Economic Evaluation of Drilling and Blasting on the Dragline Dig-ability

By

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Executive Summary

Landau Colliery is one of Anglo Thermal Coal’s mines that want to investigate the economic impact of both the drilling and blasting process on the overburden removal process (Dragline), they want to know how the drilling process, blasting process and the earth removal process economically affect the mine. The project is based at Kromdraai opencast, one of the mine’s sections which is situated in Witbank. The project is done in order to improve productivity and the cost incurred on both processes, since the mine is spending more cash on the three processes where as the productivity does not improve. The mine considered making investments on both processes; however the project analysis will assist the company to make a decision, as to which process to invest in.

During the investigation factors affecting each of the three processes will be considered in order to determine the root cause of the problems. Factors such as spacing, drill hole diameter, bench height, explosive amount, rock density etc will be considered during the analysis. Statistical and cost analysis will be used as the tools to solve the productivity and cost problems experienced at Landau Colliery. Statistical analysis will be done on accuracy, fragmentation, and dig-ability and cost analysis on the ground engagement tools. The solutions to the problems will be developed with the help of the studies that were done by other authors and by the company on fragmentation, accuracy, and dig-ability.
Acronyms

ANFO  Ammonium Nitrate Fuel Oil
BCM  Bend Cubic Meters
DOH  Direct Operating Hours
ROM  Run of Mine
GET  Ground Engagement Tools
UGS  Underground workings
UCS  Unconfined Compressive Strength
VOD  Velocity of Detonation
RBS  Relative Bulk Strength
E  Young’s Modulus
V  Poisson’s Ratio
STDEV  Standard Deviation
Min  Minimum
Max  Maximum
CB  Central Block
Definitions

Fragmentation: Fragmentation is the process of separating the overburden into fine smaller particles, which will be removable by the dragline.

Dig-ability: Dig-ability is the ability of the dragline to remove earth.

Detonation: Detonation is the violent release of energy by chemicals, which indicates that the reaction is moving through the explosive faster than the local speed of sound in the not reacted explosive creating a shock wave.

Virgin ground: the area or ground was not mined using the underground methods before.
List of Sources

- Dragline Opco Report [Appendix B]
- Tritronics Report [Appendix D]
- Blasting Report [Appendix D]
- Drilling Report [Appendix D]
- Planning Department
- Survey Department
- Geology Department
- Rock Engineering Department
- Electrical & Mechanical Engineering Department
- Mining Department
Table of Contents

1 Introduction and Background ........................................................................................................... 1

2 Project Aim ...................................................................................................................................... 2

3 Project Scope .................................................................................................................................. 3

3.1 Coal mining processes (in sequence) .............................................................................................. 3

3.2 Diagram of mining processes ......................................................................................................... 4

4 Problem Statement .......................................................................................................................... 5

4.1 Measures and linkage of the three processes ............................................................................... 6

4.2 Input/output of the three processes ............................................................................................... 7

4.3 Examples of the three processes ................................................................................................... 8

4.4 Problems or findings and causes .................................................................................................. 10

4.4.1 Problems on the Drilling process ............................................................................................. 10

4.4.2 The above problem is caused by the following: ...................................................................... 10

4.4.3 Problems associated with the blasting process ........................................................................ 10

4.4.4 Causes to problem .................................................................................................................... 10

4.4.5 Earth removal process problems ............................................................................................. 11

5 Deliverables ..................................................................................................................................... 12

6 The project environment and Literature study ............................................................................... 13

6.1 The project environment .............................................................................................................. 13

6.2 Literature study ........................................................................................................................... 14

6.2.1 Drilling ..................................................................................................................................... 14

6.2.2 Blasting .................................................................................................................................... 14

6.2.3 Parameters influencing fragmentation ..................................................................................... 15

6.2.4 Crucial factors influencing fragmentation .............................................................................. 15

7 Cost incurred due to problems ........................................................................................................ 20
14.1 Drilling Process........................................................................................................................................46
  14.1.1 Drilling Accuracy..................................................................................................................................46
  14.1.2 Improve the blast geometry ................................................................................................................46
14.2 Blasting process........................................................................................................................................46
14.3 Earth Removal Process ............................................................................................................................47
14.4 Solutions summary ....................................................................................................................................47
15 Improvement opportunities ..........................................................................................................................48
  15.1 Re-Drilling and Re-Blasting .......................................................................................................................48
  15.2 Other improvements ...................................................................................................................................48
16 Final design test and validation .......................................................................................................................49
17 Conclusion .....................................................................................................................................................50
18 Recommendations .........................................................................................................................................52
19 References .....................................................................................................................................................53
20 Appendices ..................................................................................................................................................55
  20.1 Appendix A ................................................................................................................................................55
  20.2 Appendix B ................................................................................................................................................57
  20.3 Appendix C ................................................................................................................................................58
  20.4 Appendix D ................................................................................................................................................61
  20.5 Appendix E ................................................................................................................................................63
  20.6 Appendix F ................................................................................................................................................64
  20.7 Appendix G ................................................................................................................................................65
  20.8 Appendix H ................................................................................................................................................66
  20.9 Appendix I ................................................................................................................................................67
  20.10 Appendix J ...............................................................................................................................................68
List of Figures

Figure 1: Geological Plan .................................................1
Figure 2: Old Underground Plan ...........................................1
Figure 3: Top Soil Stripping ..............................................4
Figure 4: Drilling Process ..................................................4
Figure 5: Blasting Process ..................................................4
Figure 6: Earth Removal Process .........................................4
Figure 7: Measures/Linkage of the three processes .......................6
Figure 8: Input/output of the three processes ............................7
Figure 9: Overburden Layers .............................................8
Figure 10: Drill Hole Accuracy ...........................................8
Figure 11: Blasting Process ...............................................9
Figure 12: Fragment size ...................................................9
Figure 13: Powder Factor Equation .....................................16
Figure 14: Charge Weight Equation .....................................16
Figure 15: Stemming Height ..............................................17
Figure 16: Landau Colliery Drilling Machines ..........................20
Figure 17: Accumulative Percentage and Consumables Amount ..........23
Figure 18: Landau Colliery Dragline ....................................24
Figure 19: Methodology ....................................................30
Figure 20: Fragment Size Equation ......................................31
Figure 21: Overburden and Coal layers ..................................34
Figure 22: Rock Characteristics .........................................36
Figure 23: 45 degree drill Pattern .......................................38
Figure 24: blasting method (Top Priming) ...............................39
Figure 25: Fragment Size and Blast Geometry ..........................41
Figure 27: Fragment size stark graph ...................................43
Figure 28: Average fragment size .......................................51
List of Tables

Table 1: Drilling cost .................................................................................................................................................21
Table 2: Explosives cost...............................................................................................................................................22
Table 3: Dragline cost ...................................................................................................................................................25
Table 4: Dragline cost ...................................................................................................................................................25
Table 5: Cost Summary ................................................................................................................................................26
Table 6: Fragment size v/s Dragline performance ........................................................................................................27
Table 7: Explosives (ANFO) Summary ........................................................................................................................33
Table 8: Sandstone Summary ......................................................................................................................................35
Table 9: Blast Geometry Summary .............................................................................................................................37
Table 10: Fragmentation prediction parameters ........................................................................................................40
Table 11: Fragment size count ....................................................................................................................................44
Table 12: Cost Summary & Improvement Opportunities ..........................................................................................48
1 Introduction and Background

Landau Colliery is situated on the old coronation Colliery Kromdraai section and the old Navigation Colliery mine site, which is 30 kilometers west of Witbank. These coal resources form part of the Witbank coalfields, exploited before the turn of the century. Kromdraai is an open cast coal mine, where 1 seam and 2 seam separated by a parting which is ± 600mm thick are mined. 1 seam was mined using the underground methods from 1926-1966. The inaccuracy of the old underground plans has a major effect on the drilling and blasting performance due to the fact that the pillars were never off-set.

