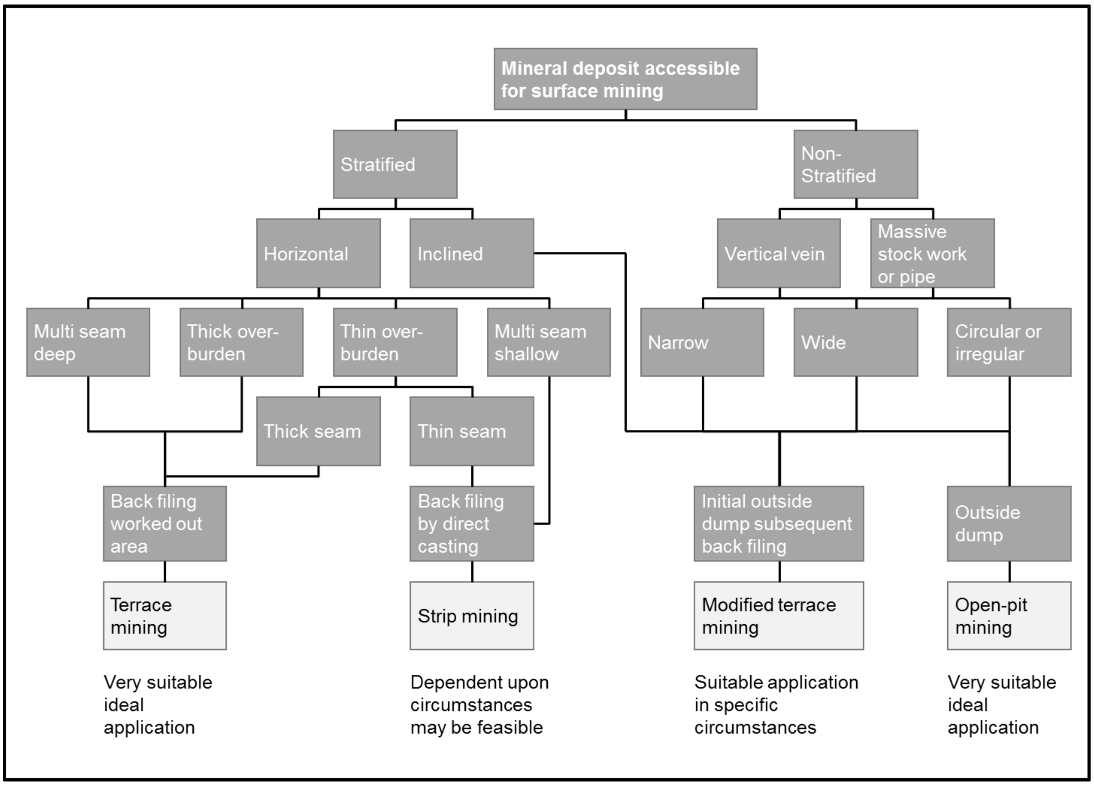

Figure 1.1: Classification of surface mining methods

Source: Thomson (2005)

As shown in Figure 1.1, the three commonly used surface coal mining methods across the world are strip mining, terrace mining and open pit mining. These methods are briefly discussed in the next sections.

1.3.1. Strip/opencast mining

Strip mining is widely used where the ground surface and the coal reserves are relatively flat lying and the coal is at a shallow depth. The favourable conditions for using strip mining methods includes, coal lying less than 50m from surface, coal inclination of less than 20 degrees and a large area of reserve to allow for longer Life of Mine (LOM). Figure 1.2 is a schematic representation of a surface coal operation using the dragline mining method (Thomson, 2005). The main types of equipment used across the world for strip mining are:

- Draglines
- Trucks
- Shovels
- Bucket wheel excavators
- Conveyors
- Scrapers
- Dozers
- Slushers and dragline hoppers, and
- Surface continuous miners

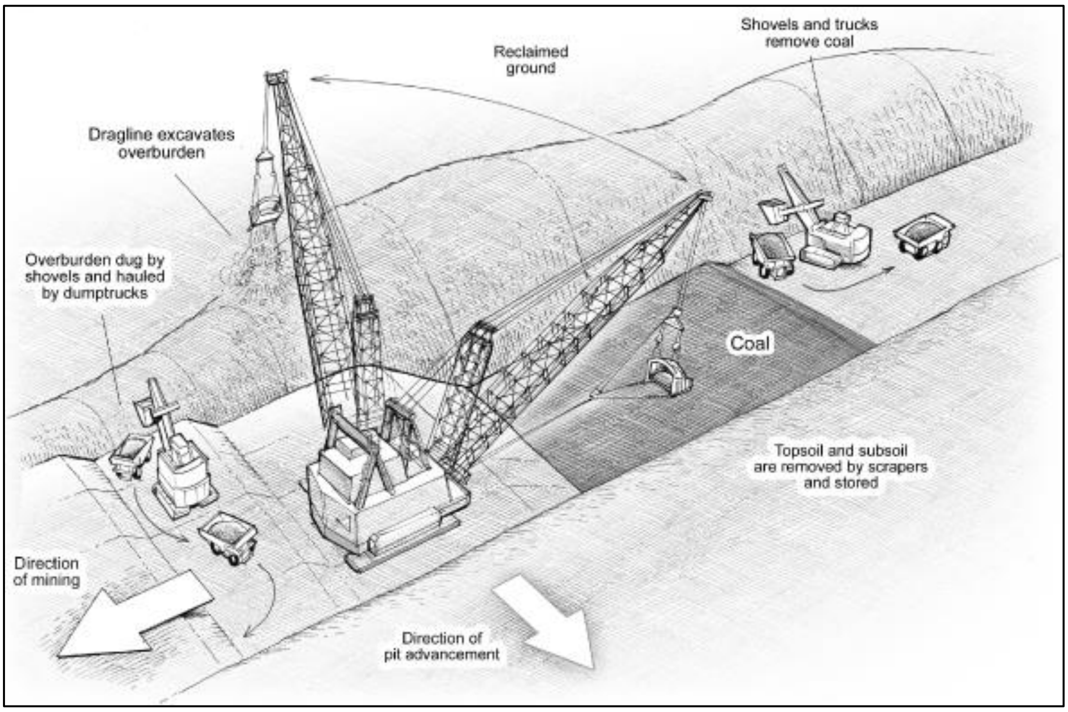

Figure 1.2: Schematic representation of strip mining using draglines

Source: Rajikorba (2013)

In the context of South African surface coal mining, the main equipment used includes draglines, trucks and shovels or a combination of both (integrated mining system). Draglines are known have the lowest operating costs in overburden removal, despite their high capital cost requirement. The use of draglines is generally restricted to large deposits to ensure adequate strip length and sufficient reserves to justify the large capital expenditure (Wescott, Pitkin & Aspinall, 2009). Figure 1.3 shows typical operating cost breakdown in South Africa's coal mines using the strip mining method.

The general characteristics of operations used to generate typical cost breakdown for strip coal mining are those of operations using draglines as the main equipment for waste removal and truck and shovel for coal removal.

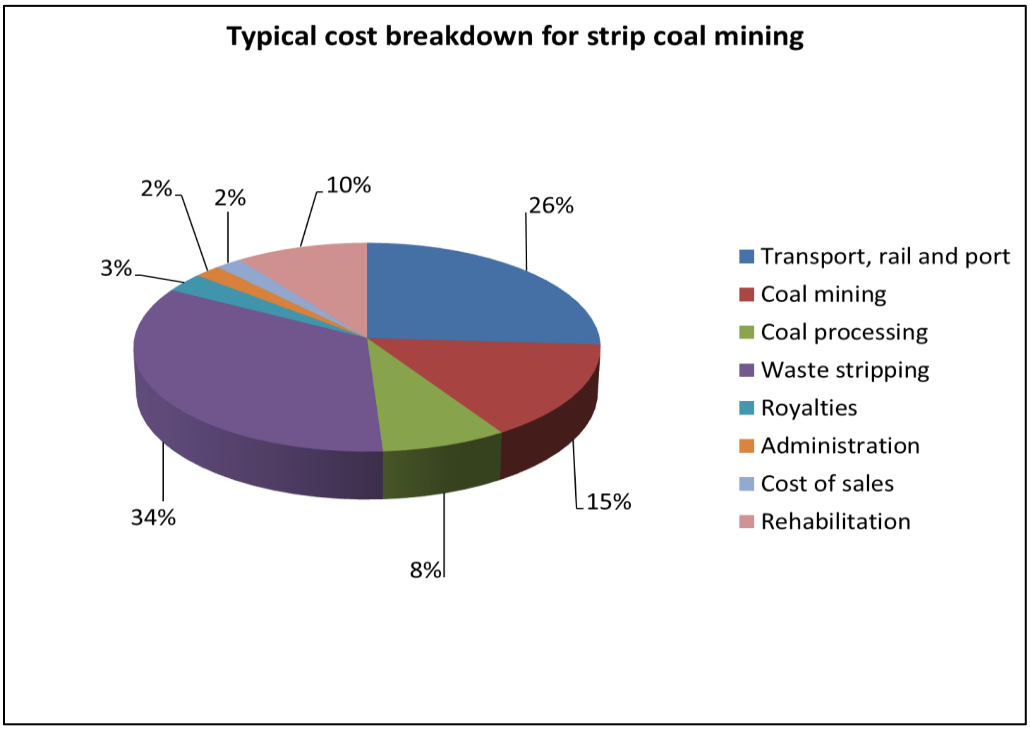

Figure 1.3: Typical operating cost breakdown for strip coal mining in South Africa

Source: Thomson (2005)

In general, mining projects which use draglines tend to have higher equipment capital costs than truck and shovel operations. Almost all the operations producing five million tonnes of Run of Mine (ROM) coal or more per annum with a LOM of more than 20 years in South Africa use integrated mining systems in order to reduce both capital and operating costs.

1.3.2. Terrace mining

As can be seen from Figure 1.1, terrace mining is widely used where the coal is lying relatively low and the overburden is thick. Where the coal is deeper, some of the operations use bucket wheel excavators to move overburden and trucks and shovels and conveyors to move the coal (Thomson,2005). This method of surface coal mining is not popular in South Africa. The use of bucket wheel excavators puts the capital costs of terrace mining on the same scale, if not more with the dragline mining method. The types of equipment used in strip mining and terrace mining makes the capital costs of these two mining methods to be fairly comparable. Figure 1.4 shows a typical terrace mining layout.

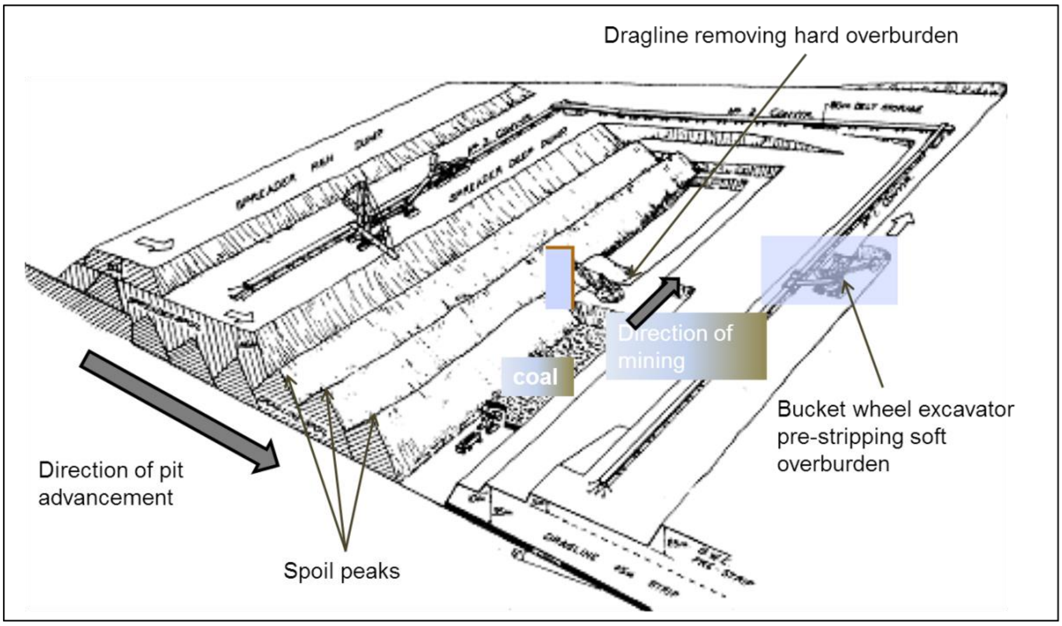

Figure 1.4: Combined terrace (pre-stripping of soft overburden) and strip mining (stripping deeper hard overburden) methods and associated equipment

Source: Bullivant (1987)

1.3.3. Open pit mining

This is a traditional cone shaped excavation that is used when the coal reserve is almost vertical or pipe shaped. This mining method exclusively uses truck and shovel for both waste removal and coal loading and hauling. The use of the truck and shovel mining method is favourable due to its flexibility in operating in a complex orebody and its ability to haul material for long distances to ensure re-handling of material will not become an issue during the life of the operation (Fox, 2011). The truck and shovel mining method also offers cheaper capital investment than mining with draglines and bucket wheel excavators. The truck and shovel mining method allows smaller reserves to be extracted at lower capital costs. However, one disadvantage associated with this type of mining is higher operating costs. Figure 1.5 shows a typical open pit coal mining layout.

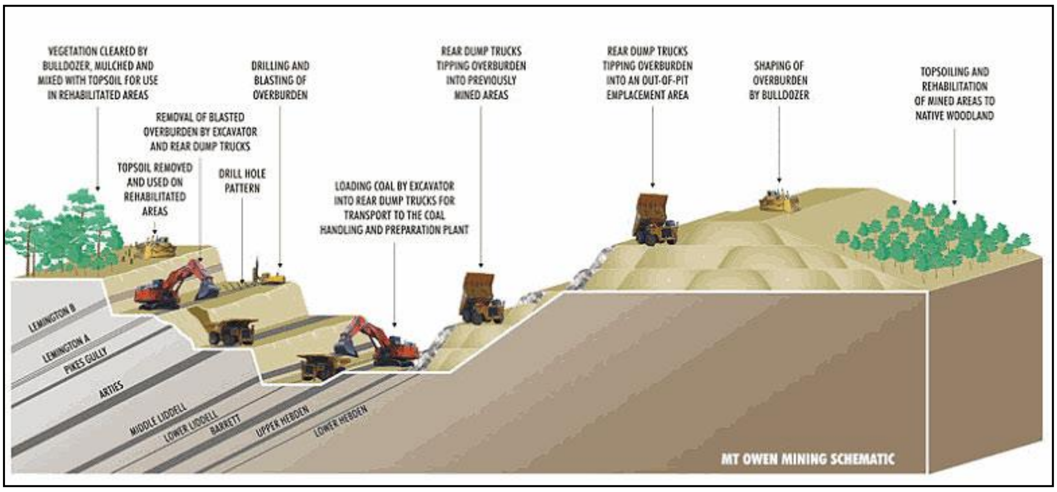

Figure 1.5: Open pit mining layout and associated operations

Source: Gaukartifact (n.d)

From the above outline of mining methods and equipment costs, it is apparent that capital costs for surface mining projects will differ significantly even when they are located in the same area. In the same context, different underground mining methods have direct influence on the capital costs and different underground mining methods are discussed in the next sections.

