DEVELOPMENT OF A FRAMEWORK FOR ESTIMATING OPERATING COSTS ON A SURFACE COAL MINING PROJECT

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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ABSTRACT

Estimation of operating cost for a mining project is essential to find out the feasibility of a new project and for conducting an economic analysis of a complete mining project. This report outlines a framework for the estimation of operating costs in surface coal mining projects. The cost estimation process makes use of the first-principles approach and is developed by breaking the mining operation into different activities. From this, a framework is developed for estimating costs against each activity or component.

Using the framework and this cost estimation approach a cost model was developed for the truck and shovel activities on surface coal mines. The model has been further explained, elaborated and verified by estimating operating costs for an example mine. The framework is validated using the Delphi method by engaging experts and incorporating their opinions and inputs to refine the model.

The research provides a new perspective on estimating operating costs for surface mining projects considering the unique variables of the project and determining the different cost components in detail to obtain the overall mine operating costs. This research also generates the cost estimation in an Excel format that can be used for cost estimation purposes and provides an opportunity to conduct a sensitivity analysis for key mining variables.

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Glossary of Terms

Ancillary cost in mining	Ancillary cost will involve the cost of dozing and grading, water sprinkling on roads, lighting cost, dewatering cost, etc.
Bench	In a surface mining operation, mineral or waste is removed in successive layers, each of these layers is called a bench. In other words, a bench is a horizontal ledge or floor on which material is mined out or worked on.
Bench height	Vertical distance between crest and toe of the bench.
Blast hole	A hole drilled into a material due to be blasted, to contain the explosive charge
Contingencies allowance	This is an allowance for unforeseen costs resulting from activities not included in the operation. A lump sum amount (or a percentage) is often set aside to cover contingencies.
Conversion factor	This is the number usually represents a numerical ratio or fraction used to convert a measurement in one set of units to the same measurement in another set of units.
Deposit	This term is used to describe an amount of ore or mineral that makes exploitation worthwhile.
Diesel Bowser	Diesel bowser is a diesel tanker used to deliver diesel to different mining equipment working in the mining area
Drilling and blasting	Drilling and blasting are the activities for breaking of hard rocks or ground so that it can be handled. Once the weathered overburden has been

	exposed following topsoil removal, to allow easier handling by stripping equipment later the unit operations of drilling and blasting to fracture the rock mass may or may not be required. Where the ground cover is hard, it is usually drilled and blasted.
Grade	This indicates the amount of mineral contained in a piece of ore
Loading and hauling	This is an activity of loading the sizable material (coal or waste) to a transporting vehicle (mine trucks widely used) and transporting the material to the plant or designated area.
Operating cost	Operating costs are the expenses which are related to the operation of a business, or to the operation of a device, component, piece of equipment or facility. They are the cost of resources used by an organization just to maintain its existence.
Overburden	Waste material lying above the coal deposit, that must be mined out to get coal out.
Powder Factor (PDF)	The term powder factor is defined as the amount required to break per unit volume of rock or coal. It is expressed in kg/BCM. The powder factor is primarily dependent upon the type of explosives to be used and type of rocks to be blasted
Resource	A naturally occurring solid, liquid, or gas in the earth's crust that can be extracted for profit.
Reserve	Resource of coal, ore or minerals which can be mined profitably under existing conditions.

Stages in life of a mine	
Prospecting	Prospecting is the first step in the mining cycle. It is the search for valuable mineral 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.
Exploration	Exploration, the second stage in the mining cycle aims at accurately determining the size and the value of the mineral deposit.
Development	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.
Production/Exploitation	In this stage, the mining of ores, and as required the subsequent processing into products ready for marketing. In this stage mining unit operations are conducted.
Rehabilitation	This means making the mined-out area in the condition in which it was originally occurring before the start of mining or the condition agreed with the local community or authority.
Stemming	The process of filling the empty part of a charged blast hole with an inert material such as gravel, sand, clay or rock cuttings to retain the products of

	the detonation of an explosive charge in an enclosed space.
Stripping	Removing of a top layer of soil or softs in surface mining method is called stripping
Strip ratio	The strip ratio is an important measurement related to the surface mining process and it represents the amount of waste material or overburden, that must be moved to extract a ton of coal or ore. Usually, in coal mining, it is represented as m^3: ton.
Types of mining study Conceptual study Pre-feasibility study Feasibility study	The study is conducted for a potential mine or a mine expansion This is the first study of a mining project. This is a study in which little information is known about the deposit of interest. Cost estimates are initially carried at an accuracy of +/- 30 % The second study is the pre-feasibility study which involves further data gathering as compared to the conceptual stage. During this stage, a better understanding of the mine project is obtained, more samples are collected, and cost estimates are done at an accuracy of +/- 20 %. The last study is a feasibility study before a mining project is approved. This requires more details about the project, even more, samples of the deposit of interest, mine plans, mine layouts, and a process plan about the project. By this stage, most of the engineering analyses have been completed and the accuracy of the project estimates will be approximate +/- 10 %.

1 Introduction

Coal is the second most important energy source, covering 30% of global primary energy consumption and it is the leading energy source in power generation with 40% of globally generated power relying on this fuel (Schiffer, 2016). South Africa is amongst the world's top 10 coal-producing countries and the country contributes to approximately 6% of the total global exports (Dudley, 2017). The significance of coal mining in the context of South Africa can be understood from the facts that over 70% of its energy requirement (electricity and liquid fuels) is from coal and the industry employed 89,647 people, representing about 19% of total employment in the mining sector, in 2018 (Africa, 2019; Chamber of Mines, 2018).

When it comes to starting a new coal mining project, it is well known that the investments required in this industry involve a substantial amount of capital, long term commitment and sequential decision making related to investment strategies(Thompson, 2005). The development of a mine is ordinarily implemented according to a carefully crafted schedule of activities that will allow the mining company to construct all the necessary elements of the operation (Hartman, 1992). Any mining project goes through the following stages in the life of a mine as depicted in Table 1-1 (Hartman, 1992). Table 1-1 also shows the typical duration and costs per stage over the life of mine.

Table 1-1: Stages in the life of a mine, (Hartman, 1992)

Stage	Procedure	Duration (years)	Typical Cost (%)
1. Prospecting (Mineral deposit)	Search for ore	1 to 3	0,70%
2. Exploration (Ore body)	Defining the extent and value of ore including PFS and FS	2 to 5	0,90%

Stage	Procedure	Duration (years)	Typical Cost (%)
3. Development (Prospect)	Opening up ore for production	2 to 5	6%
4. Production/Exploitation (Mine)	Large scale production of ore	2 to 50	90%
5. Reclamation (Real estate)	Restoration of site	1 to 50	2,40%

A mining project, in general, and coal mining in particular, consists of several geological, economic, environmental, social, technological and financial risks (Hartman, 1992). To fully understand the investment scenario of the project; it requires a cost estimation considering the appropriate equipment selection and customized operational analysis.

Operating cost estimates are essential to conducting an economic analysis of a complete mining project or mining sub-systems such as equipment selection, mine planning, or budgeting. These costs are, however, often difficult to estimate reliably. Sources of data are typically (Thompson, 2005):

- Operating mines with a history of using similar equipment or plant
- Previous studies
- Equipment manufacturers or suppliers
- Consultants, government and industry authorities
- Contractor quotations
- Generalized rules and formulae.

When attempting to use or corroborate costs from several sources listed above, there are often inconsistencies that create discrepancies in representative cost figures (Corporation, 2002). These discrepancies arise due to variable job condition factors, quality of maintenance, location, mine accounting practices or abnormally high or low costs at a mine which is not fully reported or benchmarked across the industry.

Textbooks and handbooks formulae are often too generalized and are more geared to the American and Australian mining conditions and are not always suitable for use in the local context of South Africa. To use these rules and formulae, the local cost factors need to be incorporated, and these may not be simply exchange rate correction factors, but may also be relative costs of parts, labours, mining geology, fuel, etc.

This can lead to disagreement among the entrepreneurs and junior miners on a single method of operating cost estimation, as the available methods consider only one or a few variables, leaving out multiple variables that could significantly affect the estimation of the project operating costs (Budeba, 2016). This results in the need for a systematic approach for operating cost estimation. A first-principles approach is found to be the most suitable approach for operating cost estimation purposes. The first-principles method involves the calculation of project-specific costs based on a detailed study of the resources required (Plant, Labour, Material, and Subcontract) to accomplish each activity of work contained within the project's work breakdown structure. Productivity assumptions are applied to all labour and plant costs with adjustments made to account for unique or unusual site characteristics. This study aims to provide a basis for operating cost estimates for coal mining projects and shall include:

- A step-by-step approach for operating cost estimation of a mining project,
- Factors affecting operating costs for a coal mine,
- Different operating costs involved in a surface coal mining project.

1.1 Research Area and Problem

The importance of proper cost estimation is crucial for the opening of a new mining project. The South African Government is promoting local entrepreneurs to develop business and investment proposals. In 2017, the

South African Government started implementing the Mining Charter in this context (Government, 2017). However, current junior coal miners and new coal mining aspirants do not have enough experience nor an extensive database of historical projects on which to base cost estimations. There is also a lack of literature that describes a holistic and step-by-step methodology for the operating cost estimation of mining projects.

1.2 Research Objectives and Questions

The research project intends to develop a methodology for operating cost estimation using mine's specific geotechnical parameters for better accuracy purposes. The objectives of this research are:

i. Establish the different operating cost components involved in a surface mining project,
ii. Develop a first-principles cost estimation model that can be used to develop the operating cost of a surface coal mine,
iii. Use realistic inputs to estimate the operating costs for an example mine,
iv. Validate the accuracy of the cost estimating model.

The central research question for this study is, therefore:

What is the nature of operating costs for a surface coal mining project?

1.3 Research Assumptions and Limitations

The following assumptions and limitations apply to this research:

i. The research has concentrated on a cost exercise and has not focussed on mine planning and design methods.
ii. The research assumes that the geological factors and mineralogy do not change in the due course of workings as this influence mine operating cost.
iii. The study assumes a reasonable South African working culture and workforce and hence has not covered the review of competence of the teams and detailed working culture or operating rhythm of the teams.

iv. The research is focussed primarily on the operating mining cost; however, some of the components of operating mining costs (repair and maintenance cost of equipment) are directly linked and associated with capital cost. For this reason, the equipment capital cost is used in the model to calculate the equipment repair and maintenance cost.

1.4 Research ethics

The ethics clearance was obtained from the School of Mechanical, Industrial and Aeronautical Engineering Ethics committee – non-medical. The ethics clearance certificate protocol number is MIAEC 034/19.

1.5 Structure of the report

The literature review pertaining to the estimation of the operating costs of a coal mining project is covered in chapter 2. The chapter explains the broad category of costs involved for mining in general and available literature regarding the different approaches for cost estimation of mines. Chapter 3 details the research methodology adopted and outlines the method adopted for the development of a framework for operating cost estimation. This chapter also covers the methodology adopted for the verification and validation of the framework and operating cost estimating model. Chapter 4 details the whole framework and principles to estimate the operating cost for surface coal mines. This chapter covers theories, principles, and methods which are applied to estimate the operating costs through the first-principles approach. Chapter 5 details the reliability testing of the developed framework and cost estimation model for an example mine. The validation of the framework and the cost estimating model for the example mine is described in Chapter 6. The chapter details the results of the validation of the framework and cost model using Delphi methods through a panel of experts. Chapter 7 details the discussions on the outcome obtained from the research and hence it reflects the deliberations of chapter 4, chapter 5 and chapter 6. At last chapter 8 illustrates the conclusion and recommendations with regard to the research. Also, the chapter enlightens the research contribution and limitations of the current research, and it suggests areas requiring further investigation that the candidate believes will advance the knowledge contributed by this research work.

2 Literature Review

2.1 Introduction

The objective of this chapter is to investigate the broad category of costs involved for mining in general, different approaches for cost estimation of mines and factors affecting the mining costs. The literature relevant to this research has been discussed in this chapter, however, further literature is discussed in chapter 4 while developing the framework for operating cost estimation.

Costs are to be estimated for a new mine to evaluate its profitability and competitive position compared with existing producers (Budeba et al., 2015). Cost estimation practices affect the decisions made regarding new mine projects, and underestimating or overestimating costs can result in poor decision-making that may lead to considerable financial losses through, e.g. overcapitalization of the project, adverse effects on the share price, lower than expected return on investment, non-delivery on project expectations, capital items purchased affecting outputs, and high operating costs delaying positive cash flow (Budeba et al., 2015).

2.2 Types of Costs in mining

There are several different types of costs which are incurred in a mining operation. There are also many ways in which they can be reported. Mining costs can be grouped into three cost categories: (Sontamino & Drebenstedt, 1994)

- Capital cost
- Operating cost
- General and administrative cost (G & A)

2.2.1 Capital costs

Capital costs in mining projects typically refer to the investment required for the mine and plant (Inthavongsa, 2015). Capital costs in mines can be split into start-up (initial) and stay-in-business capital (working capital) costs. Start-up costs focus on accessing the orebody, infrastructure, equipment, and licensing costs. For surface mines, it means the mine development cost and removal of initial overburden. Infrastructure covered by start-up capital includes water and electricity connections, offices, workshops, change houses, roads and employees' accommodation. In some instances, a small town needs to be developed for employee accommodation (Rudenno, 2012). 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 to get the project into production so that it starts generating revenues (Rudenno, 2012).

Once the mining project has taken off, additional infrastructure, development, equipment overhaul, and replacement are conducted using stay-in-business capital (Rudenno, 2012).

Different capital costs involved in a coal mining project could include one or more of the following:

- Equipment and plant cost,
- Licensing cost,
- Mine site establishment cost.

Equipment and plant costs are the costs involved in the purchasing of equipment and plants. Licensing cost involves the fees paid to the different statutory bodies or government agencies to get clearances and rights to conduct mining.

The mine site establishment cost for surface coal mining could include:

- Mine planning and design,
- Design and construction of a pollution control dam,

- Design and construction of a weighbridge,
- Design and construction of offices, workshops, wash bay,
- Office furniture and information technology,
- Diesel tanks and bund walls,
- Training and medical examinations for people,
- Haul road and safety signage,
- Transport of plant and equipment.

2.2.2 Operating costs

Operating costs focus on the day-to-day operations of the mine. Operating costs are the expenses which are related to the operation of a business or the operation of a device, component, piece of equipment or facility. They are the cost of resources used by an organization just to maintain its existence. Generally, operating costs are expressed in total costs per tonne of ore mined or excavation done per m^3. For example, South African coal mining costs are quoted as ZAR/tonne of coal mined or ZAR/m^3 of excavation.

The major unit operations involved in a surface mining project are ground preparation, drilling and blasting, loading and hauling, and rehabilitation. In addition to these major unit operations, there are some other miscellaneous activities involved in the operation of a mine, referred to as ancillary cost. This includes dewatering (pumping out water from mining area), water sprinkling (to suppress dust in a mining area), haul road maintenance and lighting activities. The operating costs can be reported by different unit operations (Hustrulid & Kuchta, 2006).

- Drilling
- Blasting
- Loading
- Hauling
- Other

The other category could be broken down to include dozing, grading, road maintenance, dump maintenance, pumping.

2.2.3 General & administrative (G & A) cost

The general and administrative costs pertain to operational expenses rather than expenses that can be directly related to the production of any goods or services, including rent, utilities, insurance, and managerial salaries. The G & A cost might be a yearly charge. The G & A could include one or more of the following:

- Mine office expenses
- Head office expenses
- Payroll expenses, human resources, and other administrative staff expenses
- Information technology and other auxiliary support services
- State and local taxes

A generic mining cost structure in summarised form is reflected in Figure 2-1.

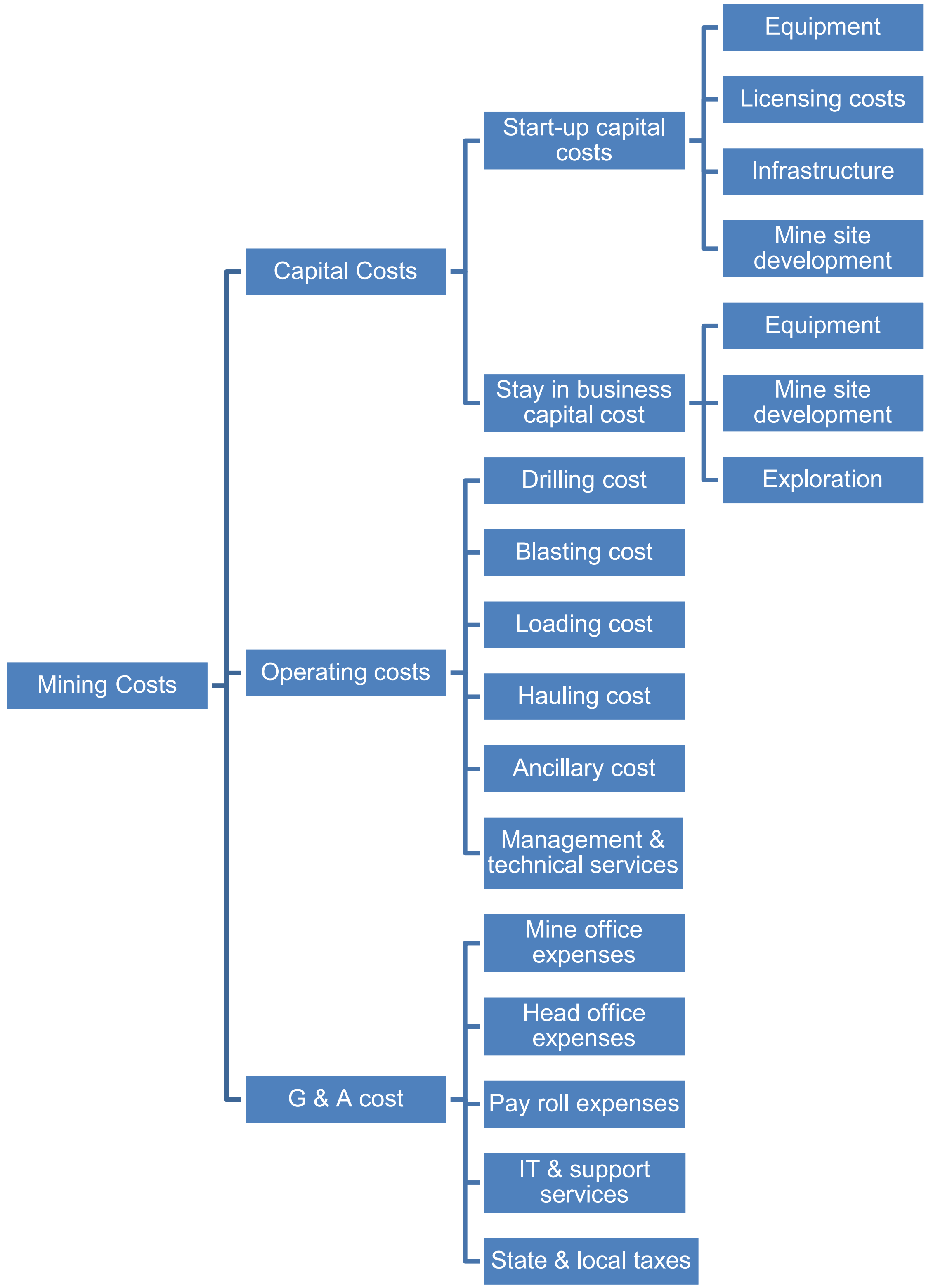

Figure 2-1 Generic mining cost structure

2.3 Cost estimation techniques

To estimate costs for a surface coal mining project it is essential to understand the surface mining method and its unit operations. Surface mining methods are popular for high productivity, low operating cost and good safety conditions (Hartman, 1992). It is widely used where the ground surface and the coal reserves are relatively flat-lying, and the coal is at a shallow depth (Thompson, 2005).

Several unit operations are common to any surface mining method; the cost of each operation can be summed to form an estimate of the cost of mining. The sequence of operation for the surface mining of coal includes (Thompson, 2005):

- Preparing the surface
- Drilling
- Blasting
- Overburden removal
- Loading the deposit
- Haulage of the mined deposit
- Rehabilitation

Cost estimates for mining projects are done at different stages of a new mine project before commencing production. The stages involve a sequence of studies named, conceptual study, pre-feasibility and feasibility study (Hustrulid & Kuchta, 2006). Various methods and tools are frequently applied for cost estimation for a new mining project at different stages over the Life of Mine (LOM). They can be grouped into statistical methods, online tools, comparative approaches, and the first-principles method approach.

2.3.1 Statistical approach

This approach is based on collecting historical cost information from past projects and then deriving some empirical formulae for the cost estimation.

Mohutsiwa & Musingwini (2015) did a parametric estimation of capital costs for establishing a coal mine using a South African case study. In the study, 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). Mohutsiwa & Musingwini (2015) used actual project costs as dependent variables whereas factors such as mine capacity, the life of mine (LOM) and stripping ratio (SR) 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 study derived the following three cost equations for estimating capital costs applicable to three different coal mining operations:

Equation 2-1 Capital cost estimate for dragline operations

$$Capital\ costs = 595.75 + (4.1\ \times\ LOM) + (16.12\ \times\ Capacity) - (64.51\ \times\ SR)$$

Equation 2-2 Capital cost estimate for truck and shovel operations.

$$Capital\ costs = 208.51 - (58.05\ \times\ LOM) + (341.35\ \times Capacity) - (9.46\ \times\ SR)$$

Equation 2-3 Capital cost estimate for bord-and-pillar mining method

$$Capital\ costs = -242.18 + (22.90\ \times\ LOM) - (12.28\ \times\ Capacity)$$

In above equations, LOM is in years, Capacity is in million tonnes of coal per annum, SR is in m^3 of overburden per tonne coal and Capital cost obtained is in million USD.

Mohutsiwa & Musingwini (2015) concluded that the above three equations can be used to estimate capital costs of establishing coal mines in South Africa with an error of magnitude level between -30% and +50%. Therefore, the above equations are only suitable for a conceptual study. They further suggested estimating the cost of establishing surface coal mines to more accurate levels, including estimating the capital cost breakdown.

Shafiee et.al, (2009) reviewed the cost of nearly 20 existing, Australian open-pit coal mines and thereafter derived the average total cost of open-pit mines in Australia. The cost equations are as follows:

Equation 2-4 Estimated Operating Cost (per tonnes) for Australian Open-pit coal mine

$$EOC = 8.744955 - (0.041556)\,DAT + (1.658269)SR - (0.000459)CC - (0.041408)PR$$

Where:

EOC = estimates operating cost (per tonne)

DAT = deposit average thickness (meters)

SR = stripping ratio (tonnes overburden per tonne coal)

CC = capital cost (in millions AUD in 2008)

PR = daily production rate (1000 tonnes)

This model for estimating operating costs focuses on deposit average thickness, stripping ratio, capital cost and daily production rate as the independent variables and operating cost as the dependent variable. This model was developed to explain the influence of independent variables on estimating the operating cost. The model shows that the capital cost and production rate have a positive effect on estimated operating cost and deposit average thickness and that the strip ratio has a negative effect on estimating the operating cost. Estimated operating costs based on the cost model (Shafiee et al., 2009) are compared to the operating costs calculated in the InfoMine website and prove that the model estimation has a ±20% range of accuracy with real data. The above model is based on Australian coal mining companies operating in Australia and this may not accurately predict the capital and operating cost of South African coal mining, as the factor of productions might differ.

O'Hara (1980), developed a cost model for USA mine projects as follows:

Equation 2-5 Capital cost

$$Capital\ cost\ (US\ \$\ M) = \$400\ 000\ (tons\ mined\ and\ milled\ daily)^{0.6}$$

Equation 2-6 Stripping cost for overburden soil

$$Stripping\ cost\ (US\ \$\ M) = \$800\ (million\ of\ tons\ of\ overburden\ soil)^{0.5}$$

Equation 2-7 Stripping cost for overburden rock

$$Stripping\ cost\ (US\ \$\ M) = \$8500\ (million\ of\ tons\ of\ overburden\ rock)^{0.5}$$

Equation 2-8 Equipment cost

$$\begin{aligned} Equipment\ cost\ (US\ \$\ M) &\\ &= \$6\ 000\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{0.7} \\ &+ \$5\ 000\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{0.5} \end{aligned}$$

Equation 2-9 Maintenance cost

$$\begin{aligned} Maintenance\ cost\ (US\ \$\ M) &\\ &= \$150\ 000\ (tons\ of\ deposit\ and\ waste\ mined\ daily\ )^{0.3} \end{aligned}$$

Equation 2-10 Labour cost

$$\begin{aligned} &Labour\ cost\ (US\ \$\ ) \\ &= \$58.563\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{-0.5} \\ &+ \$3.591\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{-0.3} \end{aligned}$$

Equation 2-11 Supplies cost

$$\begin{aligned} Supplies\ cost\ (US\ \$\ ) &\\ &= \$13.40\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{-0.5} \\ &+ \$1.24\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{-0.3} \\ &+ \$0.90\ (tons\ of\ deposit\ and\ waste\ mined\ daily)^{-0.2} \end{aligned}$$

The models were prepared in the 1980s, and they need to be updated to accommodate for the escalation of costs in the estimates. This can be done using cost indices published by different sources, such as Marshall Swift indices (Shafiee et al., 2009). The indices are used to adjust the costs, considering the effect of inflation and adjustments needed to cover costs such as mining and milling, labour, machinery, and heavy equipment. This model was derived primarily for the USA mining environment and again includes indices and factors that vary significantly in South Africa.

2.3.2 Online Tools

Mine and Mill cost equipment calculator and Mine costs (Infomine, 2019) are the two most popular online tools for cost estimation for mining. Mine and Mill cost calculator is based on a database of mining and milling equipment. The tool can be used to calculate the cost of equipment to be used in the operation. Mine Cost is another online tool, which consists of spreadsheets and curves that show capital and operating costs. It is however not clear how the costs are obtained; the tool simply generates the final total cost estimates (Shafiee et al., 2009).

2.3.3 Comparative Approach

The comparative approach involves the use of an existing mining project with characteristics like those of the mining project under study. Most of the time, estimators use the average costs of similar mining projects and operations, then adjust by a factor to account for specific site conditions, mining methods, commodity prices, and milling processes (Shafiee et al., 2009). However, there are no clear guidelines on the cost adjustments needed to reflect the conditions of the mine under evaluation. Hustrulid & Kuchta (2006) refers to this method as being the analogous method of cost estimation. They suggest that comparing similar operations should be undertaken with care because accounting practices vary as well.

2.3.4 First-principles approach

This method relies on the cost-based estimation approach, where the mining cost estimation can be done based on projected productivity, along with estimated labour, material, equipment sub-contractor and overhead cost

(Holroyd, 2000). In this method, estimation is done for each component to complete the work item and then adding together to get the overall costing.

The benefit of this cost-based estimating approach is that it can take into account the unique character of projects, geographical influences, market factors and the volatility of material prices (Holroyd, 2000). When an estimate for a project is separated into labour, material, equipment, overhead and profit, it is easier to account for unique project characteristics (Holroyd, 2000). This method can provide more accurate and defendable costs to support the investment decision on a mining project. In this research project, the same approach was followed for cost estimation.

2.4 Factors affecting mining operating costs

The mining environment can be turbulent in which some mines are successful in achieving their production target under the budgeted cost whereas some do not perform well (Thompson, 2005). Most mines face challenges that cause production uncertainty and/or increase in cost. There are many reasons and factors that influence the operating costs. The factors affecting mining operating costs can be categorized as:

- Geological factors
- Geographical factors
- Social factors
- Technical factors
- Economic factors
- Political and legislative factors

These factors include those that mine management can control called controllable or discretionary factors and those that it cannot control, known as uncontrollable or non-discretionary factors (Darling, 2011). Controllable factors are technical factors and some of the economic factors; that mine management can control (Darling, 2011). For example, mine management can have control over the production rate, the washing rate of coal, the design of the mine to generate maximum profit, the number of employees needed, and the amount and type of machinery deployed. These can be changed at the discretion of mine management, and thus they are also known as discretionary factors. Each coal project has unique characteristics that mine management cannot control, such as geological, geographical, economic and political and legislative factors (Budeba, 2016). These differentiate one mine project from another, and they are collectively known as non-discretionary factors.

Geographical factors include the location of the mine and climatic condition, in the area (Darling, 2011). Some coal deposits may be close to their markets, whereas some are located far from their markets. For a mine that is far from the port, the distance for transporting coal affects the tonnage that can be produced from the mine. Climate is another factor that influences productivity. Some coal deposits may be in regions with high rainfall, which interferes with the production and this may require frequent pumping of water. Social factors include the attitude of the people towards work, access to essential services, cross-cultural communication and corporate social responsibility.

Geological factors include characteristics and quantity of coal deposits and characteristics of host rock and waste (Darling, 2011). Some coal deposits have high calorific value, and some have high ash content. Besides, some deposits are thicker, which makes coal extraction easier, whereas others are thinner which requires special equipment for selectivity.

Economic factors include the price of coal, exchange rates, and inflation (Hustrulid & Kuchta, 2006). These economic factors change from time to time in every country, and they affect mine projects within the respective country. The other factor is legislation, which has to do with safety, health and environmental issues, such as management of dust, water quality, noise, etc. These affect the overall mining operating cost for a mine. The factors affecting mining costs can be summarised in Figure 2-2.

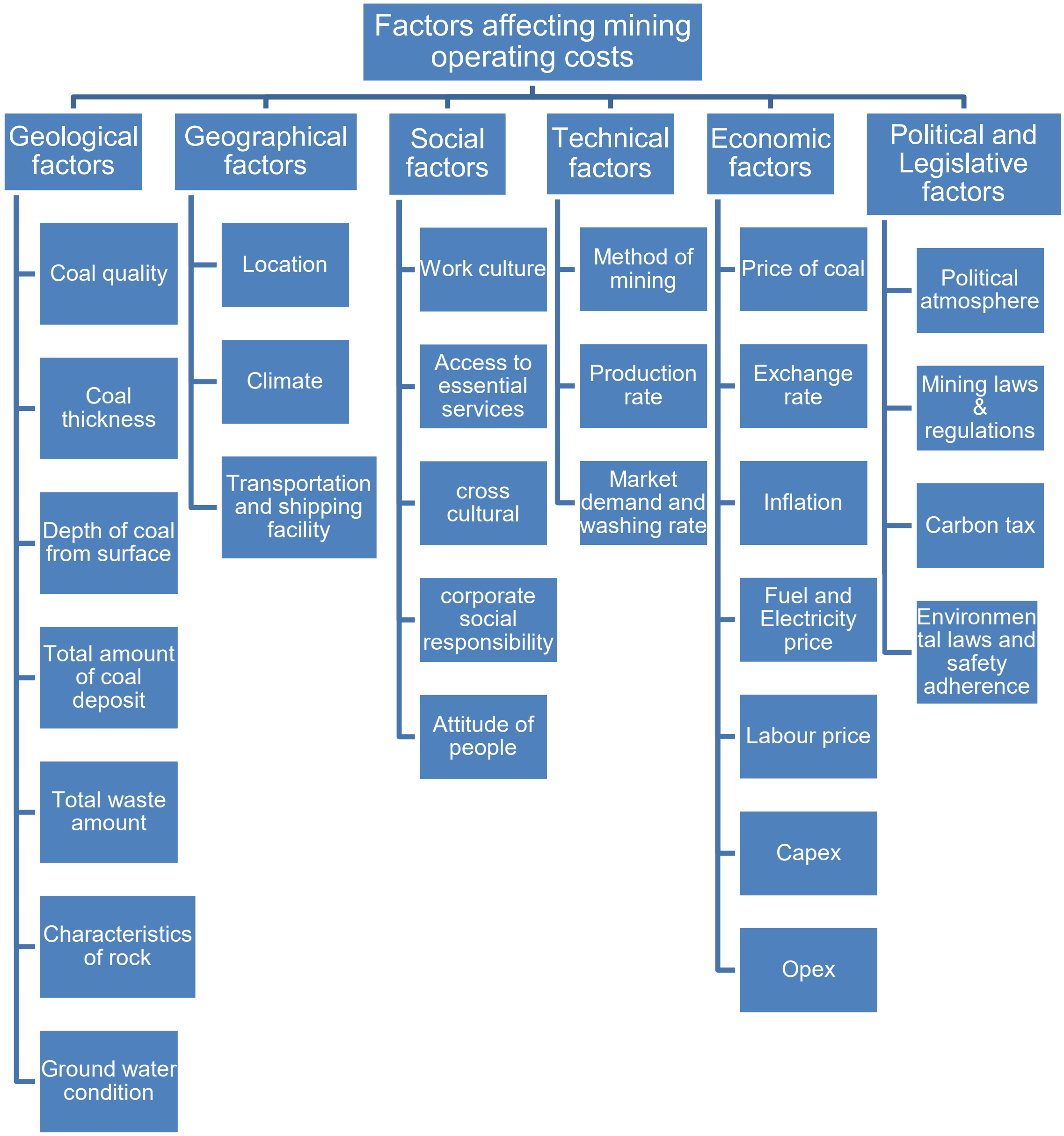

Figure 2-2 Factors affecting mining costs

2.5 Chapter conclusion

This chapter reviewed the types of costs in mining, different approaches for cost estimating in mining and the factors affecting mining costs. The researcher found that there are four major ways to do the cost estimation for a mining project and those are statistical approach, online tools, comparative approach, and first-principles approach. The researcher also observed that most of the literature is available on the statistical approach of cost estimating. Most of statistical approach had been done for the United States and Australian mining atmosphere. Also, based on the literature review, it was observed that there are six major factors that influence the costing are geological, geographical, social, technical, economic and political & legislative factors. These six influencing factors make every mining project a bit unique in nature. Looking at the gap, it will be beneficial to do the cost estimation approach following the first-principles approach as it considers the uniqueness of the project. Also, a significant amount of Literature has been discussed in chapter 4 while developing the framework for operating cost estimation.