Landau Colliery mines two types of coal, thermal coal and metallurgical coal. Both types of coal are exported and sold to local markets. 30 percent of coal production comes from mini-pit operations, they are Schoongezicht, Excelsior and Umlalazi, and all mini-pit operations are under Benicon contractors. The other 70 percent of coal production comes from Kromdraai colliery.

The coal is mined at Kromdraai colliery and gets sent through a crushing plant. It is then transported to the Navigation DMS washing Plant which is 25 km away from Kromdraai colliery by rail. The coal is washed at Navigation, stale piled and transported from there to the market. From here the coal is then transported by rail to Richards bay coal thermal where it gets exported by ship. The coal from the pits is defined as ROM (Run of Mine) which is raw coal or unwashed coal. Landau Colliery achieves a saleable yield of ± 56 percent on their ROM tons.

Figure 1: Geological Plan  
Figure 2: Old Underground Plan
2 Project Aim

An economic evaluation will be done on the drilling, blasting and on the overburden removal process (dragline) by looking at the effects of the drilling and blasting process on the overburden removal process. The company needs a model that they will use to predict overburden fragment size, which will determine how much spacing, burden, bench height and explosives in certain geological conditions should they use that will have less impact on the dragline. The aim is:

- To minimize cost incurred during the overburden removal from the drilling process to the overburden removal process
- To determine which of the three processes (Drilling, Blasting or Overburden removal) the company should invest in
- To improve productivity
3 Project Scope

The project take place at Landau Colliery (Kromdraai), one of the Anglo Thermal Coal mines. There are studies done on fragmentation of the overburden and on drilling and blasting by some of the engineers from Anglo Coal. Factors like the geological conditions, the drilling process measures like drill hole accuracy (drill hole position and depth), the blasting process measures like the powder factor, the charge length, the amount of explosives used per charge (blast) will be considered and the overburden fragment size will be determined to improve productivity and cost. And on the overburden removal process measures like the dig-ability, dragline rope life, dragline bucket life, dragline bucket teeth life, operational cost and engineering cost will also be considered.

Factors such as the distance between the drilled holes (spacing) will not be considered in this case since the drilling pattern is constrained by the old underground plan, but in a virgin ground the blast geometry is one of the most important parameters to consider when predicting fragmentation. The hilited mining processes indicate the scope of the project as to what processes are under the scope of the project. Figures 4, 5 and 6 in the next page shows a schematic drawing of the hilited mining processes under the scope of the project. Figure 2 shows the top soil removal process which is the first step of the overburden removal.

3.1 Coal mining processes (in sequence)

- Top soil removal
- Survey (drill hole demarcating)
- Drilling process
- Blasting process
- Earth removal process
- Loading and hauling
- Crushing process
- Washing process and Stale piling process
3.2 Diagram of mining processes

Figure 3: Top Soil Stripping

Figure 4: Drilling Process

Figure 5: Blasting Process

Figure 6: Earth Removal Process
4 Problem Statement

Evaluating the Impact of the Drilling and Blasting Process on Dragline Productivity and the Cost incurred due to damages on the Ground Engagement Tools. Landau Colliery considered making investments on the three processes to improve productivity and the cost of removing the overburden. Landau Colliery wants to find out which of the three processes they should invest in. The question they are asking themselves are whether they should invest in the drilling process to improve accuracy or the blasting process to improve fragmentation and dig-ability on the dragline or the overburden removal process to improve the cost incurred due to damages on the Ground Engagement Tools (GET) or on the GETs used during overburden removal or both the drilling and blasting process, since the overburden removal process depend on both the drilling and the blasting process. Statistical analysis and cost analysis will be used as tools for the problem solving.
4.1 Measures and linkage of the three processes

Figure 7: Measures/Linkage of the three processes

Figure 7 illustrate the measures of the three processes, however accuracy is the measure for the drilling process, powder factor and fragmentation are the measures for the blasting process, and dig-ability is the measure for the overburden removal process. The figure also shows that there are effects and cost incurred on the both processes and productivity on the overburden removal process. There are three ways in which fragmentation can be improved, either by improving accuracy, increasing the powder factor, or either by improving accuracy and powder factor. Fragmentation has a major impact on productivity, improving fragmentation will yield an improvement on production in terms of the volume of the overburden removed and the volume of coal exposed per cycle time and cost will also be improved. The company needs a model that will tell them how much it will cost if they pull some leavers, in terms of the amount of explosives used or changing the blast geometry for the area to be charged.
4.2 Input/output of the three processes

The three processes are dependent on each other as shown in figure 8, the blasting process depends on the drilling process, since the output of the drilling process is the input to the blasting process, so as the overburden removal process depends on both processes, Since the processes are dependent on each other, whatever effects on each of the processes affect the next process.

Figure 8: Input/output of the three processes
4.3 Examples of the three processes

Figure 9: Overburden Layers

Figure 9 shows the overburden layers after the top soil removal process and the survey process. The overburden is formed by weathered sandstone, hard sandstone, and shale.

Figure 10: Drill Hole Accuracy

Figure 10 shows a surveyor checking the drill hole accuracy. The figure also shows how the area to be charged looks like after the drilling process. The surveyors check if the drill hole is drilled at the right position, and the miner check the drill hole depth as shown in figure 10 below.
Figure 11: Blasting Process

Figure 11 shows the overburden after the drilling process and before the blasting process. Figure 11 also shows an operator measuring the hole temperature, which is the procedure that has to be followed before the holes are charged by explosive during the blasting process.

Figure 12: Fragment size

Figure 12 above shows an example of the fragments, by fragment size we are referring to the size of the blasted stones which is referred as the overburden.
4.4 Problems or findings and causes

4.4.1 Problems on the Drilling process

- Inaccurate hole in terms of position and hole depth
  - An inaccurate is a hole drilled through to the underground workings, a short hole, a hole drilled not according to the plan, a hole not drilled on the mark demarcated by the surveyors.

4.4.2 The above problem is caused by the following:

- Manual machining
- Survey mark not visible
- Underground plan versus the actual plan
- Operators stop drilling before the hole depth is reached

4.4.3 Problems associated with the blasting process

- Incorrect amount of explosives
  - A amount of explosives used, failing to fragment the overburden due to the fact that there is no enough energy required to fragment the overburden. The energy ratio compared to the rock strength ratio is smaller or not large enough.