1.4. Underground coal mining

There are two main underground coal mining methods used across the world and these methods are room and pillar and longwall mining methods. These methods are briefly discussed in detail in the next sections.

1.4.1. Room and pillar

This underground mining method is suitable for flat or nearly horizontal coal resources (U.S Department of Interior, Bureau of Mines, 1994). The rooms are empty areas where coal has been mined out and the pillars are the coal blocks left as primary support to the roof (U.S Department of Interior, Bureau of Mines, 1994). As coal depth increases, the size of the pillars also increases in order support the overlying ground thereby reducing the volume of the recoverable coal.

This method is widely used in South Africa where coal resources have high geological disturbances. About 90% of South African underground mines use the room and pillar mining method (Raw Materials Group, 2014). The room and pillar mining method can be carried out conventionally or mechanically as follows:

- ***Conventional room and pillar mining method*** – also known as drill and blast, is the oldest underground coal mining method used. The conventional room and pillar mining method is a five step process: beginning with mechanically undercutting the coalbed, drilling holes into the coal face for explosives, blasting the coal, loading blasted coal into the shuttle cars for delivery to the feeder breaker, and lastly bolting the roof to support the excavated area (U.S Department of Interior, Bureau of Mines, 1994). When compared to other mining methods, conventional room and pillar mining methods require the least capital expenditure. Figure 1.6 shows a typical layout and equipment used in conventional room and pillar coal mining method.

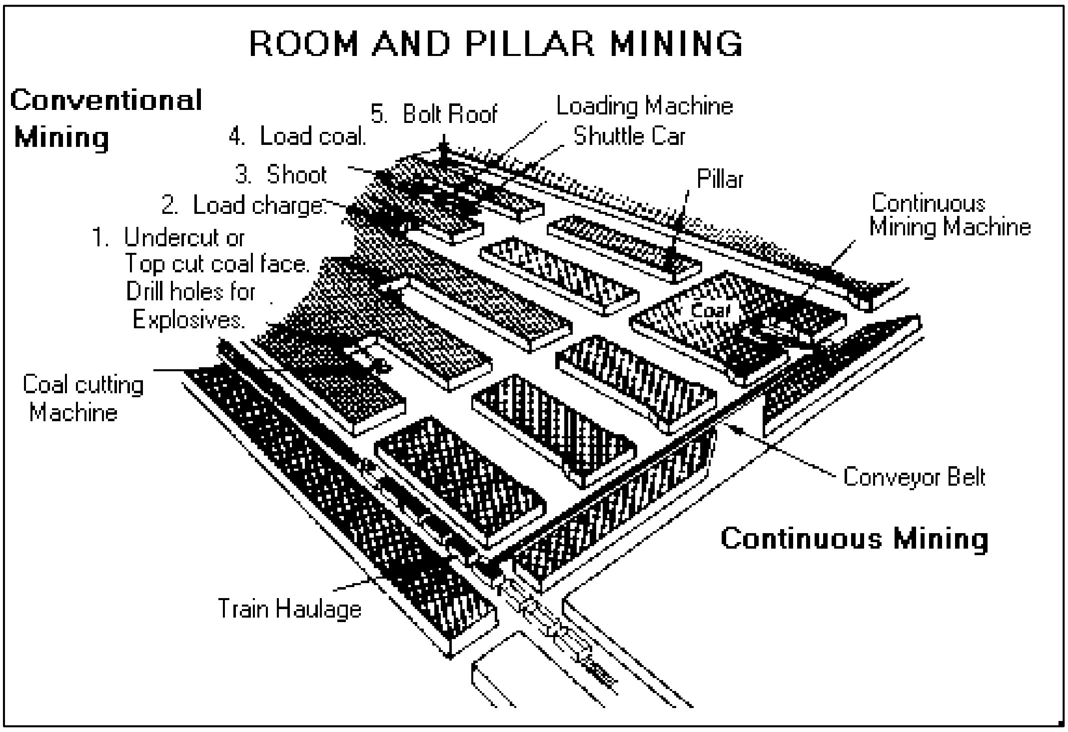

Figure 1.6: Conventional room and pillar

Source: Brestensky (1991)

- ***Mechanised room and pillar*** – almost all underground coal mines in South Africa use this method. In this method, a continuous mining machine known as continuous miner excavates the coal and loads it into the shuttle car in a single step process (U.S Department of Interior, Bureau of Mines, 1994). Despite the term continuous, the mining process is not completely continuous as it requires the continuous miner to retract after advancing for some metres into the coal face to allow the excavated area to be supported. The excavated area is supported by the use of roof bolter equipment. With reference to capital costs, the method is highly favourable in terms of low capital cost requirements and higher coal output. Figure 1.7 shows a schematic diagram of a typical "continuous" room and pillar coal mine.

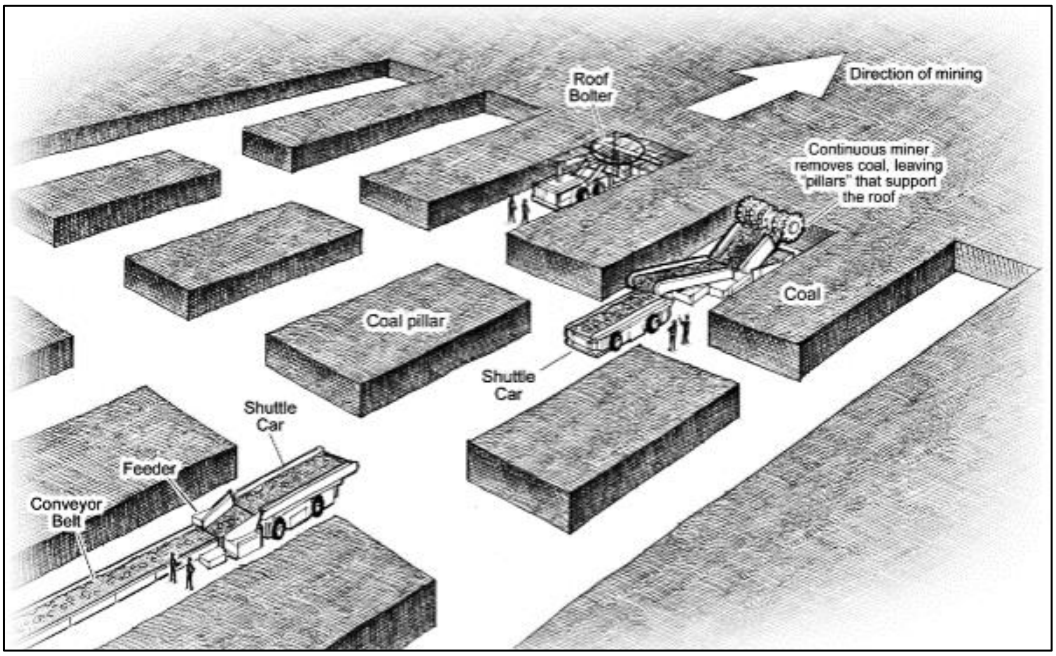

Figure 1.7: Typical underground room and pillar coal mine
Source: Bullivant (1987)

1.4.2. Longwall

The basic principle of the longwall mining method involves dividing the coal reserve into panels by excavating roadways. During the extraction process, pillars of coal are left untouched in certain parts of the mine in order to support the overlying strata (U.S Department of Interior, Bureau of Mines, 1994). The mined-out area is allowed to collapse, generally causing surface subsidence.

Extraction by longwall mining is almost an uninterrupted process involving the use of self-advancing hydraulic support (chocks), coal shearer and an armoured conveyor running parallel to the coal face as shown in Figure 1.8 (U.S Department of Interior, Bureau of Mines, 1994). The shearing machine rides on the conveyor while under the movable roof support as it cuts and dumps coal onto the conveyor to be transported out of the mine. When the shearer has cut the full length of the coal face, it reverses direction taking the next cut (U.S Department of Interior, Bureau of Mines, 1994). The roof support moves closer to the new coal face as the shearer advances, leaving the unsupported roof behind it that is allowed to collapse. The workers and equipment are protected by the steel canopies of the roof support located along the coal face (U.S Department of Interior, Bureau of Mines, 1994). Figure 1.8 shows a typical underground longwall coal mine.

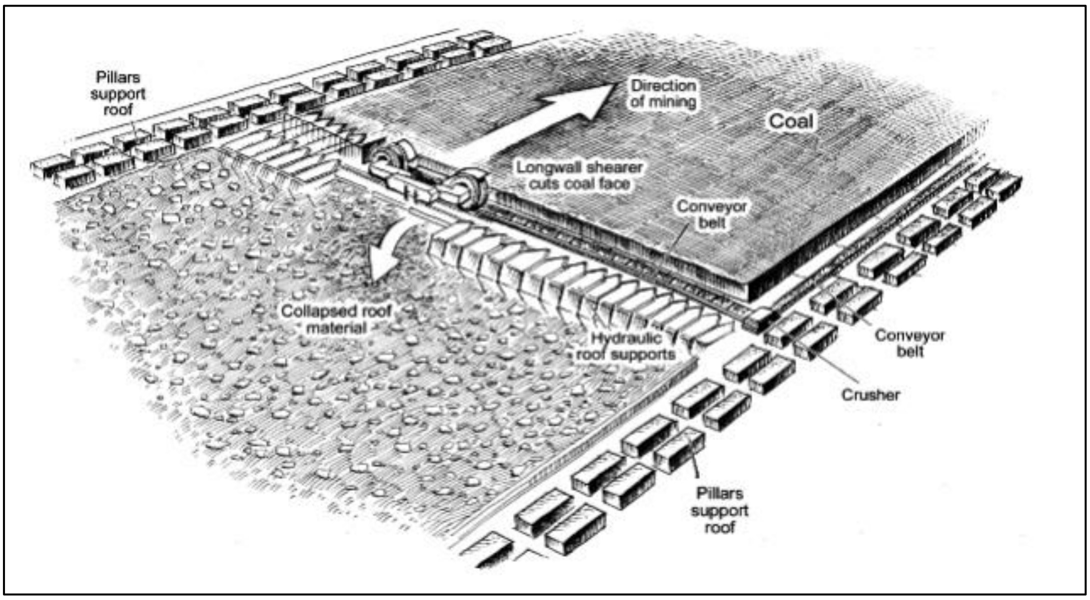

Figure 1.8: Typical underground longwall coal mine
Source: Bullivant (1987)

Some of the main challenges that have affected the popularity of longwall mining methods are the initial costs of installation and the geology of the coal reserves (Lowrie, 1968). The more significant variables which determine the cost of a specific longwall system include the length of the coal face, the geology, seam thickness and the quality and thickness of the roof.

1.5. South African coal mining context

1.5.1. History of the South African coal mining industry

According to Rutledge (2008), the production of the main fossil fuel (coal) in South Africa commenced in 1880. The production growth in Africa, as shown in Figure 1.9, grew exponentially from less than 20 Mt/annum prior to World War II to over 250 Mt in 2013 (Rutledge, 2008). The annual production decreased by approximately 26% during the Great Depression (between 1929 and 1932) and has since grown steadily.

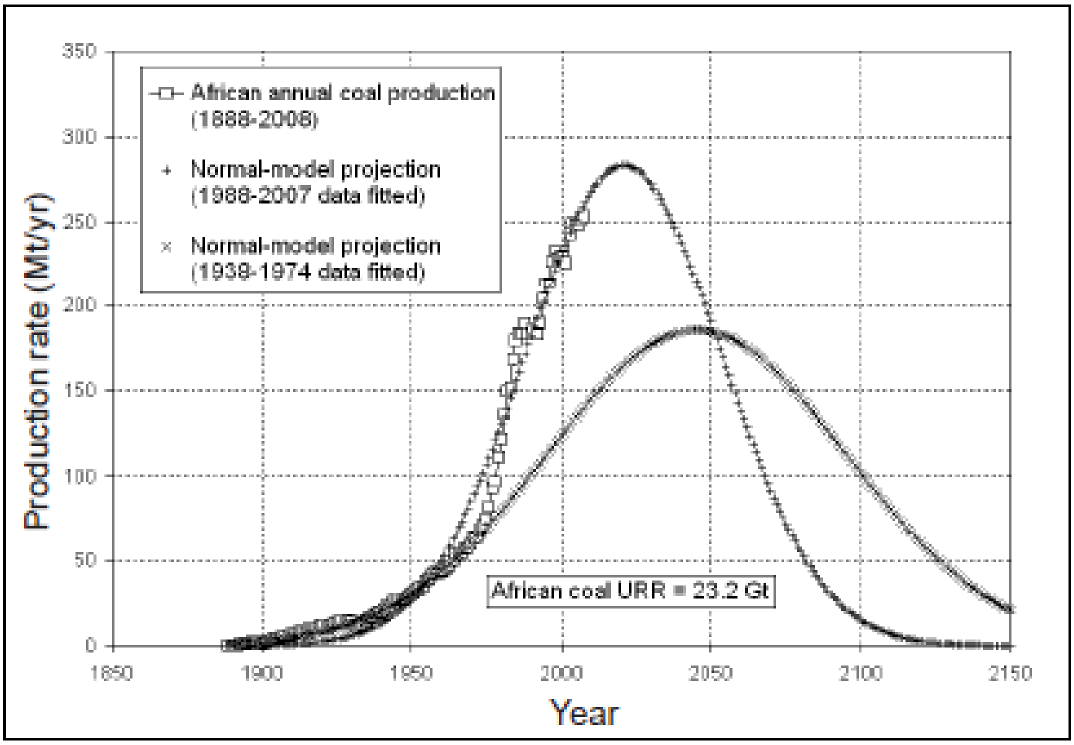

Figure 1.9: Annual production of African coal, with normal distribution models for early stage (1938-1974) and late stage (1988-2012)

Adopted from Rutledge (2008)

The South African coal production increased significantly after 1974 when the apartheid regime was subjected to international sanctions and boycott action (Hartnady, 2010). The external pressure from the international community resulted in the state-owned petrochemical corporation, Sasol, building two large coal to liquid (CTL) plants in 1980 and 1982 in order to supply fuel (petrol and diesel) to South Africa. The construction of these two plants meant that more coal had to be produced to meet the growing coal demands. In addition to the CTL plants, the state-owned Electricity Supply Commission (Eskom), constructed coal-fired power stations with one of them (Kendal) remaining among the largest coal-fired power stations in the world (Hartnady, 2010). The other largest coal-fired power stations are found in Taiwan, China and Poland. These developments amongst others increased South African coal production from merely 69 Mt in 1975 to 179 Mt in 1985. Exports markets have also contributed to the growth of South African coal production. The contribution of export market to increasing South Africa's production is discussed in the following sections.