3 Research Methodology

3.1 Introduction

This chapter details the research methodology adopted and provides an overview of the cost estimating process and the steps for preparing cost estimates. This study uses a combination of qualitative and quantitative approaches, which assists in drawing meaningful results about the operating cost of a South African surface coal mine using a first-principles methodology. The research was structured in five steps as shown in Figure 3-1.

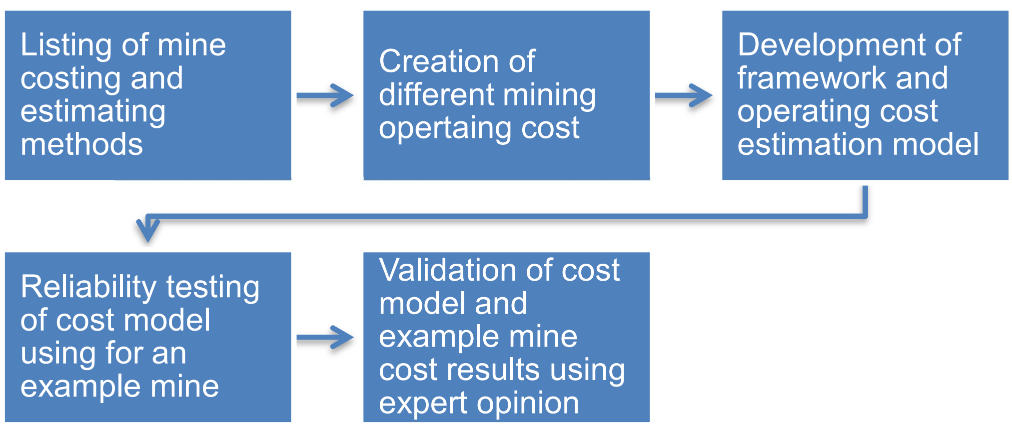

Figure 3-1 Research Methodology

A list of different cost estimating methods and the different operating cost components of a surface coal mining was developed through the literature review. Thereafter, a framework and operating cost model were developed based on the literature review and experience garnered by the researcher in the South African coal industry.

The developed cost model was tested for its reliability using data from an example medium range surface coal mine. The tested model and its results were further validated using a panel of experts in the mining industry.

The details on the first two steps of Figure 3-1 were described in the literature review. The methodology adopted to develop the last three steps has been discussed in the following sections.

3.2 Framework development and Cost model development

The approach for framework development and cost model development was a qualitative approach. The theory and principles have been compiled together to do the cost estimation on a customized basis. In this research, the focus was given to evaluate operating costs for South African Surface coal mines having drilling and blasting for breaking of ground, and truck & shovel for loading and hauling operation.

The framework development is based on the available literature, mining practices, OEMs (original equipment manufacturers) manuals, supplier's manuals & recommendations, expert's insights, and the researcher's knowledge. The framework and cost model have been developed to estimate the operating cost of a South African surface coal mine in the following six categories using the first-principles approach.

i. Drilling cost
ii. Blasting cost
iii. Loading cost
iv. Haulage cost
v. Ancillary cost
vi. Management and technical services cost

This study is reliant on quantifying the above six components of operating cost based on estimated equipment productivity, along with its estimated labour, material, equipment sub-contractor and overhead cost (Holroyd, 2000). The details of this research work will be discussed in chapter 4.

3.3 Reliability testing of cost model

A medium-range South African surface coal mine was taken as an example mine to further test the reliability of operating cost model. The operating costs for an example mine were estimated following the quantitative approach based on the developed framework.

The approach for cost estimation through the first-principles approach has been done following these steps:

Step 1- Give the annual production requirement of coal and excavation of waste to expose the coal complying the production schedule, monthly and daily production rates have been established.

Step 2- Break down the mining operation into various unit operations and activities.

Step 3- Select a basic equipment fleet to perform the unit operations and activities listed in step 2.

Step 4- Calculate the expected production rate for each equipment and thereafter calculate the number of machines required.

Step 5- Determine the number of operation employees required.

Step 6- Calculate the owning and operating costs for the equipment.

Step 7- Calculate the costing against each unit's operations and activities.

Step 8- Add all the operating costs to get total mining operating costs.

A quantitative approach was followed to establish the different operating cost components of a surface coal mine. The numeric values for operating costs have been estimated under six major components –including drilling cost, blasting cost, loading cost, hauling cost, ancillary cost and management, and technical services costs. The costing per m^3 of excavation (ZAR/m^3) was estimated under those six components and all are added together to get overall operating costs. The process for estimation of operating cost for an example mine is further summarized in Figure 3-2.

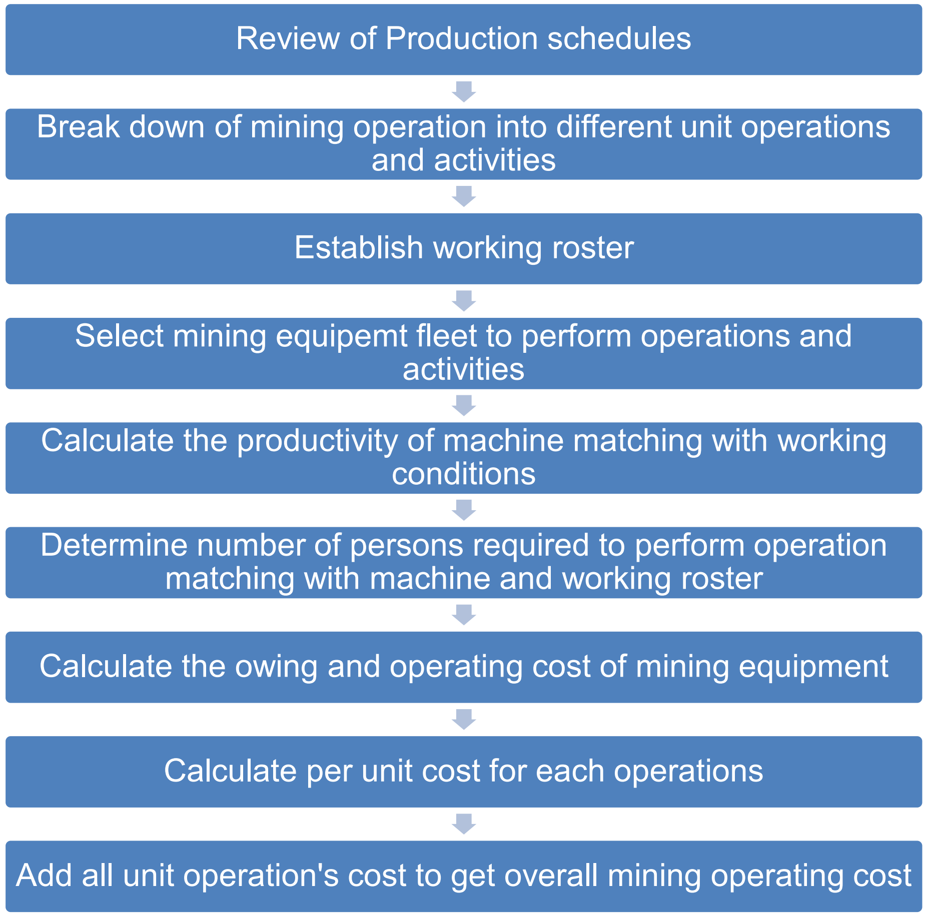

Figure 3-2 Steps for estimation of mining operating cost of a mine

The details of the operating cost estimates of the example mine have been presented in chapter 5.

3.4 Validation of cost model and mine cost results

Validation is a process by which a judgement is made as to whether a tool is fit to purpose. In considering the types of validation process, it is important to take into consideration the contexts in which the validation process is carried out. The contextual factors that likely to impact the validation process are geographical region, the cost involved in the process, and time. There are several validation methods available. Inglis (2008) suggests six different methods for validating a framework: review the research and the literature, seek input from an expert panel, undertake empirical research, undertake survey research, conduct pilot projects or draw on case studies. This study uses the review of previous research and the literature, seeks input from experts in the industry and, operating cost estimates of an example mine as a case study to validate the framework. This motivated to use the expert panel which is universally accepted for the purpose of such research. The details of the validation by the expert panel are further described in the following section.

3.4.1 Validation by an expert panel using Delphi technique

The Delphi technique has its origins in the American business community but has since been widely accepted throughout the world in other sectors such as healthcare, defence, education, information technology, and engineering (Skulmoski et al., 2007).

A Delphi technique is used to obtain the most reliable consensus among a panel of experts using sequential questionnaire and interpolation of controlled feedback (Nordin et al., 2012; Shi et al., 2020). In this research, the Delphi technique was used to validate the proposed framework and cost model by asking a sequential questionnaire to the panel of experts for his/her opinion on the cost model.

Each subsequent questionnaire is developed based on the results from the previous questionnaire. The process stops when the research question is answered, for example when consensus is reached (Skulmoski et al., 2007). The consensus is defined as an agreement between the experts in rating an item within a specific round. The minimum percentage of agreement on a particular item is considered as 75% (Nordin et al., 2012). The number of iterations rounds, therefore, differs for different studies and depends on when consensus can be reached. According to (Skulmoski et al., 2007), two or three rounds are sufficient for most research.

The Delphi method is chosen for validation based on the following positive characteristics of the technique.

- The Delphi technique is used to investigate what does not exist (Skulmoski et al., 2007), i.e. the proposed framework.
- Since the participants' identities are kept secret from each other, they can freely express their opinions without unnecessary social pressure to conform to the opinions of the rest of the group (Skulmoski et al., 2007).
- The participants are allowed to change/refine their opinions in terms of the group's progress from one round to the next (Skulmoski et al., 2007).

According to (Skulmoski et al., 2007), the process of the Delphi technique consists of the following phases, which are described in the subsequent sections:

I. Selection of panel of experts
II. Development of the research question
III. Development of round one questions
IV. Evaluate results from round 1
V. Develop round two questionnaires
VI. Verifying, generalizing and documenting research results

Figure 3-3 reflects the Delphi validation process followed for validation of the framework and cost model for operating costs for a mining project.

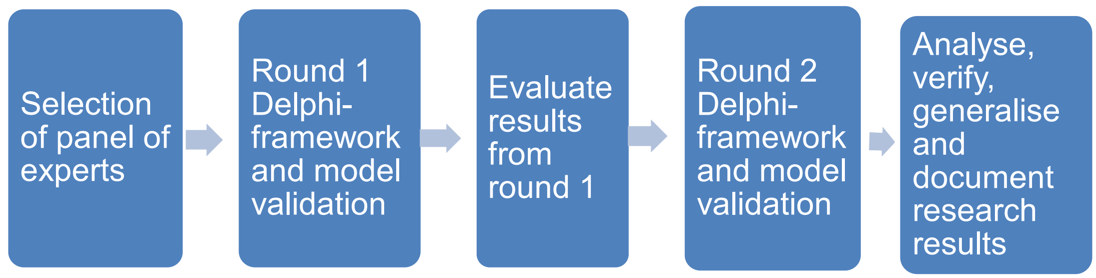

Figure 3-3 Validation process by a panel of experts

3.4.2 Selection of panel of experts

The criteria for selecting the panel of experts are the following (Skulmoski et al., 2007):

- Knowledge and experience with the issues under investigation
- Capacity and willingness to participate
- Sufficient time to participate
- Effective communication skills

According to the study done by Skulmoski et al., (2007), the number of research participants can vary between 4 and 171. However, when considering the size of the panel, the researcher must keep in mind that the representation is assessed by the quality of the panel rather than the number of experts because the Delphi technique does not call the expert panel to be a representative sample for statistical purposes but rather selects people for their expert ability to answer the research questions (Nordin et al., 2012; Skulmoski et al., 2007). According to Skulmoski et al., (2007), there are no fixed rules when selecting the panel, but the following should be kept in mind:

- If a homogeneous group is used, a smaller sample panel will be sufficient, in contrast with a more heterogeneous group.
- As the sample size increases, there will be a reduction in group error and an increase in decision quality. However, above a certain threshold, managing the process and analysing the data becomes more difficult than the increase in the advantages of a bigger sample.

- The larger the group, the more convincingly the results can be verified, and follow-up research is therefore not required.

For the purpose of validation of this research, eight experts were identified however, only seven "experts" choose to participate for Delphi process. The research focuses on "operating cost estimation" of the South African coal "mining project" and therefore, the experts were selected to have knowledge of cost estimates and have experience in the South African mining industry as a minimum basic criterion.

This was further firmed by ensuring that they met the following minimum criteria to cover all the basis of framework development while ensuring that they are experienced and qualified to formulate their opinion for the study.

i. Academic qualification- university degree qualified
ii. Employment in mining engineering domain
iii. Membership of a professional body

3.4.3 Round 1 Delphi- framework and model validation

The research questions were used to develop the first round of the questionnaire for Delphi technique. The first-round Delphi questionnaires were developed to fulfil two objectives - first was to verify the developed framework for operating cost estimation and the second was to verify the operating cost component of the example mine. Table 3-1 reflects the questions framed to validate the framework of cost model and the motivation behind those questions.

Table 3-1 Questions asked to experts to validate the framework

	Questions framed to verify and validate the framework of cost model	Motivation behind questions
Question 1	What are the top five operating cost component of surface coal mining Rate from top to bottom - drilling cost, blasting cost, loading cost, hauling	Since the study has been done to develop the framework under these cost components

	cost, ancillary cost, MTS cost? (Rate from top to bottom)	so this question has been framed to further verify whether the researcher has worked on the correct operating costs associated or not.
Question 2	Is there any other major component excluding the top five indicated above, if yes, please specify?	This is further to find out that if any major operating mining cost is left by the researcher.
Question 3	What are the main components of drilling cost?	Question 3 to question 8 are framed to get the experts inputs and confirm whether the researcher has worked on the correct details of all each operating cost or not.
Question 4	What are the main components of blasting cost?	
Question 5	What are the main components of loading cost?	
Question 6	What are the main components of hauling cost?	
Question 7	What are the main components of ancillary cost?	
Question 8	What are the main components of management and technical services cost?	

Table 3-2 reflects the questions framed to validate the results obtained from the developed cost model and the motivation behind those questions.

Table 3-2 Questions asked to validate the operating cost model results

	Questions framed to validate the operating cost model results	Motivation behind questions
Question 1	The total operating cost of a surface coal mine could be (in ZAR/ m^3 of excavation)?	This question is framed to get the experts to feedback on the total operating cost whether the model is generating correct or not and if it requires any further interrogation
Question 2	Drilling cost as a percentage of total operating cost	Question 2 to Question 7 are framed to get the different operating cost in ZAR value; as percentage multiplied by total operating cost (as obtained in question1) will give the operating cost under that component.
Question 3	Blasting cost as a percentage of total operating cost	
Question 4	Hauling cost as a percentage of total operating cost	
Question 5	Loading cost as a percentage of total operating cost	
Question 6	Ancillary cost as a percentage of total operating cost	
Question 7	Management and technical services cost as a percentage of total operating cost	
Question 8	What is your opinion on recommending the first principal approach for estimating mine operating cost?	To obtain overall feedback from experts on the cost estimation approach

Question 9	Specify any further comment on mine operating cost estimates	To obtain unbiased feedback of experts so that a fresh idea or thought may come from the expert

The round 1 questions were sent to the experts via e-mail for their responses. The abstract and research objectives were also shared along with round 1 questions for the convenient and better understanding of the research work. The responses from the experts were received via e-mail. In order to avoid any biases of experts towards the component of the operating cost, the model was not disclosed in this round. Also, a broader range was used in the first round for Delphi validation to cover the basics of operating cost for various mine size. Based on the recommendation of experts, the model was further interrogated, and it has been modified as per the recommendations of the experts.

The round 1 questions format as sent to experts have been attached as Appendix-I

3.4.4 Round 2 Delphi- framework and model validation

The responses from the first round were used as a basis to develop the questionnaire for the second round Delphi (Skulmoski et al., 2007). In this round, the developed excel cost estimation model was also shared. After the response of a panel of experts on the first round of Delphi, the operating cost components range was narrowed down. The round two questionnaires and experts panels response have been attached as Appendix-II.

3.4.5 Analyse, verify, generalize and document research results

The Delphi round two results were further analysed, and operating cost model was updated based on the expert’s recommendation. Over the two rounds of the Delphi process, finalization of the framework and cost estimation model was done.

3.5 Ethical Considerations

The ethics clearance was obtained from the School of Mechanical, Industrial and Aeronautical Engineering Ethics committee – non-medical. The ethics clearance certificate protocol number is MIAEC 034/19. Experts participant in the research were made aware of their right to withdraw from the research at any time for any reason. Full disclosure of the study’s purpose was given to participants before they responded to the questionnaire. All experts received a copy of consent form by e-mail and were asked to respond with a return e-mail indicating their willingness to participate in the study.

4 Framework development for estimating operating costs

4.1 Introduction

This chapter details the whole framework and principles to estimate the operating cost for surface coal mines. This section covers theories, principles, and methods which are applied to estimate the operating costs through the first-principles approach.

The first-principles approach was adopted for the cost estimation of a surface coal mining operation with truck and shovel mining. The operational mining costs in case of truck and shovel mining with drill and blast practices will involve the following (Abbaspour et al., 2018):

a) Drilling cost
b) Blasting cost
c) Loading cost
d) Hauling cost
e) Ancillary cost
f) Management and technical services

By combining all these costs, the overall mining operating cost was estimated.

Equation 4-1 Mining operating cost

$$\begin{aligned} Mining\ operating\ cost \\ &= drilling\ cost + blasting\ cost + loading\ cost + hauling\ cost \\ &+ ancillary\ cost + management\ and\ technical\ services\ cost \end{aligned}$$

4.2 Determining owning and operating cost of Mining Equipment

Along with the trend for mechanization adopted in mining operations; equipment costs now occupy a large proportion of the overall operating cost for a mine(Thompson, 2005). Therefore, the estimation of equipment costs has become more important. Success or failure in a mining project is dependent on the equipment costs (Thompson, 2005).

There are two types of equipment costs: owning costs and operating costs (Chaves & Dos Santos, 2016). Owning costs refer to the costs incurred even if the machine is not working. They include depreciation, interest, taxes, and insurance. Operating costs are the costs incurred in operating the machine. These include costs for repair and maintenance, fuel, lubricants, Tyres, special items (for example ground engaging tools) and operator's wages. Figure 4-1 reflects the value driver tree (VDT) of equipment operating cost.

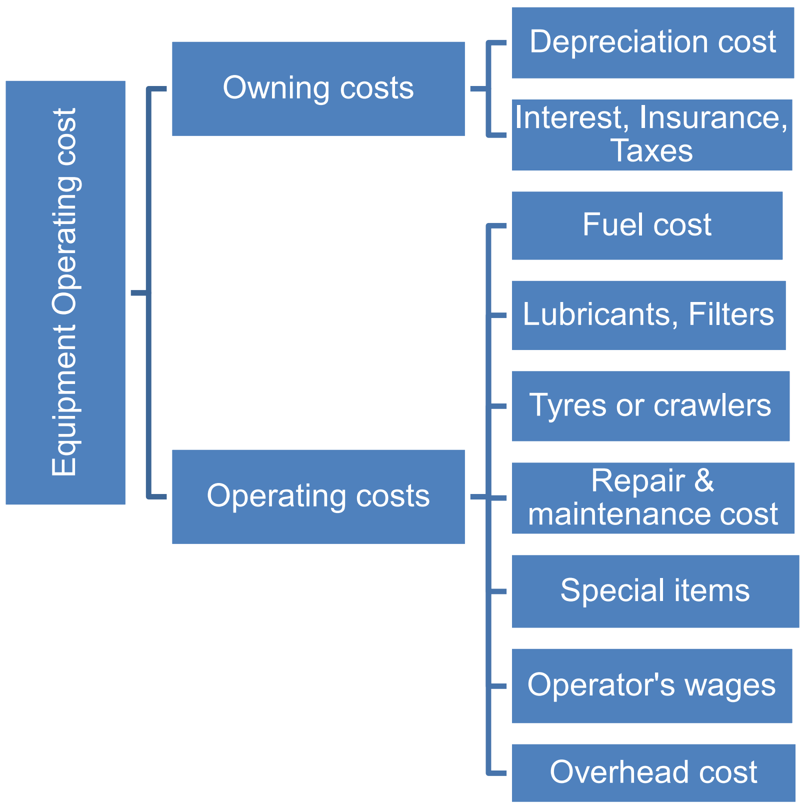

Figure 4-1 Equipment operating cost (Thomson, 2005)

In this study, the principles and method of estimating the owning and operating costs of mining equipment through the first-principles approach were formulated and this methodology was applied for the estimation of operating costs of all equipment applicable for the mining project.

4.2.1 Owning cost

The equipment owning cost is the expense required, as a matter of course, for the purchase and possession of the equipment as a property of its owner and consists of the following items (Komatsu, 2013):

- Depreciation
- Interest, insurance, and taxes

4.2.1.1 Depreciation-

Depreciation is referring to the decline in value of the original purchase price of equipment and is an assessable property (expressed in units over useful life) (Chaves & Dos Santos, 2016).

Equation 4-2 Depreciation cost

$$Depreciation = \frac{Capital\ or\ Purchase\ price - Residual\ Value}{Useful\ life\ of\ an\ equipment\ or\ plant}$$

Net depreciation value means original purchase price minus residual value. The depreciation period varies considerably according to the equipment type and operating conditions. Continuous and preventive maintenance of equipment is a significant factor in determining the economic life of the equipment. Proper maintenance will extend the life of the equipment. On the other hand, poor or improper maintenance will shorten the life of the equipment. In the mining business, it is usual to align the equipment finance period with the depreciation period to minimize negative cash flow implications. The equipment owning period is strongly affected by the economic life of the equipment (years or hours for which the equipment can be used gainfully).

Book value- Book value is the value of equipment or an asset after accounting for depreciation. The calculation of book value for an asset is the original cost of the asset minus the accumulated depreciation, where accumulated depreciation is the average annual depreciation multiplied by the age of the asset in years.

Residual value- This is the value of mining equipment at the time of resale or trade-in.

4.2.1.2 Interest, insurance, and taxes-

Whether or not, purchased equipment is in operation, the interest, insurance, and taxes (if gains are made) are to be paid. In a broad sense, interest refers to the cost of capital or the interest rate to be paid to lend the money from the financial institution.

Interest, insurance, and taxes are imposed on the book value that is the difference between the purchase price and the depreciation amount. This book value decreases every year. However, for a mining project when owning and operating costs are calculated, it is convenient to consider interest, insurance, and taxes as a constant annual amount (Patel & Kishore, 2017). A calculation is made of the average value of the book value at the beginning of each year within the depreciation period, and interest, insurance, and taxes are imposed on this value. By dividing this value by the number of hours the user expects to operate the machine in one year, the hourly value can be calculated using the following formula

Equation 4-3 Interest insurance and taxes

$$Interest, insurance, tax = \frac{Annual\ cost\ of\ interest, insurance\ and\ taxes}{annual\ use\ in\ hours}$$

The annual cost is the total cost of interest, insurance, and tax per year.

4.2.2 Operating Cost

The equipment operating costs are proportional to the time that the equipment works in the mine. Items considered for mining equipment operating costs in this category are as follows (Komatsu, 2013):

- Fuel or electricity
- Lubricants (oil and grease), filters and periodic maintenance labour
- Tyres or crawlers

- Maintenance and repair cost
- Special items (like ground engaging tools)
- Operator's wages
- Overhead cost

4.2.2.1 Fuel or Electricity cost-

Mining equipment may be fuel (diesel) driven or electric driven. This fuel or electricity consumption is a function of machine used periods and the conditions in which the machine is being used. To estimate the hourly fuel or electricity cost, job conditions based on application is selected and hourly fuel consumption is estimated as per OEM specifications.

Equation 4-4 Hourly fuel or electricity cost (Komatsu, 2013)

$$\begin{aligned} &Hourly\ Fuel\ or\ Electricity\ cost \\ &\qquad = Hourly\ fuel\ or\ electricity\ consumption \\ &\qquad \times\ Unit\ price\ of\ fuel\ or\ electricity \end{aligned}$$

4.2.2.2 Lubricants, filters and periodic maintenance labour

It is possible to measure the consumption of lubricants and grease in the same manner as the fuel consumption. The consumption values of lubricants and grease are also obtained by calculation based on lubrication intervals, but they are affected greatly by the type of machines and their operating conditions.

Equation 4-5 Hourly lubricant consumption (Komatsu, 2013)

$$Hourly\ lubricant\ consumption = \frac{Oil\ replacement\ amount\ (liters)}{Oil\ change\ interval\ (hours)}$$

The prices of lubricants vary in different geographical areas and, therefore, the local price should be used.

4.2.2.3 Tyres or Crawler cost-

Tyres or crawlers are in the category of consumable parts and for mine equipment, they are generally expensive with respect to other consumables. The tire or crawler cost is calculated by the following formula.

Equation 4-6 Hourly Tyres or crawler cost (Komatsu, 2013)

$$Hourly\ tyre\ or\ Crawler\ cost = \frac{Tyre\ or\ crawler\ price}{estimated\ life\ of\ tyre\ or\ crawler}$$

The tyre prices vary in each country or area, the prices of tyres are estimated based on quotes from the OEM for the supply of tyres in that area. The tyre life is affected by many factors; however average tyre life is estimated based on mine conditions, hardness of rock, tyre manufacturers recommendations and historical tyre life data.

4.2.2.4 Maintenance and repair cost

Components or parts of a mining machine wear in due course of time and sometimes fail. To keep a machine in a properly maintained condition, these components or parts must be replaced. It is natural for the repair cost of a machine to start from a small amount and gradually increase with time as the machine is operated(Komatsu, 2013). The repair cost of a mining machine can be estimated from the operating time. However, in general, repair cost is considered as an average of total repair costs throughout the service life of a machine. In other words, it is based on the concept that part of repair cost to be paid later should be laid aside in advance (Thompson, 2005).

In this first-principles approach, the maintenance and repair cost can be estimated using a life-cycle cost analysis approach. A life cycle cost analysis involves the analysis of the costs of a system or a component over its entire life span. Unless historical equipment has been completely used off and scraped off; it is difficult to get the actual life cycle repair and maintenance cost. To estimate the maintenance and repair cost by this approach; the cost for corrective, preventive and predictive maintenance is added together and hence this provides the maintenance and repair cost for the whole life of equipment. This is guided by the maintenance and parts replacement schedule provide by the equipment manufacturers.

Furthermore, repair costs are affected by the machine operating conditions i.e. work or job conditions, operating techniques or operator's skill, proper maintenance, etc. In this model, the life cycle costing for maintenance and repair of equipment has been taken as a percentage of the purchase price of the equipment. In this study, 90% of the purchase price of mining equipment has been considered as a life cycle costing for maintenance and repair of that equipment. This has been taken into account after consulting and discussing with mine operating company and OEMs.

4.2.2.5 Special items (Ground engaging tools)

In the objects of repair, the repair costs include the machine and its attachments. Some parts of a machine wear faster than others. These parts are the ground engaging tools and not included in the category of repair but a group of special items. In mining, bucket teeth of shovel/excavator, ripper points and ripper shanks of dozers, drill bits and drill rods of drill machine come under this category. Considering the working conditions and average life of these tools prescribed by the equipment manufacturers; the costing of these items is estimated.

4.2.2.6 Operator cost

Operator wages vary according to the country and area. Thus, the wages paid to the operator as per the industry or country norms are used for estimating the cost.

Equation 4-7 Operator cost per hour

$$Operator\ cost\ per\ hour = \frac{Number\ of\ operators\ required\ per\ month \times Monthly\ salary\ of\ an\ operator}{working\ hours\ of\ machine\ per\ month}$$

4.2.2.7 Overhead cost

Overhead costs refer to all indirect expenses of running a business. Unlike direct operating expenses, overhead cannot be traced to a specific cost unit or business activity. Usually in mining running of head offices and salary of head office personnel is taken as the account of overhead cost. Every mining company has its own overhead cost depending upon the organisational setup and revenue generation from projects.

In this research, an overhead cost of 6% of equipment cost has been considered as an overhead cost component.

4.3 Estimation of drilling cost

In surface mines, hard rocks cannot be self-excavated by a loading machine, unless it is broken. To break the hard in-situ rocks, drilling and blasting are done. Drilling of holes inside the rock is done by the help of drill machines so that explosives can be placed inside the hole and blasting can be done in a controlled manner (BME, 2018a). The drilling cost is the cost involved for drilling holes in the rock. It is typically expressed in cost per unit length of hole or cost per unit of blasted material. In South Africa coal mines, usually, it is expressed in ZAR per meter (ZAR/m) or ZAR per m^3 (ZAR/m^3)

The drilling cost in this study has been estimated from the first-principles approach, by estimating the operating cost per hour of drilling machine and productivity i.e. production meters drilled per hour for that working condition. This will be explained further in the forthcoming sections of this chapter.

4.3.1 Selection of drilling machine

The first step in the drilling process is to determine what hole diameter is most suitable for the application. This is probably the single most important factor since it will determine the size, quantity, and type of drill that will be needed. Some of the major factors are (Thompson, 2005);

- Material characteristics

- Required production
- Blast design
- Bench height
- Type and size of excavating and hauling equipment
- Terrain.

Based on the actual mechanics of the drilling machines, the drilling methods can be broken into two broad categories, and then further divided into sub-categories as follows (Thompson, 2005):

- Percussion drilling
    - Drifter (top hammer) drills
        - Air-driven
        - Hydraulic-driven
    - Down-the-hole drills (DTH)
- Rotary drilling
    - Drag bit rotary drills
    - Tri-cone rotary drills

Based on the material characteristics, bench height, blast design and type of excavating equipment the drilling method and hence machine is selected.

4.3.1.1 Material Characteristics

This refers primarily to the characteristics of the rock that lend themselves to drilling and blasting fragmentation. For drilling purposes, typically material characteristics can be specified in terms of hardness or the uniaxial compressive strength (UCS) of the rock and rock structure or existence of joints, fractures, bedding planes or faults, etc (Thompson, 2005). These can affect the blast result and hence it becomes important to have a proper distribution of the explosives in the rock. Figure 4-2 illustrates a relationship between hole diameter and rock UCS as an initial guide to selection.