4.4.4 Causes to problem

- The problems experienced in the drilling process are carried over to the blasting process, where the powder factor calculations done does not correspond with the blasting geometry, since the calculations are done without considering any errors that are done during the drilling process.
For an example a drill hole drilled on the incorrect position, which changes the blasting geometry resulting incorrect powder factor calculations.

Due to the fact that only powder factor is considered as the driving factor for the explosives amount, factors like the charge length are not considered, however they also plays an important role during the overburden fragmentation, however if such factors are not considered, they lead to poor fragmentation and poor fragmentation leads to re-drilling and re-blasting which cost the company.

Poor workmanship with regards to extension of drill rods also has effect on fragmentation, resulting capping which damages the ground engagement tools.

4.4.5 Earth removal process problems

- Bigger fragments
- Damages to GETs
- Re-handling
5 Deliverables

After the completion of the project, the following activities should be accomplished:

- Amount of explosives to be used in a drilled hole of a certain depth to achieve the required fragmentation
- The process which the company should invest in to improve dig-ability
- The amount the company should invest in each process
- A model which the company can use to predict fragmentation and cost
6 The project environment and Literature study

6.1 The project environment

A number of studies have been done on the topics, powder factor and fragmentation, drill pattern and dig-ability. The methodology of solving the problem was selected with the help of the studies already done. Several ideas and methodologies were applied by different authors to improve fragmentation, some considered the drill pattern and hole diameter, powder factor, rock type and its properties, explosive type and its properties and the amount of explosives used in kilograms per square meter, and the blasting method depending on which factors the author based the problem.

This project is based on drilling accuracy, powder factor and the amount of explosives used in kilograms per square meter to improve fragmentation, dig-ability and other factors having influence on fragmentation as well as the cost incurred. The Industrial Engineering methodology used to solve the problem is a Monte Carlo simulation. Several mines used Monte Carlo Simulation to solve a similar problem as that of Landau Colliery.
6.2 Literature study

6.2.1 Drilling

Drilling accuracy is one of the most important factors during the drilling process; however inaccuracy has a large impact on the fragmentation quality produced. As discussed in the dependence diagram earlier in the report fragmentation is dependent on both the drilling and blasting process. Drill pattern also has an influence on the fragment size produced during blasting.

Drilling effects on fragmentation

- Short holes
  - Impact the powder factor calculation
  - Limits the amount of explosives used
- Inaccurate drill holes (drill hole position and depth)
  - Impact the powder factor calculations
  - Limits the amount of explosives used
- Drill hole size (drill hole diameter)
  - Bigger diameter has effect on the velocity of detonation of the explosives
  - Requires a large amount of explosives which increases the explosive cost

6.2.2 Blasting

The proper overburden fragmentation is dependent on the charge length and the amount of explosive used, however the explosive amount depends on the powder factor, however the powder factor depends on spacing, burden, and bench height. The amount of explosives used should be adequate for rock fracturing to a fragment size easily removed by the earth removing machine equipment. Rock properties such as density, porosity, strength, and energy absorption affect fragmentation.
Explosive properties such as velocity of detonation, density, detonation pressure, borehole pressure, and water resistance also affect fragmentation. Explosive density is the ratio of explosive density to the density of water. The effectiveness of blasting is dependent on the correct amount of explosives used to the volume of overburden to be fragmented. The relationship is called powder factor, for strong sandstone a powder factor of 1.1 is required.

- Hot holes
  - Hot holes have an effect on the powder factor calculation during the blasting process, since they are not included in the calculations and charged, but the area around hot holes is also blasted. Factors like bench height and spacing plays an important role in the powder factor calculation.

**6.2.3 Parameters influencing fragmentation**

- Rock mass properties (in situ block size, unconfined compressive strength, young’s modulus, Density)
- Blast geometry (hole depth, burden, spacing, hole diameter sub-drill, stemming height)
- Explosive properties (velocity of detonation, relative weight strength, density)

**6.2.4 Crucial factors influencing fragmentation**

- Powder factor
- Spacing
- Stemming depth
- Rock properties
6.2.4.1 Powder factor

Powder factor is the factor that limits the amount of explosives used, meaning the amount of explosives used depends on the powder factor, the smaller the powder factor the lesser will be the amount of explosives used per blast area. Having fewer amounts of explosives results less explosive energy released. The powder factor has effect on the blasting process, or is an element of the blasting process.

The equation for calculating powder factor is as follows:

\[
K = \frac{Qe}{(B)(S)(H)}
\]

Where
- \( K \) = powder factor (kg per cubic meter)
- \( B \) = burden (m)
- \( S \) = spacing (m)
- \( H \) = bench height (m)
- \( Qe \) = charge weight (kg)

Figure 13: Powder Factor Equation

The equation for the charge weight is as follows:

\[
Qe = \frac{1000\pi r^2 L \rho_e}{\rho_e}
\]

Where
- \( Qe \) = charge weight (kg)
- \( r \) = hole radius (m)
- \( L \) = charge length (m)
- \( \rho_e \) = explosive specific gravity

Figure 14: Charge Weight Equation
6.2.4.2 Spacing
Spacing is the space between two drill holes. If a hole is not drilled to the correct position, has an effect on the spacing, since when calculating the powder factor the spacing is taken as a constant value, which on theory the powder factor is correct but practically it isn’t. Spacing is the element of the drilling process.

6.2.4.3 Stemming depth
Stemming depth is an element of the blasting process. The greater the stemming depth, the smaller will the volume in the hole to be filled with explosives. Since the hardest stone is sandstone which is found at top layer of the overburden as shown in figure 15 below, meaning that a smaller portion of sandstone is exposed to explosives.

Figure 15: Stemming Height
6.2.4.4 Rock properties

In common sense larger equipment are not made for handling larger fragments or larger product, but they are made for handling a larger volume of material. During the fragmentation process factors playing an important role are both the dynamic stress induced by the detonation and the expanding gases produced by the explosives. The amount of damage caused by the explosives or strength reduction varies with the distance from the explosive charge, meaning the longer the distance the smaller the strength reduction gets.

Consequently the extent of the gas pressure induced damage can be expected to decrease with depth below surface, and surface structures such as the slope will be very susceptible to gas pressure induced blast damage. Another cause of blast damage is that of fracturing induced by release of load. Poor blasting encourages pit wall instability. Scatter in the delay times used in open pit blasting systems can cause the blast hole to fire out of sequence, and this can produce poor fragmentation. Good fragmentation is noticed in closely jointed rocks, however if the joints are widely separated the chances of getting poor fragmentation increases. In widely jointed rocks, the average block size is more; hence more explosive energy must be utilized to obtain the desired product size. Whereas in thinly bedded rocks the explosive energy required would be less if a similar size of the product is to be obtained. Whereas is the opposite with thinly jointed rocks.