1.5.2. Current status of coal mining in South Africa

According to South Africa's Department of Mineral Resources (DMR) (2012), coal is one of the most abundant mineral resources in South Africa and it is used predominantly in electricity generation in the country (Department of Mineral Resources, 2012). According to Eskom's 2013 technical report, coal accounts for at least 85% of electricity produced in South Africa (Eskom, 2013). Over 80% of the saleable coal is produced by the mines controlled by private mining groups, namely: Anglo American, BHP Billiton, Exxaro, Sasol and Glencore-Xstrata (Mining Weekly, 2010). The remainder of the coal is produced by junior mining companies that have Black Economic Empowerment (BEE) partners.

South African coal is produced from coal fields located in a series of basins located in the northern and eastern parts of the country (Hartnady, 2010). Table 1.2 shows the coal basins of South Africa and the coal reserves they contain. The Witbank and Highveld basins produce almost 78% of South African coal annually (Jeffrey, 2005). The exploitation of the Waterberg coal reserves has been hindered by amongst other factors, the lack of infrastructure and the complex geology of the coal in the region (Lind & Phillips, 2001). Table 1.2 further shows South African coal reserves by year 1987, 2000 and 2010. The reserves as stated by Jeffrey (2005), is derived from subtracting the ROM production from year 1988 to 2000 from the reserves stated by Bredell (1987).

Table 1.2: South Africa coal regions and reserves over time

Region	Coal Reserves (Mt)		
	Reserves as at end of 1987 (Bredell, 1987)	**Reserves as at end of 2000 (Jeffrey, 2005)**	**Reserves as at end of 2010 (Chabedi, 2013)**
Witbank	12 460	10 140	8 331
Highveld	10 979	10 007	9 406
Waterberg	15 487	15 103	6 707
Vereeniging-Sasolburg	2 233	1 898	1 688
Ermelo	4 698	4 597	4 378
Klip River	655	570	527
Vryheid	204	122	99
Utrecht	649	585	541
South Rand	730	708	716
Somkhele & Nongoma	98	83	5
Soutpansberg	267	261	257
Kangwane	147	146	146
Free State	4 919	4 919	Not included
Springok Flats	1 700	1 700	Not included
Limpopo (Tuli)	107	107	Not included
Total	**55 333**	**50 944**	**33 118**

Source: (Jeffrey, 2005; Chabedi 2013)

South Africa's coal production and consumption levels remained stable over the past decade as shown in Figure 1.9 below. In 2012, an estimated 260 Mt of coal was produced and 187 Mt were consumed locally. The difference between produced and local consumption coal was exported.

The South African coal demand is expected to increase by between 25 and 50% by 2020 (Wood Mackenzie, 2013). This demand will be primarily driven by the growing electricity need in South Africa and the export market. Despite continued efforts by environmental organisations to curb the use of coal in order to save the environment, Eskom and Sasol are expected to increase their consumption between 2013 and 2020. Over the last decade, South African export coal volumes have been limited to approximately 70 Mt mainly due to the rail limitations (Department of Mineral Resources, 2013). With the rated capacity of 91 Mt per annum, the RBCT is capable of handling an additional 27% of export (Ryan, 2014). The unlocking of additional 27% of the export coal capacity by increasing the rail capacity will result in more production being required. Figure 1.10 further illustrates the growth trend of both the coal production and consumption.

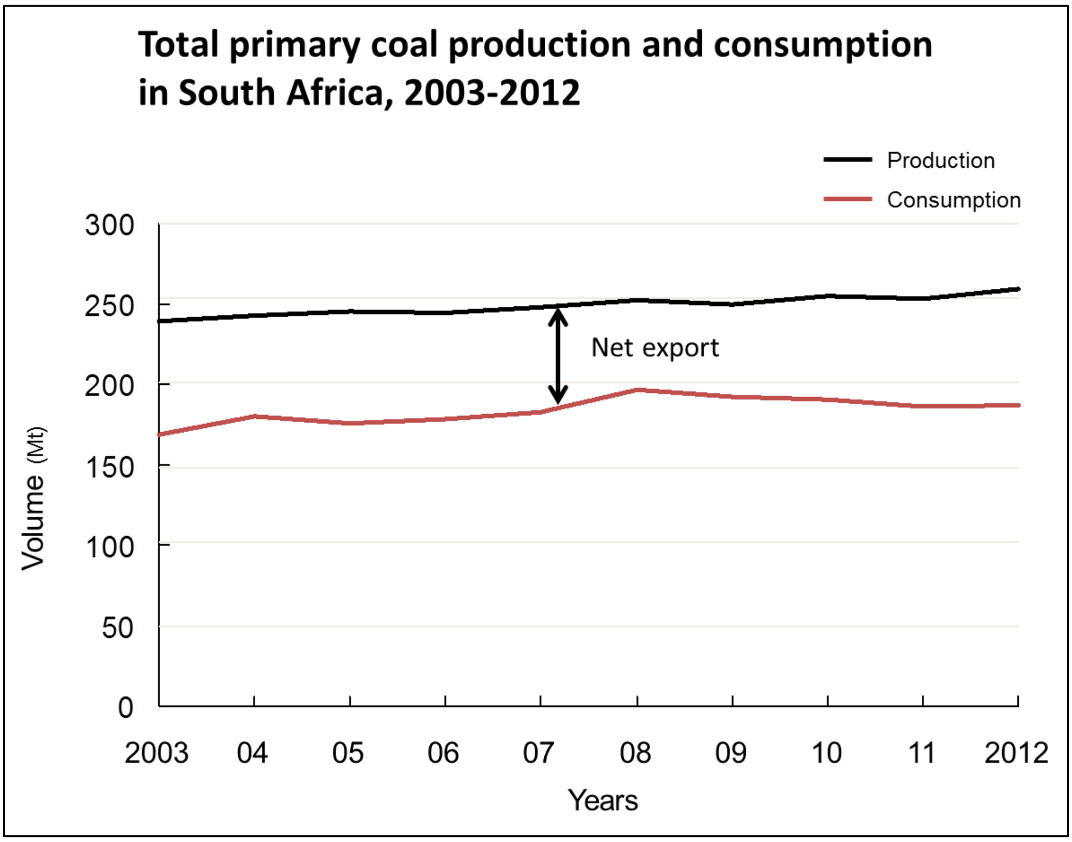

Figure 1.10: Total primary coal production and consumption in South Africa, 2003-2012

Source: EIA (2012)

As mentioned earlier, in 2012 about 72% of the coal produced in South Africa was consumed locally mainly for electricity generation by Eskom power plants and for liquid fuels by Sasol (Department of Mineral Resources, 2013). Figure 1.11 also shows the coal consumption within the domestic market.

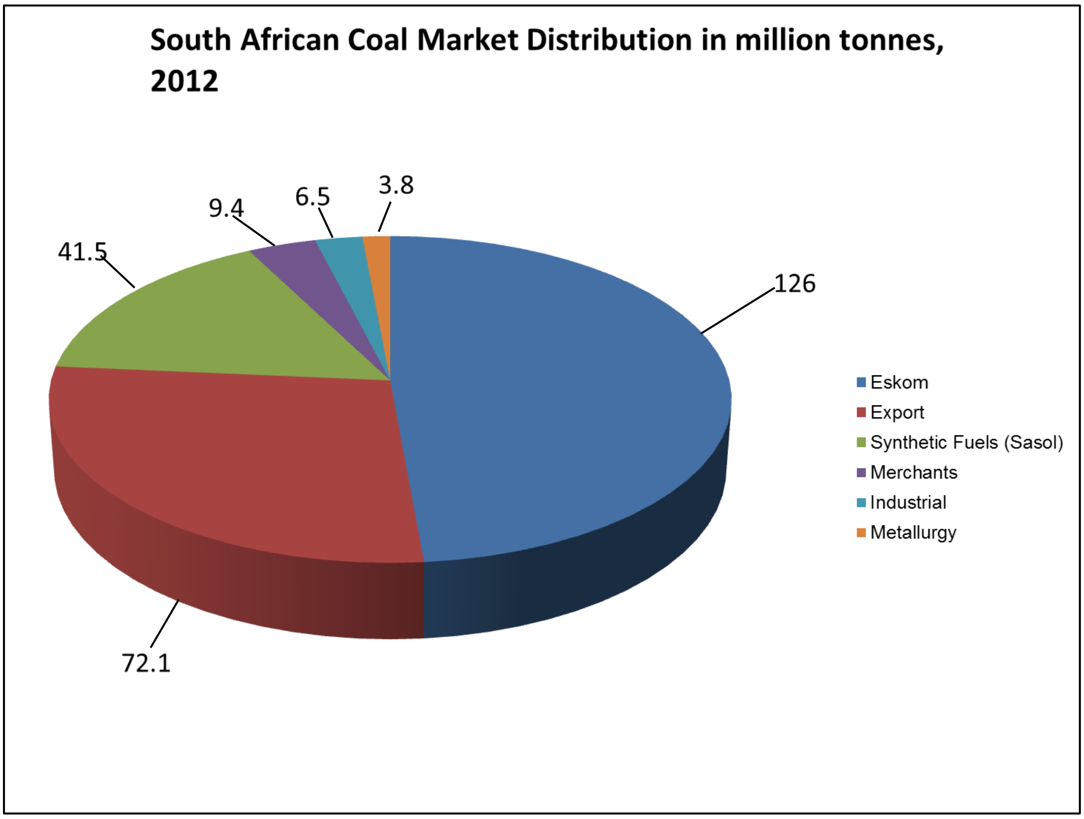

Figure 1.11: South Africa's coal market distribution in million tonnes, 2012

Source: U.S Energy Information Administration (2012)

1.5.3. The role of South African coal market plays globally

South Africa plays a vital role in the global coal market and is the fourth largest coal exporter in the world after Indonesia, Australia and Russia respectively (U.S Energy Information Administration, 2011). As illustrated in Figure 1.12, South Africa's coal exports are mostly sent to Europe, China and India.

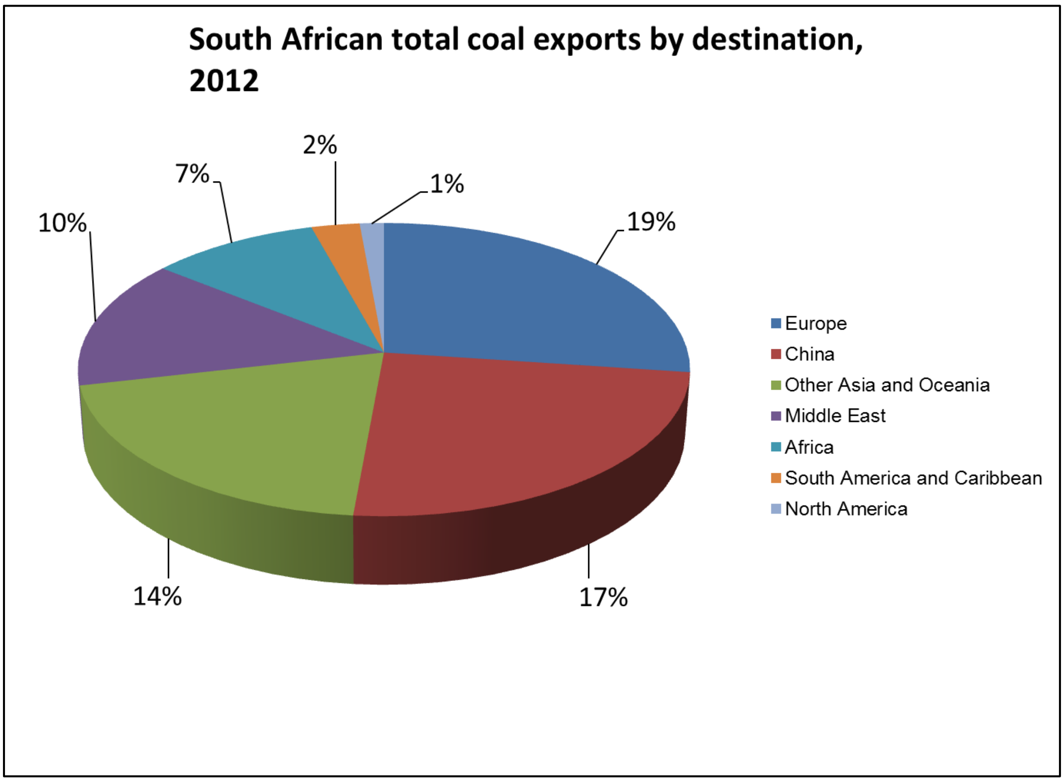

Figure 1.12: South African total coal exports by destination, 2012

Source: Global Trade Atlas and South African Revenue Services

Source: U.S Energy Information Administration (2012)

Based on the global coal reserves illustrated in Figure 1.13, South Africa's coal mining industry still has a vital role to play in the coal market. South Africa held the ninth largest coal reserves in the world by the end of 2012 (U.S Energy Information Administration, 2012). According to the BP statistical energy review, by end of 2012 South Africa held an estimated coal reserve of 27.4 billion tonnes which is different from 55.3 billion tonnes reported by the South African Coal Statistics and Coal Marketing Manual. It must be mentioned that the South African Council for Geoscience together with the Department of Mineral Resources (DMR) have undertaken an exercise to validate the South African coal reserves (Kota, 2014). If the amount of coal reserves reported by the South African Coal Statistics and Coal marketing manual is true, South Africa would become the 5th largest source of coal.

Considering the reserves mentioned by the BP statistical energy review, with 27.4 billion tonnes South Africa holds about 95% of the African coal reserves (BP statistics, 2012).

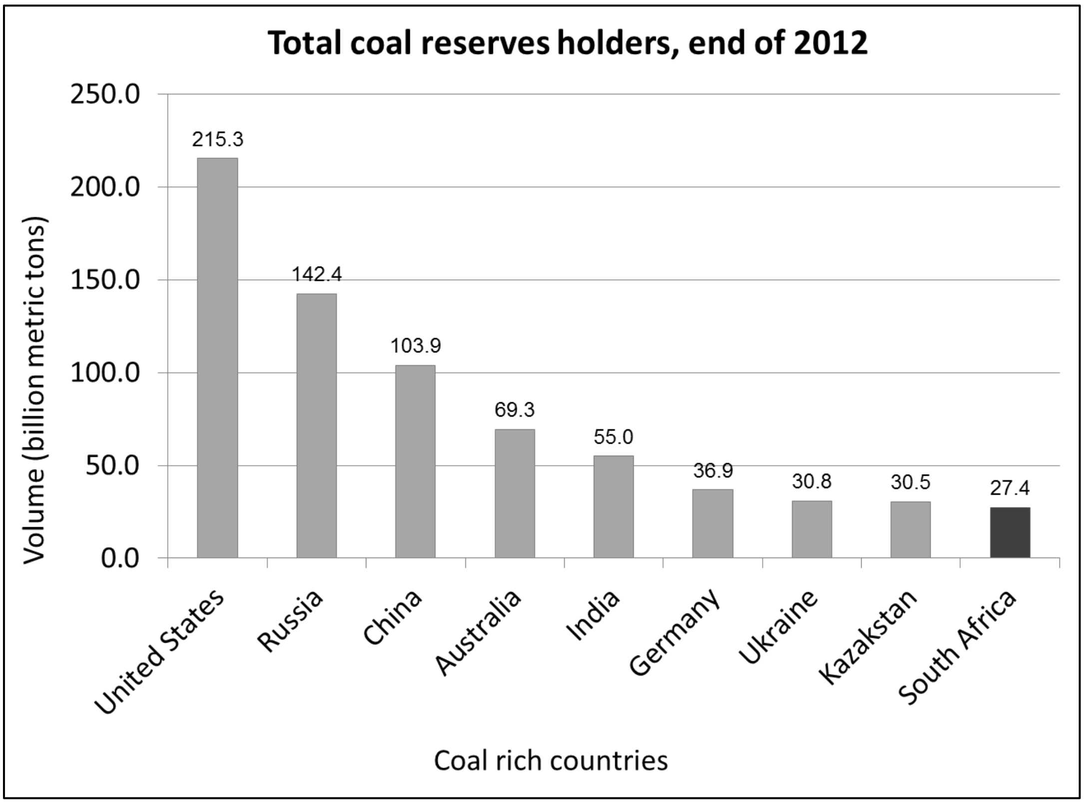

Figure 1.13: Illustration of total coal reserves holders by end of 2012

Source: U.S Energy Information Administration (2012)

1.6. Purpose of the study

The purpose of this research report is to contribute in better understanding of the area of cost estimation in mining, with a focus on coal mining in South Africa. Various cost estimation techniques were assessed to determine a suitable technique to use for this study.