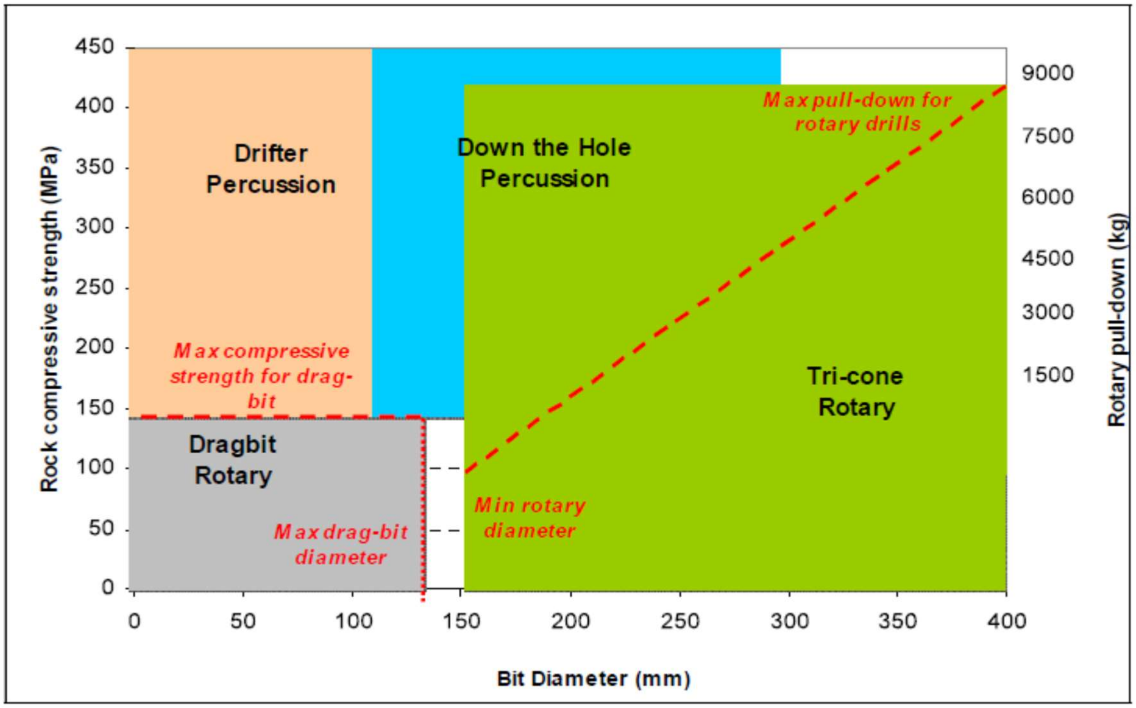

Figure 4-2 Relationship between hole diameter and rock UCS as an initial guide to drill selection (Thompson, 2005)

4.3.1.2 Bench height

Bench height is the vertical distance between crest and toe of the bench. If there is a fixed, existing bench height, then the selection of blast-hole size has to be made according to this. In many cases, bench height is pre-determined by stratigraphy, production equipment, and production requirements. In selecting equipment for a bench height, the practicality of drilling to the required depth should be considered. Percussive drills are limited in the depth to which they can effectively drill, due to losses in percussive energy in a drifter, or air loss in DTH drilling, together with the necessary to extend the drill string every 3 to 7 meters. Rotary drills are ideally applied in single pass drilling where the drill string (and masthead) is large enough to contain the length of drill string necessary to complete the hole without extensions being added. Figure 4-3 and Figure 4-4 shows a typical hole depth and diameter limitations for drilling in medium-hard abrasive and softer rock types.

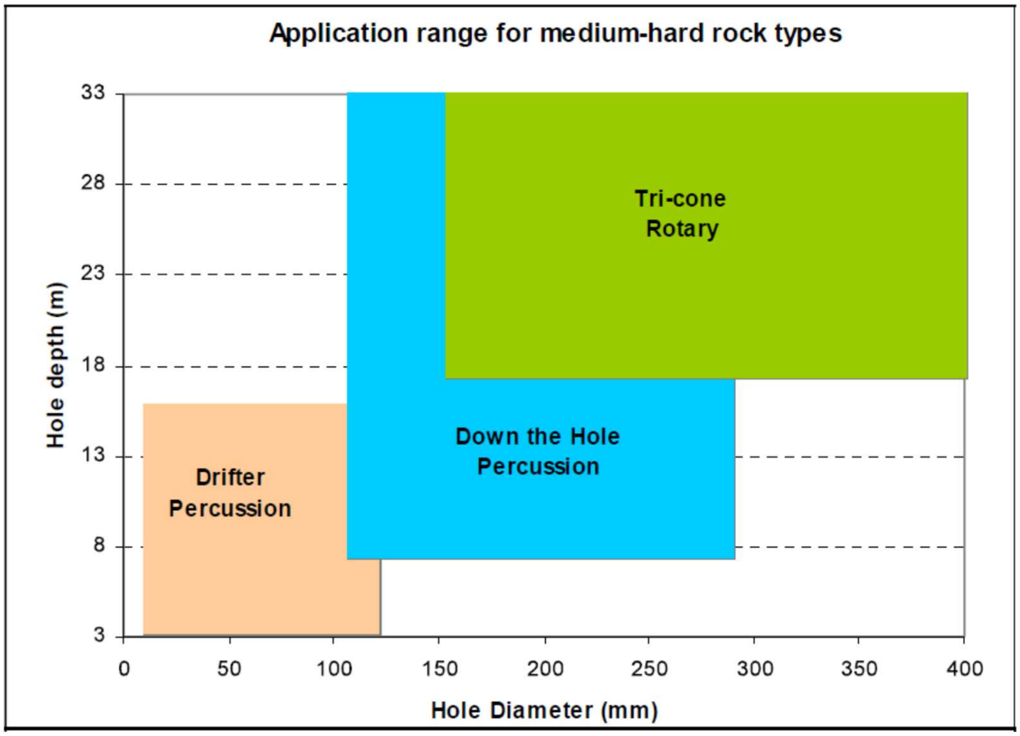

Figure 4-3 Application of medium-hard rock types (Thompson, 2005)

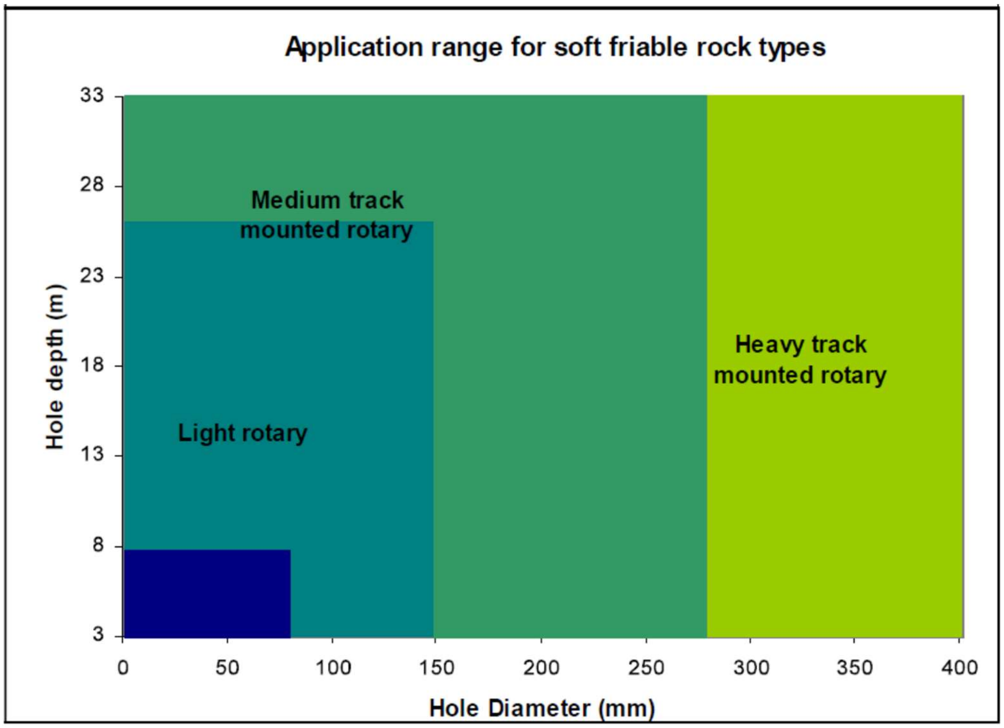

Figure 4-4 Application of soft friable rock types (Thompson, 2005)

4.3.1.3 Blast design

This is a selection factor based on the most appropriate machine for a combination of bench height, hole diameter, and material types. Blast design parameters are related to the desired fragmentation size and blasting limits (BME, 2018a). Although larger holes offer savings in cost per unit of production, it results, the more weight of explosives per hole, and unless multiple in-hole delays are used, the higher the weight per delay and the greater the vibration that results (BME, 2018a)

4.3.1.4 Type and size of excavating and hauling equipment

The primary concern here is to balance the amount of drilling required to fragment a given volume of rock. If larger excavators and haul units are employed, the blast-hole should be as large as possible (within the limits of good blast design) and the drill pattern spread since the larger size of blasted rock can be handled (Thompson, 2005). On the other hand, if excavating and hauling equipment is relatively small, then careful consideration of hole size relative to the desired fragmentation should be made.

4.3.2 Calculation of required drilling rates and no of drill machines

For cost estimation purposes, it is essential to find out the required amount of drilling based on the production requirement so that a proper number of drill machines of suitable size can be selected. The amount of drilling and blasting depends on the type of strata present in the area. The quantity of drilling per month required can be found by considering the case of overburden drilling to uncover the required amount of coal and drilling of coal (if needed). This can be found out using the following formula

Equation 4-8 Quantity of drilling per month (Thompson, 2005)

$$Q_d = \frac{V_w \times (1 + U)}{B_w \times S_w} + \frac{T_c}{B_c \times S_c \times SG_c}$$

Where Q_d = Quantity of drilling required (m) per month

V_w = Volume of waste rock required to be blasted (m3) per month

U = % of sub-drilling

B_w = Burden distance of holes for waste (m)

S_w= Spacing of holes for waste (m)

T_c = Tons of coal required to be blasted per month

B_c = Burden distance of holes for coal (m)

S_c= Spacing of holes for coal (m)

SG_c= Relative density of coal

Number of drill machine required to drill can be found out by the formula

Equation 4-9 No. of drill machine required (Thompson, 2005)

$$N_d = \frac{Q_d}{D_r \times H_e}$$

Where N_d = Number of drill machines required

D_r = Drilling rate (m/hr)

H_e = Effective hours per month available for drilling (hour)

H_e is calculated considering the working hours discounting the time spent for manoeuvring the machine from one drilling block to another drilling block. As per industry norms; manoeuvring time discounted should be 10-20% of the running hours of the machine.

4.3.3 Drilling cost estimating model

The drilling cost estimating model was established by finding out the owning and operating cost of the applicable drill machine and establishing the productivity of the drilling machine. The drill machine is selected based on the applicability and production requirement of the mine. Once the drill machine is selected; the productivity of the drill machine is established depending upon rock characteristics and drilling rate of the machine obtained from OEMs. The number of drill machines is estimated based on working hours, production requirement and productivity of drill machines. The owning and operating cost per hour of drill machine and productivity of drill machine per hour is estimated. Below is the step-by-step approach for estimating the drilling cost

Assume the purchase price of a drilling machine = PP_D (in ZAR)

Cost of tracks on drills = $COSTT_D$ (in ZAR)

Life of tracks = $LIFT_D$ (Hours)

Cost of consumables (drill bits, drill rods, connectors) = $COSTC_D$

Life of consumables in hours= $LIFC_D$

Interest rate per annum = INT_D (%)

Insurance rate per annum = INS_D (%)

Expected residual value = RV_D (in ZAR)

Overhead cost as a percentage of the equipment cost = OH_D (%)

Estimated operating period of ownership = $OPRP_D$ months

Operating hours per month from the mining schedule and roster = $MINH_D$ hours/ month

Operating machine life in hours $LIF_D = OPRP_D \times MINH_D$

Total maintenance cost over the life of machine = $MAINC_D$ (in ZAR)

Fuel consumption of machine based on OEM specification = $FCON_D$ (l/hr)

Price of fuel = POF (ZAR per Litre)

Operator's salary per month = OPS_D

No of operator's required per month = OPN_D

Overhead cost for machine = OH_D % of purchase price

Overhead cost for life of machine = $(PP_D \times OH_D)/100$

Annuity paid per month for owning the machine can be found out using the (Buchanan, 2016).

Equation 4-10 Annuity paid per month for owning the machine

$$AP_D = \quad INT_D \times \frac{\left[PP_D - \frac{RV_D}{\left\{1 + \frac{INT_D}{12}\right\}^{OPRP_D}}\right]}{\left[1 - \left\{1 + \frac{INT_D}{12}\right\}^{-OPRP_D}\right]}$$

Assuming straight line depreciation;

Depreciation per month (DP_D) = $(PP_D\text{-}RV_D)/ OPRP_D$

Interest paid per month paid (IP_D) = {AP_D – ($PP_D/OPRP_D$)-

Insurance paid per month (SP_D) = $(PP_D \times INS_D)/1200$

Overhead per month (RP_D) = $(PP_D \times OH_D)/1200$

Maintenance cost per month (MP_D) = $MAINC_D/OPRP_D$

Cost of tracks per month (TP_D) = $(COSTT_D \times MINH_D)/ LIFT_D$

Cost of consumables per month (CP_D) = $(COSTC_D \times MINH_D)/ LIFC_D$

Fuel cost per month (FP_D) = $FCON_D \times POF \times MINH_D$

Operator's cost per month (OP_D) = $OPS_D \times OPN_D$

Depreciation per hour (DPH_D) = $(PP_D\text{-}RV_D)/ (OPRP_D \times MINH_D)$

Interest paid per hour (IPH_D) = $\{AP_D - (PP_D/OPRP_D)\}/MINH_D$

Insurance paid per hour (SPH_D) = $(PP_D \times INS_D/1200)/MINH_D$

Overhead per hour (RPH_D) = $(PP_D \times OH_D/1200)/MINH_D$

Maintenance cost per hour (MPH_D) = $MAINC_D/ (OPRP_D \times MINH_D)$

Cost of tracks per hour (TPH_D) = $COSTT_D$ / $LIFT_D$

Cost of consumables per hour (CPH_D) = $COSTC_D$ / $LIFC_D$

Fuel cost per hour (FPH_D) = $FCON_D \times POF$

Operator's cost per hour (OPH_D) = ($OPS_D \times OPN_D$)/$MINH_D$

Owning cost per month (FC_D) = $DP_D + IP_D + SP_D + RP_D$

Operating cost per month (OC_D) = $MP_D + TP_D + CP_D + FP_D + OP_D$

Owning cost per hour (FCH_D) = $DPH_D + IPH_D + SPH_D + RPH_D$

Operating cost per hour (OCH_D) = $MPH_D + TPH_D + CPH_D + FPH_D + OPH_D$

Owning cost of drilling equipment per meter can be found out by dividing total owning cost per hour by drilling rate per hour (OWN_D) = FCH_D / Dr (ZAR/m)

Similarly, operating drilling cost per m can be found out by dividing total operating cost per hour by drilling rate per hour ($OPDCIF_D$) = OCH_D/D_r (ZAR/m)

Further, owning cost of drilling equipment per m^3 can be found out by dividing owning cost per meter by material generated per meter of drilling (OWN_{D1}) = OWN_D/ ($B \times S$) (ZAR/m^3)

Similarly, operating drilling cost per m^3 can be found out by dividing operating cost per meter by material generated per meter of drilling ($OPDCIF_{D1}$) = $OPDCIF_D$/ ($B \times S$) (ZAR/m^3)

4.4 Estimation of blasting cost

Once the drilling of an area or block has been done; blasting is conducted to break the rock into small fragments. So blasting is basically the process of breaking rocks through controlled explosion by placing explosives inside drilled holes. The blasting cost is the cost involved for blasting of holes in the rock. It is typically expressed in cost per unit volume of blasted material. In South Africa coal mines, usually, it is expressed in Rand per m^3 (ZAR/m^3).

The blasting cost varies from a mine site to another site; however, it is primarily dependent upon the following factors (Thompson, 2005):

- Rock mass characteristics,
- Size of blast hole (diameter),

- Bench geometry,
- Explosive type.

4.4.1 Rock mass characteristics

The blasting cost is dependent upon the rock mass characteristics. The blast design is done based on rock strength and its properties. The blast design can be divided into two activities; Identifying a suitable powder factor (PDF) the amount of explosive (kg/BCM) necessary to break a specific type of rock and the distribution of the explosive within the rock (Aarsen et al., 2012). The explosive type and blast hole size determine the weight of the explosive per meter length of blast-hole (charge density) and therefore the burden and spacing (which determine the BCM's per hole), to coincide with the powder factor.

For the cost of blasting it is essential to establish how much explosives are necessary to break one cubic meter or BCM of rock. In this case, BCM is defined as the product of burden (B), spacing (S) and bench height (H)(BME, 2018a)

Equation 4-11 Breaking one cubic meter or BCM of rock

$$BCM = B \times S \times H$$

In weak rock, a powder factor of 0, 2 kg/BCM is enough, while in hard rock, as much as 1,6 kg/BCM may be needed. Table 4-1 Estimated PDF for different types of rocks (Thompson, 2005). Table 4-1 reflects the guidelines for the estimated PDF for various types of rocks in coal mines.

Table 4-1 Estimated PDF for different types of rocks (Thompson, 2005)

ROCK	PDF (kg/BCM)
Soft laminated strata (shales, mudstones, etc.)	0,1-0,25
Med-hard sedimentary strata (sandstones)	0,3-0,45
Hard jointed rock (limestone, dolomite)	0,4-0,7
Quartzites, granite, etc.	0.65-0,90

ROCK	PDF (kg/BCM)
Massive dolerite, etc.	0,9-1,2

4.4.2 Size of blast hole

The choice of the blast hole diameter must satisfy two opposing requirements (Thompson, 2005):

- Drilling and blasting cost efficiency (larger diameter holes are cheaper per unit volume BCM)
- Fragmentation- smaller diameter holes give finer fragmentation- It is important to get the optimum fragmentation in coal to avoid the grizzly or crusher jamming as well as not to produce too much fine coals. In the case of waste or overburden blasts- size to suit excavation equipment used.

Longer holes can be cheaper in terms of costs per unit volume (BCM) but may give insignificant improvements to fragmentation and can cause an increase in overbreak, fly-rock and secondary blasting. Larger diameter blast holes require a larger bench height. But if the hole is too long, the direction control will be poor, while if it is too short, just a small (lower) part of the hole gets loaded (because of stemming length requirements) and the fragmentation (especially in the uncharged portion of the blast hole) is then poor (Thompson, 2005).
A general empirical rule is based on the bench height (H) to the blast-hole diameter (D) ratio (Thompson, 2005):

Equation 4-12 Bench height (H) to the blast-hole diameter (D) ratio

$$200 > \frac{H}{D} > 6$$

From an economic point of view:

- Unit drilling costs per BCM reduce as the diameter and length of the blast hole increase.
- Initiation costs increase with reducing hole diameter

- The sensitivity of the explosives in smaller holes may result in explosive energy not being fully utilized because of the reduction in the speed of the detonation.
- Secondary breaking is very expensive, but the savings on the drilling costs are in general much larger than larger diameter holes are drilled-this is particularly relevant where waste blasting occurs-there is no need to generate a very fine product size.
- Larger holes can result in an unfavourable layout in comparison to the joining of the block. That gives poor final wall profiles and fragmentation.

4.4.3 Blasting parameter empirical relationships

The bench geometry of a blast design is defined in Figure 4-5.

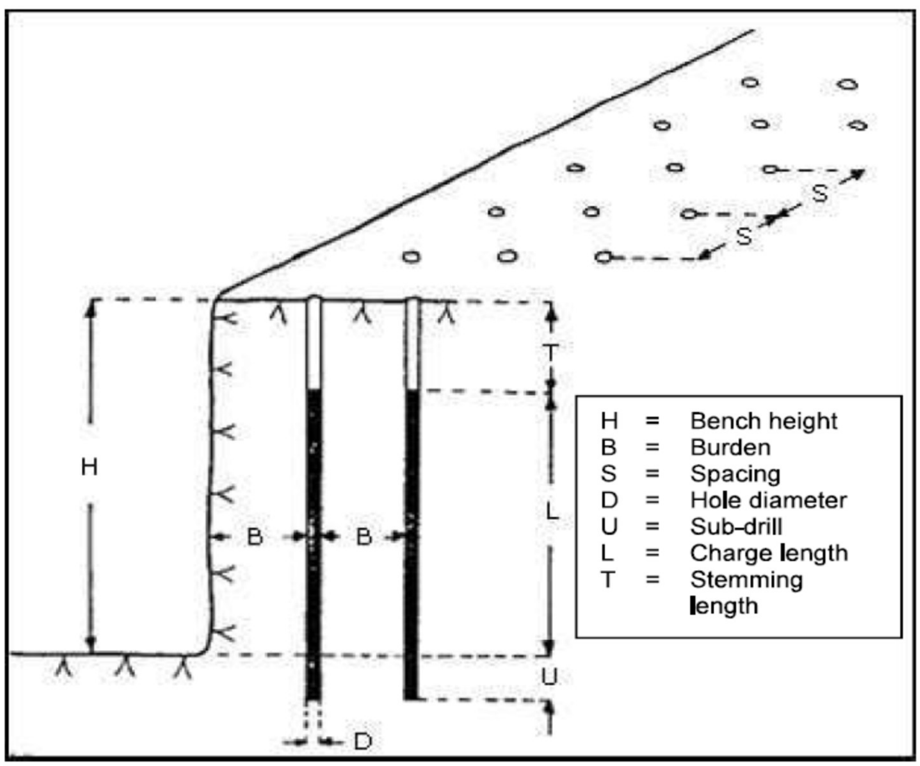

Figure 4-5 Blast Design Criteria (Thompson, 2005)

4.4.3.1 Burden (B)

The burden is the distance between two adjacent rows (parallel to free face) of drilling. As per empirical relationships, it varies from 20D to 45D. Approximately 20D in difficult conditions to 45D where rock can be broken easier. With the calculated powder factor then (Thompson, 2005) :

$$B \approx 20D, PDF > 0{,}9kg/BCM$$

$$B \approx 21D\ to\ 30D, PDF > 0{,}6kg/BCM$$

$$B \approx 45D, PDF > 0{,}3kg/BCM$$

4.4.3.2 Spacing (S)

Spacing is the distance between two adjacent holes in a row. Below is the empirical formula for spacing

$S \approx 1{,}2B$ To ensure that the explosives break the rock in the required direction.

B<S<1,5B will work with certain initiating sequences (where the spacing and burden during initiation (S' and B') can differ significantly from S and B) (BME, 2018a, 2018b). Using this rule, the results will be satisfactory irrespective of the initiation S' and B' values.

4.4.3.3 Stemming length (T)

Stemming length is the length of a portion of drill holes where there is no explosive column. Usually Stemming length varies from 0,7B to 1,1B depending upon hardness of rock and length of the blast hole.

Equation 4-13 Stemming length (BME, 2018a)

$$T \approx 0{,}7\ B\ to\ 1{,}1\ B$$

To avoid the fly-rocks minimum stemming length of 0,7B is kept.

Alternatively, a stemming length of between 15-30d can be used, with 20d being typical for competent rock (BME, 2018a)

4.4.3.4 Charge length (L)

The charge length is again dependent upon the rock hardness. The more rock that is in contact with the explosive column (charging length) the better it is for fragmentation. Below is the empirical guideline for the charge length (Thompson, 2005).

Equation 4-14 Charge length

$$L \geq 3B$$

In longer blast holes, the charge can be decked charges-next to hard layers or where the bench is very high.

4.4.3.5 Sub-grad drilling (U)

Excavation is affected by bad toe conditions caused by a combination of contaminated explosives at the bottom of the blast hole and more difficult breaking, especially for hard rocks (Sharma, 2012). Sub-drill is critical in a solid rock mass and vertical blast holes- but NOT used in overburden blasts above coal seams. In inclined holes, the toe effects are reduced, and sub-drill can be reduced (Sharma, 2012). Since sub-drill does not contribute to the broken volume (BXSXH) but does contain explosives, it will have a direct influence on PDF (referred to as the "actual" PDF) and cost per BCM broken.

4.4.4 Blasting Cost Estimation

Blasting cost typically involves explosives cost, accessory cost, stemming cost and monthly fixed cost (Sharma, 2012). Hence blasting cost can be estimated by estimating these costs individually and adding them all together. Hence,

Equation 4-15 Blasting cost

$$\begin{aligned} Blasting\ cost = {} & explosives\ cost + accessory\ cost + stemming\ cost \\ & + fixed\ cost \end{aligned}$$

In South Africa, a blasting contractor (typically explosive manufacturer or explosive supplier) is selected to supply the explosives and accessories to deliver the product to the hole. Most of surface coal mines in South Africa use site mixed emulsion explosives to blast, and shock tube initiation systems to connect the blast holes and initiate the blast (based on researcher's experience).

4.4.4.1 Explosives cost

The price of explosive is found out from the explosive manufacturers or explosive suppliers and explosive consumption per unit volume (PDF) is estimated by using the guidelines provided in Table 4-1. The explosive cost per unit volume can be estimated by the following formula:

Equation 4-16 Explosive Cost

$$Explosive\ cost\ (Xc) = PDF\ \times\ Explosive\ price$$

The prime material for bulk emulsion explosives is ammonium nitrate (AN) and fuel oil (diesel oil). So usually, the monthly price of explosives is linked with the pricing of AN and diesel. A typical price of explosive may be linked and based in the following manner as reflected in Table 4-2:

Table 4-2 Basis for pricing explosives

Component	Frequency	Reference
Ammonia	Monthly	Trading price in South Africa
Diesel	Monthly	Price in area
Labour	Yearly	Siefsa table C3
Transport	Yearly	Siefsa table L2
PPI	Yearly	Siefsa table U

The powder factor can be further estimated in the following way:

Hole diameter and bench height are the two fundamental parameters by which rest of other parameters are estimated and derived,

Assume Hole diameter = D (in mm) and Bench height = H (in m)

Burden = B (estimated as per 4.3.3.1)

Spacing = S (estimated as per 4.3.3.2)

Sub-grad drilling =U (estimated as per 4.3.3.5)

Stemming length = T (estimated as per 4.3.3.3)

Hence explosive column length (L) = H+U-T

Explosive density = ED (gm/cc)

Volume of material blasted per hole (V) = B × S × H

Explosive required per hole

Equation 4-17 Explosives required per hole

$$Qe = \frac{\pi\, D^2 \times (H+S-T)\times ED}{4000}\ \text{Kg}$$

Equation 4-18 Powder factor (PDF)

$$Powder\ factor\ (PDF) = \frac{Qe}{V}\ kg/m3$$

4.4.4.2 Accessories cost

Blast accessories include the down the hole and surface accessories (Aarsen et al., 2012). Down-the-hole accessories include cast boosters and down the hole lines (in case of shock tube initiation, down the hole shock tube unit). On the surface, it includes the surface lines (in case of shock tube initiation it is called trunk line units) required to connect from hole to hole and connecting the line to initiate the blast away from the blasting block (Aarsen et al., 2012).

Cost of accessories for a blast block can be estimated by estimating costing for each accessory and adding together

Equation 4-19 Cost of boosters

$$Cost\ of\ boosters\ (X_b) = No\ of\ holes\ \times\ Price\ of\ a\ cast\ booster$$

Equation 4-20 Cost of DTH units

$$\begin{aligned} &Cost\ of\ down\ the\ hole\ (DTH)\ line\ units\ (X_d) \\ &\qquad = No\ of\ holes\ \times\ Price\ of\ a\ DTH\ unit \end{aligned}$$

Equation 4-21 Cost of trunk line units

$$\begin{aligned} &Cost\ of\ trunk\ line\ (TLD) units\ (X_t) \\ &\qquad = No\ of\ trunk\ lines\ \times\ Price\ of\ a\ TLD\ unit \end{aligned}$$

Equation 4-22 Cost of lead lines

$$Cost\ of\ lead\ lines\ (X_l) = No\ of\ lead\ lines\ required\ for\ blast\ \times\ Price\ of\ a\ lead\ line$$

Equation 4-23 Cost of accessory

$$Cost\ of\ accessory\ for\ a\ blast = X_b + X_d + X_t + X_l$$

Equation 4-24 Accessory cost per unit volume

$$Accessory\ cost\ per\ unit\ volume\ = (X_b + X_d + X_t + X_l)/BCM$$

4.4.4.3 Stemming cost

Stemming is the process of filling the empty part of a charged blast hole with an inert material such as gravel, sand, clay or rock cuttings to retain the products of the detonation of an explosive charge in an enclosed space. Aggregates of sizes 13mm to 25 mm are used as the stemming material depending upon the size of holes. Also, some of surface coal mines, drill cuttings are used as stemming material. Using drill cuttings, no extra cost occurs for stemming, although it is not the best material for stemming purposes. The cost of stemming per hole can be calculated by multiplying the amount of stemming material per hole by the price of stemming material.

Equation 4-25 Amount of stemming material required per hole

$$Amount\ of\ stemming\ material\ per\ hole\ Qs = \frac{\pi D^2 T}{4\ \times\ 10^6}\ m^3$$

Price of aggregate = P_s (Rand per m3)

Equation 4-26 Cost of stemming material per hole

$$Cost\ of\ stemming\ per\ hole = Q_s\ \times\ P_s$$

Equation 4-27 Cost of stemming material per unit volume

$$Cost\ of\ stemming\ per\ unit\ volume\ S_C\ = \frac{Q_s\ \times\ P_s}{V}\ ZAR/m^3$$

4.4.4.4 Monthly fixed cost for blasting-

Usually, the explosive supplying contractor company charges a monthly cost for supplying the explosive down the hole and providing the blasting services and this has two major components; one is against the plants and equipment required on the site and the other is the amount of labour required for the blast. The plant and equipment required for blasting include MMUs, LDVs, site offices, magazines, silos, and blasting consumables. Further, the labour component includes blasters, MMU operators, blasting assistants, etc. Table 4-3 gives a general idea about the labour required and its costing for blasting of a 0,5 -1,0 million m^3 rock per month in South Africa.

Table 4-3 Monthly fixed costs for blasting (courtesy an explosive supplier)

Description	Units required	Unit cost	Total cost
Site Manager	1	100,000	100,000
Blast Supervisor	1	55,000	55,000
Blaster	2	35,000	70,000
MMU operators	2	15,000	30,000
Blasting Assistant	6	8,000	48,000
Magazine master	1	15,000	15,000
Admin/SHEQ	1	15,000	15,000

Further monthly fixed cost of blasting can be transferred to per-unit cost by dividing the monthly fixed cost by amount of material required to be blasted per month.

4.5 Estimation of loading cost

The loading cost is the cost involved for loading out the broken material to the truck. In most surface coal mines, loading of broken material is done by a loading machine (Darling, 2011). Those loading machines may be either an electric shovel, hydraulic shovel, dragline, or wheel loader. The broken material may be either waste or coal. First waste is loaded out or removed by loading machines to expose the minable coal. Loading cost is typically expressed in cost per unit volume or mass of material. In South African coal mines, usually, it is expressed in ZAR per bank cubic meter (BCM).

Loading cost can be estimated from the first principle approach, if operating cost per hour of loading machine and productivity i.e. production volume per hour of loading machine is estimated for that working condition.

4.5.1 Estimation of productivity of loading machine

In the mining industry, it is usual to express the productivity of the loading machine in terms of production volume per hour (m^3/h or cubic yard /h). The hourly production of a loading machine can be obtained using the following formula (Komatsu, 2013):

Equation 4-28 Hourly production of a loading machine

$$Q_l = \frac{B_c \times F_f \times E_l \times 3600}{C_l \times f}$$

Where,

Q_l = Hourly production (m^3/hr; yd^3 /hr)

B_c= Bucket capacity of the loading machine (m^3; yd^3)

F_f = Bucket fill factor of the loading machine

E_l = Job efficiency

C_l = Cycle time of loading machine (in seconds)

f = conversion factor (bulk factor)

The volume of the rock is different when it is intact and when it is broken. Since it is easier to measure the ground in in-situ conditions, so it is convenient to use in-situ m^3 (bank m^3) for calculation and estimation purposes.