An ideally fragmented rock is the rock that does not require feather treatment after the blasting process. The oldest theory of Rittinger (1867) states that the energy consumed in size reduction is proportional to the reduction in particle size. It is evident from the studies some authors have done that the greater the explosive energy utilized in blasting; the finer will be the product or the smaller will be the fragment size. As stated by some authors that the product size does not only depend on the explosive energy input but also the initial size of the rock to be fragmented.
6.2.4.5 Explosives characteristics

Detonation is the violent release of energy by chemicals, which in explosives, it indicates that the reaction is moving through the explosives faster than the local speed of sound, hence in the explosive that are not reacted it creates shock waves. The work done by the explosive depends on both the shock energy and the expanding gas produced by the explosion. The reaction equation for ANFO the simple blasting agent mixture describes the relationship of oxygen balance, detonation products, and the heat released per gram of ANFO, however the energy released depends on the amount of reactant used.

\[ 6\text{NH}_4\text{NO}_3 + \text{CH}_3 + 2\text{Al} \rightarrow \text{Al}_2\text{O}_3 + 13\text{H}_2\text{O} + \text{CO}_2 + 6\text{N}_3 \approx \text{kcal per gram} \]

The major properties of an explosive are detonation pressure and borehole pressure which is also called explosive pressure. Detonation pressure is the pressure of the detonation wave propagating through the explosive column. Borehole pressure is the pressure exerted on the borehole walls by the expanding gases of detonation after the chemical reaction has been completed. Borehole pressure is considered to be the dominant in breaking softer or weaker rocks and displacing all types of rocks encountered in blasting. ANFO and other explosives with aluminum produce low detonation but higher borehole pressures.
7 Cost incurred due to problems

7.1 Drilling cost

7.1.1 Drilling machine parts

![Drilling Machines](image)

Figure 16: Landau Colliery Drilling Machines

The figure 16 shows two drilling machines that are used at Landau Colliery, each machine has three drill rods as shown by the arrows and numbers 1 to 3 in the diagram. Meaning if the fragmentation model developed portrays that the 250mm drill rod should be replaced with a smaller drill rod e.g. of 150mm diameter to achieve a smaller fragment size six drill rods, three for each drilling machine must be bought and two drill bits one for each drilling machine. The cost of replacing the drill rods and drill bits is also included. However the drilling cost in meters drilled will remain the same since the same depth in meters has to be drilled.
### Table 1: Drilling cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill rod &amp; Bit</td>
<td>R 3 115 038.00</td>
</tr>
<tr>
<td>Drilling Cost per meter</td>
<td>R 98.81</td>
</tr>
<tr>
<td>Drilling Cost @ Ave of 2255 holes</td>
<td>R 222 816.55</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>R 3 337 854.55</strong></td>
</tr>
</tbody>
</table>

#### 7.1.2 Drilling calculated cost

The drilling cost above is calculated by using a statistical cost analysis, where past information about the drilling cost and the number of drill holes drilled per year is used to determine the average number of drill holes drilled per year, the average drill hole depth and the average drilling cost per meter.

- **Cost of drilling each hole:**
  - 49R R/m + Drill-Tech R/m = 43.39 + 55.52 = 98.91 R/m
  - The drilling cost equation above shows how the drilling cost is calculated. The drilling cost of each drill hole is the sum of the drilling cost by the 49R drilling machine and the drill tech drilling machine, where a picture of the 49R drilling machine is shown in figure 13 in the previous page and the drill Tech drilling machine is a smaller drilling machine operating by diesel with a 110mm drill rod.
7.2 Explosives cost

7.2.1 Consumables and cost of blasting a hole

<table>
<thead>
<tr>
<th>Consumables</th>
<th>Cost per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANFO (kg)</td>
<td>R 3.93</td>
</tr>
<tr>
<td>Booster Pentolite</td>
<td>R 19.77</td>
</tr>
<tr>
<td>Bench Master (30mx450m/s)</td>
<td>R 42.20</td>
</tr>
<tr>
<td>Handidets (12mx42m/s)</td>
<td>R 22.60</td>
</tr>
<tr>
<td>Handidets (15mx42m/s)</td>
<td>R 20.23</td>
</tr>
<tr>
<td>Lead In</td>
<td>R 232.08</td>
</tr>
<tr>
<td>IED</td>
<td>R 3.24</td>
</tr>
<tr>
<td>Menta Lock</td>
<td>R 27.35</td>
</tr>
</tbody>
</table>

**TOTAL ANNUAL COST ON CONSUMABLES**

R 32 519 354.00

**Blasting Cost**

<table>
<thead>
<tr>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/Hole @ Ave 22.26m</td>
</tr>
<tr>
<td>Cost/year @ Ave 2255 of Holes</td>
</tr>
</tbody>
</table>

**TOTAL COST PER ANNUM**

R 43 344 278.55

Table 2: Explosives cost

7.2.2 Blasting calculated cost

The cost of blasting each hole at an average of 22.26 meters is calculated by using the past information on blasting gathered during the course of the project, where the number of drill holes charged in each year are determine and used to calculate average number of charged and blasted in a year and the blasting cost per year is determined.
7.2.3 Blasting Process Consumables quantity

Figure 17: Accumulative Percentage and Consumables Amount

Figure 17 above shows the blasting consumables, the cost of each and the accumulative percentage cost of each consumable. As illustrated in the figure above the consumable with the highest cost is ANFO, and according to the model to achieve a smaller fragment size after the ANFO is to be used its properties especially the density should be upgraded, meaning a new contract between Landau Colliery and AEL the explosive company should be drafted with new specifications.

- Original cost of charging + Additional cost = Average blasting cost per drill hole
  - The equation above shows how the average blasting cost is calculated; the average blasting cost is the sum of the original cost of charging a drill hole and the additional cost of charging drill holes, where the additional cost is the cost incurred during re-blasting.
7.3 Dragline cost

7.3.1 Crucial dragline parts

Figure 18: Landau Colliery Dragline

Figure 18 shows a dragline used at Landau Colliery, with the arrows and numbers 1 and 2 showing the dragline ropes, numbers 3 and 4 showing the dragline bucket and bucket teeth respectively. The parts shown in the diagram are the most important part of the dragline which their life spent is dependent on the fragment size, and the coal production is dependent on the drilling, blasting and earth removal process. There is one dragline (earth removing machine) available at the mine. The bucket capacity of the dragline is 71.87 cubic meters. The dragline rope diameter is 95.25 standard.
7.3.2 Cost of dragline parts

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost Per Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dragline bucket Tooth x 6</td>
<td>R 76 944.00</td>
</tr>
<tr>
<td>141 meter Drag Rope</td>
<td>R 127 198.55</td>
</tr>
<tr>
<td>145 meter Drag Rope</td>
<td>R 130 388.29</td>
</tr>
<tr>
<td>141 meter Hoist Rope</td>
<td>R 202 407.73</td>
</tr>
<tr>
<td>145 meter Hoist Rope</td>
<td>R 205 702.98</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>R 742 641.55</strong></td>
</tr>
</tbody>
</table>