1.7. Context of the study

The aim of this study is to assess and estimate the cost of establishing coal mines in South Africa. This study was inspired by Hall (2013) who stated that, “In recent years, there has been a lack of development in standardisation of capital cost estimates in the South African coal mining industry.” Due to the fundamental role coal that the mining sector plays both locally and globally, a comprehensive understanding of the capital cost of coal mines is of paramount importance.

In 2010 South Africa's electrical power utility, Eskom, one of Africa's biggest electricity producers, announced the building of new power stations, Medupi and Kusile expected to be completed in 2016 and 2017, respectively. The new power stations will increase the amount of coal required by the power utility (Eskom, 2010). The increase in coal demand means that more new mines are needed and existing mines will have to be expanded to meet the increasing coal demand. Due to the anticipated growth in coal demand, capital expenditure in the coal industry is expected to be in the range of USD8.1 billion between 2014 and 2020 (Vermeulen, 2013).

1.8. Problem statement

Capital cost estimates play a critical role in deciding whether projects will be approved, delayed or abandoned. It is therefore important that capital cost estimates are carried out as accurately as determined by the estimation guidelines based on the level of estimation conducted (Shafiee & Topal, 2012). The lack of literature on estimation of capital costs in South Africa is adversely affecting junior miners since they do not have databases of historical projects to estimate from.

Currently, there is a knowledge gap in understanding the true costs of establishing coal mines in South Africa. Understanding of the capital costs will assist junior miners to assess whether they are over-paying, under-paying or they are paying the right amount for establishing coal mines in South Africa.

1.9. Delimitations of the study

This study had two major delimitations. Firstly, it was delimited to the estimation of capital costs of establishing coal mines in South Africa rather than a general estimation of capital costs for all coal mines across the world. This delimitation was driven by an understanding that capital costs of coal mines differ significantly based on geography. Secondly, estimation methods were delimited to the parametric estimating technique with the use of historical actual data to eliminate the errors borne within estimated costs. The delimitation to the parametric technique was due to the technique's ability to capture the economies of scale, variation in mining projects and location of mining projects.

The formulae derived in this study will be limited in application to South African/Indian Mines or any other countries with similar mining infrastructure, mineral policy and legislation.

1.10. Concluding remarks

The chapter began by shedding light into the South African coal mining context. The history of South African coal mining was discussed, focusing more on the development of the industry. The structure of the resources and mining ownership was outlined. The chapter also looked at the reserves left in the country, the coal producing regions and coal production and consumption statistics.

The role and importance of the South African coal market in the global market was also discussed. A focus was also drawn into the five stages of any mining process with in-depth discussion on the mining method to conclude the chapter. This chapter closed by stating the purpose, context and the delimitations of the study. The problem statement was also discussed.

The next chapter will focus on the literature review of cost estimation. The chapter will further look at different cost estimation techniques used in estimating costs, especially capital costs of coal mines. Cost estimation techniques from other industries will also be looked at. The next chapter will form the basis of the research methodology to be used.

2.LITERATURE REVIEW

2.1. Chapter overview

This chapter reviews the theoretical background and concepts of capital cost estimation. The chapter initially looks at the generic cost structure in the mining industry. It then discusses the background of cost estimation in the mining industry and other industries. As mentioned by Shafiee and Topal, at the preliminary stage of mining projects, costs need to be estimated and it is difficult to find sufficient data for all the phases of the operation (Shafiee and Topal, 2012). This statement by Shafiee and Topal (2012) leads to the discussion of the challenges facing cost estimation, especially in mining. This chapter continues by looking at the different cost estimation techniques including their advantages and disadvantages.

2.2. The generic cost structure in mining

There are two main types of costs in the life of mining projects. These are operating and capital costs. Below is a brief overview of what these costs entail. Figure 2.1 is a schematic generic representation of cost breakdown in mines.

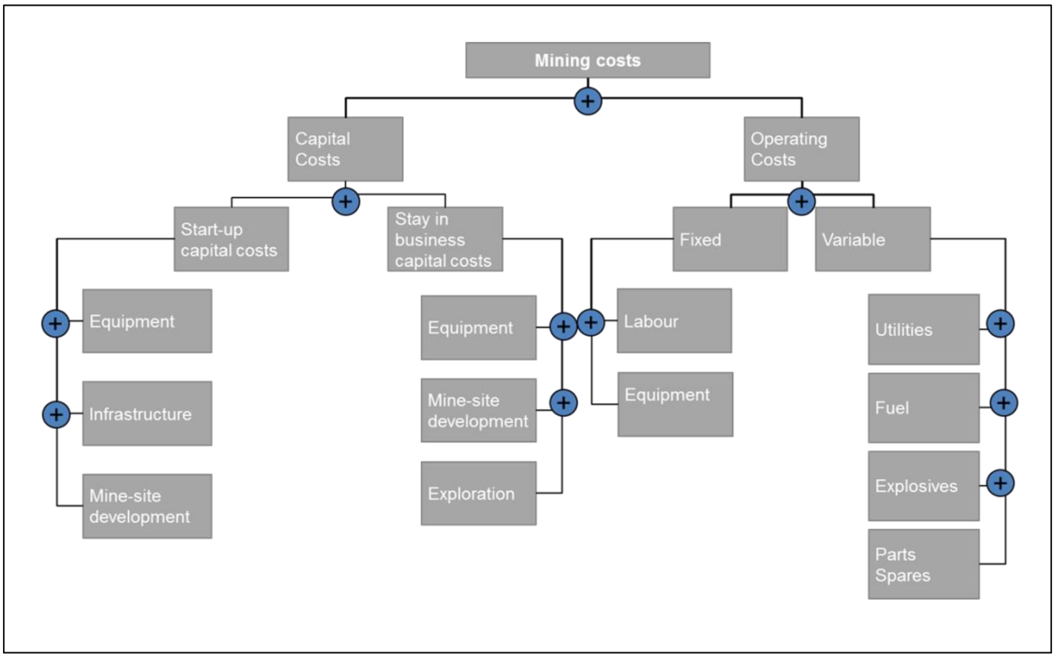

Figure 2.1: Generic mining cost structure

2.2.1. Capital costs

Capital costs in mines can be split up into start-up (initial) and stay-in-business (working) capital costs. Start-up costs focus on accessing the orebody, infrastructure, equipment and licensing costs. For underground mines, accessing the orebody means sinking shafts or adits whereas for surface mines it means the development of boxcuts and removal of initial overburden. It is a common practice in the mining industry to hire contractors to carry out the initial work (sinking shafts and developing boxcuts).

Infrastructure covered by start-up capital includes water and electricity connections, offices, workshops, change houses, roads and employees' accommodation. In some instances, small towns need to be developed to accommodate employees (Rudenno, 2009). The infrastructure requirements also include ore processing facilities referred to as the plant. The start-up capital expenditure is normally undertaken as quickly as is practically possible in order to get the project into production so that it starts generating revenues (Rudenno, 2009).

Once the mining project has taken off, additional infrastructure, development, equipment overhaul and replacement is conducted using stay-in-business capital (Rudenno, 2009). Figure 2.2 shows a typical distribution of total capital costs (initial) for relevant activities of the production cycle in open pit mines.

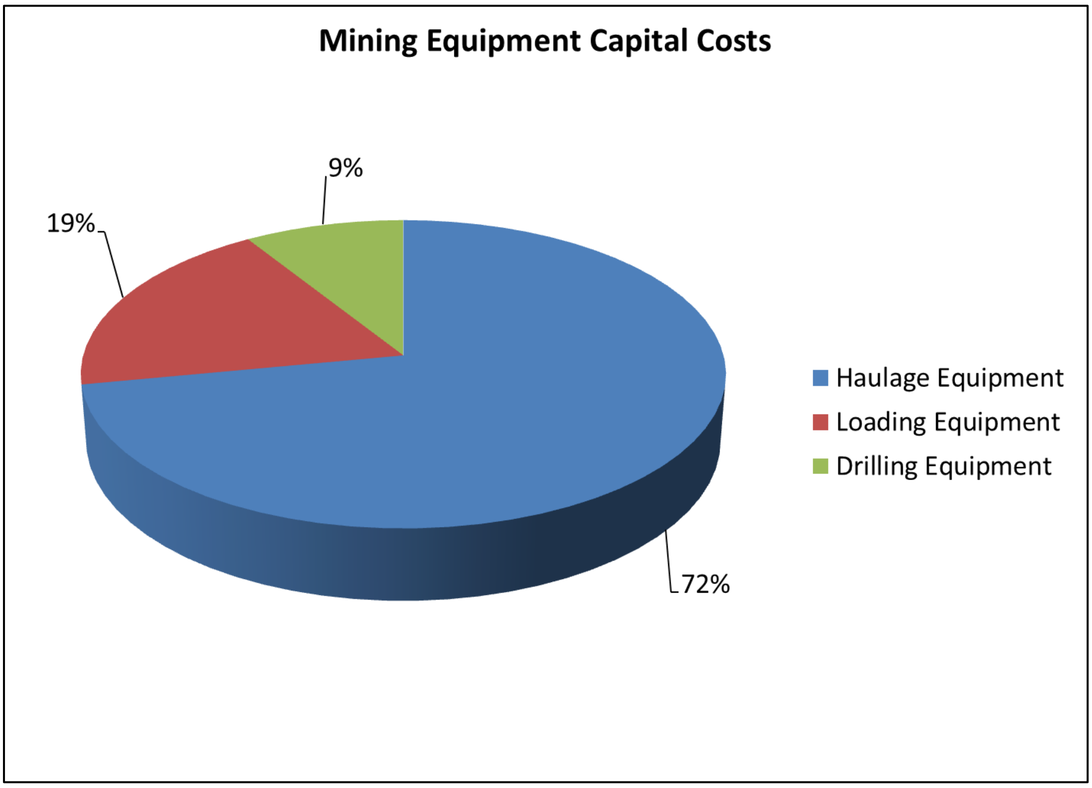

Figure 2.2: Distribution of total capital costs in open pit mines

Adopted from Bagherpour (2007)

2.2.2. Operating costs

Operating costs focus on the day-to-day running of the mine. These costs can be divided into fixed and variable costs. Variable costs vary with the tonnage produced and these costs include fuel, explosives and electricity. Fixed costs on the other hand are independent of the tonnage produced and they include labour costs and other costs not linked to production. Generally, operating costs are expressed in total costs per tonne of ore mined, for example South African coal mining costs are quoted as rands/tonne of coal mined.

Figure 2.3 shows a typical operating cost split for main activities in a production cycle in open pit mines. As shown in Figure 2.3, hauling accounts for most of the operating costs in open pit operations regardless of commodity being extracted. The lowest cost activity of the production cycle is drilling.

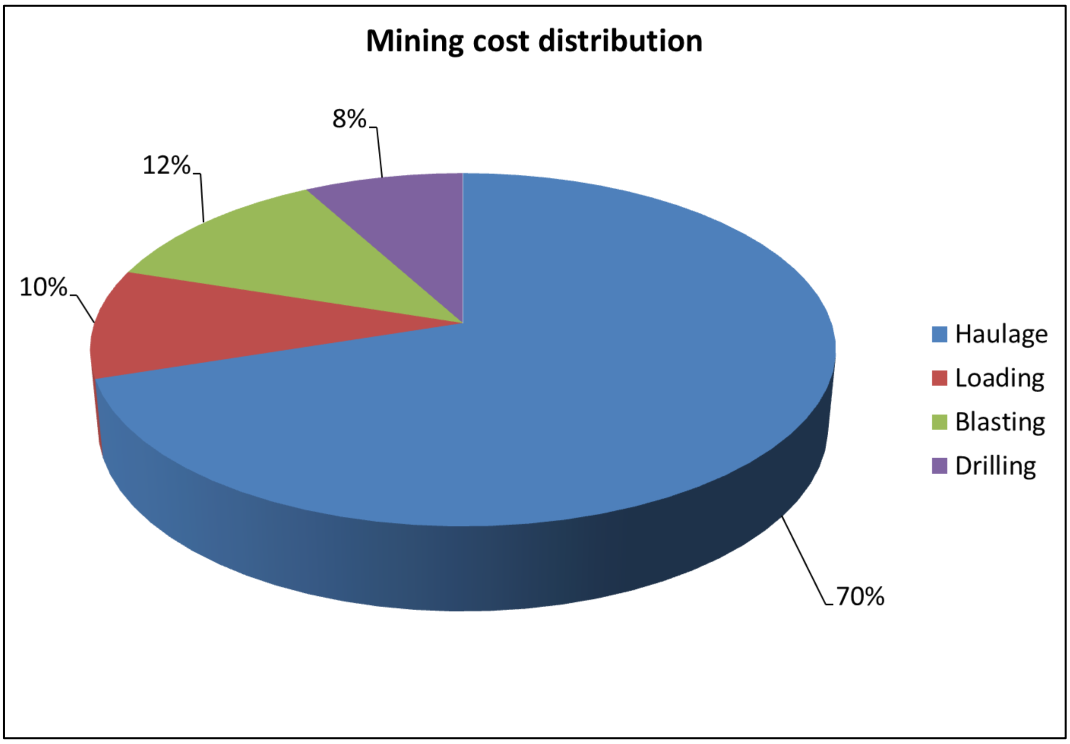

Figure 2.3: Distribution of costs for main activities of the production cycle in open pit mines

Adopted from Bagherpour (2007)

2.3. Comparison of coal mining sectors by country

Mining costs differ from country to country based on factors such as geology of the orebody, infrastructure, labour availability and the country's level of economic development. According to the World Coal Institute, there are significant similarities between South African and Indian coal mining sectors. The comparison was based mainly on coal geology, mining methods used and labour productivity. Table 2.1 shows the mining methods and percentage of coal extraction from seven coal producing countries.