4.5.1.1 Bucket fill factor (F_f)

The bucket fill factor is the percentage of an available volume of the bucket of the loading machine that is used (Komatsu, 2013). The bucket fill factor varies according to the nature of material, quality of blasts, etc. A suitable factor can be selected from the table, taking into consideration the applicable excavating conditions:

Table 4-4 Bucket fill factor of a hydraulic excavator (Komatsu, 2013)

Description	Excavating Conditions	Bucket fill factor
Easy	Excavating soil, clay, or soft material	1,0 to 1,1
Average	Loading loose soil with small diameter gravel	0.95 to 1,0
Rather difficult	Loading well-blasted rock	0,80 to 0,90
Difficult	Loading poorly blasted rock	0,70 to 0,80

4.5.1.2 *Job efficiency (E_l)*

When estimating the loading cost, the hourly productivity of the machines needed in the project is the standard productivity under ideal conditions multiplied by a certain factor. This factor is called job efficiency. Job efficiency depends on many factors such as topography, operator's skill, and proper selection and disposition of machine. Table 4-5 reflects a typical job efficiency as a rough guide.

Table 4-5 Job Efficiency for loading machine (Komatsu, 2013)

Description →	Management condition →			
Loading condition ↓	Excellent	Good	Fair	Poor
Excellent	0,84	0,81	0,76	0,70
Good	0,78	0,75	0,71	0,65
Fair	0,72	0,69	0,65	0,60
Poor	0,63	0,61	0,57	0,52

4.5.1.3 Loading Cycle time (Ct)

Cycle time of a loading machine can be typically described as the total time required to dig and load out one bucket to the hauling equipment. The cycle time of a hydraulic excavator can be described as:

Equation 4-29 Cycle time of a loading machine (Komatsu, 2013)

$$Cycle\ time = excavating\ time + swing\ time\ (loaded) + dumping\ time + swing\ time\ (empty)$$

The cycle time of a loading machine primarily depends upon condition of rock or material, digging depth and dumping condition. However, for estimation purposes, Table 4-6 can be used for cycle times of the loading machine.

Table 4-6 Cycle time for loading machine (Komatsu, 2013)

Description	Backhoe	Shovel	Wheel Loader
Small loading machine	25 sec	Not applicable	45 sec
Big loading machine	30 sec	33 sec	55 sec

4.5.1.4 Earth volume conversion factor (f)

A conversion factor is a numerical ratio or fraction used to convert a measurement in one set of units to the same measurement in another set of units. The conversion factor of earth depends on whether the soil/rock is in its natural ground condition (that is, unexcavated), loose, or compacted. The conversion factor depends on the type of soil and its operating state. To obtain the productivity of the loading machine, the earth volume conversion factor is considered so that while estimating projects, work volume is calculated in terms of unexcavated earth or compacted earth. Table 4-7 provides a guideline for the conversion factors for different materials.

Table 4-7 Earth volume conversion factor (Komatsu, 2013)

Nature of earth	Initial	Condition of the earth to be moved		
		Bank condition	Loosened condition	Compacted condition
Sand	(A)	1,00	1,11	0,95
	(B)	0,90	1,00	0,86
	(C)	1,05	1,17	1,00
Sandy Clay	(A)	1,00	1,25	0,90
	(B)	0,80	1,00	0,72
	(C)	1,11	1,39	1,00
Clay	(A)	1,00	1,43	0,90
	(B)	0,70	1,00	0,63
	(C)	1,11	1,59	1,00
Gravelly soil	(A)	1,00	1,18	1,08
	(B)	0,85	1,00	0,91
	(C)	0,93	1,09	1,00
Gravel	(A)	1,00	1,13	1,03
	(B)	0,88	1,00	0,91
	(C)	0,97	1,10	1,00
Solid or rugged gravel	(A)	1,00	1,42	1,29
	(B)	0,70	1,00	0,91
	(C)	0,77	1,10	1,00
Broken limestone, sandstone, and other soft rocks	(A)	1,00	1,65	1,22
	(B)	0,61	1,00	0,74
	(C)	0,82	1,35	1,00
Broken granite, basalt, and other hard rocks	(A)	1,00	1,70	1,31
	(B)	0,59	1,00	0,77
	(C)	0,76	1,30	1,00
Broken rocks	(A)	1,00	1,75	1,40

Nature of earth	Initial	Condition of the earth to be moved		
		Bank condition	Loosened condition	Compacted condition
	(B)	0,57	1,00	0,80
	(C)	0,71	1,24	1,00
Blasted bulky rocks	(A)	1,00	1,80	1,30
	(B)	0,56	1,00	0,72
	(C)	0,77	1,38	1,00

(A) Bank condition (B) Loosened condition (C) Compacted condition

4.5.2 Loading cost estimating model

The loading cost estimating model was established by finding out the owning and operating cost of the applicable loading machine and establishing the productivity of the loading. The loading machine is selected based on applicability and production requirement of the mine. Once the loading machine is selected; the productivity of the loading machine is established as explained in section 4.5.1. First, owning and operating cost per hour of a loading machine is estimated and then dividing the owning and operating cost per hour by productivity per hour; owning cost per hour and operating cost per hour for loader is estimated. Below is the step-by-step approach for estimating the loading cost.

Assume the purchase price of a loading machine = PP_L (in ZAR)

Cost of tracks or undercarriage unit = $COSTT_L$ (in ZAR)

Life of tracks or undercarriage unit = $LIFT_L$ (Hours)

Interest rate per annum = INT_L (%)

Insurance rate per annum = INS_L (%)

Expected residual value = RV_L (in ZAR)

Overhead cost as a percentage of the equipment cost = OH_L (%)

Estimated operating period of ownership = $OPRP_L$ months

Operating hours per month from the mining schedule and roster = $MINH_L$ hours/ month

Operating machine life in hours $LIF_L = OPRP_L \times MINH_L$

Total maintenance cost over the life of machine = $MAINC_L$ (in ZAR)

Fuel consumption of machine based on OEM specification = $FCON_L$ (l/hr)

Price of fuel = POF (ZAR per Litre)

Operator's salary per month = OPS_L

No of operator's required per month = OPN_L

Overhead cost for machine = OH_L % of purchase price

Overhead cost for life of machine = $(PP_L \times OH_L)/100$

Annuity paid per month for owning the machine can be found out using the formula

Equation 4-30 Annuity paid per month for owning the loading machine

$$AP_L = \quad INT_L \times \frac{\left[PP_L - \dfrac{RV_L}{\left\{1 + \dfrac{INT_L}{12}\right\}^{OPRP_L}}\right]}{\left[1 - \left\{1 + \dfrac{INT_L}{12}\right\}^{-OPRP_L}\right]}$$

Assuming straight line depreciation

Depreciation per month (DP_L) = $(PP_L\text{-}RV_L)/ OPRP_L$

Interest paid per month paid (IP_L) = $\{AP_L – (PP_L/OPRP_L)\}$

Insurance paid per month (SP_L) = $(PP_L \times INS_L)/1200$

Overhead per month (RP_L) = $(PP_L \times OH_L)/1200$

Maintenance cost per month (MP_L) = $MAINC_L/OPRP_L$

Cost of tracks or undercarriage per month (TP_L) = $(COSTT_L \times MINH_L)/ LIFT_L$

Fuel cost per month (FP_L) = $FCON_L \times POF \times MINH_L$

Operator's cost per month (OP_L) = $OPS_L \times OPN_L$

Depreciation per hour (DPH_L) = $(PP_L\text{-}RV_L)/ (OPRP_L \times MINH_L)$

Interest paid per hour (IPH_L) = $\{AP_L – (PP_L/OPRP_L)\}/MINH_L$

Insurance paid per hour (SPH_L) = (PP_L × INS_L/1200)/$MINH_L$

Overhead per hour (RPH_L) = (PP_L × OH_L/1200)/$MINH_L$

Maintenance cost per hour (MPH_L) = $MAINC_L$/ ($OPRP_L$ × $MINH_L$)

Cost of tracks or undercarriage unit per hour (TPH_L) = $COSTT_L$ / $LIFT_L$

Fuel cost per hour (FPH_L) = $FCON_L$ × POF

Operator's cost per hour (OPH_L) = (OPS_L × OPN_L)/$MINH_L$

Total owning cost per month (FC_L) = DP_L + IP_L + SP_L +RP_L

Total operating cost per month (OC_L) = MP_L + TP_L + FP_L + OP_L

Total owning cost per hour (FCH_L) = DPH_L+ IPH_L + SPH_L +RPH_L

Total operating cost per hour (OCH_L) = MPH_L + TPH_L + FPH_L + OPH_L

Total owning cost of loading equipment can be found out by dividing total fixed cost per hour by production per hour, i.e. Owning cost = FCH_L/ Q_l (ZAR/m^3)

Similarly, operating loading cost can be found out by diving total variable cost by production per hour i.e. operating loading cost = OCH_L/Q_l (ZAR/m^3)

4.6 Estimation of hauling cost

Hauling in surface mining is another most important unit operation involved. In most of surface coal mines, blasted material is loaded by loading machines to mine trucks. Based on the body design and drive system, the mine trucks may be broadly classified into either Rigid Dump Truck (RDT) or Articulated Dump Truck (ADT) (Martin, 2018). RDTs are rear-wheel drive trucks having a heavy-duty frame and body design and have having greater payload capabilities, while ADTs are all-wheel drive and having limited payload capabilities and lighter body and frame. RDTs require properly maintained haul road and gentle gradient of roads while ADTs can negotiate with a steep gradient and rough ground conditions.

To carry out mining operations a suitable number of mine trucks are matched with the applicable loader. The hauling cost is the cost involved for hauling out the broken material from the mine to the dump/ stockpiles or crushers (Burt &

Caccetta, 2014). Usually, in a surface coal mine, waste is hauled to the designated waste dump or mined out area and coal is hauled to the crusher or stockpiles. Hauling cost is typically expressed in cost per unit volume or mass of material. In South Africa coal mines, usually, it is expressed in ZAR/ BCM. The hauling cost from the first principle approach in this study has been estimated by estimating the operating cost per hour of mine truck (ZAR/hour) and productivity of mine truck in the specific working condition.

4.6.1 Estimation of productivity of a hauling machine

In the mining industry, it is usual to express the productivity of the hauling machine in terms of production volume per hour (m^3/h or cubic yard/h). The hourly production of a mine truck is estimated using the following formula:

Equation 4-31 Hourly production of a mine truck (Komatsu, 2013)

$$Q_t = \frac{N \times B_c \times F_f \times E_t \times 60}{C_t \times f}$$

Where,

Q_t = Hourly production of a mine truck (In-situ m^3/h)

N = number of cycles required for the loading machine to fill mine truck

F_f = Bucket fill factor of loading machine, as explained in section 4.5.1.1;

f = conversion factor, as explained in section 4.5.1.4.

B_c= Bucket capacity of loading machine (m3)

E_t = Job efficiency of mine truck.

C_t = Cycle time of mine truck (in minute)

4.6.1.1 Job efficiency (E_t)

The job efficiency of hauling machines is very much like the job efficiency of the loading machine. Like the loading efficiency, hauling efficiency is also influenced by factors such as haul road condition, topography, operator's skill, and loading machine. Table 4-8 shows typical job efficiency as a rough guide and the same is used in this model.

Table 4-8 Job efficiency (Et) (Komatsu, 2013)

Operating conditions	Job efficiency
Good	0,83
Average	0,80
Rather Good	0,75
Poor	0,70

4.6.1.2 Estimating Cycle time of mine truck (C_t)

The cycle time of a dump truck consists of the following factors and can be calculated as shown in Equation 4-32 Estimating cycle time of a mine truck (Komatsu, 2013)

(A) Loading time: Time required for loading machine to fill mine truck = $N \times C_l$

(B) Hauling time = D/ V_1

(C) Dumping time: Time required for unloading (dumping) plus time extended for standby until unloading is started = T_1

(D) Returning time: Time required for returning= D/ V_2

(E) Spot and delay time: Time required for a dump truck to be positioned for loading and for the loader to start loading= T_2

Equation 4-32 Estimating cycle time of a mine truck (Komatsu, 2013)

$$C_t = N \times C_l + \frac{D}{V_1} + T_1 + \frac{D}{V_2} + T_2$$

Where, N: Number of cycles required to fill the dump truck

Equation 4-33 Number of cycles required to fill a dump truck (Komatsu, 2013)

$$N = \frac{B_d}{(B_f \times B_c)}$$

B_d = Rated bin capacity of mine truck (loose m3)

B_f = Bucket fill factor of the loader

B_c = Bucket capacity of loader (Loose m3)

C_t = Cycle time of mine truck (min)

D = Hauling distance of mine truck (m)

V_1 = Average speed of loaded truck (m/min)

V_2 = Average speed of empty truck (m/min)

T_1 = time required for dumping + time required for standby until dumping started (min)

T_2= Time required for the truck to be positioned and for the loader to start loading (min)

4.6.1.2.1 Loading time

The time required for a loader to load a mine truck which can be obtained by the following:

Equation 4-34 Loading time for a mine truck (Komatsu, 2013)

$$Loading\ time = Cycle\ time\ of\ loader\ (C_l) \times\ No.of\ cycles\ to\ fill\ mine\ truck\ (N)$$

C_l = The cycle time of loader is dependent on the type of loader (excavator, wheel loader, backhoe, etc.).

N = Number of cycles required for a loader to fill dump truck full (N):

The payload of mine truck depends on the capacity or weight.

Where the payload is determined by the capacity,

Equation 4-35 Number of cycles required for a loader to fill a dump truck determined by the capacity

$$N = \frac{Rated\ capacity\ (m^3\ )of\ dump\ truck}{bucke\ \ capacity\ (m^3) \times Bucket\ fill\ factor}\ \text{(Caterpillar, 2015)}$$

Where the payload is determined by the weight,

Equation 4-36 Number of cycles required for a loader to fill a dump truck determined by weight

$$N = \frac{Payload\ rated\ capacity\ (Ton)of\ dump\ truck}{bucke\ \ capacity\ (m^3) \times Bucket\ fill\ factor \times Specific\ weigh}$$

(Caterpillar, 2015)

4.6.1.2.2 Material hauling time and returning time

The time taken to haul a load and return empty can be calculated by dividing the haul road into sections and assigning the maximum speed limit according to the road conditions (Komatsu, 2013). The speed of the truck is primarily affected by the rolling resistance and grade resistance. Rolling resistance is the resistance of the ground or plane when a matter is rolled on the ground or plane and the grade resistance is the force due to gravity which resists the movement of mine truck up a slope (Caterpillar, 2015)

.

The maximum speed thus assigned is a theoretical value, and to convert this maximum speed to a practical average speed, the speed should be multiplied by a speed factor. An applicable speed factor can be selected from the following table:

Table 4-9 Table Speed factors(Komatsu, 2013)

Distance of each section of haul road(m)	Speed factor when making a standing start	Speed factor when running into each section
0-100	0,25-0,50	0,50-0,70
100-250	0,35-0,60	0,60-0.75
250-500	0,50-0,65	0,70-0,80
500-750	0,60-0,70	0,75-0,80
750-1000	0,65-0,75	0,80-0,85
1000 above	0,70-0,85	0,80-0,90

Thus, the average speed can be obtained in the following manner:

Equation 4-37 Average speed of a truck

$$Average\ speed = Maximum\ allowable\ speed\ \times\ Speed\ factor$$

The following can be cited as factors retarding a vehicle speed

- Vehicles passing each other on a narrow road
- A sharp curve or many curves on the road
- Points giving poor visibility
- Narrow bridges or at railway crossings, intersections of roads
- Potholes on roads
- Un-experienced or unskilled operators

If the hauling distance in each section is divided by the average speed as obtained in the preceding paragraph, the hauling time in each section will be obtained (Komatsu, 2013). If all these times (for hauling and returning) are added together, they will give the total hauling and returning time.

Equation 4-38 Hauling time and returning time of a mine truck (Komatsu, 2013)

$$Hauling\ time\ and\ returning\ time\ in\ each\ section(V) = \frac{Lengt\ \ of\ section(m)}{Average\ speed\ (m/min)}$$

4.6.1.2.3 Dumping time

This is the period from the time when the dump truck enters the dumping area, to the time when the dump truck starts its return journey after completing the dumping operation. The length of the dumping time depends on the operating conditions but average dumping times for favourable average and unfavourable conditions are given by the following table.

Table 4-10 Dumping time (Komatsu, 2013)

Operating conditions	T_1 (min)
Favourable	0,5 to 0,7
Average	1,0 to 1,3
Unfavourable	1,5 to 2,0

4.6.1.2.4 Positioning time

The time required for the truck to be positioned and for the loader to begin loading also depends on the operating conditions. As a general, a suitable value can from the table.

Table 4-11 Positioning time and waiting time (Komatsu, 2013)

Operating conditions	Positioning and waiting time T_2 (min.)
Favourable	0,1 to 0,2
Average	0,25 to 0,35
Unfavourable	0,4 to 0,5

4.6.2 Estimating the number of mine trucks required (M) for a loader

The number of dump trucks required for use in combination with a loader working at its maximum operating efficiency can be estimated using the following formula:

Equation 4-39 Number of mine trucks required for a loader (Komatsu, 2013)

$$M = \frac{Cycle\ time\ of\ dump\ truck}{Loading\ time} = \frac{C_t}{N \times C_l} \text{ (Round off to the whole number)}$$

Where, N =Number of cycles required for a loader to fill a dump truck

C_t= Cycle time of dump truck (min.)

C_l = Cycle time of loader (min.)

4.6.3 Hauling cost estimating model

The hauling cost estimating model was established by finding out the owning and operating cost of the hauling machine and establishing the productivity of the hauling machine. Usually, the mine trucks are selected for hauling purposes. The productivity of the mine truck is established as explained in section 4.6.1. Firstly, the owning and operating cost per hour of mine truck is estimated and then dividing the owning and operating cost per hour by productivity per hour; owning cost per hour and operating cost per hour for mine truck has been estimated. Below is the step-by-step approach for estimating the loading cost

Assume the purchase price of a hauling machine = PP_H (in ZAR

Cost of Tyres = $COSTT_H$ (in ZAR)

Life of Tyres = $LIFT_H$ (Hours)

Interest rate per annum = INT_H (%)

Insurance rate per annum = INS_H (%)

Expected residual value = RV_H (in ZAR)

Overhead cost as a percentage of the equipment cost = OH_H (%)

Estimated operating period of ownership = $OPRP_H$ months

Operating hours per month from the mining schedule and roster = $MINH_H$ hours/ month

Operating machine life in hours $LIF_H = OPRP_H \times MINH_H$

Total maintenance cost over the life of machine = $MAINC_H$ (in ZAR)

Fuel consumption of machine based on OEM specification = $FCON_H$ (l/hr)

Price of fuel = POF (ZAR per Litre)

Operator's salary per month = OPS_H

No of operator's required per month = OPN_H

Overhead cost for machine = OH_H % of purchase price

Overhead cost for life of machine = $(PP_H \times OH_H)/100$

Annuity paid per month for owning the machine can be found out using the formula

$$AP_H = \quad INT_H \times \frac{\left[PP_H - \frac{RV_H}{\left\{1 + \frac{INT_H}{12}\right\}^{OPRP_H}}\right]}{\left[1 - \left\{1 + \frac{INT_H}{12}\right\}^{-OPRP_H}\right]}$$

Assuming straight-line depreciation.

Depreciation per month (DP_H) = $(PP_H - RV_H)/ OPRP_H$

Interest paid per month paid (IP_H) = {AP_H – (PP_H/$OPRP_H$)}

Insurance paid per month (SP_H) = (PP_H × INS_H)/1200

Overhead per month (RP_H) = (PP_H × OH_H)/1200

Maintenance cost per month (MP_H) = $MAINC_H$/$OPRP_H$

Cost of Tyres per month (TP_H) = ($COSTT_H$ × $MINH_H$)/ $LIFT_H$

Fuel cost per month (FP_H) = $FCON_H$ × POF × $MINH_H$

Operator's cost per month (OP_H) = OPS_H × OPN_H

Depreciation per hour (DPH_H) = (PP_H-RV_H)/ ($OPRP_H$ × $MINH_H$)

Interest paid per hour (IPH_H) = {AP_H – (PP_H/$OPRP_H$)}/$MINH_H$

Insurance paid per hour (SPH_H) = (PP_H × INS_H/1200)/$MINH_H$

Overhead per hour (RPH_H) = (PP_H × OH_H/1200)/$MINH_H$

Maintenance cost per hour (MPH_H) = $MAINC_H$/ ($OPRP_H$ × $MINH_H$)

Cost of Tyres per hour (TPH_H) = $COSTT_H$ / $LIFT_H$

Fuel cost per hour (FPH_H) = $FCON_H$ × POF

Operator's cost per hour (OPH_H) = (OPS_H × OPN_H)/$MINH_H$

Total owning cost per month (FC_H) = DP_H + IP_H + SP_H +RP_H

Total operating cost per month (OC_H) = MP_H + TP_H + FP_H + OP_H

Total owning cost per hour (FCH_H) = DPH_H + IPH_H + SPH_H +RPH_H

Total operating cost per hour (OCH_H) = MPH_H + TPH_H + FPH_H + OPH_H

Total owning cost of loading equipment can be found out by dividing total fixed cost per hour by production per hour, i.e. Owning cost = FCH_H/ Q_t (ZAR/m^3)

In a similar way, operating loading cost can be found out by diving total variable cost by production per hour i.e. operating loading cost = OCH_H/Q_t (ZAR/m^3)

4.7 Estimation of Ancillary Cost

The costs of general services in open-pit mines include pit maintenance costs, road grading, and waste dump grading, pumping and supervising of open-pit (Bagherpour, 2007). The ancillary costs typically involve the following:

- Cost of dozing
- Cost of grading

- Cost of water trucks and diesel browser
- Lighting cost
- Dewatering cost

4.7.1 Cost of Dozing

The cost of dozing can be estimated by estimating the cost of running a dozer per hour and finding out the productivity of a dozer per hour.

The operating cost of dozer per hour can be exactly estimated following the same principles as explained for excavators; however, the calculation of productivity is going to differ.

4.7.1.1 Productivity of dozer (Hourly production of a dozer)

Hourly production of a dozer can be estimated using the following formula (Komatsu, 2013):

Equation 4-40 Hourly production of a dozer

$$Q_d = \frac{q \times a \times 60 \times e \times E_d}{C_d \times f}$$

Where, Q_d = Hourly production (m3/hr); C_d = Cycle time (in minutes)

q = Blade capacity (m^3); a = Blade fill factor; E_d = Job efficiency; e = Grade factor; f = conversion factor

When calculating the standard productivity of a dozer, the productivity of dozer differs with the type of soil, so the blade fill factor is used to adjust this figure. Table 4-12 provides guidelines for the fill factor (a).

Table 4-12 Dozing condition and blade fill factor (Komatsu, 2013)

Dozing conditions		Blade fill factor (a)
Easy dozing	Full blade of soil can be dozed as completely loosened soil. Low water content, no- compacted sandy soil, general soil, stockpile material.	1,1 to 0,9

Average dozing	Soil is loose but impossible to doze full blade of soil. Soil with gravel-sand, finely crushed rock	0,9 to 0,7
Rather difficult dozing	High water content and sticky clay, sand with cobbles, hard dry clay and natural ground	0,7 to 0,6
Difficult dozing	Blasted rock or large pieces of rock	0,6 to 0,4

4.7.1.2 Cycle time of dozer (C_d)

The time required for a dozer to complete one cycle (dozer, reversing and gear shifting) is calculated using the following formula (Komatsu, 2013):

Equation 4-41 Dozer cycle time

$$C_d\ (min.) = \frac{D_d}{F} + \frac{D_d}{R} + Z$$

Where, D_d = Push distance (m), F = Forward speed (m/min.)

R = Reverse speed (m/min.), Z = Time required for gear shifting (min.)

As a rule, a speed range of 3-5 km/h for forward and 5-7 km/h for reverse should be chosen.

The time required for gear shifting may be chosen to 0,2 min.

4.7.1.3 Grade factor (e)

The production dozing is affected by the grade of the ground when dozing. The grade factor can be selected from Figure 4-6.

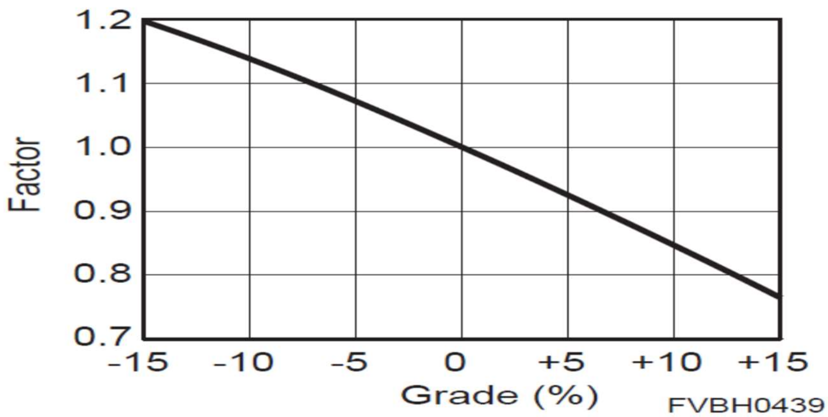

Figure 4-6 Grade factor graph (Komatsu, 2013)

4.7.1.4 Job efficiency (E)

Table 4-13 presents typical job efficiency as a rough guide for the estimation of the production figures.

Table 4-13 Job efficiency of grader (Komatsu, 2013)

Operating conditions	Job efficiency
Good	0,83
Average	0,75
Rather poor	0,67
Poor	0,58

4.7.2 Cost of Grading

The motor grader is used for many purposes such as maintaining roads, final finishing of earthmoving projects, trenching and bank cutting. Therefore, there are many methods for expressing its operating capacity.

The cost of grading can be estimated by estimating the cost of running a grader per hour and finding out the productivity of a grader per hour.

The operating cost of a grader per hour can be estimated following the same principles as explained for trucks; however, the calculation of productivity is going to differ.

4.7.2.1 Productivity of grader (Hourly operating area of a grader)

The hourly productivity of grader is measured in terms of hourly operating area (m^2/h) and it can be estimated using the following formula:

Equation 4-42 Productivity of grader (Komatsu, 2013)

$$Qa = V \times (Le - Lo) \times 1000 \times E_g$$

Where, Q_a = Hourly operating area (m^2/h), V = Working speed (km/h)

Le = Effective blade length (m), Lo= Width of overlap (m)

E_g = Job efficiency

4.7.2.2 Working speed (V)

Table 4-14 is the guideline for working speed (V) for estimation purposes.

Table 4-14 Working speed of a grader (Komatsu, 2013)

Working condition	Working speed
Road repair	2 to 6 km/h
Bank finishing	1,6 to 2,6 km/h
Field grading	1,6 to 4 km/h
Trenching	1,6 to 4 km/h
Snow-removal	7 to 25 km/h
Levelling	2 to 8 km/h

4.7.2.3 Effective blade length (Le), Width of overlap (Lo)

Since the blade is normally angled when cutting or grading the surface, the effective blade length depends on the angle.

The width of overlap is usually 0, 3 m. The following Table 4-15 gives the values to be used when applying the formula for estimation

Table 4-15 Effective blade length for a grader (Komatsu, 2013)

Blade length (m)	Effective blade length (m)	
	Blade angle 60°	Blade angle 45°
2.2	1,9	1,6
2,5	2,2	1,8
2,8	2,4	2,0
3,05	2,6	2,2
3,1	2,7	2,2
3,4	2,9	2,4
3,7	3,2	2,6
4,0	3,5	2,8
4,3	3,7	3,0
4,9	4,2	3,5

4.7.2.4 Job Efficiency (E)

The job efficiency is dependent on the operating conditions. Table 4-16 presents a guideline for using the job efficiency for different working conditions for estimation purposes.

Table 4-16 Job efficiency (Komatsu, 2013)

Operating conditions	Job efficiency
Road repair, levelling	0,8
Snow-removal	0,7
Spreading, grading	0,6
Trenching, snow-removal	0,5

4.6.2.5 *Time required to finish a specific area*

The time required to finish grading of a specific area can be estimated using the following formula:

Equation 4-43 Time required to finish grading of a specific area (Caterpillar, 2015)

$$T = \frac{N_g \times D_g}{V \times E_g}$$

Where, T =working time (h), N_g = Number of trips, D_g =Working distance (km) E_g= Job efficiency, V= Working speed (km/hr)

When a grader is operating in a job site and levelling parallel strips, the number of trips (N_g) can be calculated using the following formula:

Equation 4-44 Number of trips (Ng) grader (Caterpillar, 2015)

$$N_g = \frac{W}{Le - Lo} \times n$$

Where W= Total width to be levelled (m), L_e= Effective blade length (m)
Lo= Width of overlap (m), n= number of grading required to finish the surface to the required flatness.

4.7.3 Cost of water trucks and diesel bowser

The water truck is used on haul roads and working benches to suppress dust while working. The amount of water spraying is highly dependent on weather conditions (Darling, 2011). During the summer and dry days requirement of water, spraying is high while during the rainy days; it is not required at all.
The cost of water spraying can be estimated by estimating the cost of running a water truck per hour and finding out the requirement of the number of water trucks to be operated per hour.
The operating cost of water truck per hour can be exactly estimated following the same principles as explained for trucks. However, the required number of water trucks is calculated as follows:

The time required to finish wetting of a specific area can be estimated using the following formula,

Equation 4-45 Time required to finish wetting of a specific area (Caterpillar, 2015)

$$T_w = \frac{N_w \times D_w}{V_w}$$

Where, T_w =working time (h), N_w = Number of trips, D_w =Working distance (km) V_w = Working speed (km/hr)

When a water truck is operating in a job site, and doing water spraying parallel strips, the number of trips (N_w) can be calculated using the following formula

Equation 4-46 Number of trips (Nw) of water truck (Caterpillar, 2015)

$$N_w = \frac{W}{Lw}$$

Where, *W*= Total width to be water sprayed (m), *Lw*= Effective spraying width of water truck (m)

The cycle time of water truck to finish the spraying of one load of water truck (Tw) can be expressed as

Equation 4-47 Cycle time of water truck (T_w) (Caterpillar, 2015)

$$\begin{aligned} T_w = {} & Empty\ travel\ time\ to\ filling\ station + Filling\ time \\ & + loaded\ water\ travel\ time\ to\ spraying\ area \\ & + Actual\ water\ spray\ time \end{aligned}$$

The diesel bowser is used to fill the fuel to the equipment which does not come to the fuel filling point. Usually, diesel bowser is used for the filling of track-mounted machines.

The operating cost of diesel bowser per hour can be estimated following the same principles as explained for trucks. However, for a coal mine having excavation below of 1,2 million m^3 per month; 1 to 2 diesel bowsers of 18 000 litres capacity is enough to fuelling of the mining equipment.

4.7.4 Lighting cost

Whenever a mine is going to be operated during the night hours; lighting is required for the working areas and haul roads. Since in a coal mine; mining and backfilling are done concurrently, movable lighting towers are used at most of the working places. Some of the mines where haul roads are permanent or semi-permanent in nature; fixed lights are used through lighting poles. This fixed lighting is considered as part of the capital cost.

To calculate the operating lighting cost; it can be considered that one lighting tower is required for each working face and each dumping area. Usually, as a rule of thumb, the required number of lighting towers/plants shall be 2 to 3 times the number of loading machines (based on researcher's experience).

Equation 4-48 Number of lighting towers/plants required

$$Number\ of\ lighting\ towers\ required = 2\ to3\ times\ of\ number\ of\ loading\ machines$$

Once the required number of lighting plants is estimated, the lighting cost is established by operating the cost of lighting plants per month divided by monthly excavation volumes.