Table 3: Dragline cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dragline Bucket Teeth &amp; Ropes</td>
<td>R 5 869 396</td>
</tr>
<tr>
<td>Dragline - Electrical</td>
<td>R 2 506 762</td>
</tr>
<tr>
<td>Dragline - Mechanical</td>
<td>R 14 544 857</td>
</tr>
<tr>
<td>Specials &amp; Others Repairs</td>
<td>R 2 140 515</td>
</tr>
<tr>
<td><strong>TOTAL ANNUAL COST</strong></td>
<td><strong>R 23 135 530</strong></td>
</tr>
</tbody>
</table>

Table 4: Dragline cost

The dragline bucket cost a million rand, however in a good run the dragline bucket is changed every three months. The bucket tooth cost R 12 824.00, where each dragline bucket requires six (6) solid teeth. The dragline ropes are separated into two sets, drags and hoist which in each set there is 141 and 145 meters rope. However each 141m drag rope cost R 127 198.55, a 145m cost R130 388.29, each 141m hoist rope cost R202 407.73 and a 145m cost R 205 702.98. There is also a rigging cost on the bucket which is charged per total cubic meters moved by the dragline per period, where the rigging cost depends on the price of steel from the suppliers.
If the steel price goes down the rigging cost goes down and vise versa. The cost of moving the overburden is also charged per total cubic meters moved by the dragline bucket per period. The electrical and mechanical cost include the electrical and mechanical special costs and stores, where the special cost are the costs of the small parts that can be purchased in any store i.e. pick n Pay, where the store are the parts that are purchased from the suppliers and kept at the stores. There are also WCS electrical and mechanical costs.

7.4 Cost Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Cost</td>
<td>R 3 337 854.55</td>
</tr>
<tr>
<td>Blasting Cost</td>
<td>R 43 344 278.55</td>
</tr>
<tr>
<td>Dragline Cost</td>
<td>R 23 135 641.55</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>R 69 817 663.10</strong></td>
</tr>
</tbody>
</table>

Table 5: Cost Summary
8 Relationship between fragment size and dragline performance

<table>
<thead>
<tr>
<th>Decrease in Fragment Size (cm)</th>
<th>Increase in Dragline Performance in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>5</td>
</tr>
<tr>
<td>180</td>
<td>10</td>
</tr>
<tr>
<td>160</td>
<td>15</td>
</tr>
<tr>
<td>140</td>
<td>20</td>
</tr>
<tr>
<td>120</td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 6: Fragment size v/s Dragline performance

Table 6 above shows the fragment size and the dragline performance in percentages; however the table shows the estimated percentages of the dragline performance estimated by the dragline specialist. The table also shows the relationship between the fragment size and the dragline performance. If the fragment size decreases from 220cm to 200cm the dragline performance increases by 5 percent and so on as seen in the table above.

The dragline performance model developed. Unfortunately there is no relationship model or studies done on fragmentation and the dragline performance so far, but the bucket fill factor can be used to form a relationship between the fragment size and the dragline performance. Referring to the stones and cup example describe early in the document, the volume of the overburden removed by the dragline of a specific fragment size can determine the relationship between the dragline performance and the fragment size in percentages.
9 Assumptions

- Landau Colliery (Kromdraai) has a virgin ground, meaning area was not mined before using the underground methods
- The coal will not be fines after the blasting process in all situations
- Stemming length is considered in the fragmentation model developed
- There are cracks and cavities leading to siphoning of explosives to the underground workings
- There is no menta lock failure due to the explosive over weight
- There are no misfires either by handidets fault from the factory, handidets not connected or handidets pinched by a rock and damaging insulation
10 Development of conceptual design

10.1 Industrial engineering methods and tools

A statistical analysis was used to solve the problem, where a stochastic model termed as Monte Carlo Simulation is developed. A sensitivity analysis was used to model the situation, where random values are used to evaluate fragmentation at different conditions for the three categories of fragmentation and their input parameters. Statistical control charts will be used to control quality of fragmentation during the test and test and validation of the fragmentation model designed.

10.2 Model formulation

During the modeling of fragmentation three categories of the rock mass characteristics were considered, an area with average rock mass characteristics, worst than average, and better than average. The correlation between the fragmentation simulation model and the dragline performance will be done by consulting dragline specialist from a company called GBI. A comparison between the results from the model and historical data of the three categories of rock mass characteristics will be done, considering all the factors influencing fragmentation including powder factor.

After the fragmentation analysis the dragline analysis will follow, which will be the dig-ability comparison between the historical dragline performance and the dragline performance of the modeled results. The analysis described above is a production related analysis, which a cost analysis will include the dragline cost incurred to remove earth in the three categories of rock mass characteristics, the amount of explosives used and the powder factor that was used as well as the blasting geometry. The most important analysis will be done last, which is the comparison between the three processes, drilling, blasting, and earth removal process as to which process(s) should the company invest in.
Figure 19: Methodology

Figure 19 illustrates the methodology that was used to solve the problem at kromdraaii. The methodology used is a Monte Carlo Simulation, with fixed and flexible variables as inputs and the average fragment size in a graph format as the output of the model. The output from the model has to be correlated with the dragline performance input in order to evaluate the dragline performance in terms of production and cost, where production and cost are the output of the dragline performance model, where production is calculated in bend cubic meters per DOH. Stochastic model or a Monte Carlo Simulation was used by most authors in several mines to predict fragmentation, similarly in this project a Monte Carlo simulation model will be used to predict fragmentation. Microsoft excel will be used as a tool for the modeling of the situation.

When modeling the situation using the Monte Carlo simulation variable and fixed inputs will be considered, where the rock mass properties are considered fixed and the rock mass properties are categorized in three categories, which are average, worst than average and better than average. However dragline specialists will be consulted for the guidelines on dragline performance and the fragmentation results from the simulated model in order to determine the relationship between fragment size and dragline performance.
The diagram above shows the three inputs rock mass properties, blast geometry and the explosive properties, each associated with a certain distribution. Random values will be generated in the model with specified ranges as inputs. The bucket full factor will then be used to compare the fragmentation results from the developed simulation model and the overburden volume removed as well as the volume of coal exposed by the dragline bucket in order to measure the dragline performance.

Monte Carlo simulation can be described as a simulation method where the simulation results are based on the model where the input values are developed randomly from representative statistical distributions that describe those inputs. And the results themselves describe a statistical distribution. A Monte Carlo simulation method is used where there is uncertainty in the inputs, and the calculated uncertainty of the results reflects the uncertainty of the input data.

The equation for calculating fragment size is as follows:

\[ X_m = A(K)^{-0.8}(115/S_{anfo})^{0.8}(Q)^{1/6} \]

Where:

- \( X_m \) is the average fragment size (cm)
- \( A \) is the rock factor
- \( K \) is the powder factor (kg of explosives/m³)
- \( S_{anfo} \) is the relative weight strength of the explosives relative to ANFO

Figure 20: Fragment Size Equation
11 Supplementary methods

The Ruz-Ram model can be used to predict blast fragmentation. The model uses a single hole to predict fragmentation, with the same parameters as that used to predict fragmentation in a Monte Carlo simulation. The Ruz-Ram model can be used in one of two ways to predict the size distribution of the fragments.