Table 2.1: Percentages of annual coal production in selected countries, divided into room and pillar extraction and longwall mining method

Country	**Room and Pillar**	**Longwall**
	(Percentage of underground mines)	
India	91	5
South Africa	91	9
USA	55	45
Australia	28	72
China	No information	20
Germany	0	100
United Kingdom	<1	99

Adopted from Raw Materials Group (2013)

From Table 2.1, the similarities between South African and Indian coal mining are evident and these similarities play a significant role later on in this report in both the capital costs and operating costs between these two countries. South African room and pillar mining methods occur at shallow depths (generally less than 100m) while the average range in India is about 300 to 350m (Xie, 2008).

Mining costs in Indian coal mines are about 35% higher than those in coal mines in leading coal exporting countries such as Australia, Indonesia and South Africa (Santra & Bagaria, 2014). The higher mining costs in India are driven mainly by low labour productivity. Despite higher mining costs in Indian coal mines when compared to South Africa, in 2013 India forecast a production increase of 3% while South Africa forecast only a 2% increase.

2.4. Background to cost estimation

Cost estimation can be defined as a predictive process used to quantify costs and price of the resources required (Leo & Knotowicz, 2005). Cost estimation can also be regarded as a process used to predict the uncertainty of future costs and in this context, the goal of cost estimating is to minimise the uncertainty of the estimate given the level of scope and definition (Leo & Knotowicz, 2005). The cost estimating process is generally applied during each phase of the project's life cycle and whenever the project scope is re-defined, modified and refined. As the level of scope definition increases, the estimating methods used become more definitive and produce estimates with increasingly narrower probabilistic cost distributions.

The two fundamental approaches to estimating costs are the top-down and bottom-up approaches. The top-down approach uses historical data from similar projects. It is best used when alternatives are still being developed and refined (Sullivan, Wicks and Koelling, 2012). The bottom-up approach on the other hand is more detailed and works best when the detail concerning the desired output (product or service) has been defined and clarified (Sullivan, Wicks and Koelling, 2012). In general, the bottom-up approach is more detailed than the top-down approach. Figure 2.4 shows the simplified cost estimation process for the bottom-up and top-down approaches.

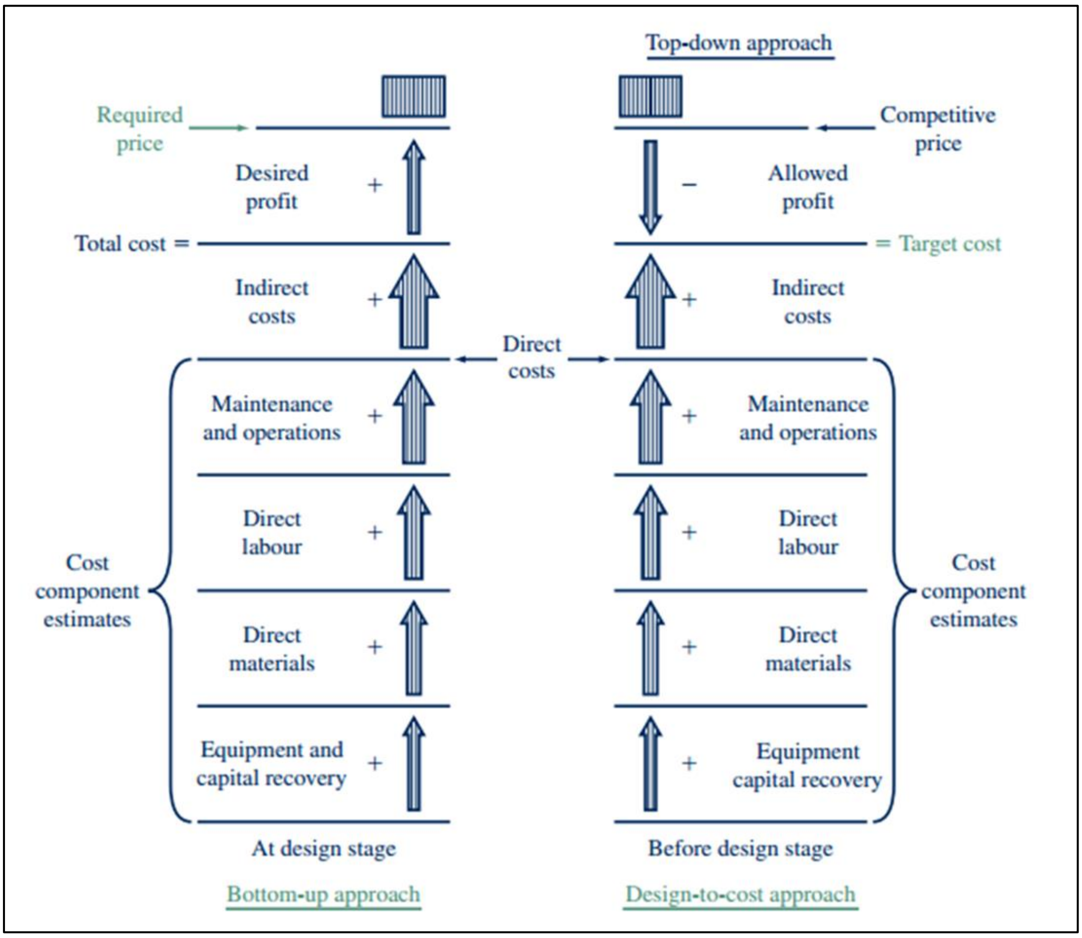

Figure 2.4: Simplified cost estimation process for bottom-up and top-down approaches

Source: Novellaqalive2 (n.d)

Results of cost estimation are used for a variety of purposes such as to:

- provide for planning the appropriate funds
- enable decisions on the viability of feasibility studies
- provide project analyses and evaluations in the research and development phase
- enable a company to evaluate alternative investments
- serve as a basis for cost control activity during job execution

2.5. Types of cost estimates

Different types of estimates reflect the range of accuracy expected from the estimate. Three common types of project estimates are order of magnitude, preliminary and definitive estimates. Table 2.2 shows the accuracy associated with each type of estimate.

Table 2.2: Types of estimates

Type of Estimate	Accuracy	Applicable type of study
Order of magnitude	-30 +50 %	Scoping study
Preliminary Estimate	-15 +30%	Pre- Feasibility Study
Definitive estimate	-5% +15%	Feasibility Study

In this classification of cost estimates, order of magnitude value is a very rough estimate, preliminary estimate is generally associated with budget approval and definitive estimate is associated with cost control on the budget. There are many cost estimating techniques that can be used within the mining industry and other industries depending on the project scope and estimate purpose. The different cost estimating techniques are discussed in the next sections.

2.5.1. Detailed estimating technique

The detailed estimating method is normally the most definitive of the estimating methods used as it uses information down to the lowest level of detail available. This method uses detailed items such as labour hours, material costs, equipment costs and subcontractor costs. Due to the details required for the method, all quantities should be objective, discrete and measurable. The costs are constantly refined as more detailed information becomes available. According to the United States Cost Estimation Guide, some of the advantages offered by the detailed estimating method are:

- A higher level of confidence;
- More detail that can be used for better monitoring of the projects costs;
- More detail on individual activities; and
- Detailed quantities to establish more accurate metrics.

Some of the disadvantages of the detailed estimating techniques include:

- The estimate takes longer to develop; and
- More expensive to develop than relationship estimating techniques.

With mining projects, it is difficult to obtain detailed cost information from the public domain and as a result this method could not be used for this study.

2.5.2. End product unit technique

The End Product Unit Method is used when enough historical data is available from similar work based on the capacity of that work. The method does not take into account the economies of scale, or location or timing of the work (Dysert, 2005). This method uses data from previous projects to extrapolate based on the circumstances of the project being estimated.

This method was discounted for this study on the basis that is does not account for economies of scale which plays a fundamental role in operating and capital costs of mines.

2.5.3. Physical dimension technique

The Physical Dimension Method is used when enough historical data is available from work based on the area or volume of that work. As with the End Product Unit technique, this method also does not take into account any economies of scale, or location or timing of the work. This method was also discounted for use in this study on the basis that it does not account for economies of scale which plays a fundamental role in coal mining operating and capital costs.

2.5.4. Capacity factored estimates

Capacity factored estimates (CFE) are used to provide a relatively quick and sufficiently accurate means of determining whether a proposed project should be continued or if an alternative design or equipment needs to be selected. "Capacity factored estimates use the cost of a similar known project with a known capacity to derive the cost of a similar projected project with a similar capacity" (Dysert 2005:5). It relies on the non-linear relationship between capacity and cost. Formula 2.1 is the basic estimating formula which is used for capacity factored estimation:

$$Cost_B / Cost_A = (Cap_B / Cap_A)^r \qquad \textbf{Formula 2.1}$$

where: $Cost_A$ and $Cost_B$ are the costs of two similar projects A and B, Cap_A and Cap_B are the capacities of the two projects and "r" is the exponent that drives the non-linear relationship.

The value of the exponent typically lies between 0.5 and 0.85, depending on the type of project. The exponent "r" is also the slope of the logarithmic curve that reflects the change in the cost plotted against the change in capacity. It can be determined by plotting cost estimates for several different operating capacities where the slope of the best line through the points is r.

According to Sanchez (2011), the CFE technique should be used cautiously. It needs to ensure that the new and existing known projects are near duplicates, including the risk in case of dissimilar process and size. Location and escalation adjustments should be applied to normalise costs and the capacity factor formula used to adjust for project size. In addition, appropriate cost indices should be used to accommodate the inflationary impact of time and adjustment for location. Any additional costs that are required for new projects, but were not included in the known project should be added. This method was not used due to the fact that mining projects vary. It is nearly impossible to find identical mining projects. Capacity and location between two mining projects may be identical, but grade, mining method, depth of the mineral may vary which will make the two projects not identical.

2.5.5. Parametric estimating techniques

Parametric cost estimates are used to estimate equipment cost and finally the total costs at an acceptable error percentage when there is little technical data on the equipment and other capital cost items (Sanchez, 2011). It involves development of a parametric model based on data on equipment costs from specific time duration. Then, using statistical methods, the model’s coefficients are obtained and their accuracy and estimation capabilities determined. Completed projects are the best source for reliable data. Applying data from previous projects, using regression methods and statistical tests, a final model is derived.

A parametric model is a mathematical representation of cost relationships that are logical and predictable due to a correlation between physical quantities and resultant costs (Sanchez, 2011). Capacity and equipment-factored estimates are simple parametric models. More sophisticated parametric models involve several independent variables or cost drivers.

Data collected from previous projects needs to be normalised (Sanchez, 2011). Data normalisation is an adjustment done to account for escalation, location, site conditions, system specifications and cost scope. Once cost data has been normalised, it is then analysed as the next step in developing a parametric model (Rose, 1982). Data is analysed by performing regression of costs versus selected design parameters to determine the key drivers for the model. The regression involves iterative experiments to find the best-fit or mathematical relationship that describes how the data behave. As a formula is established that appears to provide reliable results it must tested to ensure that it properly explains the data.

The equation that is the best fit for the data will typically have the highest R-squared (R^2) value, which provides a measure of how well the formula predicts the calculated costs (Sanchez, 2011). A high value of (R^2) does not by itself imply the relationships between the dependent and independent variables are statistically significant. If the relationship from the model appears to be reasonable, then additional tests such as t-test and f-test can be run to determine the statistical significance and to verify that the model is providing results with an acceptable error percentage.

This technique is useful for early stage project cost estimation. Some of the advantages offered by the parametric cost estimation are (Dysert, 1999):

- *Efficiency*– Estimates can be prepared in much less time than other detailed methods and require less engineering and level of project definition to support the estimate.
- *Sensitivity* – It is easier to produce sensitivity analysis by varying input parameters and recording the changes on the results.
- *Consistency* – If two estimators input the same values for parameters, they will get the same resulting cost. Parametric models also provide a consistent estimate format and estimate documentation.
- *Versatility* – A parametric relationship can be derived at any stage based on the availability of data and can be easily updated when the data changes.
- *Objectivity* – Parametric models require quantitative inputs that are linked to formulae providing quantitative outputs. All costs are traceable.

As with most estimating techniques, parametric estimates have disadvantages and some of these are:

- *Complexity* – Non-linear relationship between independent variables and costs may result in complicated formulae that may be difficult for others to understand.
- *Currency* – The costs need to be updated periodically to capture current costs.
- *Database requirements* – Normalising data to ensure consistent and reliable inputs is time consuming.

This is the technique that the author used in this study to estimate the cost of establishing coal mines in South Africa. This method was chosen because it uses data that is publicly available. The method was also chosen due to its ability to capture the influence of economies of scale on mining projects as well as capturing the variations in mining projects.

2.6. Mining cost indices

Cost indexes provide a means of adjusting out dated capital and operating costs for the effect of inflation (Dipu, 2011). They are based on the statistical averages of costs for each of surface and underground coal mining and coal processing (preparation) operations, which are calculated taking into account several completed projects as well as several economic indices. A cost index can therefore be defined as a ratio of the cost of an item today to its cost at some point in the past (Novellaqalive2, 2014). This means that the index is a dimensionless number that shows the relative cost change over time.

According to D'Adda (2012), the need for a cost index is due to the fact that cost data are valid only on the day when they are materialised and in a relatively short time they become out of date due to inflation. As a result, a cost index is needed to keep the cost up to date. The commonly used index is the consumer price index (CPI), which shows the relationship between present and past costs for many of the things that "typical" consumers must buy.

Indices for specific cost items such as labour, equipment, transportation, fuel, explosives, tyres and electric power are available and are being used by the industry and regulators to calculate escalations of capital and operating costs. The general formula used for updating costs through the use of a cost index over a period from time *t = 0* (base) to another time *t* is:

$$\boldsymbol{C_t = C_0\left(\frac{I_t}{I_0}\right)}$$ **Formula 2.2**

Where C_t = estimated cost at present time *t*

C_0 = cost at previous time t_0

I_t = index value at time *t*

I_0 = index value at time t_0

Generally, the indices for equipment and materials are made up of a mix of components which are assigned certain weights, with the components sometimes further subdivided into more basic items.

2.7. Capital intensity

The mining industry is very capital intensive as compared to other industries (Rudenno, 2009). The high capital costs are attributed to:

- *Exploration* – Substantial funds are needed to find new mineral resources and some of these searches return no new minerals. The magnitude of exploration budgets is shown in the annual reports of leading mining companies, for example in 2013 Anglo American spent US$207 million on exploration activities while BHP Billiton spent US$675 million during the same period (Anglo American Annual Report 2013; BHP Billiton Annual Report 2013).
- *Economies of scale* – In the mining industry, bigger operations tend to be more profitable than smaller ones and this is attributable to economies of scale. When costs are spread over higher volumes of production, the overall costs per tonne are reduced.