4.7.5 Pumping Cost

Groundwater often exists at various depths below the existing ground level. When mining activities at depths below the existing water table is planned, the groundwater can obstruct the mining operations (Darling, 2011). It is essential to lower the water table to allow work to be done in a dry environment. For this purpose, pumping out of water is required for those workings. In most of the surface mines, a sump is established to collect the water from the working area and then the sump water is pumped out to keep the sump at a controlled water level.

The pumping cost is also site-specific, and it varies with the weather. To estimate the pumping cost, the level of the groundwater table is found out from geological/hydrological report and compared with the mining horizon. If the mining horizon is below the groundwater table; the inflow of groundwater and inflow of seasonal water (from catchment area) is calculated and based on this the pumping system and its costing is estimated.

4.8 Estimation of mine management and technical services cost

To run a mining operation safely and productively a team of management and technical personnel is required. The amount and type of these personnel depend upon the size of the mining operation, type of mining, and equipment deployed. A typical surface coal mine requires the following personnel as mine management and a technical team as shown in Table 4-17

Table 4-17 List of mine management and technical personnel (based on researcher's experience)

	Description		Description
1	Mine manager	8	Mine foreman
2	Production manager	9	Health & safety officer
3	Drilling and blasting manager	10	Junior health & safety officer
4	Geologist	11	Engineer Intern
5	Strata control officer	12	Training/QA officer
6	Mining engineer	13	Mine surveyor
7	Pit superintendent	14	HR officer

4.9 Chapter Conclusion

Hence this chapter covered theories, principles, and methods which are applied to estimate the operating costs for a mining project through the first-principles approach. The focus has been given to develop the framework for estimating operating costs under six major headings and those were drilling cost, blasting cost, loading cost, hauling cost, ancillary cost and management & technical services cost. The mining operating costs have been represented in summary as a value driver tree (VDT) in Figure 4-7.

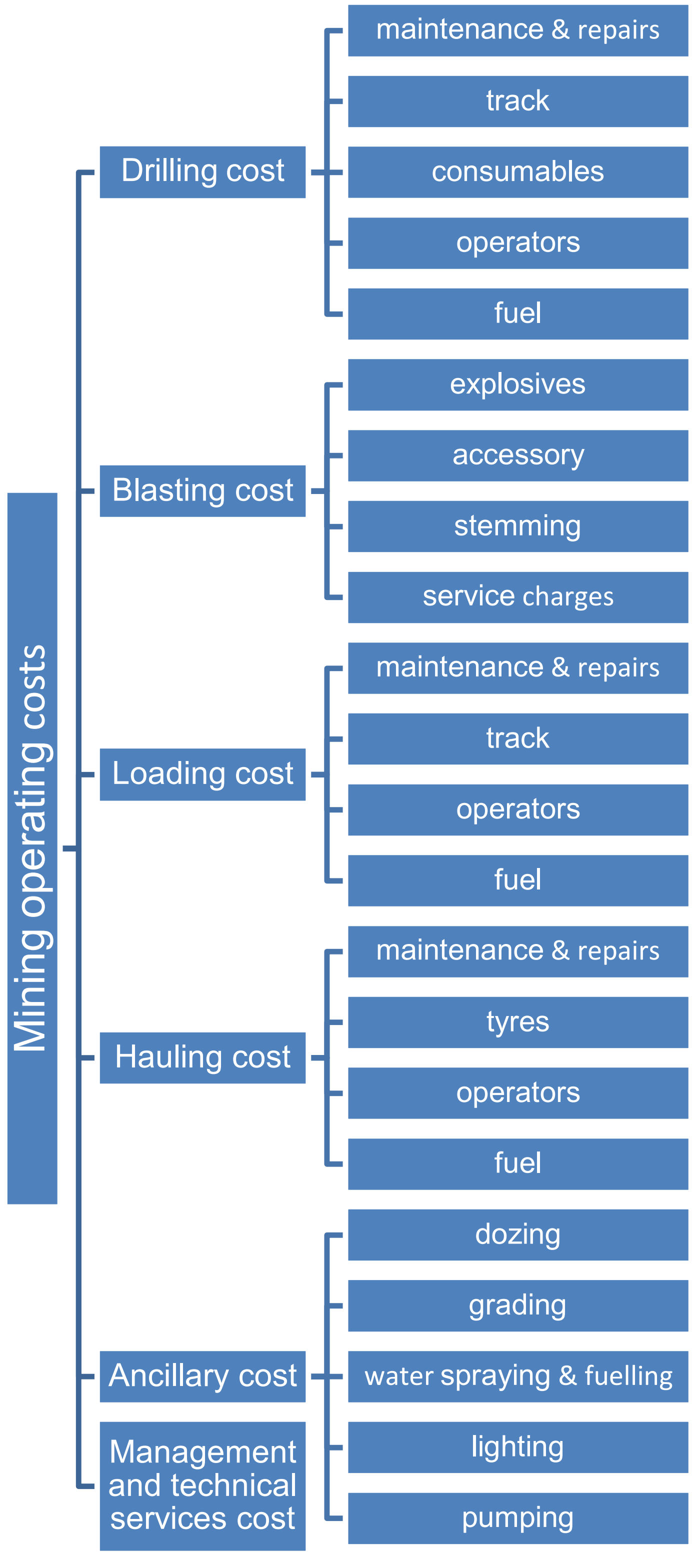

Figure 4-7 Summary of different operating mining costs

5 Operating cost estimation – An example mine

5.1 Introduction

This chapter details the operating cost estimation for an example mine. This has been done to test the reliability of the cost model whether the developed model is giving realistic data or not. The excel cost model developed for the example mine has been presented in this chapter.

An example surface coal mine case study was assumed to verify and demonstrate the proposed operating cost estimation model. This has been done based on the framework developed in Chapter 4. This case study has been done to further provide a deeper and practical understanding of the way of operating cost estimation for a mining project through the first-principles method. The excel cost model can be used for estimation of operating costs of other surface coal mines by customizing the mine variables and equipment variables for the specific mining project.

5.2 Mine Project Details

The example coal mine is a typical medium scale surface coal mine having drilling and blasting practices for the breaking of the ground and truck and shovel practices for the handling of the material. The information about the mining project is realistic and is based on the researcher's professional experience.

5.2.1 Project details

1. The life of the project is for 81 months. This is based on the mine planning, design, and scheduling
2. The host rock is sandstone and shale
3. The first three months is allocated to the development phase where initial box-cut, ramp development and opening of bench is done
4. Table 5-1 represents the summary of the production schedule for mine

Table 5-1 Production schedule summary

Description	Unit	Month-1	Month-2	Month-3	Month-4 onwards
Total waste excavation	m^3	300 000	350 000	370 000	350 000
Total ROM coal	tonnes	0	29 063	40 000	75 000
Stripping ratio	m^3: tonnes			9.25	4.67
TOTAL VOLUME	m^3	300 000	368 750	395 000	398 387

5.2.2 Review of the Production schedule

Table 5-2 shows the review of the production schedule to get orientation for the annual and monthly production requirements of the mine. This is done to select the equipment and manpower to meet the annual and monthly targets.

Table 5-2 Review of the production schedule

Material	Unit	Annual production	Monthly production
Topsoil	m^3	136 596	11 383
Softs	m^3	1 017 509	84 792
Hards	m^3	1 036 998	86 416
B-Seam Coal (SG = 1,66)	tonnes	441 419	36 785
CU Waste	m^3	1 589 298	132 442
CU-Seam Coal (SG = 1,55)	tonnes	259 823	21 652
CL Waste	m^3	391 236	32 603
CL-Seam Coal (SG = 1,43)	tonnes	198 833	16 569
Total waste excavation	m^3	4 171 637	347 636
Total ROM coal	tonnes	900 076	75 006
Stripping ratio	m^3: tonnes	4.63	4.63
TOTAL VOLUME	m^3	4 744 224	395 352

5.2.3 Stratigraphy of the mine

Table 5-3 shows the lithology of the mine to know the nature of deposition of the rock. This is considered to establish the productivity of the equipment for different layers and the requirements for drilling and blasting. As softs strata do not require drilling and blasting and in general productivity of excavators is higher for softer strata.

Table 5-3 Stratigraphy of the mine

Material	Average thickness (m)
Topsoil	1.0
Softs	7.5
Hards	7.6
B-Seam Coal (SG = 1,66)	1.9
CU Waste	11.6
CU-Seam Coal (SG = 1,55)	1.4
CL Waste	2.9
CL-Seam Coal (SG = 1,43)	1.1
Total depth	35.0

5.2.4 Labour rate

Working hours in a month is assumed to be 200 hrs for monthly wage calculation. Table 5-4 shows labour wage rate assumed in the operating cost estimation model.

Table 5-4 Labour wage rate

Item No.	Category	Unit	Normal	Reference
1	Excavator operator	ZAR/Hr	115.69	SA labour rates
2	ADT operator	ZAR/Hr	91.67	SA labour rates
3	Drill operator	ZAR/Hr	115.69	SA labour rates
4	Dozer operator	ZAR/Hr	102.48	SA labour rates
5	Grader operator	ZAR/Hr	102.17	SA labour rates
6	Water Bowser operator	ZAR/Hr	91.67	SA labour rates
7	Fuel Truck operator	ZAR/Hr	91.67	SA labour rates
8	Master operator	ZAR/Hr	128.29	SA labour rates
9	Control room operator	ZAR/Hr	82.36	SA labour rates
10	General worker	ZAR/Hr	77.97	SA labour rates
11	Cleaner	ZAR/Hr	76.45	SA labour rates
12	Pump attendants	ZAR/Hr	79.82	SA labour rates
13	Drill assistants	ZAR/Hr	79.82	SA labour rates
14	Blasting assistants	ZAR/Hr	82.36	SA labour rates

5.2.5 Fuel Consumption rates per machines

The fuel consumption rates have been assumed referring to the OEM specifications. Table 5-5 provides the fuel consumption rates for mine equipment assumed in the operating cost estimation model.

Table 5-5 Fuel consumption rates for mine equipment

Item no	Equipment	Unit	Diesel usage	Reference
1	Excavator-85t-90 t (5 m^3 bucket)	Litre/Hr	60	OEM Manual
2	Drill machine-Atlas Copco D65	Litre/Hr	55	OEM Manual
3	Articulated dump truck-40 t (24 m^3)	Litre/Hr	25	OEM Manual
4	Hydraulic excavator-30 t (1,69 m^3 bucket)	Litre/Hr	23	OEM Manual
5	Tracked dozer-51 t (blade 14,6 m^3)	Litre/Hr	55	OEM Manual
6	Tracked dozer-28 t (blade 6,86 m^3)	Litre/Hr	28	OEM Manual
7	Grader-15 t/146 kw (blade 3710 mm)	Litre/Hr	18	OEM Manual
8	Fuel truck 18 KL	Litre/Hr	12	OEM Manual
9	Water bowser	Litre/Hr	12	OEM Manual

5.2.6 Working Roster

The working roster in every mine differs depending upon production volumes and working conditions. From the working roster, the effective operating hours of equipment are estimated. Table 5-6 provides the break-up of the working roster for the example mine.

Table 5-6 Working roster for the mine

Description	*value*	unit
Working Days in Years	365	days
Public Holidays	4	days
Rain Days	24	days
Planned Workdays	337	days
Availability	90%	%
Utilization	90%	%
Effective Utilisation	81%	%
No. Of Shifts Per Day	2	
Shift Hours	10	hours
Work Hrs. in Day	20	hours
Effective Work Hr. in Day	16.2	hours

Description	*value*	unit
Work Hrs. in Year	5459	hours
Months in Year	12	
Work Hrs. per Month	455	hours

5.2.7 Equipment and operators required to operate the mine

Based on the production requirement and considering the working roster; the equipment fleet and the required number of operators are estimated. Table 5-7 provides the required equipment fleet and number of operators to operate the mine.

Table 5-7 Required equipment fleet and number of operators

Item no	Equipment	Fleet required	Operators required per shift	No of Operators for 3 shifts	Operator's wages per month (ZAR)
1	Excavator-85t-90 t (5 m^3 bucket)	4	4	12	277 656
2	Drill machine-Atlas Copco D65	2	2	6	138 828
3	Drill machine-Atlas Copco D65- Assistant	2	2	6	95 784
4	Articulated dump truck-40 t (24 m^3)	14	14	42	770 028
5	Hydraulic excavator-30 t (1,69 m^3 bucket)	1	1	3	69 414
6	Tracked dozer-51 t (blade 14,6 m^3)	2	2	6	122 976
7	Tracked dozer-38 t (blade 6,86 m3)	1	1	3	61 488
8	Grader-15 t/146 kw (blade 3710 mm)	1	1	3	61 302
9	Fuel truck 18 KL	1	1	3	55 002
10	Water bowser	2	2	6	110 004
	Total	30	30	90	

5.3 Estimation of drilling cost

The drill hole diameter is the most fundamental input in this cost model. Based upon drill hole diameter the other drilling parameters are derived. Also, the purchase price, interest rate, and insurance rates are the basic input parameters for the model. In addition to this, the life cycle costing approach is considered to find out the maintenance cost of the drill machine. For simplicity purposes, life cycle maintenance cost was considered as the percentage of the purchase price. Table 5-8 represents the Excel cost model for estimating drilling cost.

Table 5-8 Excel cost model for estimating drilling cost

Description	Symbol	Unit	Value	Reference
Quantity of drilling required per month	*Qd*	meter	15572	$Q_d = \frac{V_w\ X\ (1+U)}{B_w\ X\ S_w} + \frac{T_c}{B_c\ X\ S_c\ X\ SG_c}$
Diameter of blast holes	*D*	mm	140	selection of drill machine
Volume of waste rock required to be blasted per month	*Vw*	m^3	251461	from mine schedule
Burden distance of holes for waste rock	*Bw*	meter	3.9	B = 20 D to 40 D
Spacing distance of holes for waste rock	*Sw*	meter	4.5	S= 1,0-1,2 B
% of sub-drilling	*U*	%	0	No sub-drilling as waste is lying above the coal
Tons of coal required to be blasted per month	*Tc*	tonnes	75006	from mine schedule
Burden distance of holes for coal	*Bc*	meter	5.6	B = 20 D to 40 D
Spacing of holes for coal	*Sc*	meter	6.4	S= 1,0-1,2 B
Relative density of coal	*SGc*		1.55	geology data
Number of drill machines required	*Nd*		2	
Drilling rate	*Dr*	meter/Hour	30	
Effective hours per month available for drilling	*He*	hour	280	(He =Available utilized hours - manoeuvring hours)
Purchase price of equipment	PP_D	ZAR	9000000	(Refer to quotes from OEM)

Description	Symbol	Unit	Value	Reference
Interest rate per annum	INT_D	%	12.50%	As per financial institution offer
Interest rate per month	$INT_D/12$	%	1.04%	Interest rate per month = Interest rate per annum /12
Insurance rate per annum	INS_D	%	0.4	As per the offer from an insurance company
Overhead cost	OH_D	%	6%	Industry norms 4 % to 8%
Expected residual %	RV_D	%	10	expected as per industry trend
Machine life in hours	LIF_D	Hours	18000	As per OEM
Machine operating life in hours	$OLIF_D$	Hours	18000	As per mining schedule
Minimum operating hours	$MINH_D$	Hours	350	from the mining schedule and roster
Operating period in months	$OPRP_D$	Months	51	(Machine life/Minimum operating hours per month)
Expected residual value (10%)	RV_D	ZAR	900000	
Cost of crawlers on drill	$COSTT_D$	ZAR	390000	(As per OEM price)
Life of crawlers	$LIFT_D$	Hours	4000	(As per OEM specification)
Cost of consumables	$COSTC_D$	ZAR	133189	
Life of consumables	$LIFC_D$	Hours	1200	
Maintenance cost	$MAINC_D$	ZAR	8100000	Life cycle costing approach (90 % of PP)
Fuel consumption of machine	$FCON_D$	Litre/Hour	55	(as per machine specifications)
Price of fuel	POF	ZAR/Litre	16.5	(Market price for fuel)
Overhead cost for life of machine	OH_D	ZAR	540000	Industry norms 4 % to 8%
PMT/EMI paid per month	PMT_D	ZAR	213611	
Interest paid over the full period	IFP_D	ZAR	1985710	(PMT x No of periods)-Purchase price
Depreciation over the machine life	DFP_D	ZAR	8100000	(Purchase price- Residual value)
On a straight line, depreciation per month	DP_D	ZAR	157500	(Depreciation over the machine life /Life of machine in months)

Description	Symbol	Unit	Value	Reference
Interest per month	IP_D	ZAR	38611	(Interest paid over full period/Life of machine in months)
Insurance per month	SP_D	ZAR	3000	(Insurance paid over full period/Life of machine in months)
Total overhead per month	RP_D	ZAR	10500	(Overhead cost /Life of machine in months)
Maintenance cost per month	MP_D	ZAR	157500	(Maintenance cost /Life of machine in months)
Track cost per month	TP_D	ZAR	34125	(Cost of tracks x Minimum hours per month/Life of Tyres in hours)
Consumables cost per month	CP_D	ZAR	31077	(Cost of tracks x Minimum hours per month/Life of Tyres in hours)
Operator cost per month	OP_D	ZAR	234612	(No of operators required per month x operator's salary)
Owning cost per month	FC_D	ZAR	209611	(Depreciation + Interest+ Insurance + Overhead)
Operating cost per month	OC_D	ZAR	191625	(maintenance cost + track cost + consumables cost+ operator's cost)
Depreciation per hour	DPH_D	ZAR	450.0	(Depreciation per month/ minimum hours)
Cost of Interest per hour	IPH_D	ZAR	110.3	(Interest per month/ minimum hours)
Cost of Insurance per hour	SPH_D	ZAR	8.6	(Insurance per month/ minimum hours)
Cost of overhead per hour	RPH_D	ZAR	30.00	(Overhead cost per month/ minimum hours)
Maintenance cost per hour	MPH_D	ZAR	450.00	(Maintenance cost per month/ minimum hours)
Track cost per hour	TPH_D	ZAR	97.50	(Track cost / Track life in hours)
Consumables cost per hour	CPH_D	ZAR	110.99	(Consumables cost / Consumable life in hours)
Operator's cost per hour	OPH_D	ZAR	361.60	(Operator's cost per month / minimum hours per machine x no of machines)
Fuel cost per hour	FPH_D	ZAR	907.50	(Fuel consumption per hour x fuel price)

Description	Symbol	Unit	Value	Reference
Owning cost per hour	FCH_D	ZAR	598.89	(Depreciation + Interest+ Insurance + Overhead)
Operating cost per hour excluding fuel	OCH_D	ZAR	1020.09	(maintenance cost + track cost+ consumables cost + operator's cost)
Operating cost per hour including fuel	$OCHIF_D$	ZAR	1927.59	(maintenance cost + track cost + consumables cost + operator's cost + fuel cost)
Owning cost per m	OWN_D	ZAR	19.96	(Owning cost per hour/drilling rate per hour)
Operating cost per m excluding fuel	OPC_D	ZAR	34.00	(Operating cost per hour/drilling rate per hour)
Operating cost per m including fuel	$OPCIF_D$	ZAR	64.25	(Operating cost per hour including fuel/drilling rate per hour)
Owning cost per m^3	OWN_{D1}	*ZAR*	*1.13*	*(Owning cost per meter /material produced per meter)*
Operating cost per m^3 excluding fuel	OPC_{D1}	*ZAR*	*1.92*	*(Operating cost per meter /material produced per meter)*
Operating cost per m^3 including fuel	$OPCIF_{D1}$	*ZAR*	*3.64*	*(Operating cost per m including fuel/material produced per meter)*
Owning and operating cost including fuel		*ZAR*	*4.77*	

5.4 Estimation of blasting cost

The drill hole diameter and bench height are the most fundamental input in this cost model. Based upon drill hole diameter the other blast parameters are derived. Also, the explosive price, accessory price interest rate and monthly fixed cost for blasting are the basic input parameters for the model. Table 5-9 represents the Excel cost model for estimating blasting cost.

Table 5-9 Excel cost model for estimating blasting cost

Description	Symbol	Unit	Value	Reference
Hole diameter	*D*	mm	140	selected as per bench height and rock characteristics

Description	Symbol	Unit	Value	Reference
Bench height	*H*	m	12	from mine planning and design
Bench width	*BW*	m	40	from mine planning and blast design
Bench length	*BL*	m	100	Blast design
Burden	*B*	m	3.9	*B = 20 D to 40 D*
Spacing	*S*	m	4.5	*S= 1,0-1,2 B*
Sub-grad drilling	*U*	m	0	no sub-grad drilling in coal benches
Hole Length	*H1*	m	12	*H1= H + U*
Stemming material				Aggregates of approx. sizes of 10 % of hole diameter
Stemming length	*T*	m	2.7	$T \approx 0{,}7\ B\ to\ 1{,}1\ B$
Explosives column length	*L*	m	9.3	
Explosive density	*ED*	gm/cc	1.1	Obtained from explosive supplier for HEF 100 explosive
No of holes per blast	N_h		226	$N_h = (BW\ X\ BL)/\ (B\ X\ S)$
Volume of material blasted per hole	*BCM*	m^3	212	*BCM = B x S x H*
Explosive required per hole	*Qe*	kg	157	$Qe = \frac{\pi\ D2\ X\ (H+S-T) X\ ED}{4000}$
Powder factor	*PDF*	kg/m^3	0.74	
Stemming material required per hole	*Qs*	m^3	0.04	$Qs = \frac{\pi\ D^2 T}{4\ X\ 10^6}$
Accessories consumption				considering shock tube initiation system
Number of cast booster required per hole	N_b	No.	1	
Number of DTH units required per hole	N_d	No.	1	Length of trunk line should be of 3m extra than spacing for proper blast connection

Description	Symbol	Unit	Value	Reference
Number of Trunk lines required per hole	N_t	No.	2	Length of trunk line should be of 3m extra than spacing for proper blast connection
Number of leading lines required per blast	N_l	No.	2	500 m length
Price of explosives	P_e	ZAR/ kg	7.77	From explosive supplier HEF 100
Price of cast boosters	P_b	ZAR per unit	51.01	From explosive supplier 400 gm cast booster
Price of DTH units	P_d	ZAR per unit	64.88	From explosive supplier 15 m down the hole
Price of TLD unit	P_t	ZAR per unit	45.45	From explosive supplier 8,4 m TLD
Price of lead lines	P_l	ZAR per unit	1431.11	From explosive supplier 500 m in length
Price of aggregate	P_s	ZAR per m^3	580	Quotes taken from aggregate supplier
Explosive cost	Xc	ZAR per m^3	5.74	Explosive cost (X_c) = PDF × Explosive price
Accessory cost	Ac	ZAR per m^3	1.03	*Accessory cost* $= [N_b \times P_b + N_d \times P_d + N_t \times P_t + (N_l \times P_l)/N_h]/BCM$
Monthly service charges	Mc	ZAR per m^3	0.33	Refer table 4-3
Stemming	Sc	ZAR per m^3	0.12	$Sc = (Qs \times Ps)/V$
Total blast cost per m3	Bc	*ZAR per m^3*	*7.22*	$(Bc = Xc + Ac + Mc + Sc)$

5.5 Estimation of loading cost

The bucket capacity of the loading machine and material characteristics (swell factor and bucket fill factor derived based on this) are the most fundamental input in this cost model. Based upon the bucket capacity and material characteristics; the productivity of loading machine is calculated. Also, the purchase price, interest rate, and insurance rates are the basic input parameters for the model. In addition to this, the life cycle costing approach is considered to find out the maintenance cost of the loading machine. For simplicity purposes, life cycle maintenance cost was considered as the percentage of the purchase price. Table 5-10 represents the Excel cost model for estimating loading cost.

Table 5-10 Excel cost model for estimating loading cost

Description	Symbol	Unit	Value	Reference
Loader Hourly Production	Q_l	m^3/hr	224.64	$Q_l = \frac{B_c\ X\ F_f\ X\ E_l\ \ X\ 3600}{C_l\ X\ f}$
Bucket capacity of the loading machine	B_c	m^3	4.5	Equipment Suppliers Manual
Bucket fill factor of the loading	F_f		0.8	Refer to Table 4-4
Job Efficiency	E_l		0.65	Refer to Table 4-5
Cycle time of loading machine	C_l	sec	25	Refer table 4-6
Conversion factor	*f*		1.5	Refer table 4-7
Purchase price of equipment	PP_L	ZAR	8 700 000	(Refer to quotes from OEM)
Interest rate per annum	INT_L	%	12.50%	As per financial institution offer
Interest rate per month	$INT_L/12$	%	1.04%	Interest rate per month = Interest rate per annum /12
Insurance rate per annum	INS_L	%	0.4	As per the offer from an insurance company
Overhead cost	OH_L	%	6%	Industry norms 4 % to 8%
Expected residual %	RV_L	%	10	expected as per industry trend
Machine life in hours	LIF_L	Hours	18 000	As per OEM
Machine operating life in hours	$OLIF_L$	Hours	18 000	As per mining schedule
Minimum operating hours	$MINH_L$	Hours	455	from the mining schedule and roster
Operating period in months	$OPRP_L$	Months	40	(Machine life/Minimum operating hours per month)
Expected residual value (10%)	RV_D	ZAR	870 000	10% of Purchase price of equipment
Cost of a set of tracks/undercarriage	$COSTT_L$	ZAR	750 000	(As per OEM price)

Description	Symbol	Unit	Value	Reference
Life of tracks/undercarriage	$LIFT_L$	Hours	6 000	(As per OEM specification)
Maintenance cost	$MAINC_L$	ZAR	7 830 000	Life cycle costing approach (90 % of PP) maybe 100% as well as
Fuel consumption of machine	$FCON_L$	Litre/Hour	60	(as per machine specifications)
Price of fuel	POF	ZAR/Litre	16.5	(Market price for fuel)
Overhead cost for life of machine	OH_L	ZAR	522 000	Industry norms 4 % to 8%
PMT/EMI paid per month	PMT_L	ZAR	251 576	
Interest paid over the full period	IFP_L	ZAR	1 252 476	(PMT x No of periods)- Purchase price
Depreciation over the machine life	DFP_L	ZAR	7 830 000	(Purchase price-Residual value)
On a straight line, depreciation per month	DP_L	ZAR	197 925	(Depreciation over the machine life /Life of machine in months)
Interest per month	IP_L	ZAR	31 660	(Interest paid over full period/Life of machine in months)
Insurance per month	SP_L	ZAR	2 900	(Insurance paid over full period/Life of machine in months)
Total overhead per month	RP_L	ZAR	13 195	(Overhead cost /Life of machine in months)
Maintenance cost per month	MP_L	ZAR	197 925	(Maintenance cost /Life of machine in months)
Track cost per month	TP_L	ZAR	56 875	(Cost of Tyres x Minimum hours per month/Life of Tyres in hours)
Operator cost per month per machine	OP_L	ZAR	69 414	(No of operators required per month x operator's salary)/no of machines
Owning cost per month	FC_L	ZAR	245 680	(Depreciation + Interest+ Insurance + Overhead)

Description	Symbol	Unit	Value	Reference
Operating cost per month	*OC_L*	ZAR	324 214	(maintenance cost + track cost + operator's cost)
Depreciation per hour	*DPH_L*	ZAR	435.0	(Depreciation per month/ minimum hours)
Cost of Interest per hour	*IPH_L*	ZAR	69.6	(Interest per month/ minimum hours)
Cost of Insurance per hour	*SPH_L*	ZAR	6.4	(Insurance per month/ minimum hours)
Cost of overhead per hour	*RPH_L*	ZAR	29.00	(Overhead cost per month/ minimum hours)
Maintenance cost per hour	*MPH_L*	ZAR	435.00	(Maintenance cost per month/ minimum hours)
Tyre cost per hour	*TPH_L*	ZAR	125.00	(Tyre cost / Tyre life in hours)
Operator's cost per hour	*OPH_L*	ZAR	152.56	(Operator's cost per month per machine / minimum hours)
Fuel cost per hour	*FPH_L*	ZAR	990.00	(Fuel consumption per hour x fuel price)
Owning cost per hour	*FCH_L*	ZAR	539.96	(Depreciation +Interest + Insurance +Overhead)
Operating cost per hour excluding fuel	*OCH_L*	ZAR	712.56	(maintenance cost + track cost+ operator's cost)
Operating cost per hour including fuel	*$OCHIF_L$*	ZAR	1702.56	(maintenance cost + track cost + operator's cost + fuel cost)
Owning cost per m^3	*OWN_L*	*ZAR*	*2.40*	*(Owning cost per hour/loader hourly production)*
Operating cost per m^3 excluding fuel	*OPC_L*	*ZAR*	*3.17*	*(Operating cost per hour/loader hourly production)*
Operating cost per m^3 including fuel	*$OPCIF_L$*	*ZAR*	*7.58*	*(Operating cost per hour including fuel/loader hourly production)*

Description	Symbol	Unit	Value	Reference
Owning and operating cost including fuel		*ZAR*	*9.98*	

5.6 Estimation of hauling cost

The productivity of the truck is directly linked to the productivity of the loading machine, lead distance and gradient of topography on which mine truck is travelling. The bin capacity of the mine truck and haul distance are the most fundamental input in this cost model. Based upon the productivity of loading machine, bin capacity of truck and lead distance; the productivity of hauling machine is calculated. Also, the purchase price, interest rate, and insurance rates are the basic input parameters for the model. In addition to this, the life cycle costing approach is considered to find out the maintenance cost of the hauling machine. For simplicity purposes, life cycle maintenance cost was considered as the percentage of the purchase price. Table 5-11 represents the Excel cost model for estimating hauling cost.