1. It can predict the average size distribution for the entire blast from the average values of the input parameters.
2. It can predict the size distribution around a single hole from the actual values of the input parameters associated with that hole.

In real life the input parameters will have some variations associated with it; however average values of the input parameters or actual values around a single hole will not yield an accurate size distribution.
12 Data analysis

12.1 Blasting design (Procedure) hot holes

Hot holes are classified by the temperature in the hole which is above 40 degrees Celsius. Holes with temperature that is above 40 are not charged. Not charging a hole has an effect in the calculations of the powder factor. The effect brought by the hot hole in the calculation of the powder factor does not reflect the reality in terms of spacing length.

12.2 Current values of parameters influencing fragmentation

12.2.1 Explosive Properties

- Density ranges from 0.80 to 0.83 in kilograms per cubic meters
- Velocity of detonation ranges from 3600 to 4100 m/s
- Relative bulk strength is 100 at 20 mpa
- And the ideal delivery energy is 2.84 (mj/kg)

<table>
<thead>
<tr>
<th>Description</th>
<th>Density (kg/m³)</th>
<th>Velocity of Detonation (m/s)</th>
<th>Relative Bulk Strength (mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.82</td>
<td>3850.00</td>
<td>100@20</td>
</tr>
<tr>
<td>Min</td>
<td>0.80</td>
<td>3600.00</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0.83</td>
<td>4100.00</td>
<td></td>
</tr>
<tr>
<td>STDEV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Explosives (ANFO) Summary
Table 7 above shows the explosives summary of ANFO properties used at Landau Colliery during the blasting process. The fragment size predicted in the model is simulated with the values above, which are the explosive parameter.

12.2.2 Rock mass characteristics

The types of rocks available at the mine are sand stone, silt stone and the shale stone. The hardest rock of them all is sand stone followed by the silt stone and the last is shale stone. At the top of the overburden sand stone is found, below that are silt stone and the shale stone. 23.08 m is the average overburden depth at Kromdraai open pit. It is measured in volume of the overburden exposed by the dragline and by the swings. The surveyors use the width, depth and the length in a block to determine the overburden volume exposed. The width and length of a block is 60×100 meters. Dig-ability is dependent on fragmentation, the finer the overburden is fragmented the effective the dig-ability.
<table>
<thead>
<tr>
<th>Description</th>
<th>Density</th>
<th>Unconfined Compressive Strength</th>
<th>Young's Modulus</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>2.49</td>
<td>85.38</td>
<td>29.14</td>
<td>0.43</td>
</tr>
<tr>
<td>Min</td>
<td>2.48</td>
<td>83.30</td>
<td>26.50</td>
<td>0.38</td>
</tr>
<tr>
<td>Max</td>
<td>2.50</td>
<td>88.10</td>
<td>36.40</td>
<td>0.47</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.01</td>
<td>2.00</td>
<td>3.96</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 8: Sandstone Summary

Table 8 above shows the rock characteristics of sandstone summary at Landau Colliery. The table shows the minimum, average, maximum and the standard deviation of the characteristics. The above parameters shown above are the parameters regarded as fixed parameters since they can not be changed.
Figure 22: Rock Characteristics

The diagram above shows the rock characteristics distribution at Landau Colliery, where the rock properties was taken in each drill hole, however a sample of 4 drill holes were used.

12.2.3 Blast geometry

The drilling machines that are used for drilling holes have drill rods of 250 millimeters in diameter; therefore the diameter of the holes is 250mm, with the spacing of 12.2X6.1 meter square standard, the average stemming length of 4 meters, bench height ranges from 23-33 meters.
### Blast Geometry Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Hole Depth</th>
<th>Stemming Height</th>
<th>Burden</th>
<th>Spacing</th>
<th>Bench Height</th>
<th>Hole Diameter</th>
<th>Powder Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>21.81</td>
<td>4.27</td>
<td>12.20</td>
<td>6.10</td>
<td>28.00</td>
<td>250.00</td>
<td>0.49</td>
</tr>
<tr>
<td>Min</td>
<td>13.43</td>
<td>4.00</td>
<td>12.20</td>
<td>6.10</td>
<td>23.00</td>
<td>250.00</td>
<td>0.31</td>
</tr>
<tr>
<td>Max</td>
<td>25.00</td>
<td>9.00</td>
<td>12.20</td>
<td>6.10</td>
<td>33.00</td>
<td>250.00</td>
<td>0.76</td>
</tr>
<tr>
<td>STDEV</td>
<td>2.52</td>
<td>0.91</td>
<td>0.00</td>
<td>0.00</td>
<td>7.07</td>
<td>0.00</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 9: Blast Geometry Summary

Table 9 above shows the summary of the blast geometry at Landau Colliery as well as the powder factor values that have been used in the past years. The burden and spacing values are constant since they are constrained by the UGS.

#### 12.2.3.1 Drill pattern

Since the coal was mined using the old underground methods, the drill pattern is fixed. The drill pattern type that is used at Landau Colliery (Kromdraai) is called 45 degree angle. There are two R49 drilling machines used and a drill tech which is used to drill extra holes. The drill tech operates with diesel and is smaller than the R49. The R49 operate using electricity.
Figure 23: 45 degree drill Pattern

Figure 23 shows the drilling pattern used at Kromdraai as described earlier in the report. The Blue arrow shows how the drilling machine moves from one drill hole to the next, and the black arrow shows the direction of the drilling machine relative to vertical line which is the beginning of the area to be drilled.
12.2.3.2 Blasting method

The blasting method that is used currently is Top priming. Top priming is when the booster is placed 3 meters above the drill hole floor as shown in figure below, where three meters is filled with explosives.

Figure 24: blasting method (Top Priming)
13 Model results presentation

The model results are the results of the fragment size calculated using the data gathered on the parameters influencing fragmentation, blast geometry, rock mass characteristics, and the explosive properties. A random sample size of 400 sets of fragmentation or blast is used and the fragment size is calculated in excel, where a sensitivity analysis was done using random numbers to test the changes in the rock mass characteristics, blast geometry and explosives properties, where the random numbers of the parameters are shown in the table below.