- *Isolation* – Mining projects exist and operate from where the mineral resources are recovered. As a result, basic infrastructure is developed in conjunction with the project thereby increasing the capital costs. In recent history, some companies have opted to flying their operators in and out of remote areas so as to avoid some infrastructure costs such as employees' villages.
- *Power and water* – These are critical requirements for every mining project. Power requirements can be in the form of fuel and electricity. In some mining projects due to the lack of infrastructure, electricity is generated by diesel powered generators. Natural energy like solar is also receiving popularity within the mining industry so as to reduce the operating costs attributable to energy. It is common practice for mining companies to team up with local government in extending electrical power lines where possible so as to reach the mine sites. Construction of water pipelines is usually necessary for consistent and reliable water supply.

Figure 2.5 shows a typical distribution of capital costs for a coal mine constructed in South Africa. The breakdown is developed from analyses of eight Anglo American Thermal Coal completed projects. The distribution will vary depending on the location and type of mine amongst other things.

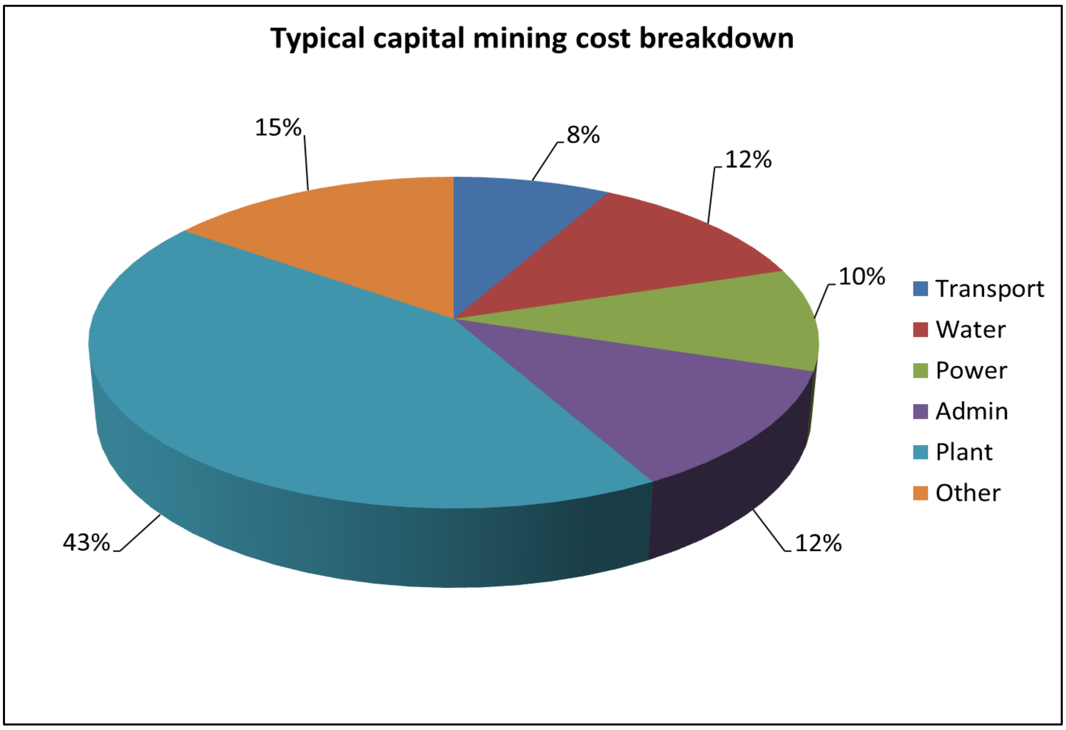

Figure 2.5: Typical capital costs breakdown

Adopted from Anglo American Thermal Coal projects database (2013)

2.8. Cost estimation in mining

According to Hall (2013), there is a lack of general estimate of capital costs of establishing coal mines in South Africa. In 2008, the Australian Average Capital Costs (ACC) for developing an open pit mine could be estimated at AUD 53million plus AUD 33 million per 1 million tonne per annum of coal produced and treatment capacity (Harper, 2008). For the same year, Australian underground mine establishment costs could be estimated at AUD 37 million plus AUD 68 million per 1 million tonne per annum of coal production and treatment capacity (Harper, 2008).

In 2011 costs, the capital costs of Indian coal surface mines were estimated to range from USD 31.65 to 44.30 per tonne of rated capacity. This means that a one million tonne per annum capacity mine can be expected to cost approximately USD 44.3 million in 2011 (Dipu, 2011). The above estimation is based on a stripping ratio of 4:1 and appropriate adjustments can be made to account for higher or lower stripping ratios.

For underground mining, the estimates ranged between USD 40.7 and USD 59.05 per tonne of rated capacity. This means that in 2011, a one million tonne per annum rated Indian coal mine would require an estimated capital cost of USD 59.09 million (Dipu, 2011). The underground estimates are applicable to shallow mines (within 150 metres depth) mined with semi-mechanised bord and pillar mining method.

2.9. Capital cost estimation in open pit mines

The capital costs for coal mining projects typically include costs of land, capital equipment and infrastructure to support the mining process (Dipu, 2011). Project costs may also include capitalised expenses for clearances and approvals needed for mining to begin. With most mining projects, the costs of equipment dominate the overall project costs, therefore equipment selection is at the core of determining the capital costs. In surface mining, the equipment selection takes into account geological features such as partings between coal seams and the expected bench heights.

Several authors have derived formulae and equations for estimating the capital costs of coal mining projects. Bagherpour (2007) formulated a set of equations to estimate both operating and capital costs. In his study, Bagherpour segmented capital costs into different activities to derive equations to estimate capital costs of these activities. With regard to estimating all operating costs of loading and haulage equipment, formulae 2.3 to 2.6 can be used for obtaining the size and number of equipment and then the capital costs are calculated by the use of formulae 2.7 and 2.8 (Bagherpour, 2007):

S = 0.13 * $T^{0.4}$ **Formula 2.3**

N_S **= 0.007 *** $\frac{T^{0.8}}{S}$ **Formula 2.4**

t = 8 * $S^{1.1}$ **Formula 2.5**

N_t ***= 0.2 **** $\frac{T^{0.8}}{t}$ **Formula 2.6**

***Capital costs for loading equipment* ($) =** N_t *** 499813 *** $S^{0.73}$ **Formula 2.7**

***Capital costs for haulage equipment* ($) =** N_t *** 19558 *** $t^{0.85}$ **Formula 2.8**

In the above formulae T is the production rate of waste and ore in short tons per day, S is the optimal nominal capacity of shovel bucket on a cubic yard basis, N_s is the number of required shovels, t is the optimal size of truck in short tonnes and N_t is the number of trucks required.

The above formulae are based on the assumptions of an open pit mine with a daily production capacity of 43 000 short tons, mining an oval shaped periphery pit with a depth of 120 – 150m, width of 670m, length of 1430m, height of benches 12m, overall slope 57 degrees in competent rock and 43 degrees in oxidised or altered rocks, gradient of roads inside the pit were 9 percent on average (Bagherpour, 2007). Cost indices were applied to all the costs to account for inflation and other factors.

Due to the differences in units between the formulae provided above and the standard units used in South Africa, the formulae will not be applicable in South Africa unless adjustments are made to convert the formulae to South African units.

2.10. Concluding remarks

This chapter opened by highlighting the cost structure of mining operations. Emphasis was put on the capital and operating costs, showing typical distributions of these costs in coal mining. A background to cost estimation was presented, drawing attention to the fundamental approaches used in cost estimation. Once the overall picture of cost estimation had been drawn, the chapter looked into the different types of cost estimates and the main estimating techniques used. The estimation techniques were then explained in more detail.

Greater emphasis was put on the technique used in this study. Mining cost indices, a parameter that supports estimation was a process that was also explained. Cost estimation was discussed and narrowed down to the mining sector. Mining sectors across different countries were compared focusing more on South African and Indian mining operations since similarities were drawn between coal mining in these two countries. The report further looked at the formulae that are used in other countries to estimate the mining costs. The chapter concluded by looking deeper into the surface and underground coal mines cost estimation. The next chapter describes the research methodology used in this study.

3.METHODOLOGY

3.1. Chapter overview

This chapter focuses on the research methodology used in this study. The chapter begins with the description of the chosen method of research and the reasons why the method was chosen. The data utilised is then discussed together with the data limitations.

3.2. Brief description of the parametric cost estimation methodology

Cost estimation was conducted using a parametric estimation model. A parametric cost estimation model is a mathematical representation of cost relationships that provide a logical and predictable correlation between the physical or functional characteristics of a project and its resultant cost (International Society of Parametric Analysts, 2008). According to Dysert (2005), parametric cost estimating models are useful tools for preparing early conceptual estimates where there is little technical detail available to provide a basis to support the use of more detailed estimating methods.

In this study, actual project costs were used as dependent variables whereas factors such as mine capacity, life of the mine and stripping ratio were used as independent variables. Relationships between dependent and independent variables from historical data on global coal mines were used to estimate costs for future coal mining projects in South Africa. The model runs from an excel spreadsheet and the results aim at estimating capital costs to an order of magnitude level. With all the cost models, data is normalised to ensure consistency.

The first step in developing the model was determining the scope. The capital cost drivers for coal mines were identified to be studies, project management, site preparation, infrastructure, equipment, stores and sundry. The above mentioned capital cost drivers were not looked at individually in estimating the total capital cost due to lack of detail in the data. Figure 3.1 illustrates the methodology followed in this study

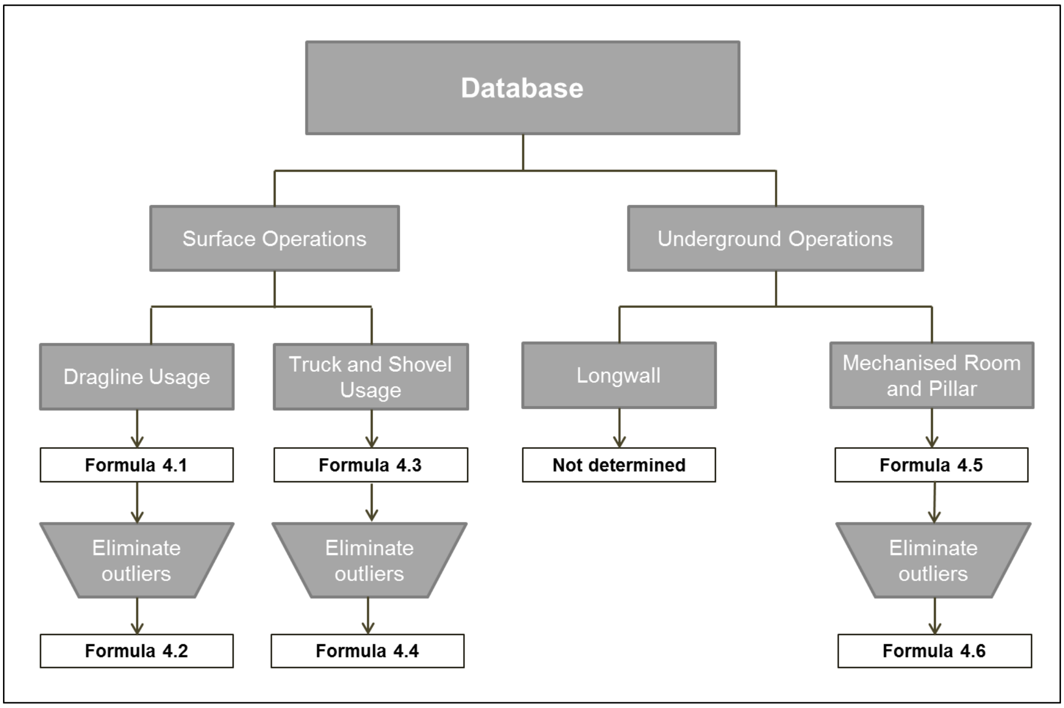

Figure 3.1: Methodology followed in estimating the capital costs of establishing a coal mines in South Africa

In estimating the capital cost of coal mines in South Africa, data was obtained from Anglo American Thermal Coal and RMG's databases. The cost data looks into actual costs, designed production capacities, stripping ratios and ROM production.

As shown in Figure 3.1, data was first segmented into surface and underground operations. The rationale behind splitting the database into underground and surface mining operations is to capture the influence of different mining methods on capital costs. Data on surface mining operations is further split into dragline operations and truck and shovel operations. Dragline operations consider the combination of truck and shovel and dragline as the main waste removal equipment. Underground operations are also divided into room and pillar and longwall operations. Due to a lack of longwall operations in South Africa and no immediate plans to build such operations imposed by the country's coal geology constraints, capital costs were not estimated for this mining method.

3.3. Data utilised

The model uses actual cost data from operations across the world, mostly from India and South Africa. The reason for selecting Indian mining operations is due to similarities between South African and Indian mining operations. As mentioned earlier, the main sources of data are RMG mining database and Anglo American Thermal coal projects database. Of the mining projects sampled, 76% are surface mining operations and 24% are underground mining projects.

Cost data is captured at a fairly low level of detail to allow an in-depth analysis. Due to data requirement at such level, most of the cost data from mining operations in South Africa could not be used. The cost data year and location of the projects were collected to allow for normalisation. Cost data was normalised to USD currency and by use of mining indices escalated to 2013 financial terms.

3.4. Cost estimation formulae

Multiple regression analyses which are a parametric estimation technique were used to determine the formulae for estimating capital costs. This method was employed so as to obtain greater understanding of what and how the independent variables contributed to the dependent variable (Nimon, Gavrilova, & Roberts 2010; Zientek, Capraro, & Capraro, 2008). Multiple regressions allow researchers to consider the role(s) that multiple independent variables play in accounting for variance in a single dependent variable.

The interpretation of the regression results relies heavily on the beta value. Other variable and analyses tool looked at include error and ANOVA.

3.5. Concluding remarks

This chapter discussed and clarified the methodology used in this research. The chapter looked at how mining operations are split based on type of mining method used to ensure consistency of the outcome of the method employed. The chapter concluded by describing the parametric estimation technique of multiple regression analyses and why it was used in this study.

4. RESULTS AND DISCUSSION

4.1. Chapter overview

This section of the report presents and discusses the results of the analyses. Tables, figures and formulae are used for presentation and interpretation of the results. This section begins by presenting the regression results of surface mines followed by underground mines. Outputs such as formulae derived from regression results are then presented and discussed. Data from South African mines are then used to test the formulae for accuracy by calculating error margins.

4.2. Surface mining operations

Cost data for surface mining operations includes data from open pit, strip and opencast mining methods. The cost data is normalised for the type of main equipment used in the operation. For primary waste removal, some of the operations use draglines, others use truck and shovel systems while others use a combination of draglines and truck and shovel systems. As mentioned in the literature review, the type of surface mining method and the type of equipment an operation uses has an effect on the quantum of capital cost required. Surface mines are split into dragline and truck and shovel operations.

As with South Africa, Indian coal stratigraphy consists of multiple coal seams that can be extracted profitably (Haque, 2013). Both South Africa and India produce mainly thermal coal. India’s coal seam thickness averages 6 m while South Africa’s average coal thickness is 5.5 m.