Table 5-11 Excel cost model for estimating hauling cost

Description	Symbol	Unit	Value	Reference
Dump truck hourly Production	Q_t	m^3/hr	88	$Q_t = \frac{N\ X\ B_c\ X\ F_f\ X\ E_t\ X\ 60}{C_t\ X\ f}$
Number of cycles required to fill dump truck	N		7	N = $B_d/(B_f \times B_c)$
Bucket capacity of the loading machine	B_c	m^3	4.5	Equipment Suppliers Manual
Rated bin capacity of mine truck	B_d	m^3	24	Equipment Suppliers Manual
Bucket fill factor of the loading machine	F_f		0.8	Refer table 4-4
Job Efficiency of truck	E_t	%	0.65	Refer table 4-8
Cycle time of dump truck	C_t	min	8.2	$C_t = N\ X\ C_l + \frac{D}{V_1} + T_1 + \frac{D}{V_2} + T_2$
Conversion factor	f		1.3	Refer table 4-7
Cycle time of loader	C_l	sec	25	Refer table 4-6
Hauling distance of mine truck (m)	D	meter	600	from mine plan
Average speed of a loaded truck	V_1	m/min	300	Refer table 4-9 & equation 4-20

Description	Symbol	Unit	Value	Reference
Average speed of empty truck	V_2	m/min	350	Refer table 4-9 & equation20
Time required for dumping	T_1	min	1.2	Refer table 4-10
Time required for the truck to be positioned	T_2	min	0.35	Refer table 4-11
Purchase price of equipment	PP_H	ZAR	7 800 000	(Refer to quotes from OEM)
Interest rate per annum	INT_H	%	12.50%	As per financial institution offer
Interest rate per month	$INT_H/12$	%	1.04%	Interest rate per month = Interest rate per annum /12
Insurance rate per annum	INS_H	%	0.4	As per the offer from an insurance company
Overhead cost	OH_H	%	6%	Industry norms 4 % to 8%
Expected residual %	RV_H	%	10	expected as per industry trend
Machine life in hours	LIF_H	Hours	25 000	As per OEM
Machine operating life in hours	$OLIF_H$	Hours	25 000	As per mining schedule
Minimum operating hours	$MINH_H$	Hours	400	from the mining schedule and roster
Operating period in months	$OPRP_H$	Months	62.5	(Machine life/Minimum operating hours per month)
Expected residual value (10%)	RV_H	ZAR	780000	
Cost of a set of Tyres/tracks/undercarriage	$COSTT_L$	ZAR	560 000	(As per OEM price)
Life of tyres/tracks/undercarriage	$LIFT_H$	Hours	6 000	(As per OEM specification)
Maintenance cost	$MAINC_H$	ZAR	7 800 000	Life cycle costing approach (90 % of PP)
Fuel consumption of machine	$FCON_H$	Litre/ Hour	25	(as per machine specifications)
Price of fuel	POF	ZAR/ Litre	16.5	(Market price for fuel)
Overhead cost for life of machine	OH_H	ZAR	46 8000	(Industry norms 4 % to 8%)
PMT/EMI paid per month	PMT_H	ZAR	161 511	
Interest paid over the full period	IFP_H	ZAR	2 294 433	(PMT x No of periods)- Purchase price

Description	Symbol	Unit	Value	Reference
Depreciation over the machine life	DFP_H	ZAR	7 020 000	(Purchase price-Residual value)
On a straight line, depreciation per month	DP_H	ZAR	112 320	(Depreciation over the machine life /Life of machine in months)
Interest per month	IP_H	ZAR	36 711	(Interest paid over full period/Life of machine in months)
Insurance per month	SP_H	ZAR	2 600	(Insurance paid over full period/Life of machine in months)
Total overhead per month	RP_H	ZAR	7 488	(Overhead cost /Life of machine in months)
Maintenance cost per month	MP_H	ZAR	124 800	(Maintenance cost /Life of machine in months)
Tire cost per month	TP_H	ZAR	37 333	(Cost of Tyres x Minimum hours per month/Life of Tyres in hours)
Operator cost per month per machine	OP_H	ZAR	55 002	(No of operators required per month x operator's salary)/no of machines
Owning cost per month	FC_H	ZAR	159 119	(Depreciation +Interest + Insurance+ Overhead)
Operating cost per month	OC_H	ZAR	217 135	(maintenance cost + tyre cost + operator's cost)
Depreciation per hour	DPH_H	ZAR	280.8	(Depreciation per month/ minimum hours)
Cost of Interest per hour	IPH_H	ZAR	91.8	(Interest per month/ minimum hours)
Cost of Insurance per hour	SPH_H	ZAR	6.5	(Insurance per month/ minimum hours)
Cost of overhead per hour	RPH_H	ZAR	18.72	(Overhead cost per month/ minimum hours)
Maintenance cost per hour	MPH_H	ZAR	312.00	(Maintenance cost per month/ minimum hours)
Tire cost per hour	TPH_H	ZAR	93.33	(Tyre cost / Tyre life in hours)

Description	Symbol	Unit	Value	Reference
Operator's cost per hour	*OPH_H*	ZAR	137.51	(Operator's cost per month per machine / minimum hours)
Fuel cost per hour	*FPH_H*	ZAR	412.50	(Fuel consumption per hour x fuel price)
Owning cost per hour	*FCH_H*	ZAR	397.80	(Depreciation + Interest+ Insurance+ Overhead)
Operating cost per hour excluding fuel	*OCH_H*	ZAR	542.84	(maintenance cost + tyre cost+ operator's cost)
Operating cost per hour including fuel	*$OCHIF_H$*	ZAR	955.34	(maintenance cost + tyre cost + operator's cost + fuel cost)
Owning cost per m^3	*OWN_H*	*ZAR*	*4.52*	
Operating cost per m^3 excluding fuel	*OPC_H*	*ZAR*	*6.17*	
Operating cost per m^3 including fuel	*$OPCIF_H$*	*ZAR*	*10.85*	
Owning and operating cost including fuel			*15.37*	

5.7 Estimation of ancillary Cost

5.7.1 Ancillary Cost- Dozer

The productivity of the dozer is dependent upon the blade capacity, material characteristics, push distance and gradient of topography on which dozer is working (Caterpillar, 2015). The blade capacity of the dozer and push distance is the most fundamental input in this cost model and based upon this productivity of dozer calculated (Caterpillar, 2015). Also, the purchase price, interest rate, and insurance rates are the basic input parameters for the model. In addition to this, the life cycle costing approach is considered to find out the maintenance cost of the dozer. For simplicity purposes, life cycle maintenance cost was considered as the percentage of the purchase price. Table 5-12 represents the Excel cost model for estimating dozing cost.

Table 5-12 Excel cost model for estimating dozing cost

Description	Symbol	Unit	Value	Reference
Dozer Hourly Output	*Qd*	BCM /hr	247	$Q_d = \frac{q \ X \ a \ X \ 60 \ X \ e \ X \ E_d}{C_d \ X \ f}$
Blade capacity of the dozer	*q*	m^3	9.34	Equipment Suppliers Manual
Blade fill factor of the dozer	*a*		0.6	Refer table 4-12
Job Efficiency	E_d		0.75	Refer table 4-13
Grade factor	*e*		0.9	Refer figure 4-5
Cycle time of dozer	C_d	min	0.575	*Cd = D/F + D/R +Z*
Conversion factor	*f*		1.6	Refer table 4-7
Push distance	D_d	m	15	Assumed for pushing in the waste dump
Forward speed of dozer	*F*	m/min	66.7	speed range of 3-5 km/h for forward
Backward speed of dozer	*B*	m/min	100	speed range of 5-7 km/h for forward
Time required for gear shifting	*Z*	min	0.2	
Purchase price of equipment	*PPz*	ZAR	6 600 000	(Refer to quotes from OEM)
Interest rate per annum	*INTz*	%	12.50%	As per financial institution offer
Interest rate per month	*INTz*/12	%	1.04%	Interest rate per month = Interest rate per annum /12
Insurance rate per annum	*INSz*	%	0.4	As per the offer from an insurance company
Overhead cost	*OHz*	%	6%	Industry norms 4 % to 8%
Expected residual %	*RVz*	%	10	expected as per industry trend
Machine life in hours	*LIFz*	Hours	18 000	As per OEM
Machine operating life in hours	*OLIFz*	Hours	18 000	As per mining schedule
Minimum operating hours	*MINHz*	Hours	350	from the mining schedule and roster
Operating period in months	*OPRPz*	Months	51.43	(Machine life/Minimum operating hours per month)
Expected residual value (10%)	*RVz*	ZAR	660 000	
Cost of a set of tracks/undercarriage	*COSTTz*	ZAR	700 000	(As per OEM price)

Description	Symbol	Unit	Value	Reference
Life of tracks/undercarriage	*LIFTz*	Hours	8 000	(As per OEM specification)
Maintenance cost	*MAINCz*	ZAR	5 940 000	Life cycle costing approach (90 % of PP)
Fuel consumption of machine	*FCONz*	Litre/Hour	35	(as per machine specifications)
Price of fuel	*POF*	ZAR/Litre	16.5	(Market price for fuel)
Overhead cost for life of machine	*OHz*	ZAR	396 000	Industry norms 4 % to 8%
PMT/EMI paid per month	*PMTz*	ZAR	156 648	
Interest paid over the full period	*IFPz*	ZAR	1 456 188	(PMT x No of periods)- Purchase price
Depreciation over the machine life	*DFPz*	ZAR	5 940 000	(Purchase price- Residual value)
On a straight line, depreciation per month	*DPz*	ZAR	115 500	(Depreciation over the machine life /Life of machine in months)
Interest per month	*IPz*	ZAR	28 315	(Interest paid over full period/Life of machine in months)
Insurance per month	*SPz*	ZAR	2 200	(Insurance paid over full period/Life of machine in months)
Total overhead per month	RPz	ZAR	7 700	(Overhead cost /Life of machine in months)
Maintenance cost per month	*MPz*	ZAR	115 500	(Maintenance cost /Life of machine in months)
Track cost per month	*TPz*	ZAR	30 625	(Cost of Tyres x Minimum hours per month/Life of Tyres in hours)
Operator cost per month per machine	OPz	ZAR	61 488	(No of operators required per month x operator's salary)/no of machines
Total owning cost per month	*FCz*	ZAR	153 715	(Depreciation + Interest+ Insurance + Overhead)
Total operating cost per month	*OCz*	ZAR	146 125	(maintenance cost + track cost + operator's cost)
Depreciation per hour	*DPHz*	ZAR	330.0	(Depreciation per month/ minimum hours)
Cost of Interest per hour	*IPHz*	ZAR	80.9	(Interest per month/ minimum hours)

Description	Symbol	Unit	Value	Reference
Cost of Insurance per hour	*SPHz*	ZAR	6.3	(Insurance per month/ minimum hours)
Cost of overhead per hour	*RPHz*	ZAR	22.00	(Overhead cost per month/ minimum hours)
Maintenance cost per hour	*MPHz*	ZAR	330.00	(Maintenance cost per month/ minimum hours)
Track cost per hour	*TPHz*	ZAR	87.50	(Track cost / Crawler life in hours)
Operator's cost per hour	*OPHz*	ZAR	175.68	(Operator's cost per month / minimum hours)
Fuel cost per hour	*FPHz*	ZAR	577.50	(Fuel consumption per hour x fuel price)
Owning cost per hour	*FCHz*	ZAR	439.19	(Depreciation + Interest+ Insurance + Overhead)
Operating cost per hour excluding fuel	*OCHz*	ZAR	417.50	(maintenance cost + track cost+ operator's cost)
Operating cost per hour including fuel	*OCHIFz*	ZAR	995.00	(maintenance cost + track cost + operator's cost + fuel cost)
Owning cost per m^3	*OWNz*	*ZAR*	*1.78*	*(Owning cost per hour/dozer hourly production)*
Operating cost per m^3 excluding fuel	*OPCz*	*ZAR*	*1.69*	*(Operating cost per hour/dozer hourly production)*
Operating cost per m^3 including fuel	*OPCIFz*	*ZAR*	*4.03*	*(Operating cost per hour including fuel/dozer hourly production)*
Owning and operating cost including fuel		*ZAR*	*5.81*	

5.7.2 Ancillary Cost- Grader

The blade capacity of the grader and the working area (primarily haul road) are the most fundamental input in this cost model and based upon this productivity of grader calculated. Also, the purchase price, interest rate, and insurance rates are the basic input parameters for the model. In addition to this, the life cycle costing approach is considered to find out the maintenance cost of the dozer. For simplicity purposes, life cycle maintenance cost was considered as the percentage of the purchase price. Table 5-13 represents the Excel cost model for estimating grading cost.

Table 5-13 Excel cost model for estimating grading cost

Description	Symbol	Unit	Value	Reference
Grader hourly operating area	Q_a	m^2 /hr	16 320	$Qa = V\ X\ (Le - Lo)\ X\ 1000\ X\ E_g$
Working speed of grader	V	km/h	6	Refer table 4-14
Effective blade length	L_e	m	3.7	Refer table 4-15
Width of overlap	L_o	m	0.3	Usually overlap is 0,3 m
Job efficiency	E_g		0.8	Refer table 4-16
Time required for finishing an area	T	h	4.4	$T = \frac{N_g\ X\ D_g}{V\ X\ E_g}$
Number of trips	N_g		11	$N_g = \frac{W}{Le - Lo}\ X\ n$
Total width to be levelled	W	m	18	consider 18 m haul road width
No of trips to do to finish the required flatness	n		2.0	
Working linear distance	D_g	km	2.0	For road grading, it may be road length
Average monthly production of mine		m^3	395 352	
Purchase price of equipment	PP_G	ZAR	3 250 000	(Refer to quotes from OEM)
Interest rate per annum	INT_G	%	12.50%	As per financial institution offer
Interest rate per month	$INT_G/12$	%	1.04%	Interest rate per month = Interest rate per annum /12
Insurance rate per annum	INS_G	%	0.4	As per the offer from an insurance company
Overhead cost	OH_G	%	6%	Industry norms 4 % to 8%
Expected residual %	RV_G	%	10	expected as per industry trend
Machine life in hours	LIF_G	Hours	14 000	As per OEM
Machine operating life in hours	$OLIF_G$	Hours	14 000	As per mining schedule
Minimum operating hours	$MINH_G$	Hours	350	from the mining schedule and roster
Operating period in months	$OPRP_G$	Months	40.00	(Machine life/Minimum operating hours per month)

Description	Symbol	Unit	Value	Reference
Expected residual value (10%)	RV_G	ZAR	325 000	
Cost of a set of Tyres	$COSTT_G$	ZAR	240 000	(As per OEM price)
Life of tyres/tracks/undercarriage	$LIFT_G$	Hours	4 000	(As per OEM specification)
Maintenance cost	$MAINC_G$	ZAR	2 925 000	Life cycle costing approach (90 % of PP)
Fuel consumption of machine	$FCON_G$	Litre/Hour	18	(as per machine specifications)
Price of fuel	POF	ZAR/Litre	16.5	(Market price for fuel)
Overhead cost for life of machine	OH_G	ZAR	195 000	Industry norms 4 % to 8%
PMT/EMI paid per month	PMT_G	ZAR	93 174	
Interest paid over the full period	IFP_G	ZAR	476 978	(PMT x No of periods)- Purchase price
Depreciation over the machine life	DFP_G	ZAR	2 925 000	(Purchase price- Residual value)
On a straight line, depreciation per month	DP_G	ZAR	73 125	(Depreciation over the machine life /Life of machine in months)
Interest per month	IP_G	ZAR	11 924	(Interest paid over full period/Life of machine in months)
Insurance per month	SP_G	ZAR	1 083	(Insurance paid over full period/Life of machine in months)
Total overhead per month	RP_G	ZAR	4 875	(Overhead cost /Life of machine in months)
Maintenance cost per month	MP_G	ZAR	73 125	(Maintenance cost /Life of machine in months)
Track cost per month	TP_G	ZAR	21 000	(Cost of Tyres x Minimum hours per month/Life of Tyres in hours)
Operator cost per month	OP_G	ZAR	61 302	(No of operators required per month x operator's salary)/no of machines

Description	Symbol	Unit	Value	Reference
Owning cost per month	FC_G	ZAR	91 008	(Depreciation + Interest+ Insurance + Overhead)
Operating cost per month	OC_G	ZAR	155 427	(maintenance cost + track cost + operator's cost)
Operating cost per month including fuel	$OCIF_G$	ZAR	259 377	
Depreciation per hour	DPH_G	ZAR	208.9	(Depreciation per month/ minimum hours)
Cost of Interest per hour	IPH_G	ZAR	34.1	(Interest per month/ minimum hours)
Cost of Insurance per hour	SPH_G	ZAR	3.1	(Insurance per month/ minimum hours)
Cost of overhead per hour	RPH_G	ZAR	13.93	(Overhead cost per month/ minimum hours)
Maintenance cost per hour	MPH_G	ZAR	208.93	(Maintenance cost per month/ minimum hours)
Tire cost per hour	TPH_G	ZAR	60.00	(Tyre cost / Tyre life in hours)
Operator's cost per hour	OPH_G	ZAR	175.15	(Operator's cost per month / minimum hours)
Fuel cost per hour	FPH_G	ZAR	297.00	(Fuel consumption per hour x fuel price)
Owning cost per hour	FCH_G	ZAR	260.02	(Depreciation + Interest+ Insurance + Overhead)
Operating cost per hour excluding fuel	OCH_G	ZAR	444.08	(maintenance cost + track cost+ operator's cost)
Operating cost per hour including fuel	$OCHIF_G$	ZAR	741.08	(maintenance cost + track cost + operator's cost + fuel cost)
Owning cost per m^3	OWN_G	*ZAR*	*0.23*	*(Owning cost per month/Average production per month)*
Operating cost per m^3 excluding fuel	OPC_G	*ZAR*	*0.39*	*(Operating cost per month/Average*

Description	Symbol	Unit	Value	Reference
				production per month)
Operating cost per m^3 including fuel	*$OPCIF_G$*	*ZAR*	*0.66*	*(Operating cost per month including fuel/Average production per month)*
Owning and operating cost including fuel			*0.89*	

5.7.3 Ancillary Cost-Water tanker (18000 Litre)

For calculation of ancillary cost for a water tanker, the owning cost is directly assumed (as derived for mine truck) and minimum operating hours are assumed based on roster. Table 5-14 represents the cost estimating calculation for water tankers.

Table 5-14 Cost estimation calculation for water tankers

Description	Unit	Value	Reference
Considering the purchasing price of 6 500 000 and minimum operating hours of 250 hours per month; the owning cost per hour for water tanker using the same methodology used for mine truck is calculated. Owning cost per hour is ZAR 403.			
Average monthly production of mine	m3	395 352	
Owning cost per hour for water tanker	ZAR	403	
Minimum hours per month		250	
Fuel consumption per hour	Litre/Hour	16	
Price of fuel	ZAR/Litre	16.5	
Operator's cost per month	ZAR	110 004	
Fuel cost per month	ZAR	132 000	
No of water tanker required		2	
Owning cost per month for 2 water tankers		201 500	
Owning cost per m^3	*ZAR*	*0.51*	*(Owning cost per month/Average production per month)*
Operating cost per m^3 excluding fuel	*ZAR*	*0.28*	*(Operating cost per month/Average production per month)*

Operating cost per m^3 including fuel	*ZAR*	*0.61*	*(Operating cost per month including fuel/Average production per month)*

5.7.4 Ancillary Cost- Diesel browser (18000 Litre)

For calculation of ancillary cost for diesel bowser, the owning cost is directly assumed (as derived for mine truck) and minimum operating hours are considered based on working roster. Table 5-15 represents the cost estimating calculation for diesel bowser.

Table 5-15 Cost estimation calculation for diesel browser

Description	Unit	Value	Reference
Owning cost per hour for diesel bowser	ZAR	440	
Minimum hours per month		180	
Fuel consumption per hour	Litre/Hour	16	
Price of fuel	ZAR/Litre	16.5	
Operator's cost per month	ZAR	55 002	
Fuel cost per month	ZAR	95 040	
No of diesel bowser required		1	
Owning cost per month for diesel bowser		79 200	
Owning cost per m^3	*ZAR*	*0.20*	*(Owning cost per month/Average production per month)*
Operating cost per m^3 excluding fuel	*ZAR*	*0.14*	*(Operating cost per month/Average production per month)*
Operating cost per m^3 including fuel	*ZAR*	*0.38*	*(Operating cost per month including fuel/Average production per month)*

5.7.5 Ancillary Cost- Lighting

For calculation of lighting cost, the cost of hiring of lighting plant has been taken as the prime input cost in the cost model. Table 5-16 represents the cost estimating calculation for water tankers.

Table 5-16 Cost estimation for lighting cost

Description	Unit	Value	Reference
Number of lighting plant required	No.	8	(2 x Number of loading machines)
Cost of hiring of one lighting plant	ZAR	13 250	
Cost for hiring 8 lighting plants	ZAR	106 000	
Fuel consumption per hour per plant	Litre/Hour	0.5	
Average working per day	Hours	10	
Fuel consumption per day per plant	Litres	5	
Fuel consumption per day for 8 plants	Litres	40	
Fuel cost per month for all lighting plants	ZAR	16 500	
Operating cost for lighting plants excluding fuel	ZAR/m^3	0.27	(Operating cost per month/Average production per month)
Operating cost for lighting plants including fuel	ZAR/m^3	0.31	(Operating cost per month including fuel/Average production per month)

5.8 Estimation of management and technical services (MTS) cost

The management and technical services cost are dependent upon the size of operation and method of working. The personnel required to manage and operate the mine site is derived from the working roster. Typically, a mine requires operation manager to lead the project and production manager and drilling and blasting manager to head the production and drill & blast team respectively. A pit superintendent and a pit supervisor are required to run the shift operation of the mine. Table 5-17 represents the cost estimating calculation for management and technical services cost for the mine.

Table 5-17 Cost estimation for management and technical services cost

Description	Unit	Quantity	Rate	Net amount
Operation manager	Month	1	136 179	136 179
Production manager	Month	1	86 549	86 549
Drilling and blasting manager	Month	1	86 549	86 549
Geologist	Month	1	110 000	110 000
Strata control officer (part-time appointment)	Month	0.5	110 000	55 000
Mining engineer	Month	1	110 000	110 000
Pit Superintendent	Month	3	54 983	164 949
Shift Foreman	Month	3	43 658	130 974
Drilling Foreman	Month	3	43 658	130 974
Health & Safety officer	Month	1	62 556	62 556
Junior H&S	Month	1	33 622	33 622
Engineer Intern	Month	1	33 622	33 622
Training / QA	Month	1	18 799	18 799
Site clerk	Month	2	18 799	37 598
Mine surveyor	Month	1	65 000	65 000
Survey assistant	Month	1	16 492	16 492
Site Security	Month	5	25 000	12 5000
Cleaner	Month	1	12 166	12 166
Control room operator	Month	3	16 492	49 476
	TOTAL			1 465 505
Production per month	m^3		395 352	
MTS cost per unit	ZAR/m^3		3.71	

5.9 Chapter conclusion

This chapter presented the detail for estimating the operating costs for a mining project through the first-principles approach. This further validates the reliability of the developed framework and cost model for estimation of mining operating cost. The focus has been given to further develop the estimating operating cost model under six major headings and those were drilling cost, blasting cost, loading cost, hauling cost, ancillary cost, and management & technical services cost and as a result, the numeric value of operating cost (ZAR/m^3) under all six headings have been established. Table 5-18 reflects the summary of different operating mining costs resulted for the example mine.

Table 5-18 Summary of mining operating costs of the example mine

Descriptions	Unit	unit cost	%
Drilling Cost	ZAR/ m^3	4.77	9,7%
Blasting cost	ZAR/ m^3	7.22	14,7%
Loading cost	ZAR/ m^3	9.98	20,4%
Hauling cost	ZAR/ m^3	15.37	31,3%
Ancillary cost	ZAR/ m^3	8.00	16,3%
MTS cost	ZAR/ m^3	3.71	7,6%
Total cost	ZAR/ m^3	49.05	100,0%

Figure 5-1 represents the percentage distribution of different mining costs obtained for the example coal mine.

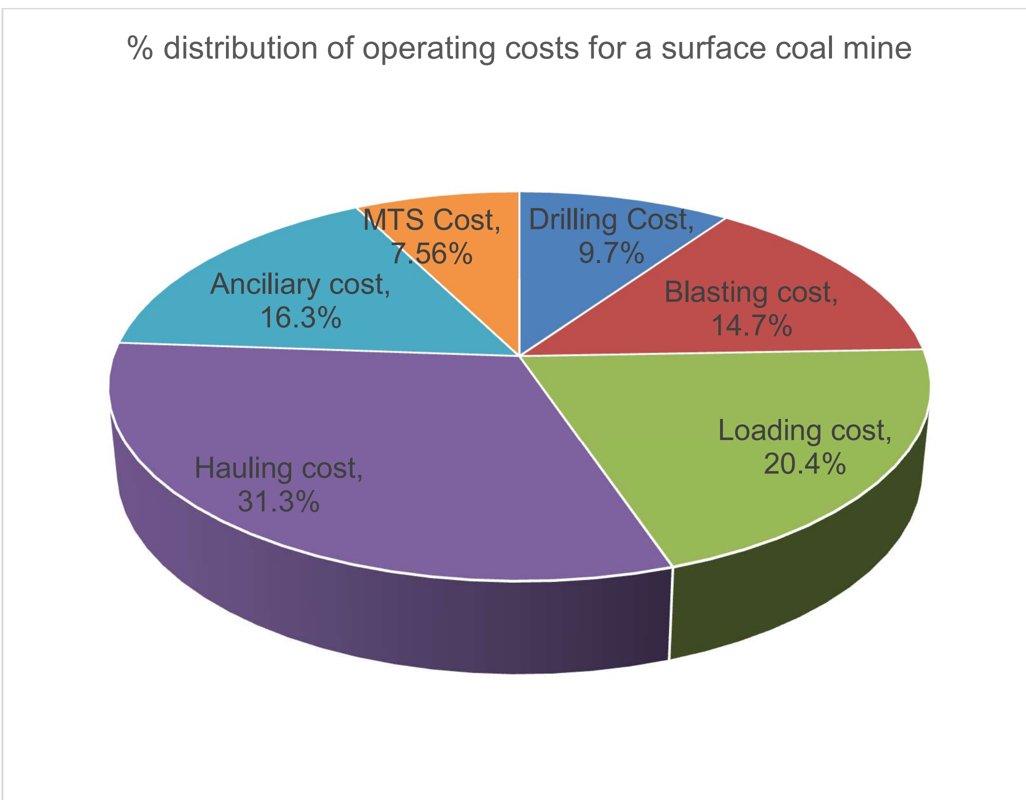

Figure 5-1 percentage distribution of different mining operating cost for a coal mine

6 Cost Model Validation

The Delphi method was used for the validation of the cost model. The following section details the results of validation of the research.

6.1 Competence confirmation of Delphi experts

Table 6-1 provides the details of the experts who participated in the review of the study and model.

Table 6-1 Details of Delphi experts

Experts	Educational Qualification	Accreditation	Mining Industry Experience
Expert-1	Postgraduate	ECSA Registered, SAIMM Registered	5-10 years
Expert-2	Graduate	Mining Manager ticket	5-10 years
Expert-3	Postgraduate	Others	10-15 years
Expert-4	Postgraduate	SAIMM Registered, Others	>15 years
Expert-5	Postgraduate	Others	>15 years
Expert-6	Postgraduate	SAIMM Registered	>15 years
Expert-7	Graduate	Others	5-10 years

83.3% of the participants have postgraduate degrees and almost all the participants were affiliated to some accredited institutions such as Engineering Council of South Africa (ECSA) or Southern African Institute of Mining and Metallurgy (SAIMM) or owned a mine manager's ticket. More than 90% of the participants have more than 10 years of experience and greater than 50% of the participants have more than 15 years of experience. All the participants have confirmed that they have been exposed to cost estimation which confirms that all participants meet the criteria for selection as an expert based on the requirements that formed part of the Delphi validation process.

6.2 Delphi Round 1 Results

To validate the framework; expert opinion was considered in Delphi round 1 without sharing the framework and cost model. In this section, the results of the Delphi round 1 questions have been presented.

Figure 6-1 reflects the expert's responses in Delphi round 1 on top five operating costs in mining.

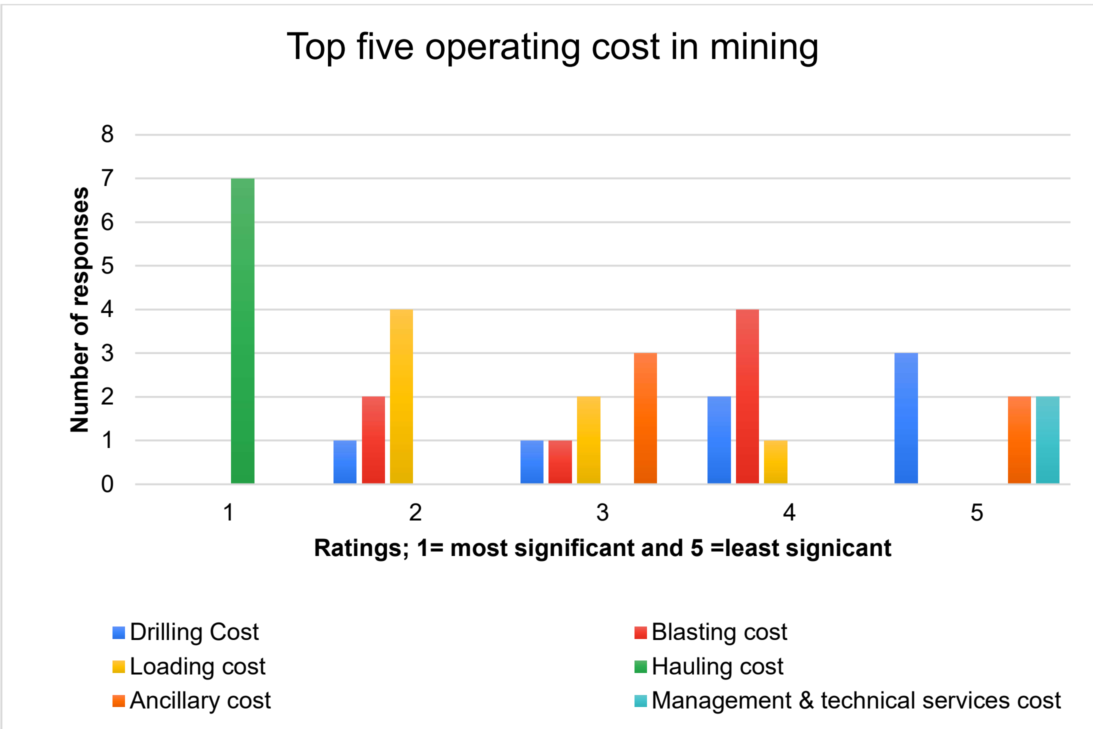

Figure 6-1 Expert's responses for top five operating cost component of surface coal mining

Figure 6-2 represents the expert's opinion of components of drilling cost. The horizontal axis represents the number of experts expressing their opinion and the vertical axis represents different components of drilling cost.

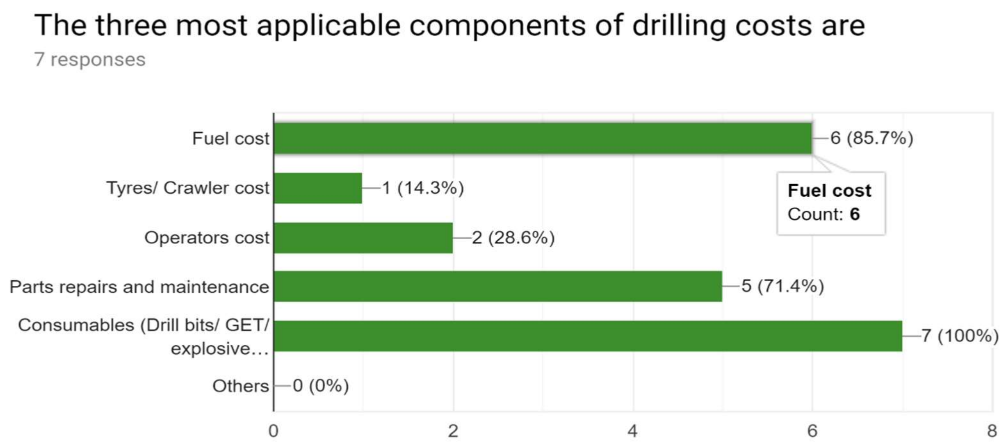

Figure 6-2 Expert's responses for three most applicable component of drilling cost

Figure 6-3 represents the expert's opinion of components of blasting cost. The horizontal axis represents the number of experts expressing their opinion and the vertical axis represents different components of blasting cost.

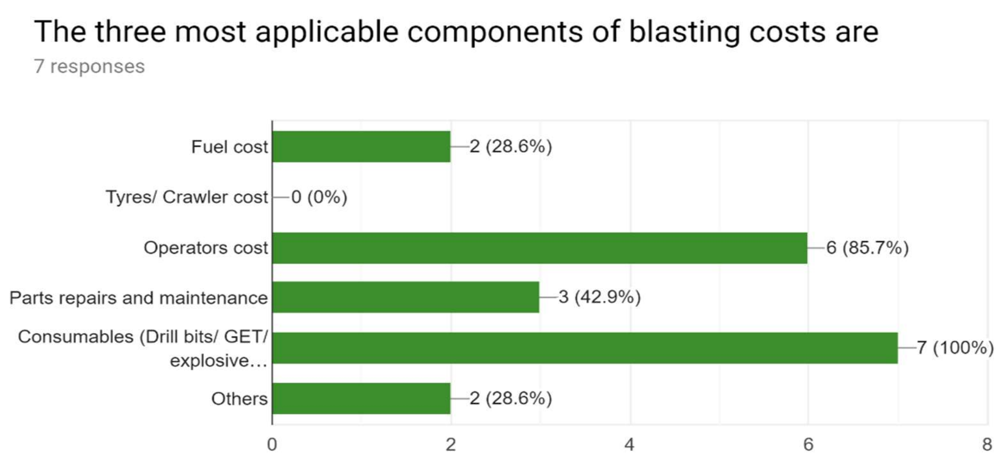

Figure 6-3 Expert's responses for three most applicable component of blasting cost

Figure 6-4 reflects the expert's opinion of components of loading cost. The horizontal axis represents the number of experts expressing their opinion and the vertical axis represents different components of loading cost.