<table>
<thead>
<tr>
<th>Charge Length</th>
<th>Sandstone Density</th>
<th>Explosive Density</th>
<th>Bench Height</th>
<th>Spacing</th>
<th>Burden</th>
<th>Hole Radius</th>
<th>Combinations</th>
<th>Explosive weight</th>
<th>Powder factor</th>
<th>Average fragment size</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>2.48</td>
<td>0.83</td>
<td>23</td>
<td>6</td>
<td>12</td>
<td>0.045</td>
<td>Combination A</td>
<td>126.7259</td>
<td>0.0765</td>
<td>479.784</td>
</tr>
<tr>
<td>33</td>
<td>2.48</td>
<td>0.85</td>
<td>28</td>
<td>8</td>
<td>16</td>
<td>0.045</td>
<td>Combination A</td>
<td>178.4468</td>
<td>0.0498</td>
<td>731.1711</td>
</tr>
<tr>
<td>42</td>
<td>2.5</td>
<td>0.88</td>
<td>33</td>
<td>10</td>
<td>20</td>
<td>0.045</td>
<td>Combination A</td>
<td>235.1299</td>
<td>0.0356</td>
<td>970.7988</td>
</tr>
<tr>
<td>24</td>
<td>2.48</td>
<td>0.83</td>
<td>23</td>
<td>6</td>
<td>12</td>
<td>0.055</td>
<td>Combination B</td>
<td>189.3065</td>
<td>0.1143</td>
<td>390.9096</td>
</tr>
<tr>
<td>33</td>
<td>2.48</td>
<td>0.85</td>
<td>28</td>
<td>8</td>
<td>16</td>
<td>0.055</td>
<td>Combination B</td>
<td>266.5687</td>
<td>0.0744</td>
<td>560.0902</td>
</tr>
<tr>
<td>42</td>
<td>2.5</td>
<td>0.88</td>
<td>33</td>
<td>10</td>
<td>20</td>
<td>0.055</td>
<td>Combination B</td>
<td>351.2434</td>
<td>0.0532</td>
<td>783.6339</td>
</tr>
<tr>
<td>24</td>
<td>2.48</td>
<td>0.83</td>
<td>23</td>
<td>6</td>
<td>12</td>
<td>0.075</td>
<td>Combination C</td>
<td>352.0163</td>
<td>0.2126</td>
<td>253.9385</td>
</tr>
<tr>
<td>33</td>
<td>2.48</td>
<td>0.85</td>
<td>28</td>
<td>8</td>
<td>16</td>
<td>0.075</td>
<td>Combination C</td>
<td>495.6856</td>
<td>0.1383</td>
<td>376.8817</td>
</tr>
<tr>
<td>42</td>
<td>2.5</td>
<td>0.88</td>
<td>33</td>
<td>10</td>
<td>20</td>
<td>0.075</td>
<td>Combination C</td>
<td>653.1386</td>
<td>0.099</td>
<td>518.8307</td>
</tr>
<tr>
<td>24</td>
<td>2.48</td>
<td>0.83</td>
<td>23</td>
<td>6</td>
<td>12</td>
<td>0.125</td>
<td>Combination D</td>
<td>1602.065</td>
<td>0.9674</td>
<td>100.3691</td>
</tr>
<tr>
<td>33</td>
<td>2.48</td>
<td>0.85</td>
<td>28</td>
<td>8</td>
<td>16</td>
<td>0.125</td>
<td>Combination D</td>
<td>2255.92</td>
<td>0.6294</td>
<td>144.0123</td>
</tr>
<tr>
<td>42</td>
<td>2.5</td>
<td>0.88</td>
<td>33</td>
<td>10</td>
<td>20</td>
<td>0.125</td>
<td>Combination D</td>
<td>2972.507</td>
<td>0.4504</td>
<td>202.8381</td>
</tr>
</tbody>
</table>

Table 10: Fragmentation prediction parameters
Figure 25 shows the graphs of the fragment size with the blast geometry parameters. The graphs above indicate the current situation at Landau Colliery. At the current situation the fragment size achieved is not acceptable since the bucket fill factor is low and the dragline bucket and the bucket teeth are replaced in a short period of time. The diagram below shows the fragment size at the current situation which requires re-drilling and re-blasting, as indicated by the cycled fragments in the diagram below. The blasting geometry at Landau Colliery is constrained by the underground workings, the only parameters they can change are the charge length, drill hole diameter and the explosive amount used per charge or per hole.
Figure 26: Fragment size v/s Charge weight

The figure above shows the average fragment size and the charge weight related to the fragment size achieved. 4 combinations of the rock characteristics, blast geometry, and explosive properties were considered. The 4 combinations are formed by the difference in the drill hole radius, where a drill hole radius of 45mm, 55mm, 75mm and 125mm were used. The graph shows the relationship between fragment size, drill hole radius and the charge weight or the explosive amount. The increase in the drill hole radius result the increase in the explosive amount used and a smaller fragment size.
Figure 27: Fragment size stark graph

The stack graph above shows the statistical values of the fragment size is between a certain values. As displayed by the graph the number of times the fragment size is less than 100 cm with the increase in the drill hole radius.
The figure in appendix E shows the fragment size from the developed fragmentation model. As it can be seen from the diagram above, fragment size depends on the explosives weight. At the average explosive weight used at Landau Colliery, the fragment size in most cases is less than 100 centimeters or less than a meter. Which means fragment size is dependent on the amount of explosives used; the larger the explosive weight the smaller will be the fragment size.

The figure in appendix F shows the fragment size at average charge length. However the fragment size is less than 150 centimeters in most cases, which implies that the larger the charge length the better or the smaller will be the fragment size as it can be seen from the diagram above.
The figure in appendix G also shows the fragment size compared with the blast geometry parameters. However in this case we are mostly focusing on the effect of the overburden size on the fragment size. The diagram above does not give too much detail, the fragment size equation described in the conceptual design and the powder factor equation described in the crucial factors influencing fragmentation shows the relationship between burden size and the fragment size. What the two equations describes is that the smaller the burden the larger the powder factor will be, however if the powder factor is larger the smaller will the fragment size be.

The figure in appendix H clearly shows the relationship between fragment size and the spacing between drill holes. According to the model the smaller the spaces between the drill holes the larger will be the effect of spacing on the fragment size, which implies that decreasing the spacing between the drill holes will result in smaller fragment size as indicated by figure 24. The figure in appendix I illustrate the relationship of the fragment size and the blast geometry parameters, charge length, and the explosives density in different conditions.

If the drill rod size is getting smaller the fragment size is getting bigger and bigger as illustrated by the figure in appendix J. Making the drill rod smaller decreases the drill hole volume and decreasing the drill hole volume will result in the decrease in the amount of explosives used per hole. The powder factor equation describes the relationship between fragment size and explosives weight. If the explosives weight is smaller the fragment size will be larger, of which the overburden with larger fragment sizes has effect on the dragline bucket fill factor. For an example if you take bigger stones in put them in a cup and smaller stones in the similar cup of the same size as the bigger stones cup, the volume occupied by the smaller stones will be greater than the volume occupied by the bigger stones in the cup.
14 Possible solutions/ Solutions to problem

14.1 Drilling Process

14.1.1 Drilling Accuracy
- Install GPS system with the drilling plan displaying the drill hole number, position and depth

14.1.2 Improve the blast geometry
- Decrease the drill hole radius to 150mm
- The spacing should range from 6-10 meters between drill holes
- The charge length should range from 24-42 meters per blast
- The burden should range from 12-20 meters

14.2 Blasting process
- Improve the explosive properties
- Powder factor will be determined from the blast geometry
- The amount of explosives used per charge depends on the blast geometry; as derived from the fragmentation model developed, in this case where the rock density ranges from 2.48-2.5 the explosives amount should be between 350 000 and 653 000 kilograms per charge. Table 10 shows the explosives amount related to the charge length, burden, spacing, drill hole radius, rock density, explosive density and the bench height.
- Average explosives amount to be used per charge (blast) should be 334 333 kilograms
14.3 Earth Removal Process

- Improve the fragment size to 100 cm or less than 100 cm
- Improving fragmentation will improve the life of the ground engagement tools especially the dragline bucket, bucket teeth and ropes by reducing the number of swings by the dragline in an hour
- And obviously by improving the bucket fill factor.