4.2.1. Dragline operations

Dragline operations include the mines that use a combination of dragline and ‘truck and shovel’ systems for primary waste removal. Table 4.1 shows 12 global operations used in this study to develop a formula for estimating the capital costs of establishing dragline type surface coal mines in South Africa. The actual project costs were normalised (adjusted to 2013 fiscal year) by using mining indices. The reason behind using a global sample instead of only South African operations is due to lack of data availability on projects for such operations in South Africa.

Table 4.1: Dragline type surface operations

Name	Country	Actual Project Cost (USD million)	Mine life years	Capacity Mt/yr	Stripping ratio (#)
Amlohri Coal Mine	India	245.1	20	4.0	7.17
Bina Coal Mine	India	36.2	12	6.0	7.26
Dudhichua Coal Mine	India	70	20	10.0	7.07
Jayant Coal Mine	India	227.2	20	10.0	7.07
Khadia Coal Mine	India	319.1	20	4.0	7.11
Nigahi Coal Mine	India	451.4	20	15.0	7.26
Vista Coal Deposit	Canada	444.5	20	6.0	5.10
Washpool Coal Deposit	Australia	354.9	16	7.0	6.50
ATCOM OP Coal Mine	South Africa	407	20	2.4	4.0
Middelburg Coal Mine	South Africa	975	20	17.0	2.0
New Largo Coal Mine Project	South Africa	530	20	15.0	6.0
Isibonelo	South Africa	68	15	4.1	5.0

Table 4.1 shows that draglines are generally considered where the LOM exceeds 10 years and LOM is in part attributable to selection of dragline equipment. Variation in production capacity shown in Table 4.1 illustrates that draglines are also useable in operations with less than 5Mtpa capacity.

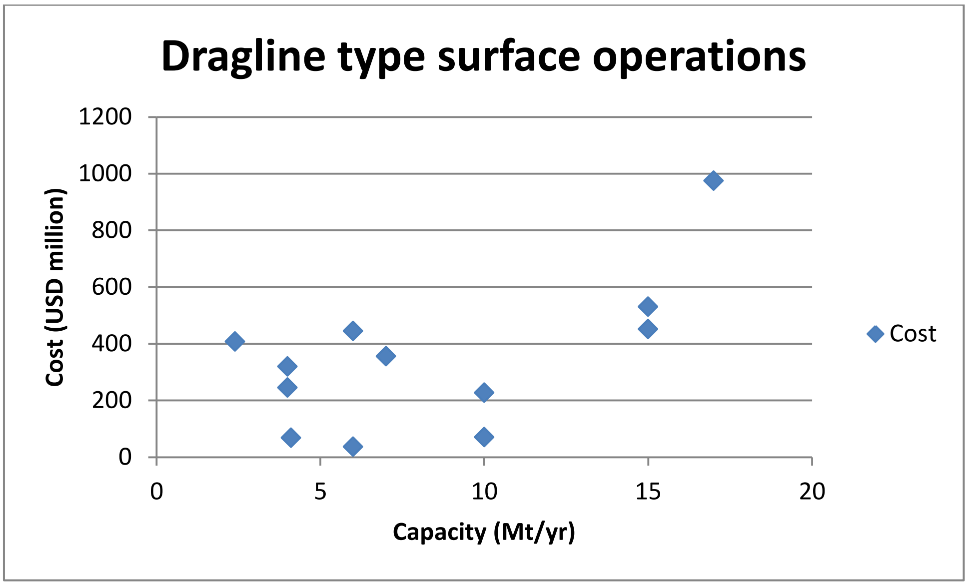

Figure 4.1: Capacity versus cost for dragline type surface operations

According to O'Hara, 1980, as the size of the mine increases, the capital costs decreases. The reduction in capital costs as the capacity increases is attributable to the spread of costs over large amount of tonnes. As depicted in Figure 4.1, one data point shows an anomaly and can therefore be regarded as an outlier. In general, Figure 4.1 does not depict what is expected based on O'Hara's findings which show a gradual decrease in capital costs as the capacity increases.

Table 4.2 shows the regression results used to develop a formula for surface coal mines using draglines. Based on the regression results in Table 4.2, R^2 is equal to 0.9189 meaning that 91.89% of the variation within the dragline operations used in the analysis is explained.

Table 4.2: Regression statistics table for dragline type operations

Regression Statistics	
Multiple R	0.958608356
R Squared	0.91892998
Adjusted R Squared	0.67571992
Standard Error	49.60320905
Observations	12

Additional regression analysis data is shown in Table 4.3. The coefficient table was used to determine the formula for estimating the capital costs.

Table 4.3: Coefficient table for dragline type operations

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	595.750	311.935	1.909	0.307	-3367.770	4559.272
X Variable 1	4.104	13.908	0.295	0.817	-172.619	180.829
X Variable 2	16.115	5.579	2.888	0.212	-54.781	87.012
X Variable 3	-64.512	28.128	2.293	0.262	-421.914	292.888

A summary output is that the fitted line is

$$\mathbf{CS} = \mathbf{595.75} + (\mathbf{4.1} \times \mathbf{LOM}) + (\mathbf{16.12} \times \mathbf{capacity}) - (\mathbf{64.51} \times \mathbf{SR}) \qquad \textbf{Formula 4.1}$$

Where:

CS is the capital costs

LOM is the life of mine

SR is the stripping ratio

Table 4.4: Estimation results for dragline type operations

Name	Actual project cost (USD million)	Country	Estimated project cost (USD million)	Percentage error
Amlohri Coal Mine	245.1	India	279.74	14%
Khadia Coal Mine	319.1	India	283.62	-11%
Nigahi Coal Mine	451.4	India	451.21	0%
Vista Coal Deposit	444.5	Canada	445.52	0%
Washpool Coal Deposit	354.9	Australia	354.9	0%
ATCOM OP Coal Mine	407	South Africa	458.47	13%
Middelburg Coal Mine	975	South Africa	822.78	-16%
New Largo Coal Mine Project	530	South Africa	532.50	0%
Isibonelo	68	South Africa	400.83	489%

Using Formula 4.1, the error between actual project costs and estimated project costs range between 0% and 489%. Based on the order of magnitude percentage error limits, three of the Indian operations were classified as outliers and removed from the regression analysis. The Isibonelo operation had a high percentage error because some of the main equipment used to establish the operation were not purchased but rather moved from other existing operations. Based on the calculated error, Formula 4.1 cannot be used to estimate capital cost of establishing coal mines in South Africa to an order of magnitude level.

Re-running the regression analysis without the outlier (Isibonelo) results in Formula 4.2, yielding estimation error ranging from -23% to 13%. The resultant formula without the outlier is shown below.

$$\mathbf{CS} = \mathbf{704.80} + (\mathbf{1.21} \times \mathbf{LOM}) + (\mathbf{21.30} \times \mathbf{capacity}) - (\mathbf{79.76} \times \mathbf{SR}) \qquad \textbf{Formula 4.2}$$

Based on the estimation error from using Formula 4.2, it can be concluded that Formula 4.2 is suitable to be used to estimate the capital costs of establishing surface dragline based operations in South Africa to an ‘error of magnitude’ estimation level.

4.2.2. Truck and shovel operations

As mentioned in Chapter 2, surface operations using truck and shovel systems are the most commonly used type of mining method for surface coal mining. The operations were not standardised for neither truck nor shovel size. The actual project costs were normalised (adjusted to 2013 fiscal year) by using mining indices. The reason behind using a combination of Indian and South African sample instead of limiting the sample to South African operations is due to a lack of detail in the data of completed operations in South Africa. Table 4.5 shows the truck and shovel operations used in this study.

Table 4.5: Truck and shovel type operations

Name	Country	Project actual cost (USD million)	Mine life years	Stripping ratio	Capacity Mt/yr
Balaram Coal Mine	India	85.4	20	2.76	8.0
Baround Top Seam Coal Mine	India	42.7	20	2.92	1.0
Basundhara Coal Mine	India	38.6	20	2.76	2.4
Gevra Coal Mine	India	293.2	20	2.99	25.0
Hingula Coal Mine	India	74.9	20	2.76	8.0
Kaniha OP Coal Mine	India	100.2	20	2.76	10.0
Kulda Coal Mine	India	293.1	20	3.60	10.0
Kusmunda Coal Mine	India	98.6	20	2.99	3.5
Moabsvelden Coal Deposit	South Africa	31.8	15	1.95	3.0
Middelburg O/C	South Africa	975	20	5.00	20.0

Figure 4.2 below shows a deviation from the expected relationship between capacity and costs based on O'Hara model. The capital cost increases with capacity as opposed to decreasing.

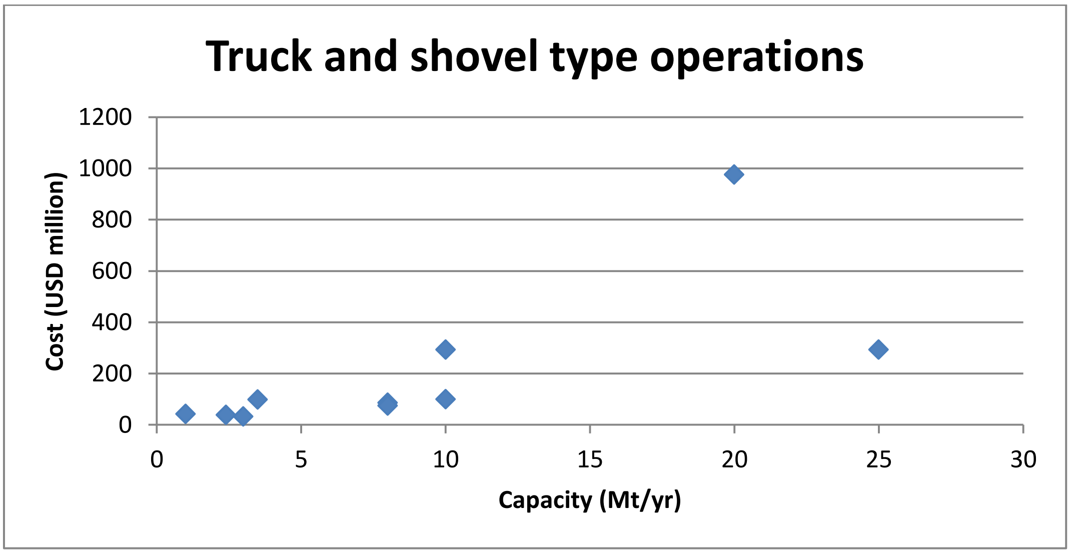

Figure 4.2: Capacity versus cost for truck and shovel type operations

The operations used are based in South Africa and India. The design capacity of the operations used range from 1.0 to 25.0 million tonnes per annum of ROM material. The variation of the design capacity is an indication of the flexibility of truck and shovel operations.

Table 4.6 shows the regression results used to develop a formula for surface coal mines using truck and shovel systems. Based on the regression Table 4.6, R^2 is equal to 0.9882 meaning that 98.82% of the variation between dependent and independent variables within the truck and shovel operations used for analysis is explained.

Table 4.6: Regression statistics table for truck and shovel type operations

Regression Statistics	
Multiple R	0.994113
R Squared	0.98826
Adjusted R Squared	0.982391
Standard Error	38.20446
Observations	10

The standard error was found to be 38.20%. Additional regression results are shown in Table 4.7.

Table 4.7: Coefficient table for truck and shovel type operations

	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***
Intercept	208.5111	161.3671	1.2922	0.2438	-186.3398	603.3621
X Variable 1	-58.0484	9.2174	-6.2977	0.0007	-80.6025	-35.4943
X Variable 2	341.3471	21.2495	16.0638	0.0000	289.3515	393.3427
X Variable 3	9.4626	1.9520	4.8475	0.0029	4.6861	14.2391

From Table 4.7 a formula for estimating capital costs of establishing surface coal mines that use truck and shovel system was determined to be:

$$CS = 208.51 - (58.05 \times LOM) + (341.35 \times capacity) + (9.46 \times SR)$$ **Formula 4.3**

The results of estimating the costs using Formula 4.3 are shown in Table 4.8.

Table 4.8: Estimation results for truck and shovel type operations

Name	Country	Actual project cost (USD million)	Estimated project cost (USD million)	Percentage error (%)
Balaram Coal Mine	India	85.4	65.36	-23%
Baround Top Seam Coal Mine	India	42.7	53.74	26%
Basundhara Coal Mine	India	38.6	12.37	-68%
Gevra Coal Mine	India	293.2	304.74	4%
Hingula Coal Mine	India	74.9	65.36	-13%
Kaniha OP Coal Mine	India	100.2	84.29	-16%
Kulda Coal Mine	India	293.1	371.02	27%
Kusmunda Coal Mine	India	98.6	101.29	3%
Moabsvelden Coal Deposit	South Africa	31.8	31.80	0%
Middelburg O/C	South Africa	975	943.53	-3%

From Table 4.8, it can be seen that Basundhara coal mine in India is an outlier as a result, calculated error between actual and estimated projects costs range from -68% to 27%. Based on the definition and error limits of "error of magnitude" estimation level, it can be concluded that Formula 4.3 cannot be used to estimate the cost of establishing surface truck and shovel operations to a an error of magnitude level.

Re-running the regression analysis without the outlier (Basundhara coal mine) gives Formula 4.4, yielding estimation error ranging from -29% to 8%. In can therefore be concluded that Formula 4.4 can be used to estimate the capital costs of establishing underground bord and pillar operations in South Africa to an ‘error of magnitude’ estimation level.

$$\mathbf{CS = 228.69 - (59.58 \times LOM) + (342.07 \times capacity) - (9.91 \times SR)} \quad \textbf{Formula 4.4}$$

4.3. Underground mining operations

Cost data used in underground operations only considered room and pillar operations. The decision to focus only on bord and pillar operations was motivated by lack of historical data and lack of future plans for longwall mining operations in South Africa. Since the South African coal mining operations are comparable to those in India, Indian mines cost data were used to estimate capital costs of South African underground mines.

4.3.1. Room and pillar mining method

The bord and pillar mining method as used in this report is limited to mechanised coal mining. The capital cost differences between mechanised and conventional mining methods made it impractical to combine the cost data of these two mining methods. Table 4.9 shows the operations used in the regression analyses.

Table 4.9: Room and pillar underground type operations

Name	Country	Actual project cost (USD million)	Mine life (years)	Capacity (Mt/yr)
Irenedale Coal Mine	South Africa	32.1	15	7
Mbila Anthracite Coal Deposit	South Africa	88	15	0.8
Penumbra Coal Mine	South Africa	36.4	13	0.8
Mooiplaats U/G	South Africa	141.5	20	5.0
Tumelo U/G	South Africa	126.8	20	6.0
Twistdraai U/G	South Africa	215.4	20	2.0

Similar to Figure 4.2, the capital cost of bord and pillar operation shown in Figure 4.3 increases with increasing capacity.

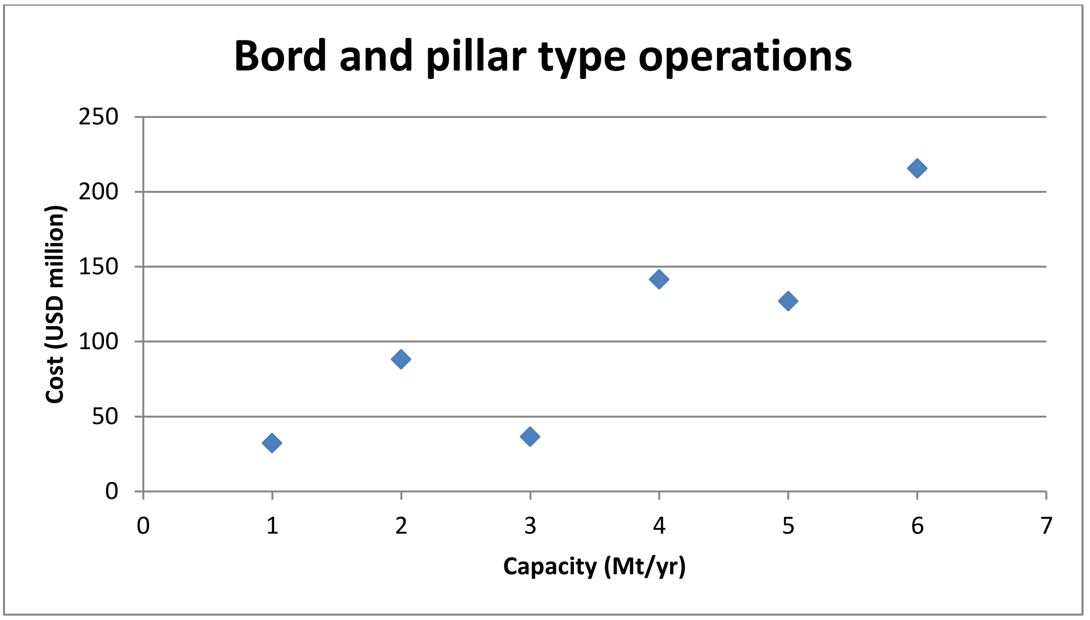

Figure 4.3: Capacity versus cost for bord and pillar type operations

Table 4.10 shows the statistical output of the regression analysis of underground room and pillar operations. Based on the results, 90.58% of the variance between actual costs, and mine life, and capacity can be explained by a formula derived from these results. Table 4.10 further shows the number of operations used in the regression analyses.

Table 4.10: Regression statistics table for room and pillar type operations

Regression Statistics	
Multiple R	0.971336
R Squared	0.943493
Adjusted R Squared	0.905821
Standard Error	21.38871
Observations	6

The regression output also provides the coefficient table shown as Table 4.11 below. From Table 4.11, the intercept is calculated to be -242.18, LOM coefficient calculated as 22.90 and capacity coefficient calculated as -12.28.

Table 4.11: Coefficient table for room and pillar type operations

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-242.18	52.8036	-4.5865	0.0195	-410.2278	-74.1388
X Variable 1	22.90	3.2469	7.0520	0.0059	12.5643	33.2308
X Variable 2	-12.28	3.7763	-3.2521	0.0474	-24.2989	-0.2629

Once the coefficients were determined, a formula for estimating capital costs was developed as shown in Formula 4.5. Formula 4.5 was then used on the initial cost data to estimate the capital costs.

$$\mathbf{CS - 242.18 + (22.90 \times LOM) - (12.28 \times capacity)} \qquad \textbf{Formula 4.5}$$

From Table 4.12 it can be observed that the calculated error ranges from -52% to +27%. Irenedale mine cost data was regarded as an outlier as its error fell outside the order of magnitude error limit. Some of the factors that contributed to high Irenedale mine costs data are the relatively deeper shafts as compared to other operations and establishment of a surface overland conveyor.

Table 4.12: Estimation results for room and pillar type operations

Name	Country	Actual project cost (USD million)	Estimated project cost (USD million)	Percentage error (%)
Irenedale Coal Mine	South Africa	32.1	15.31	-52%
Mbila Anthracite Coal Deposit	South Africa	88	90.96	3%
Penumbra Coal Mine	South Africa	36.4	46.27	27%
Mooiplaats U/G	South Africa	141.5	154.36	9%
Tumelo U/G	South Africa	126.8	142.08	12%
Twistdraai U/G	South Africa	215.4	191.21	-11%

Based on the parameters of order of magnitude estimation level, it can be concluded that Formula 4.5 does not fit the requirements due Irenedale coal mine estimation error. Re-running the regression analysis without the outlier gives for Formula 4.6, with an estimation error ranging between -13% and +21%.

$$\mathbf{CS} = \mathbf{333.57} + (\mathbf{29.57} \times \mathbf{LOM}) - (\mathbf{22.78} \times \mathbf{capacity}) \qquad \textbf{Formula 4.6}$$

Based on the resultant estimation error from using Formula 4.6, it be concluded that Formula 4.6 is suitable to be used in estimating the capital costs of establishing mechanised underground room and pillar coal mining operations in South Africa to an order of magnitude level.

4.4. Concluding remarks

This chapter presented and discussed the results of estimating the capital costs of establishing coal mines in South Africa. The results are based on leveraging similarities between South African and Indian coal mining operations. Using a combination of global operations, but mainly South African and Indian operations data, six formulae were developed to estimate capital costs of establishing coal mines in South Africa to an error of magnitude estimation level. From the six formulae developed, only three are able to estimate the capital costs within order of magnitude error level.

This chapter further showed the resultant error from estimated capital costs compared to actual costs. The following chapter discusses the conclusion and the recommendations.

5.CONCLUSIONS AND RECOMMENDATIONS

5.1. Chapter overview

This chapter summarises the findings of this study. It then states the recommendations for mining cost estimators in South Africa. Suggestions for further research are then discussed.

5.2. Conclusions of the study

There are two main conclusions that can be drawn from this research. Firstly, the availability of mining capital costs to lowest cost activity level is a challenge in the mining industry. Secondly, most databases only provide data at higher cost activity level (total capital costs) without providing any cost breakdown.

From the six formulae developed in this study, three indicated that they can be used to estimate capital costs of establishing coal mines in South Africa to an error of magnitude level of between -30% and +50%. The correlation between capital costs required for establishing coal mines in South Africa and India is noticeable from the resultant error calculated between actual and estimated costs. No formula could be developed for estimating capital costs of establishing underground longwall mines due to a lack of actual costs data from such mines in both South Africa and India.

In conclusion, this study was able to establish formulae that estimators can use in the early stages of coal mining projects to estimate the costs of establishing underground coal mines in South Africa to an order of magnitude estimation level.

5.3. Recommendations

The first consideration is that different mining methods, location of mines and type of equipment used have a significant influence on the capital costs of establishing mines. It is vital to classify mines using criteria mentioned in this study before carrying out any exercise to develop any formula for estimation of capital costs in coal mining. The last consideration is looking at the similarities between South African and other countries with the similar mining conditions.

5.4. Suggestion for further research

Further research could be done to estimate the cost of establishing surface coal mines to more accurate levels, including estimating the capital cost breakdown. Since this study focused on South Africa, other countries could also be examined.

6.REFERENCES

Anglo American Annual Report, (2013) INTERNET, http://www.angloamerican.com/~/media/Files/A/Anglo-American-Plc/reports/annual-report-2013/annual-report2013.pdf cited on 01 June 2014

Bagherpour R, (2007) *Technical and economical optimization of surface mining processes – Development of a data base and a program structure for the computer-based selection and dimensioning of equipment in surface mining operations*, Dissertation, Department of Energy and Management, Technical University of Clausthal

BHP Billiton Annual Report (2013) http://www.bhpbilliton.com/home/investors/reports/Documents/2013/BHPBillitonAnnualReport2013.pdf cited on 01 June 2014

BP Statistics., (2012) *BP Statistical Review*, INTERNET, http://www.bp.com/liveassets/bp_internet/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/coal_section_2012.pdf cited 26 April 2014

Bredell, J.H., (1987) *South African coal resources explained and analysed*, Geological Survey of South Africa, Unpublished Report 1987-0154

Brestensky. D., (1991) *The Early Coal Miner;* Conference Proceedings April 13-14, 1989 PennState Fayette Campus Uniontown, Pennsylvania. Connellsville, Pa: Connellsville Printing Company

Bullivant, D. A., (1987) *Current Surface Mining Techniques*, Journal for the Transportation of Materials in Bulk: Bulk Solids Handling, vol 7, n6, pp827-833.

Chabedi, K.C (2013) *Analysis of technical factors for underground mining of deep Waterberg resources*, Dissertation, Johannesburg, South Africa, University of the Witwatersrand

D'Adda, C., (2012) *Italy and the Euro*, University of Bologna, Italy

Department of Mineral Resources (DMR)., (2012) *South African coal outlook*, Pretoria, South Africa

Department of Mineral Resources (DMR)., (2013) DMR annual performance plan 2013/14, INTERNET, http://www.dmr.gov.za/publications/annual-report/viewcategory/26-annual-reports.html cited 15 on May 2015

Dipu, D., (2011) Capital costs of Indian coal mining project – an analyst view, INTERNET, http://www.coalspot.com/news/1888/capital-costs-of-indian-coal-mining-project/1 cited on 28 May 2014

Dysert, L. R., (1999) *Developing a Parametric Model for Estimating Process Control Costs,* AACE Transactions, AACE International, 1999

Dysert, L, R., (2005*) So You Think You're an Estimator?,* AACE International Transaction, EST.01

Eskom., (2010) Integrated Report, INTERNET. http://www.eskom.co.za cited 6 November 2013

Eskom., (2013) Eskom Technical Team presentation to investors, Megawatt park Sunninghill Johannesburg

Fox, R., (2011). *A study on the effectiveness of mine design software for pit optimisation and scheduling at the Mt. Thorley Warkworth Coal Mine*, BE Thesis, School of Mining Engineering, The University of New South Wales

Gaukartifact., (n.d) *Surface Mining for Mineral & Metals,* http://gaukartifact.com/ cited on 21 August 2014

Hall, I., (2013) Personal Interview dated 02 August 2013 held at 55 Marshal Street Marshalltown Johannesburg

Haque, E., (2013) *Indian coal production and ways to increase coal suppliers*, International Journal of Scientific and Research Publications, Volume 3, Issue 2

Harper, P., (2008) *What does a feasibility study cost?* International Mining, April 2008, pp 60- 61

Hartman, H.L and Mutmansky, J.M., (2002) *Introductory Mining Engineering, second edition*, John Wiley & Sons, New York

Hartnady, C., (2010) *South Africa's diminishing coal reserves*, South African Journal of Science, 10, 369 – 374

International Society of Parametric Analysts (ISPA)., (2008) *Parametric Estimating handbook*, Fourth Edition, US Government

Jeffrey, L. S., (2005) *Characterization of the coal resources of South Africa*, SAIMM proceedings of Sustainability of Coal, 7-9 September 2004

Kota, M., (2014) Personal Interview dated 05 March 2013 held at Pretoria, South Africa

Lowrie, R. L., (1968) *Recovery Percentage Of Bituminous Coal Deposits In The United States (In Two Parts) Part 1. Underground Mines,* [Washington, D.C.]: U.S. Dept. of the Interior, Bureau of Mines

Leo, W., and Knotowicz, W., (2005) *Project Estimate Reviews*, AACE International Review

Lind, G. and Phillips, H., (2001). *The South African Coal Industry - a millennium Review*. Journl of Mines, Metals and Fuels, 49(6).F

Mining Weekly. (2010*) A brief look at SA's coal-mining industry*. INTERNET. http://www.miningweekly.com/article/a-brief-look-at-sas-coal-mining-industry-2010-09-03 cited on 24 November 2012

Nimon, K., Gavrilova, M., & Roberts, J. K (2010) *Regression results in human resource development research: Are we reporting enough?* I C. Graham & K.Dirani (Eds.) Proceeding of the Development 2010 International Conference (pp. 803-812),

Novellaqalive., (n.d) *Cost estimation and Indirect Cost Allocation*, INTERNET, http://novellaqalive2.mhhe.com/sites/dl/free/007096310x/591328/ch18_CostEstimation.pdf cited 25 May 2014

Rajikorba., (2013) *Mining methods in India*, INTERNET, http://rajikorba.blogspot.com/ cited on 26 June 2014

Raw Materials Group (RMG)., (2014*) Global Mining Database*, Coal Mining, South Africa

Rose, A., (1982) *An Organized Approach to Parametric Estimating*, Transactions of the Seventh International Cost Engineering Congress of 1982

Rudenno, V., (2009) *The Mining Valuation Handbook: mining and and energy valuation for investors and management,* 3rd edition, Milton, Queensland, Australia

Rutledge, D., (2008) *Hubbert's peak, the coal question and climate change,* available from http://rutledge.caltech.edu

Ryan, B., (2014) *Richards Bay Coal Terminal sets coal export record*, INTERNET. http://www.bdlive.co.za/business/transport/2014/01/07/richards-bay-coal-terminal-sets-coal-export-record cited on 6 April 2014

Sanchez, R., (2011) *Cost Estimating Guide,* U.S Department of Energy, DOE G 413.3-21

Santra., S. and Bagaria, N., (2014) *Labour productivity in coal mining sector in India: With a special focus on major coal mining states,* Researchjournali's Journal of Human Resource, vol 2, No 1 January

Shafiee, S. and Topal, E,. (2012) *New approach for estimating total mining costs in surface coal mines*, Institute of Materials, Minerals and Mining. Transactions. Section A: Mining Technology 121 (3): 109-116.

Statssa., (2014) Statistical release, Gross domestic product, INTERNET http://beta2.statssa.gov.za/publications cited on 13 August 2014

Sullivan, W., Wicks, E and Koelling, C., (2012) *Engineering Economy*, 15th Edition, Prentice Hall, Cloth

Thomson, R.J., (2005) *Surface Strip Coal Mining Handbook*, South African Collieries Managers Association, Marshalltown, Johannesburg

U.S Department of the Interior, Bureau of Mines, (1994) *Overview of Surface mines*, Proceedings of a conference held in Pittsburgh, PA on April 24-29, 1994

U.S Energy Information Administration., (2011) *International Energy Outlook 2011*. INTERNET. http://www.eia.gov/forecasts/ieo/pdf(0484(2011).pdf cited on 6 April 2014

U. S Energy Information Administration., (2012) *Where our coal comes from*. INTERNET http://www.eia.gov/energyexplained/index.cfm?page=coal_home cited on 15 May 2014

Vermeulen, A. (2013) *South Africa's coal mining industry facing numerous challenges*, Mining Weekly, 15th March 2013

Wescott, P., Pitkin, G. and Aspinall, T. (2009) *Open-cut mining. In. Australisian Coal Mining Practice*, Chapter 18, Monograph 12, Third Edition, Eds. Kininmouth, R.J and Baafi, E.Y. pp. 410-458, AusIMM, Melbonurne, Vicoria, Australia

Wood Mackenzie. (2013) *South African Coal Mines*. INTERNET. www.woodmac.com, cited on 26 November 2013

Xie, G., (2008) *Influence of thickness to the mechanical characteristics of gateways at FMTC faces,* Journal of Coal Science Engineering (China), March

Zientek, L. R., Capraro, M. M., & Capraro, R. M. (2008) *Reporting practices in quantitative teacher education research*, Educational Research*, 34*, 208-216