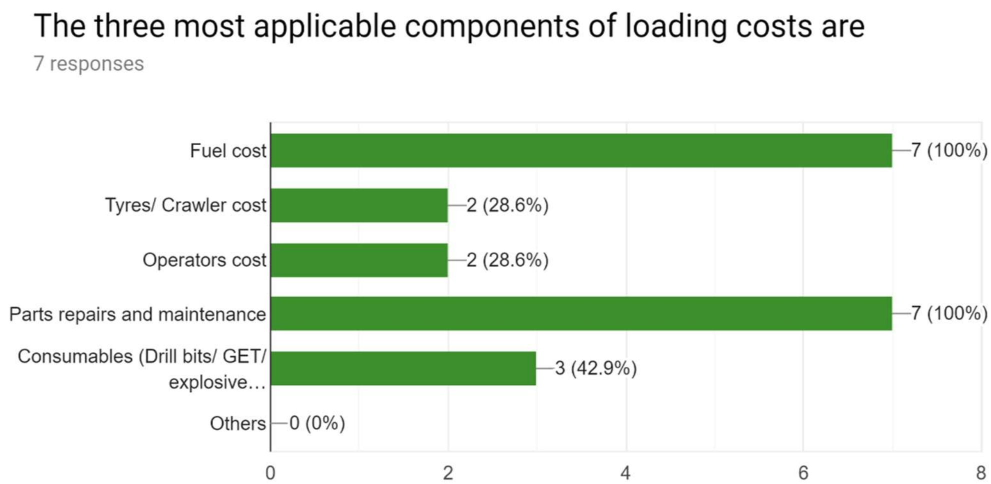

Figure 6-4 Expert's responses for three most applicable component of loading cost

Figure 6-5 represents the expert's opinion of components of hauling cost. The horizontal axis represents the number of experts expressing their opinion and the vertical axis represents different components of hauling cost.

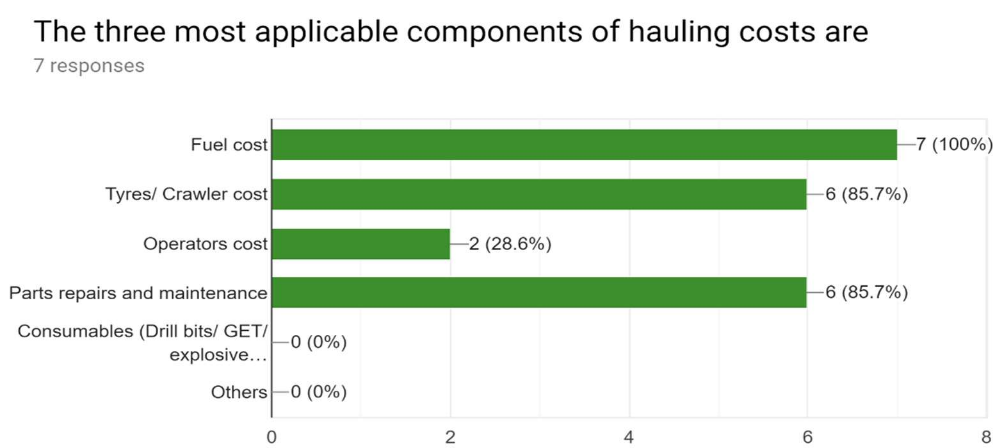

Figure 6-5 Expert's responses for three most applicable component of hauling cost

Figure 6-6 represents the expert's responses on components of ancillary cost. The horizontal axis represents the number of experts expressing their opinion and the vertical axis represents different components of ancillary cost.

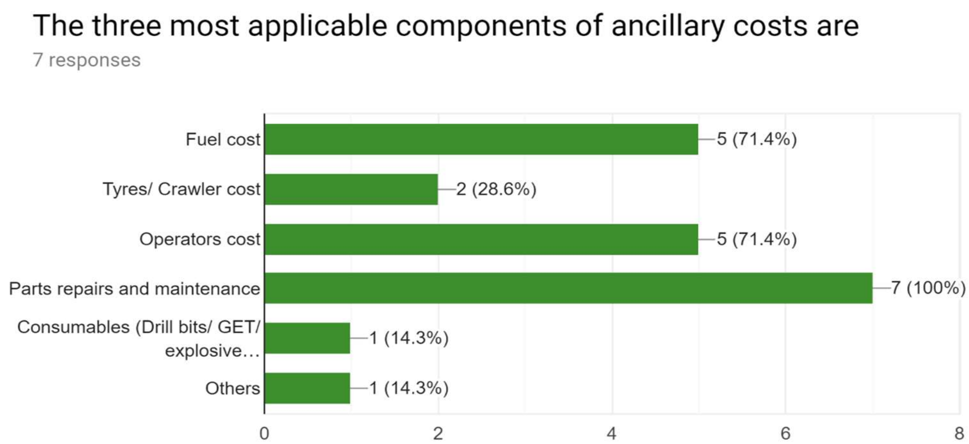

Figure 6-6 Expert's responses for three most application component of ancillary cost

Figure 6-7 represents the expert's responses about total operating cost (ZAR/m^3) of a surface coal mine.

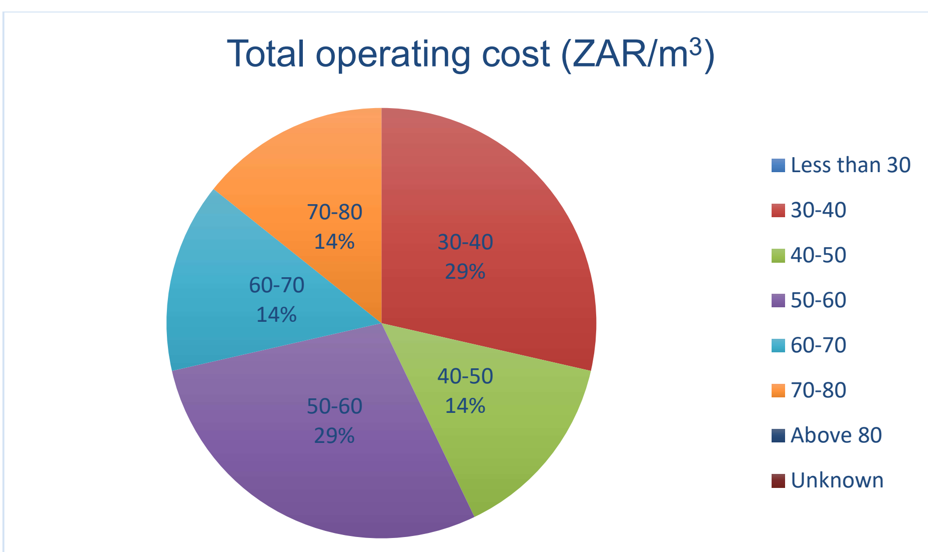

Figure 6-7 Expert's responses on total operating cost of a surface coal mine

Figure 6-8 represents the expert's responses on percentage contribution of drilling cost in total operating costs of a surface coal mine.

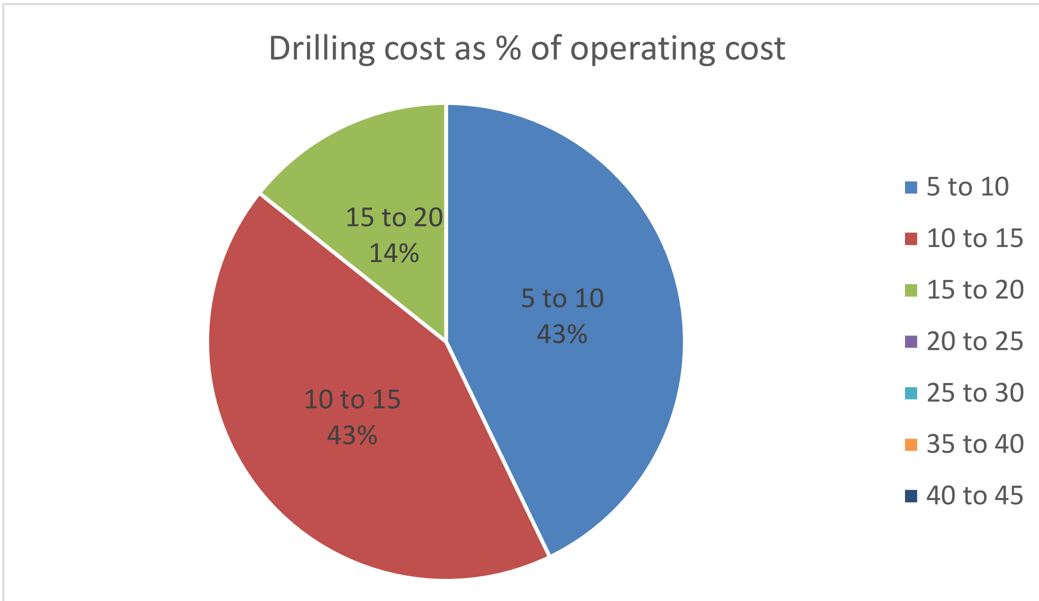

Figure 6-8 Expert's responses for drilling cost

Figure 6-9 represents the expert's responses on percentage contribution of blasting cost in total operating costs of a surface coal mine.

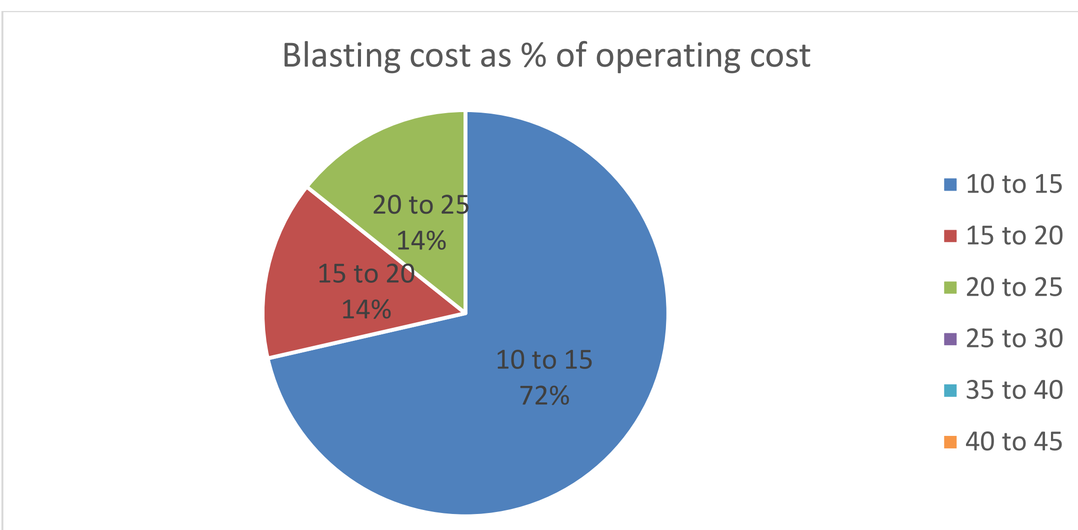

Figure 6-9 Expert's responses for blasting costs

Figure 6-10 represents the expert's responses on percentage contribution of loading cost in total operating costs of a surface coal mine.

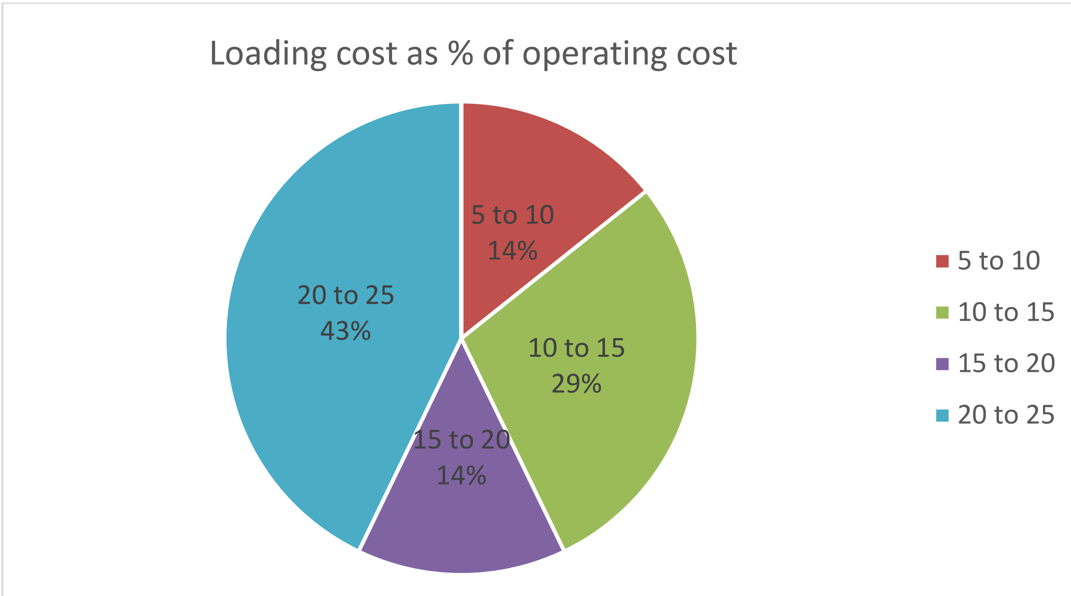

Figure 6-10 Expert's responses for Loading cost

Figure 6-11 represents the expert's responses on percentage contribution of hauling cost in total operating costs of a surface coal mine.

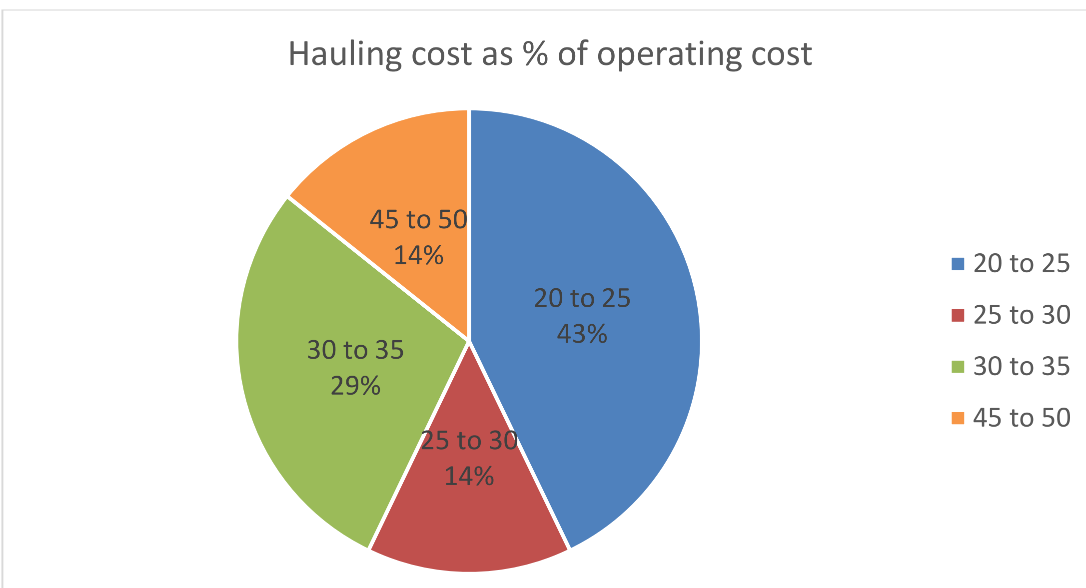

Figure 6-11 Expert's responses for hauling cost

Figure 6-12 represents the expert's responses on percentage contribution of ancillary cost in total operating costs of a surface coal mine.

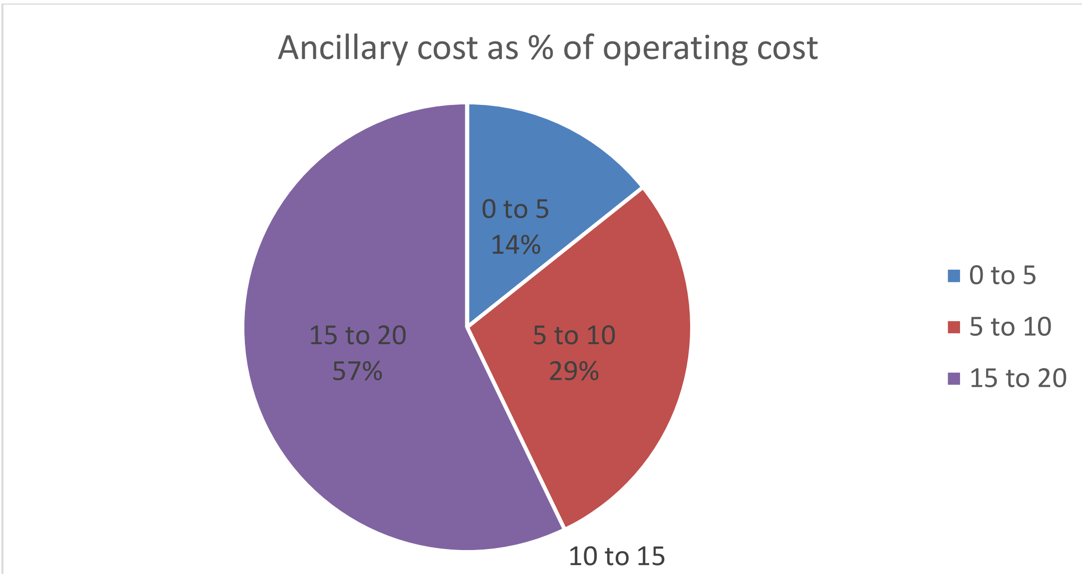

Figure 6-12 Expert's responses for ancillary cost

Figure 6-13 represents the expert's responses on percentage contribution of management & technical services cost in total operating costs of a surface coal mine.

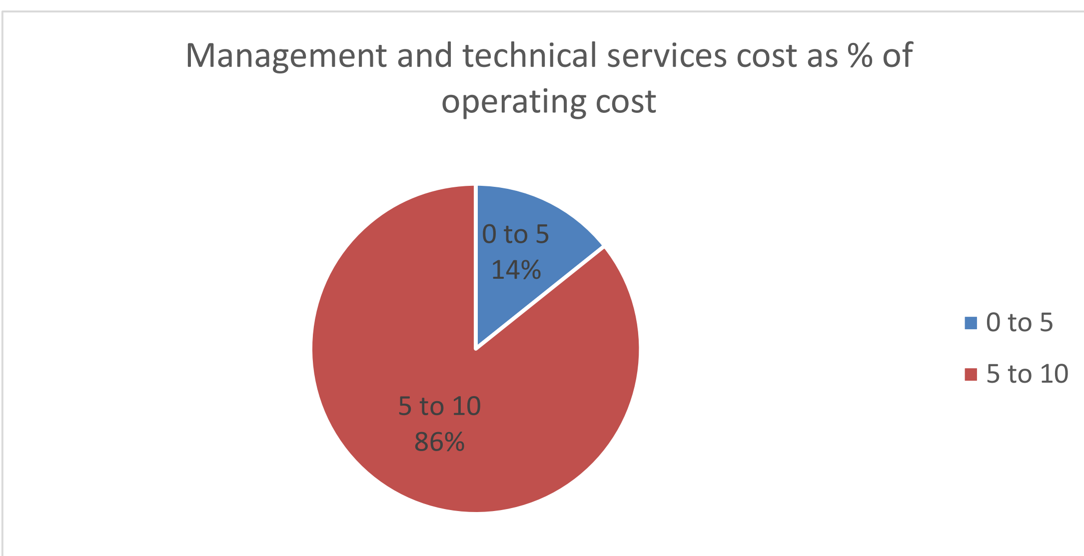

Figure 6-13 Expert's responses for management and technical services cost

6.3 Delphi Round 2 Results

In this section, the results of the Delphi round 2 have been presented. In Delphi round 2, four experts have participated.

Figure 6-14 represents the expert's responses in Delphi round 2 about total operating cost (ZAR/m^3) of a surface coal mine.

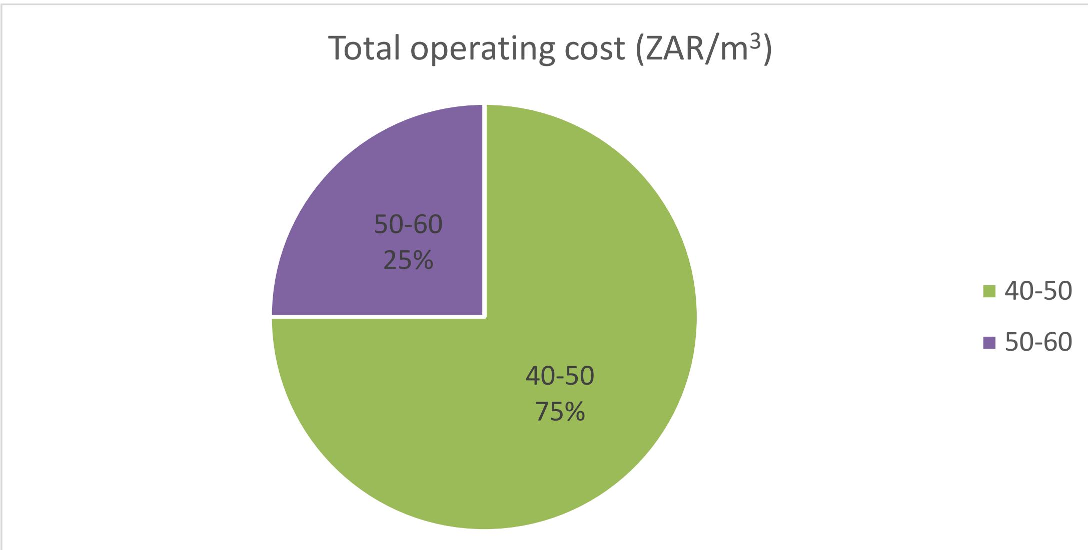

Figure 6-14 Expert's response for total operating mining cost (ZAR/m^3) in Delphi round 2

Figure 6-15 represents the expert's responses in Delphi round 2 about percentage contribution of drilling cost on total operating cost of a surface coal mine.

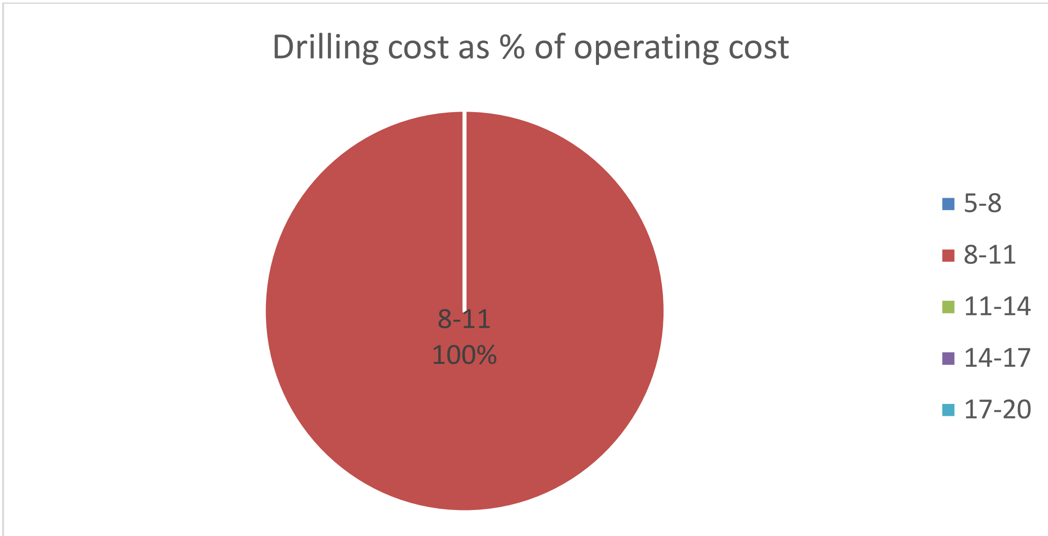

Figure 6-15 Expert's response for drilling cost (Delphi round 2)

Figure 6-16 represents the expert's responses in Delphi round 2 about percentage contribution of blasting cost on total operating cost of a surface coal mine.

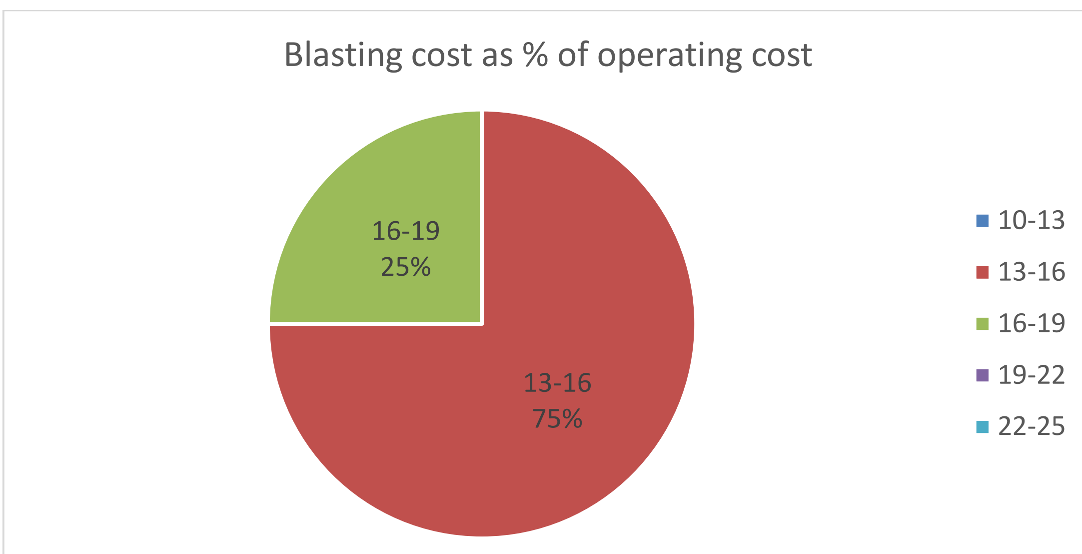

Figure 6-16 Expert's response for blasting cost (Delphi round 2)

Figure 6-17 represents the expert's responses in Delphi round 2 about percentage contribution of loading cost on total operating cost of a surface coal mine.

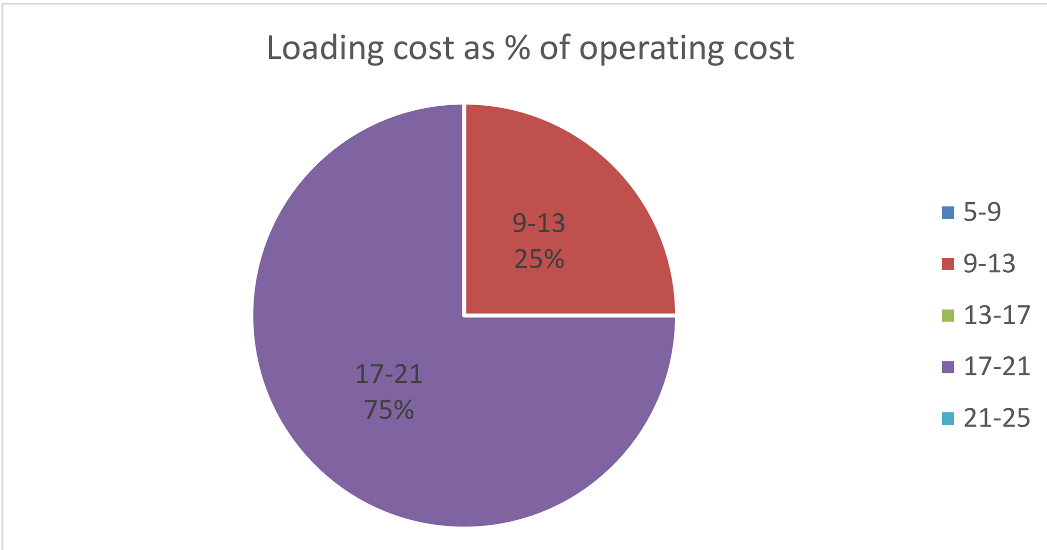

Figure 6-17 Expert's response for loading cost (Delphi round 2)

Figure 6-18 represents the expert's responses in Delphi round 2 about percentage contribution of hauling cost on total operating cost of a surface coal mine.

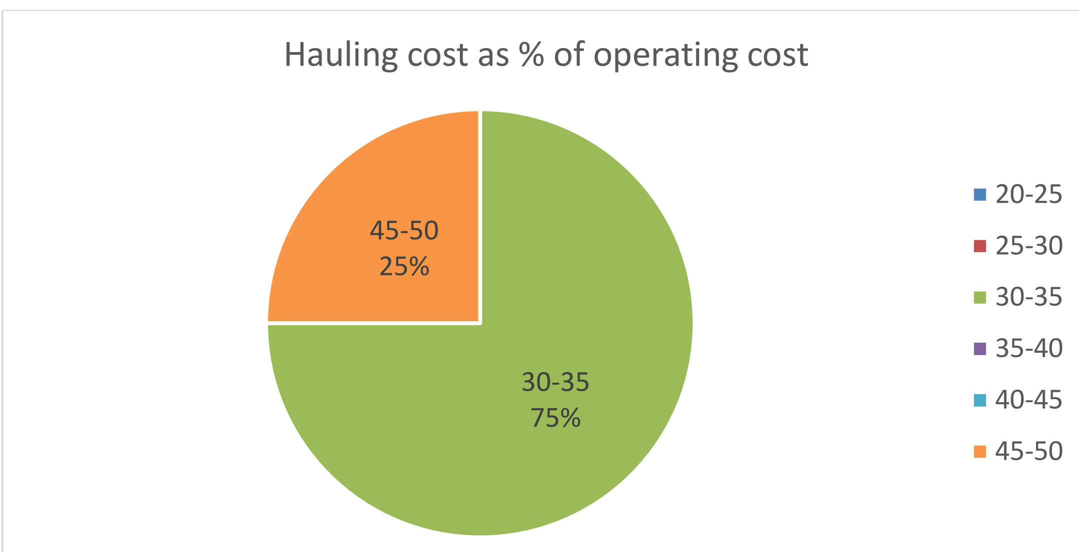

Figure 6-18 Expert's response for hauling cost (Delphi round 2)

Figure 6-19 represents the expert's responses in Delphi round 2 about percentage contribution of ancillary cost on total operating cost of a surface coal mine.

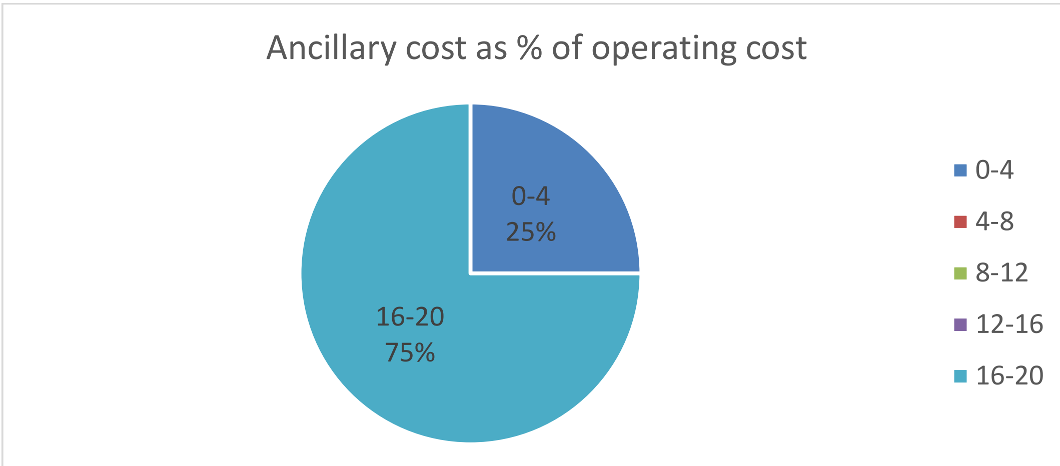

Figure 6-19 Expert's response for ancillary cost (Delphi round 2)

Figure 6-20 represents the expert's responses in Delphi round 2 about percentage contribution of management & technical services cost on total operating cost of a surface coal mine.