14.4 Solutions summary

GPS system should be installed in the drilling machines. To improve and achieve an average fragment size of 0.375m with an average explosives amount of 334 333 kilograms used per charge (blast) the following parameters should be considered indicated by the fragmentation model developed:

- Spacing – 8 m
- Burden – 16 m
- Charge length – 33 m
- Rock density – 2.48
- Explosives density – 0.85 kg/m3
- Bench height – 28 m
- Drill hole radius – 0.075 m
- Explosive amount – 334 333 kg
15 Improvement opportunities

15.1 Re-Drilling and Re-Blasting

<table>
<thead>
<tr>
<th>Description</th>
<th>Annual Cost (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-Drilling Cost/Hole (18/p.m)</td>
<td>R 427 291</td>
</tr>
<tr>
<td>Re-Charging Cost/Hole (18/p.m)</td>
<td>R 931 617</td>
</tr>
<tr>
<td>Total</td>
<td>R 1 358 908</td>
</tr>
<tr>
<td>Improvement Opportunity</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>R 135 891</td>
</tr>
<tr>
<td>20%</td>
<td>R 271 782</td>
</tr>
<tr>
<td>50%</td>
<td>R 679 454</td>
</tr>
</tbody>
</table>

Table 12: Cost Summary & Improvement Opportunities

The above figures are calculated using the last year’s information on re-drilling and re-blasting of the company. Table 12 shows the total cost re-drilling and the re-charging and the improvement opportunities. There are 18 holes on average to be re-drilled and re-charged per month due to poor fragmentation or bad blasting. For an example 10 percent improvement will yield R 135 891 savings annually, on the money spent on both drilling and blasting process.

15.2 Other improvements

Improving fragmentation will not only improve the re-drilling and re-blasting cost but also the following:

- Bucket life
- Bucket teeth life
- Rope life
- Other GETs cost and
- Operational cost
16 Final design test and/ validation

The final design test and validation is not part of this project, the description bellow describes how the model of this project can be tested and validated before it can be implemented. The company will set up the model with the required input parameters of the area to be charged, the rock characteristics, blast geometry and the amount of explosives should be known. The charge length, the explosives amount, the spacing between drill hole, etc will be extracted from the model results after running it. The holes will be drilled, charged and blasted and the overburden will be removed by the dragline. The design will then be tested by performing a study on the dragline performance, in terms of the overburden cubic meters of removed in a certain period as well as the coal amount in cubic meters exposed by the dragline at a certain period.
17 Conclusion

Fragmentation is dependent on a lot of factors including the blast geometry, rock characteristics, and explosive properties. Fragmentation is not only dependent on spacing, burden, and the bench height of the blast geometry, but it is also dependent on factors such as the drill hole diameter, charge length and other factors that I do not know about. According to the authors that did studies on fragmentation, it is one of the most important processes in the mining industry; more attention has to be paid on fragmentation. The analysis done implies that achieving better fragment size, much time and money should be to spend on the drilling process and blasting process since they are the core processes for fragmentation. The fragmentation model developed depicts that Landau Colliery should invest on both the drilling and blasting process to improve productivity and cost. Figure 28 below illustrate the relationship between the fragment size and charge weight or the amount of explosives, where the average fragment size of 0.375m is achieved under the following conditions:

- Spacing – 8 m
- Burden – 16 m
- Charge length – 33 m
- Rock density – 2.48
- Explosives density – 0.85 kg/m3
- Bench height – 28 m
- Drill hole radius – 0.075 m
- Explosive amount – 334 333 kg
Figure 28: Average fragment size
18 Recommendations

I recommend that Landau Colliery invest in both the drilling process and the blasting process in order to improve their productivity at less cost and in an effectively and efficiently. Considering buying drill rods and drill bits of 110 mm in diameter smaller than the 250mm diameter being used currently will improve fragmentation at Landau Colliery, since the size of the drill hole and the charge length are the only parameters that can be changed so far. Further studies must be done on fragmentation. Landau Colliery should consider studies on the dragline performance and fragment size relationship, since that has not been done yet or there are no indicators for fragmentation in relation with the dragline performance. A Matlab Code should be generated in order to predict fragmentation with all the constraint required for the model to run properly, for example the cost budgeted, the fragment size to be achieved, the acceptable coal size as well as the blast geometry, rock characteristics, and explosive properties.
19 References


## 20 Appendices

### 20.1 Appendix A

**ANGLO COAL DRAGLINES**

**AN ANGLO COAL MINE**

**A DIVISION OF ANGLO OPERATIONS LIMITED**

**DRAGLINE GENERAL SPECIFICATIONS**

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1570W H&D Ropes - Anglo have standardised on 95.25 dia.
# Dragline Production Report

**Mine:** Kromdraai  
**Period:** 28 Mar 2009 07:00:00 to 28 Apr 2009 07:00:00

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20.2 Appendix B
20.3 Appendix C
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20.4 Appendix D

LANDAU COLLIERY
An Anglo Coal Mine
A Division of Anglo Operations Limited

BLASTING REPORT 2009

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TOTAL

AVERAGE

MONTHLY BUDGET (UNITED)

MONTHLY BUDGET COSTS

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T.P. NTIMBA
# LANDAU COLLIERY
An ANGLO COAL mine
A Division of Anglo Operations Limited
South African Coal Estates

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<td>31.30</td>
<td>47.76</td>
<td>921.00</td>
<td>19.29</td>
<td>247,634</td>
<td>0.00</td>
<td>46531</td>
</tr>
</tbody>
</table>

TOTAL METERS: 247,634
20.5 Appendix E

![Fragment Size Prediction at Aver. Explosive Density](image)
20.6 Appendix F

Fragment Size Prediction at Aver. charge length

- Charge length (m)
- Burden (m)
- Spacing (m)
- Bench Height (m)
- Fragment Size (cm)
20.7 Appendix G

Fragment Size Prediction at Min Burden

- Charge length (m)
- Burden (m)
- Spacing (m)
- Bench Height (m)
- Fragment Size (cm)
20.8 Appendix H

Fragment Size Prediction at Min Spacing

![Graph showing fragment size prediction at minimum spacing with various variables plotted against axis.](image-url)
20.9 Appendix I

Fragment Size Prediction at Minimum Parameter Value

- Charge length (m)
- Burden (m)
- Spacing (m)
- Bench Height (m)
- Fragment Size (cm)
20.10 Appendix J

Fragment Size Prediction at 170mm Drill Rod Diameter

[Graph showing various data points related to fragment size prediction]