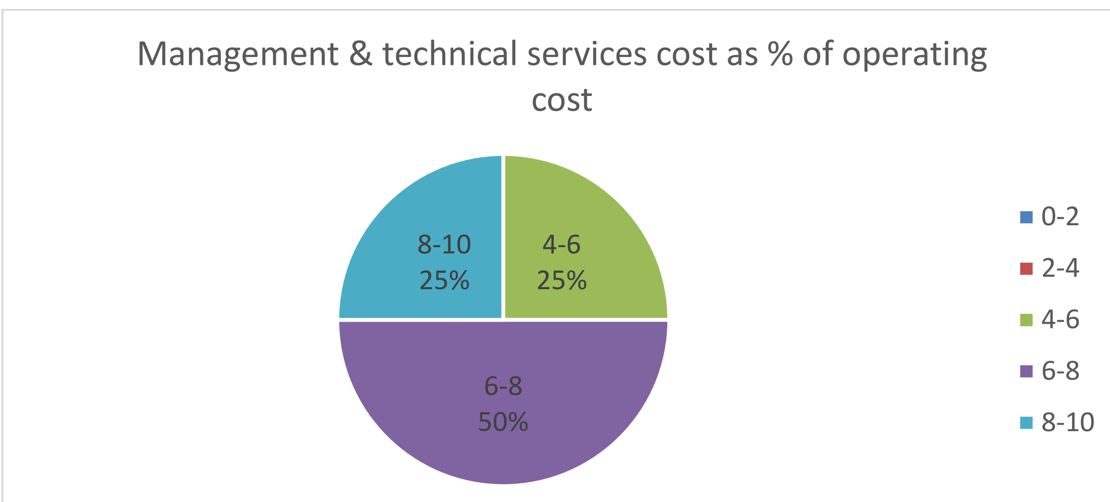

Figure 6-20 Expert's response for management and technical services cost (Delphi round 2)

6.4 Chapter conclusion

This chapter presented the validation results of the framework and model by the panel of experts using Delphi method.

7 Discussion of Results

7.1 Introduction

The purpose of this chapter is to summarise and relate the results and findings of chapter 4, chapter 5 and chapter 6. In addition to this, the results obtained from the study have also been analysed and scrutinised to obtain conclusive remarks. The following paragraph describes the approach followed in discussing the drilling cost.

- The discussion of the drilling operating cost starts with a framework covering a major component of the drilling cost
- This followed by a discussion of the drilling cost results obtained from the operating cost model
- This followed with the discussion of the Delphi round 1 and round 2 results in the context of model and framework.
- Finally, the discussion of the component concludes with a summary and its application.

All other operating cost components such as blasting cost, loading cost, hauling cost, ancillary cost, and MTS are also discussed in a similar order.

7.2 Key Findings & Results

Before discussing the results of this research in detail it is useful to summarize the main findings of the research. Details of the results and findings referred to below can be found in chapter 5 and chapter 6.

7.2.1 Operating cost estimation- An example mine

- The total drilling cost obtained from the cost model for the example mine is 4.77 ZAR/m^3. This is 9.7% of the overall operating cost.
- The blasting cost obtained for the example coal mine is 7.22 ZAR/m^3. This is 14.7% of the overall operating cost.

- The loading cost obtained from the cost model used on example mine is 9.98 ZAR/m^3. This is 20.4% of the overall operating cost.
- the Hauling cost obtained from the cost model used on example mine is 15.37 ZAR/m^3. This is 31.3% of the overall operating cost.
- The ancillary cost obtained from the cost model used on example mine is 8.00 ZAR/m^3. This is 16.3% of the overall operating cost.
- The total MTS cost obtained from the cost model for the example mine is 3.71 ZAR/m^3. This is 7.6% of the overall operating cost.
- Total operating cost obtained from the cost model for the example mine is 49.05 ZAR/m^3.

7.2.2 Cost Model Validation

- All experts believed that hauling costs are the most significant cost component.
- The next three most significant costs include loading cost, blasting cost, and drilling cost.
- In the final Delphi round, 75% of the participants indicated that the total operating mining costs for a surface coal mine fall within the range of 40-50 ZAR/m^3.
- In the final round (round 2) of Delphi, 75% of the experts agreed that the contribution to the total operating cost is as follows: drilling cost at 8-11%, blasting cost at 13-16%, loading cost at 17-21%, hauling cost at 30-35%, ancillary cost at 16-20% and MTS cost at 7,6%.

7.3 Drilling cost

The drilling cost (ZAR/m^3) in this study has been estimated from the first-principles approach by estimating the operating cost per hour of drilling machine and productivity i.e. production meters drilled per hour for that working condition. The productivity of the drilling machine is a primary factor of material characteristics and mining conditions. The model has been developed to estimate the productivity of the drill machine as described in section 4.3.2.

In addition to direct operating cost; there is a capital cost to be charged against the material drilled. The drilling machine will be amortized over the amount of material drilled. Hence, the drilling cost has been primarily divided into two components owing cost and operating cost. From the cost model, it is clear that owning cost is a factor of the capital cost of the machine, minimum working hours of the machine, interest rate and tax rates. The direct operating cost components of drilling have been developed under the components of fuel cost, operators cost, maintenance & repair cost, crawler cost and consumables cost.

In Delphi round 1, experts were requested to give their opinion on major components of the drilling cost. The findings show that the three most significant components of drilling costs are fuel cost, consumables cost, and parts & maintenance costs. In Section 4.3.3, all three components have been derived and discussed.

Further, the reliability testing of the developed cost model was done by estimating the drilling cost for an example mine as described in section 5.3. The owning cost obtained for the example cost mine was 1.92 ZAR/m^3 and the operating cost including fuel was 4.77 ZAR/m^3. The total drilling cost obtained from the cost model for the example mine was 6.69 ZAR/m^3. The total drilling cost was estimated as 9.7% of the total operating cost.

In Delphi round 1, experts were asked to give their opinion on total mining operating cost (ZAR/m^3) and drilling cost as a percentage component of operating cost so that the aggregate drilling cost can be obtained by multiplying the consensus operating cost amount by percentage component of drilling cost in overall mining operating cost. The findings show that the drilling cost falls in the range of 5%-20% of the total operating cost. However, due to variation in total operating cost and a wider range on the percentage, a further Delphi round was used.

In Delphi round 2, the model was shared with experts specifying the scale of mining and other assumptions. The range for percentage was narrowed to 5-20% for the drilling cost as opposed to the Delphi round 1 of 0-100%. It was found in Delphi round 2 that all the participants agreed that the drilling cost falls in the range of 8-11% for surface coal mining projects. The results obtained from the cost estimation model was 9.7% and were within the range specified by the panel of experts.

The total drilling cost obtained from the cost model for the example mine was 4.77 ZAR/m^3. These results could be useful for South African junior coal miners and new coal mining aspirants to benchmark their project operating cost. The framework developed in this study can be used by coal miners to calculate the more accurate operating cost of their coal mines. The cost model can be also used by surface coal miners to identify a potential area of improvement in drilling cost component for further optimisation.

7.4 Blasting cost

The blasting cost (ZAR/m^3) in this study has been estimated under the components of explosives cost, accessory cost, stemming cost and fixed cost. The model has been developed to estimate the requirement of explosive, accessory and stemming per unit volume of in-situ material. By applying the pricing obtained from explosive manufacturers or supplier, blasting cost per unit volume has been estimated. Further in South Africa, explosive manufacturers or suppliers charge a fixed amount of monthly charges as a fixed component.

From the cost model as developed in section 4.4, it is clear that apart from the explosive and accessories pricing; blasting cost is a factor of material characteristics, mining method and type of drilling machine. In Delphi round 1 experts were requested to give their opinion on major components of blasting cost. The three most significant components of blasting costs are found to be explosives cost, operator's cost, and parts & maintenance costs. However, the model assumes the explosive supplier shall supply explosives to the mine so the mining company does not maintain the equipment, machinery and manpower for blasting purposes. Therefore, the blasting cost calculated in the section 4.4.4 reflects the fixed charges as an inclusive of operator cost and parts & maintenance.

Further, the reliability testing of the developed cost model was done by estimating the blasting cost for example mine as described in section 5.4. The blasting cost obtained for the example cost mine was 7.22 ZAR/m^3 and as a percentage of total operating cost it was14.7%.

In the Delphi round 1 experts were asked to give their opinion on total mining operating cost (ZAR/m^3) and blasting cost as percentage component of operating cost so that the aggregate blasting cost can be obtained by multiplying on consensuses operating cost amount by percentage component of blasting cost in overall mining operating cost. The findings show that the blasting cost falls in the range of 10-25 % of overall operating cost. However, 72% of experts indicated that blasting cost falls in the range of 10-15 % which was in line with the 14.7% as obtained from the model. Furthermore, due to variation in total operating cost and the wider range of percentage a further Delphi round was used, narrowing the blasting cost range to 10-25 %.

In Delphi round 2, 75% of participants agreed that the blasting cost falls within the range of 13-16% for surface coal mining projects which is in line with the14.7% as obtained from the cost model.

The total blasting cost obtained from the cost model for the example mine was 7.22 ZAR/m^3. It is further observed that the explosive costs are the biggest cost component of the blasting cost. Similar to drilling cost these results could be also useful for the South African coal miners and new coal mining aspirants to benchmark their project operating cost. Also, the framework developed in section 4.4 can be used for establishing blasting parameters for a surface mining operation.

7.5 Loading cost

The loading cost (ZAR/m^3) in this study has been estimated using a first-principles approach, by estimating the operating cost per hour of loading machine and productivity i.e. production per hour for that working condition. The productivity of the loading machine is a primary factor of material characteristics and condition of mining. The model has been developed to estimate the productivity of the loading machine as described in section 4.5.1. In addition to direct operating cost, there is a capital cost to be charged against the material loaded out. The loading machine will be amortized over the amount of material mined out and only a small component of residual value will be leftover. The loading cost has been primarily divided into two components: owning cost and operating cost.

From the cost model, it is clear that owning cost is a factor of the capital cost of the loading machine, minimum working hours of the machine, interest rate and tax rates. The direct operating cost components of loading have been developed under the components of fuel cost, operators cost, maintenance & repair cost, crawler cost and ground GETs cost. In Delphi round 1, experts were requested to give their opinion on the major components of loading cost. All the experts acknowledged that fuel costs and parts & maintenance costs are the two most significant components of loading costs. Experts also expressed that crawler cost, operators cost and GET cost are other important components of loading cost and they did not express any additional costs under the category of others. In section 4.5.2, all these have been derived and discussed.

Further, the reliability testing of the developed cost model was done by estimating the loading cost for an example mine as described in section 5.5. The owning cost for loader obtained from the example cost mine was 2.40 ZAR/m^3 and the operating cost including fuel was 7.58 ZAR/m^3 and hence the total loading cost obtained from the cost model used on example mine was 9.98 ZAR/m^3, expressed as a percentage of total operating cost as 20.4%.

In Delphi round 1, experts were asked to give their opinion on total mining operating cost (ZAR/m^3) and loading cost as a percentage component of operating cost so that the aggregate loading cost can be obtained by multiplying the consensus operating cost amount by the percentage component of loading cost in the overall mining operating cost. In Delphi round 1, it was found that the loading cost falls in the range of 5-25 %. In the next round of Delphi validation, the range was narrowed down to 5-25% for the loading cost as opposed to the current 0-100% to obtain a more precise figure.

In Delphi round 2, the model was shared with experts specifying the scale of mining and other assumptions. It was found in Delphi round 2 that 75% of the participants agreed that the loading cost for a surface coal mining falls within the range of 17-21% of the total operating cost which is in-line with the 20.4 % as obtained from the model. The loading cost is the second-largest component of a surface coal mining operating cost.

The total loading cost obtained from the cost model for the example mine was 9.98 ZAR/m^3. The details obtained in the research on loading cost could be useful for coal mining aspirants in estimating their project operating cost. Further, the framework developed in this study can be used as a guideline for the selection of loading equipment to match the productivity of the mine. From the cost model, it is observed that fuel cost and maintenance and repairs costs are the two big components of loading cost. Hence this also provides an idea to coal miners to identify the most promising and potential area of improvement in loading cost for further cost optimisation in their existing mines.

7.6 Hauling cost

The hauling cost in this study has been estimated using a first-principles approach, by estimating the operating cost per hour of hauling machine and productivity i.e. production per hour for that working condition. The productivity of the hauling machine is dependent upon loading machine cycle time, material characteristics, blast results, haul road condition and hauling distance to dump or tip the material. The cost model was developed to estimate the productivity of the hauling machine as described in section 4.6.3. In addition to direct operating cost, there is a capital cost to be charged against the material mined out. The hauling machine will be amortized over the amount of material mined out and only a small component of residual value will be leftover. Hence, the hauling cost has also been divided into two components owning cost and operating cost.

From the cost model, it is clear that owning cost is a factor of the capital cost of a hauling machine, minimum working hours of the machine, interest rate and tax rates. The direct operating cost components of hauling have been developed under the components of fuel cost, operators cost, maintenance & repair cost and tyre cost. In Delphi round 1 experts were asked to give their opinion on major components of hauling cost. The majority of experts acknowledged that fuel costs, tyre costs, and parts & maintenance costs are the three most significant components of hauling costs. In the framework and cost model, these costs have been derived and discussed.

Further, reliability testing of the developed cost model was done by estimating the hauling cost for an example mine as demonstrated in section 5.6. The owning cost for the haul truck obtained for the example cost mine was 4.52 ZAR/m^3 and the operating cost including fuel was 10.85 ZAR/m^3 and hence the total hauling cost obtained from the cost model used on example mine was 15.37 ZAR/m^3 and as a percentage of total operating cost, it was 31.3%.

In Delphi round 1, experts were asked to give their opinion on total mining operating cost (ZAR/m^3) and hauling cost as percentage component of operating cost so that the aggregate hauling cost can be obtained by multiplying the consensus operating cost amount by percentage component of loading cost in overall mining operating cost. In Delphi round 1, it was found that the hauling cost falls in the range of 20-50%. In the next round of Delphi validation, the range was narrowed down to 20-50% for the hauling cost as opposed to the current 0-100% to get a more precise figure. The possible wider range could be the lead distance; as the lead distance has the greatest influence on hauling cost.

In the Delphi round 2, the model was shared with experts specifying the scale of mining and lead distances for dumping. In Delphi round 2, 75% of the participants agreed that the hauling cost for a surface coal mining falls within the range of 30-35% of the total operating cost of a surface coal mining and is the largest component of the surface coal mining operating cost. This percentage component was in-line with the 31.3 % as obtained from the model and hence no further round of Delphi was conducted.

The total hauling cost obtained from the cost model for the example mine was 15.37 ZAR/m^3. Similar to loading cost, fuel cost and maintenance & repairs costs are the two big components of hauling cost as well as. Further, the haul distance and haul road conditions are the biggest influencing factors on hauling costs. The framework developed can be used by mining contractors and coal miners to estimate their operating cost on a customized basis.

7.7 Ancillary cost

The ancillary cost in this study has been estimated under different activity-based components namely dozing cost, grading cost, water spraying cost, re-fuelling cost (cost for running of diesel bowser), pumping cost and lighting cost. This ancillary cost varies widely for different mining projects; as this involves six different activity-based costings. These costings are further estimated by calculating the requirement of a particular activity and obtaining the operating cost per hour of that activity or machine. The ancillary cost is dependent upon material characteristics, blast results, haul road condition, hauling distance and climatic conditions. Furthermore, for dozer, grader, water tanker, diesel bowser, pumps and lighting plants owning and operating cost have been derived. Also operating cost for these machines were derived using the cost model and the prime cost components were parts and maintenance cost, fuel cost, operators cost and tyre or crawler cost.

In Delphi round 1, all the experts acknowledged that parts & maintenance cost is the most significant components of ancillary cost and again the majority of experts expressed that fuel cost and operator costs are the other two most significant components of ancillary cost. In the framework and cost model, these costs have been derived and discussed.

The reliability testing of the developed cost model was done by estimating the ancillary cost for an example mine as described in section 5.7. The ancillary cost obtained from the cost model used on example mine was 8.00 ZAR/m^3 and as a percentage of total operating cost, it was 16.3%.

In Delphi round 1, it was found that the ancillary cost falls in the range of 0-20%. In the next round of Delphi validation, the range was narrowed down to 0-20% for the ancillary cost as opposed to the current 0-100%.

In Delphi round 2, 75% of the experts converged at 16-20% of the total operating cost which validates the cost model as ancillary cost from the cost model was 16.3%.

The total ancillary cost obtained from the cost model for the example mine was 8.00 ZAR/m^3. These results could be useful for the South African contract mining companies and junior coal miners to estimate a more accurate ancillary cost involved for their surface coal mines on a customized basis. Also from the model, it is observed that there incurs a cost in case of idling of machines in form of owning cost. So mining companies have to be cautious while selecting the ancillary equipment for a specific mining project.

7.8 Management and technical services (MTS) cost

To run a mining operation safely and productively a team of management and technical personnel is required. The MTS cost is obtained by estimating the required number of personnel to run the mining project. The number of personnel depends upon the size of the mining operation, type of mining, and equipment deployed. A list of management and technical personnel for a typical surface coal mine has been formulated and an average salary was applied for each required personnel. The MTS cost is estimated by dividing the total monthly salary for all those personnel by quantity of material mined out monthly.

The reliability testing of the developed cost model was done by estimating the MTS cost for example mine. The MTS cost obtained from the cost model used on example mine was 3.71 ZAR/m^3 and as a percentage of total operating cost, it was 7.6%.

In Delphi round 1, it was found that the MTS cost falls in the range of 0-10%. In the next round of Delphi validation, the range was narrowed to 0-10% as opposed to the current 0-100%.

In Delphi round 2, 75% of the experts converged at 4-8% of the total operating cost which validates the cost model as ancillary cost arriving in the cost model was 7.6%. The total MTS cost obtained from the cost model for the example mine was 3.71 ZAR/m^3. These results could be useful for the South African junior coal miners and new coal mining aspirants to benchmark their project operating cost.

7.9 Total Mining operating cost

The total mining operating cost obtained by using the cost model for the example mine was 49.05 ZAR/m^3. In Delphi round 1, experts' response for the total operating mining cost was within the range of 30 ZAR/m^3 to 80 ZAR/m^3. This validates the operating cost obtained from the model although the range from the experts was wide. Some of the possible reasons for this could be the scale of mining, non-clarity of owning cost component and overhead cost variation as the cost model was not shared with the experts during round 1.

In Delphi round 2, the cost model was shared with experts and their opinion was obtained for the overall mining operating cost. In Delphi round 2, 75% of the participants indicated that the total operating mining cost for a surface coal mining fell within the range of 40-50 ZAR/m^3 showing convergence and therefore negating the need for a further Delphi round.

8 Research Conclusions and Recommendations

Estimating the operating costs for a coal mining project makes it possible to determine the feasibility of a new mining project and ultimately whether the mining project should be started in the current techno-economic scenario. Furthermore, it helps with the economic evaluation of a specific project i.e. to calculate the profitability of the mining project and rate of return on project capital. For a running mine, the operating cost estimation helps in taking decisions on the expansion or downsizing of the project.

The cost estimation of both new and operating surface mines should be done based on the details of mining geology, rock characteristics, method of mining, equipment selection, and the mining schedule. These factors are required as the prime inputs for cost estimation. In addition to these factors, it is also important to have labour rates for different activities and operations needed in the mining project.

The first-principles method involves the calculation of project-specific costs based on a detailed study of the resources required (Plant, Labour, Material, and Subcontract) to accomplish each activity of work contained within the project's work breakdown structure. Productivity assumptions are applied to all labour and plant costs with adjustments made to account for unique or unusual site characteristics.

This research explored the cost estimation exercise for a surface coal mining project using the first-principles method. Furthermore, the research developed a framework that can help to estimate the operating cost for a surface coal mine.

8.1 Research Findings

The central research question stated in Chapter 1 is: *What is the nature of operating costs for a surface coal mining project?*

To answer the central research questions; the four objectives of the research were established.

Objective1 was to establish the different operating costs component involved in a surface mining project. This was done in detail in chapter 4. In the research, mining operating cost has been established under six major costs and those were drilling cost, blasting cost, loading cost, hauling cost, ancillary cost, and management & technical services cost. Drilling cost was further calculated under the components of maintenance & repair, track, operator, consumables and fuel. Blasting cost was estimated under explosives, accessories, stemming and service charges cost components. Loading cost was further calculated under the components of maintenance & repair, track, operator, and fuel. The hauling cost was calculated under the components of maintenance & repair, Tyres, operator, and fuel. Ancillary cost was established under the dozing cost, grading cost, water spraying & fuelling, lighting and pumping costs.

Objective 2 was to develop a first-principles cost estimation model which can be used to estimate the operating cost of a surface coal mine. This was done and discussed comprehensively in chapter 4. The principles for estimating the costs against six major components i.e. drilling, blasting, loading, hauling, ancillary and management and technical services were compiled and formulated. Thereafter the cost model for each component was developed separately and then all operational cost component added together to obtain the overall operating costs estimates for the mine.

Objective 3 was to estimate the operating costs for an example mine. This was done in detail in chapter 5 following the framework and principles developed in chapter 5. The example mine was a surface coal mine having drilling and blasting practices for breaking of rock with a truck and shovel system. The operating cost per unit volume of excavation (ZAR/m^3) was calculated under six major costs component based on the framework developed in chapter 5.

O***bjective 4*** was to validate the framework and cost estimating model. This was done by the Delphi method consulting with the experts. It was validated by the experts that five major mining operating costs are from drilling cost, blasting cost, loading cost, hauling cost, ancillary cost, and management & technical services cost and out of these; the hauling cost is the topmost operating cost in a mining project.

8.2 Research contribution

The research provides a new perspective on estimating operating costs for surface mining projects considering the unique variables of the project and determining the different cost components in detail and getting overall operating costs to evaluate the project feasibility and profitability. Thus, the research contributes to the literature on cost estimation for mining projects. Mining companies can use the developed cost estimation model to evaluate the costing for a future mine or expansion of the existing mine by adjusting the input variables of the project. The cost estimation for the example mine shall further assist coal miners to understand the operating cost for a typical medium scale surface coal mine with a shovel and truck system. The research generated the cost estimation in excel format that can be used by mine management for cost estimation purposes and it can also give the guidance to do the sensitivity analysis against key variables.

8.3 Significance of Research

Estimation of operating cost for a mining project is essential to find out the feasibility of a new project and for conducting an economic analysis of a complete mining project. The study identifies a deficiency in current cost estimation practices for surface coal mines as they are not customised to the local South African situation and suggests a back-to-basics practical approach using first-principles as the way forward. The cost estimation process makes use of the first-principles approach and is developed by breaking the mining operation into different activities. From this, a framework is developed for estimating costs against each activity or component.

Using the framework and this cost estimation approach a cost model was developed for the truck and shovel activities on surface coal mines which can be further be used as a template that industry players can use to evaluate operational costs in medium-range surface coal mining projects by adopting it to specific circumstances of the particular mine. Also, the research provides a new perspective on estimating operating costs for surface mining projects considering the unique variables of the project and it has a potential to become a generic tool with widespread application in the industry. Also, by using the cost model may assist in conducting a sensitivity analysis for key mining variables.

8.4 Limitations of Study

The research has concentrated on a cost exercise and has not focussed on mine planning and design methods. Also, the study assumes a reasonable South African working culture and workforce and hence has not covered the review of competence of the teams and detailed working culture or operating rhythm of the teams. The research is focussed primarily on the operating mining cost; however, some of the components of operating mining costs (repair and maintenance cost of equipment) are directly linked and associated with capital cost. Maintenance and repair cost can only be achieved on equipment that has been decommissioned as that is when the full history can be known. For this reason, the equipment capital cost is used in the model to calculate the equipment repair and maintenance cost based on life cycle costing approach. The equipment life cycle maintenance and repair cost assumed in the study is 90% of the purchase price; however actual may vary depending upon working condition, operator's skill and actual maintenance plan followed.

Also, an overhead cost of 6% of the capital cost of equipment has been considered in the model to take account of overhead cost. However, this may differ from organization to organization depending upon organizational structures and number of operating projects.

The cost model is developed focussing primarily on a medium scale surface coal mine having truck and shovel and drill and blast activities. The cost estimation approach can be used for different scale of mine as well as; however, the model requires to be adjusted for the specific mining project.

8.5 Suggestions for further research

The research was done focusing on surface coal mining projects having drill and blast operations with truck and shovel mining systems. Future research may be done for the estimating of operating costs for underground mining projects. Also, further investigation is required for estimating surface coal mining projects having a different method of mining like dragline mining or continuous surface mining. Also, nowadays many old underground coal mines are converted to do the mining with surface mining methods. In that kind of coal mining project, additional costs occur, which require further investigation and a modified cost model can be developed following the first-principles approach.

8.6 Recommendations

The framework and cost model for estimating operating costs were developed for the surface coal mining having drill and blast with truck and shovel mining system. This framework and cost model can be used in cost estimation for mining projects with characteristics like those that were discussed in the research. Before carrying out the operating cost estimation through the first-principles methods; the project must be broken down to different operation and activity-based and then based on equipment, materials, and labour; the cost can be estimated for different operations and hence overall operating cost can be estimated by adding the costs against all operations.

9 References

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Appendix-I

Mine Operating cost estimate questionnaire

*Required

1. **Name** *

2. **Email** *

3. **Educational Qualification** *

Mark only one oval.

- Graduate
- Postgraduate
- Doctorate
- Other:

4. **Accreditation** *

Tick all that apply.

- ECSA Registered
- Mining Manager ticket
- GCC
- SAIMM Registered
- Others

5. **Mining Industry Experience** *

Mark only one oval.

- <5 years
- 5-10 years
- 10-15 years
- >15 years

6. **Exposure to cost estimation**

Mark only one oval.

- Yes
- No

Operating cost Estimation Questionnaire

7. **What are the top five operating cost component of surface coal mining, Rate from 1 to 5 (1 is the most significant and 5 is the least significant component)? ***

Mark only one oval per row.

	Drilling Cost	Blasting cost	Loading cost	Hauling cost	Anciliary cost	Management and Technical Services	Others
1	⬭	⬭	⬭	⬭	⬭	⬭	⬭
2	⬭	⬭	⬭	⬭	⬭	⬭	⬭
3	⬭	⬭	⬭	⬭	⬭	⬭	⬭
4	⬭	⬭	⬭	⬭	⬭	⬭	⬭
5	⬭	⬭	⬭	⬭	⬭	⬭	⬭

8. **Is there any other major component excluding the top five indicated above, if yes, please specify? ***

____

____

____

____

____

9. **The three most applicable components of drilling costs are ***

Tick all that apply.

- [ ] Fuel cost
- [ ] Tyres/ Crawler cost
- [ ] Operators cost
- [ ] Parts repairs and maintenance
- [ ] Consumables (Drill bits/ GET/ explosives)
- [ ] Others

10. **The three most applicable components of blasting costs are ***

Tick all that apply.

- [ ] Fuel cost
- [ ] Tyres/ Crawler cost
- [ ] Operators cost
- [ ] Parts repairs and maintenance
- [ ] Consumables (Drill bits/ GET/ explosives)
- [ ] Others

11. **The three most applicable components of loading costs are ***

Tick all that apply.

- [ ] Fuel cost
- [ ] Tyres/ Crawler cost
- [ ] Operators cost
- [ ] Parts repairs and maintenance
- [ ] Consumables (Drill bits/ GET/ explosives)
- [ ] Others

12. **The three most applicable components of hauling costs are** *

Tick all that apply.

- [ ] Fuel cost
- [ ] Tyres/ Crawler cost
- [ ] Operators cost
- [ ] Parts repairs and maintenance
- [ ] Consumables (Drill bits/ GET/ explosives)
- [ ] Others

13. **The three most applicable components of ancillary costs are** *

Tick all that apply.

- [ ] Fuel cost
- [ ] Tyres/ Crawler cost
- [ ] Operators cost
- [ ] Parts repairs and maintenance
- [ ] Consumables (Drill bits/ GET/ explosives)
- [ ] Others

14. **Total operating cost of a surface coal mine could be (in ZAR/ m3 of excavation)?** *

Mark only one oval.

- ◯ <30 ZAR/ m3
- ◯ 30-40 ZAR/ m3
- ◯ 40-50 ZAR/ m3
- ◯ 50-60 ZAR/ m3
- ◯ 60-70 ZAR/ m3
- ◯ 70-80 ZAR/ m3
- ◯ >80 ZAR/ m3
- ◯ Unknown

15. **Drilling cost as percentage of total operating cost is** *

Mark only one oval.

- ◯ 0-5
- ◯ 5-10
- ◯ 10-15
- ◯ 15-20
- ◯ 20-25
- ◯ 25-30
- ◯ 30-35
- ◯ 35-40
- ◯ 40-45
- ◯ 45-50
- ◯ >50
- ◯ Unknown

16. **Blasting cost as percentage of total operating cost is** *

Mark only one oval.

- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- 30-35
- 35-40
- 40-45
- 45-50
- >50
- Unknown

17. **Hauling cost as percentage of total operating cost is** *

Mark only one oval.

- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- 30-35
- 35-40
- 40-45
- 45-50
- >50
- Unknown

20. **Management and technical services cost as percentage of total operating cost is** *
Mark only one oval.

- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- 30-35
- 35-40
- 40-45
- 45-50
- >50
- Unknown

21. **What is your opinion on recommending the first principle approach for estimating mine operating cost** *
Mark only one oval.

- Highly recommended
- Recommended
- Recommended upto some extent
- Not recommended

22. **Please specify if you have any further comment on mine operating cost estimates** *

Appendix-II

Mine Operating cost estimate questionnaire

*Required

1. **Name** *

Operating cost Estimation Questionnaire

2. **Total operating cost of a surface coal mine producing 75000 tonnes per month with stripping ratio of ~4.5 (m3 : t) with in-pit dumping could be (in ZAR/ m3 of excavation)?** *

   Mark only one oval.

   - <30 ZAR/ m3
   - 30-40 ZAR/ m3
   - 40-50 ZAR/ m3
   - 50-60 ZAR/ m3
   - 60-70 ZAR/ m3
   - 70-80 ZAR/ m3
   - >80 ZAR/ m3
   - Unknown

3. **Drilling cost as percentage of total operating cost is** *

   Mark only one oval.

   - 5-8
   - 8-11
   - 11-14
   - 14-17
   - 17-20

4. **Blasting cost as percentage of total operating cost is** *

   Mark only one oval.

   - 10-13
   - 13-16
   - 16-19
   - 19-22
   - 22-25

5. **Hauling cost as percentage of total operating cost is** *
Mark only one oval.

- 20-25
- 25-30
- 30-35
- 35-40
- 40-45
- 45-50

6. **Loading cost as percentage of total operating cost is** *
Mark only one oval.

- 5-9
- 9-13
- 13-17
- 17-21
- 21-25

7. **Ancillary cost as percentage of total operating cost is** *
Mark only one oval.

- 0-4
- 4-8
- 8-12
- 12-16
- 16-20

8. **Management and technical services cost as percentage of total operating cost is** *
Mark only one oval.

- 0-2
- 2-4
- 4-6
- 6-8
- 8-10

9. **Please specify if you have any further comment on mine operating cost estimates** *

Appendix-III

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF MECHANICAL, INDUSTRIAL AND AERONAUTIAL ENG. ETHICS COMMITTEE
CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: MIAEC 034/19**

PROJECT TITLE	Development of a framework for estimating operating costs on a surface, coal mining project
INVESTIGATOR	Mr Alok Kumar
SCHOOL/DEPARTMENT OF INVESTIGATOR	Mechanical, Industrial and Aeronautical Engineering
DATE CONSIDERED	15 Month 2019
DECISION OF THE COMMITTEE	Approved unconditionally
EXPIRY DATE	Date of submission of the project report

ISSUE DATE OF CERTIFICATE 19 Month 2019 **CHAIRPERSON** ________
(Dr. Emwanu)

cc: Supervisor : Mrs. Teresa Hattingh

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** returned to the Chairperson of the School/Department ethics committee.

I fully understand the conditions under which I am are authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Alok Kumar
Signature **Date** 26 / 03 / 2019

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES