CAPTURING ECONOMIC BENEFITS FROM BLASTING

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ABSTRACT
Blasting is one of the primary functions in any mining operation. Despite the fact that it generally constitutes between 30% to 40% of the mining cost, blasting also affects the cost-effectiveness of down steam activities such as load and haul, safety, tyre life for haul trucks, crushing and milling.

Over the past three decades, significant progress has been made in the development of new technology in an attempt to reduce costs and increase efficiencies and productivities of blasting activities. Mine to mill project concepts have paved the way for such developments. Other advancements have included sophisticated computer modelling technologies for blast design and performance analysis.

There are many factors that affect the cost of blasting. These can be divided into two categories; controllable and uncontrollable. The latter includes costs related to depreciation, exchange rates and government legislation with the former category including contractor versus owner blasting costs, efficiency and productivity issues and product quality. Controllable factors have one common denominator which can determine their outcome; direct site management influence. Excavator digging rates and final floor conditions give a good measure of blasting performance, and alternatively cost effectiveness.

This paper is aimed at benchmarking against a blast optimisation database, understanding the relationship between costs and identifying opportunities for improvement. Understanding the cost drivers allowed a typical cost model to be developed for the current mining operation at Geita and this was used to drive continuous improvement with emphasis on closing the information loop.

1. INTRODUCTION

Geita Gold Mine (GGM) is an operation owned and managed by AngloGold Ashanti. The mine is located in the Geita district in northwest Tanzania, 295 kilometres and 590 kilometres from Serengeti National park and Mount Kilimanjaro respectively (Figure 1). Mining in this area has taken place for many years with the last major operation being an underground mine, which operated from the 1930s through to the 1960s and produced almost 1 Moz of gold. Some small-scale mining continues to this day.
The modern Geita Gold Mine has been operating since mid 1999, with ore processing commencing in mid-2000. The mine operates under a special mining license that was granted in June 1999. Geita Gold Mine currently operates five open pits;

- Nyankanga Cutback 4, NYC4
- Nyankanga Cutback 5, NYC5
- Nyankanga Cutback 6, NYC6
- Geita Hill West Cutback 2, GHW2
- Lone Cone Central, LCC

Annual production is approximately 25Mt of which 7.6 Mt is ore.

In August 2005, the mine changed from Contractor Mining to Owner Mining.

The current open pit mining fleet consists of:

- 1 x O&K RH340 face shovel (25 m$^3$)
- 4x 994 Back hoe excavators; and
- 4 x Komatsu PC 1800 back hoe excavator (15 m$^3$)
- 15 x Caterpillar 777D haul truck (100 tonnes)
- 35 x Komatsu HD785 haul truck (100 tonnes)
- 9 x Terex haul trucks (200 tones).
Geita Gold mine is classified as a hard rock mining operation, with the main pits requiring drilling and blasting. In total, blasting activities range from paddock blasting in soft laterite and oxide to hard rock blasting in sulphides. Drilling and blasting operations are carried out using ROC L8’s, DML’s and a Pantera drill rig. All explosives are managed and supplied by AEL (Explosive contractor). The current drill fleet consists of:

- 10 ROC L8 (Atlas Copco)
- 5 DML HP (Atlas Copco) and
- 1 Tamrock Pantera.

The recent rollout of continuous improvement initiatives across the mine is one of the motivating forces for this case study. This study covers aspects of the economics associated with blasting at Geita with the opinion that the drill and blasting continuous improvement strategy will significantly improve blasting associated costs at the Geita operations. The project is a joint undertaking between the GGM drill and blast department and explosives supply contractor (African Explosives Limited (AEL)).

1.1 Current Blasting Practise at Geita Gold Mine

**History**

The Geita blasting operations are currently undertaken in oxide to fresh materials using both ROC L8 and DML drilled blast holes. Typical drill and blast parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>EXPLOSIVE</th>
<th>NYC4 - Fresh(Waste)</th>
<th>NYC4 - Fresh(Ore)</th>
<th>NYC5 - Fresh(Hard)</th>
<th>GH02 - Transition</th>
<th>GH02 - Oxide</th>
<th>GH02 - Oxide</th>
<th>LCC - Oxide</th>
<th>MT2 - Transition</th>
<th>Previous - NYC4 -3</th>
<th>Fresh(Waste)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPLOSIVE Type</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
<td>P400</td>
</tr>
<tr>
<td>Explosive Mass Per Hole (kg)</td>
<td>119.83</td>
<td>119.84</td>
<td>126.17</td>
<td>121.33</td>
<td>119.88</td>
<td>127.60</td>
<td>119.85</td>
<td>159.65</td>
<td>159.64</td>
<td>159.64</td>
</tr>
<tr>
<td>Effective Charge Diameter (mm)</td>
<td>127.00</td>
<td>127.00</td>
<td>229.00</td>
<td>127.00</td>
<td>127.00</td>
<td>229.00</td>
<td>127.00</td>
<td>127.00</td>
<td>127.00</td>
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</tr>
<tr>
<td>Average Initiate Density (g/cm³)</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
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**Table 1: Geita current drilling patterns**

AEL bulk explosive products used at Geita are
Emulsion P400 (65% ammonium nitrate),
P700 (80% ammonium nitrate) and
Ammonium Nitrate fuel oil (ANFO)
Two types of initiation systems are used: non-electric detonation (Nonel) and electronic detonation, Smartdet. All other accessories are a mix of AEL products and third party products supplied by AEL.

Blasting quality control

After design and drilling quality checks; the charging and blasting activities are also checked. Pumped emulsion is checked for gassing and calibration by measuring two 25kg buckets of bulk explosive against the pump flow meters. Explosive is then pumped into each blast hole and the Kg’s recorded against individual hole IDs.

Holes are remeasured to confirm gassing has occurred and the correct (design) stemming height achieved.

Holes are stemmed after gassing. Gassing time ranges from 30 minutes to 40 minutes whereby 0.8 m to 1 m of column rise in a 127mm hole is achieved.

Further effort is required in blasting practice to:

- Avoid hard toe – survey control of hole position and application of ‘stitch holes’ between blast boundaries
- Attain optimum fragmentation – typically at Geita this involves quick timing between spacing and calibrated timing against the burden.
- Minimise ore loss and dilution – blast material movement is directed along strike
- Achieve the final wall and grade – Slopes in the Nyankanga pit are steep. Limit blasting must result in a clean hard face that is on design.

Blast evaluation is obtained from Geology, Geotechnical and Load and Haul groups. Good blasting results are when there is minimal impact on ore dilution berms and final walls are achieved and good fragmentation and dig rates are achieved. The combined evaluation is simply measured by total cost. The traditional interpretation of the optimum cost per bcm is shown in Figure 2. (McKenzie 1965, Dinis da Gama 1990, and Elolanta 1995).
Types of Blasting performed at Geita Gold Mine

All blast designs at GGM are completed by the Drill & Blast Engineers with input from Production, Geotechnical and Geology departments.

Production Blast

Production blasts are large and are generally allocated at the centre of the pit. They are designed in such a way that they do not cut ore blocks more than once. The volume per blast ranges from 50,000 m$^3$ to 100,000 m$^3$ and are fired along the ore strike. All blasts are evaluated prior to digging and this includes blast videos that are taken to access stemming performance and timing. Once excavation starts digital photos are taken for fragmentation analysis using SPLIT DESKTOP.

Trim blast

Blast blocks along the high wall in particular pits are given special attention to protect the high wall. The face of all trim shots is cleared to provide a clean free face before firing. Trim shots are 10 to 15m wide depending on the adjacent berm width in Nyankanga Cutbacks 4 and 5. Trims in Geita Hill Pit are 30m wide. It is recognised that 30m wide trim may result in significant rebounded energy propagating into the high wall. However; the slope is design at 55 degrees with only 10m face, hence the rockfall risk from potential “backbreak” is considered low.

David Mc Mahon (2006) recommended full free facing of waste trim shots to minimise the amount of vibration which might affect the integrity of the high wall. These
recommendations come about to strike a balance between drill and blast and geotechnical objectives.

Presplit blast

Presplit are currently only used at Nyankanga cutback 4 and occasionally cutback 5 to achieve final wall. Recent results from the Nyankanga cut 5 trim blast have resulted in load and haul achieving 90% to 98% of the design toe after buffer line adjustments without putting in a presplit.

2. WHAT DOES BLASTING ECONOMICS MEAN?

For any profit-based company the main goal is to maximise the rate of return on its investment. The profit earned per bcm of broken material is the difference between the price of the valuable material from the ore it uncovers and the cost of producing it. Total profit can be estimated from the following equation:

\[
\text{Profit} = \text{Revenue} - \text{Operating Cost} - \text{Fixed Cost}
\]

Where,

\[
\text{Operating Cost} = \text{Unit Operating Cost} \times \text{Throughput}
\]

\[
\text{Unit Operating Cost} = \text{Unit Cost of } \left\{ \text{Drilling, Blasting, Loading, Hauling, Crushing, Grinding, Liberation} \right\}
\]

\[
\text{Fixed Cost} = \text{Cost of capital and overhead}
\]

Depending on the type of mining operation involved, a blast will have a varying degree of influence on both revenue and the cost of operation. In this paper the influence that blasting has on the operating cost of the current Geita Gold Mine is described. Figure 3 illustrates an approach to the evaluation of the total mining cost based on blast performance.
Blasting performance is usually evaluated from loading performance and crushing efficiency. It is important to be able to understand the impact of blasting in relation to company revenue. M J Cameron (1996) demonstrated the following common elements on the performance and cost relationship for operations.

- Suspension and frame life versus loading unit. Suspension and frame life is sensitive to rolling resistance and running surface and loading faces and tires life at loading face
- Crusher efficiency versus power consumption, throughput versus blasting fragmentation.
- Ore loss and dilution versus blasting initiation techniques in relationship to loading priority.

It is necessary to look beyond the obvious inherent performance and costs to the marginal and underlying cost components that tend to become increasingly significant with increasing production.
3. TECHNOLOGY (LICENSING) AND MANAGEMENT SERVICE AGREEMENTS

Today most profit based companies realize that to produce economically they must use modern technology and efficient management systems. In mining industries, software engineering has developed quickly and it plays a big role in day to day mining activities.

Many software systems are available to assist blasting simulations. Fragmentation, blasting cost per ton, and muckpile shape are common predictions available. Louis S. Wells Jr (2000) recommended that licensing agreements and technical assistance agreements should be designed to encourage technology transfer.

Shotplan and Winblast are two of the blasting simulation software tools currently available to help design the initiation timing for a shot. The use of the simulation tools helps to identify designs that provide better blasting movement in respect to ore orientation, heave and muckpile level. Experience and knowledge to use software is required; training for blasters, engineers is vital for this process.

4. BLAST MANAGEMENT SYSTEM AND COSTS

A blast management and cost control system is needed to track the quality of blast implementation and its impact on downstream processes in an operations environment. A joint venture team from PPRust – platinum mine in South Africa, a Datamine team from UK and South Africa and the GGM Geotechnical department worked with the Geita blasting team to implement a “mine to mill” project.

The geotechnical model was developed and is maintained by the Geotechnical section. The model is based on orientated drillhole data and Rockmass mapping. The pit has been divided into Geotechnical domains and Rockmass rating (RMR & MRMR) assigned to the rock. The Drill & Blast function in the model calculates out Energy Factors required to produce an optimum fragmentation sized based on the Rockmass Rating. The use of fragmentation measuring tools like WIPFLAG or SPLIT DESKTOP or SIROFLAG was also recommended by this team; with Split Desktop currently being used by the Geotechnical Department to analyse fragmentation and validate the model.

A modified blasting monitoring system relevant to Hunter et al, 1990 shown in Figure 9 was implemented to track all relevant information required for analysis. All information relating to blasting is collected in a central database and a Blast Atlas has been implemented to:

- Assist blasting engineers on a day-to-day basis for blast design and reporting
- To track the downstream processes benefits over a long period to drive blast optimisation.
- Quick easy investigation of blast results
The cost and benefits related to energy savings on crushing, grinding and liberation are outside the scope of this report.

Figure 9: Blast Atlas
4.1 Blast design data

All blasts are designed using the 3-dimensional software package, the design package stores standard and applies these standards to user specified blocks also calculating the explosives requirements. It is intended to export all designs to timing designed software as a routine later this year (2007). The data associated with blasts are stored in the Geita Reporting System (GRS) which reports on blast costs. The GRS reported cost trends for 2006 can be seen in Appendix 1. The Geotechnical model has been implemented and is currently under a structural mapping and fragmentation validation process to prove the confidence in the data. Table 2, shows a summary of the cost data that the model produces and the current blast data being used at GGM.

A report generated from Vulcan, shows each hole ID and its depth and for the entire bench floor a unique ID is assigned to individual holes. Insufficient bench floor pick up from the survey section requires the blasting engineers to issue a depth sheet and explosives loading sheet to the blast crew for actual data collection. Since Geita is a multi-pit operation, all data is kept in different pit locations in the database.

Table 2: Current Geita Gold Mine Blast data
Field data

<table>
<thead>
<tr>
<th>Field data</th>
<th>Previous NVC4/5 Fresh 127mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NVC4 Fresh (Ore) - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Explosive Cost/Hole</td>
<td>$0.91</td>
</tr>
<tr>
<td>Initiation Cost/Hole</td>
<td>$0.09</td>
</tr>
<tr>
<td>Overhead Cost/Hole</td>
<td>$0.04</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 Fresh (Waste) - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
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</tr>
<tr>
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<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 Fresh (Hard) - 229mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 Transitional - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 Oxide - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
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<tr>
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<tr>
<td>Total Cost</td>
<td>$2.82</td>
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<tr>
<td></td>
<td>NVC4 LCC Oxide - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 LCC Oxide - 229mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 MT2 Oxide - 127mm</td>
</tr>
<tr>
<td>Drilling Cost/Hole</td>
<td>$1.79</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$2.82</td>
</tr>
<tr>
<td></td>
<td>NVC4 MT2 Oxide - 229mm</td>
</tr>
<tr>
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<tr>
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<td>Total Cost</td>
<td>$2.82</td>
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</tbody>
</table>

4.2 Dispatch data

GGM has a modular mining system tracking the performance of the loading and hauling fleet and generating a performance report. The instantaneous digging rate per location per blast is monitored, and a blast snapshot photo is included with the data on the central server. Production engineers and Blast engineers track the dig-rates of any given blast to help with blast design, test program management and general training. Figure 4 shows a
photo of a middle mining flitch taken at Nyankanga cutback 4 indicating good results of fragmented size. Takis Katsabanis et al, 2005) concluded that stochastic simulation of the actual load-haul time studies shows that a shovel in a good digging can handle more trucks than those in poor digging.

Figure 4: A photo of Nyankanga cut 4 (from 1040mrl to 1030mrl)-1030#04 middle (103mrl) flitch

4.3 Tracking blast performance benefit

The benefit of increasing the powder factor on the blast block containing ore and increasing the pattern for blast blocks containing waste has been compared with the previous practise of having a single pattern size. To date improvements have been clearly demonstrated but only in limited conditions because cost benefit analysis is currently only being measured from instantaneous digging rate.

Blasting has a direct impact on equipment productivity and the cost of subsequent operations. Figure 5 is captured from the Modular Mining System and illustrates that the speed of loading resulting from good fragmented rock has reduced the overall unit cost. It also indicates that the instantaneous shovel-digging rate is high compared to Figure 6.
Figure 5: Excavator Instantaneous digging rate for Nyankanga Cut 5- NYC5- Previous Pattern1

Figure 6: Excavator Instantaneous digging rate for Nyankanga Cut 5- NYC5-New Pattern2
The optimisation criteria to assess blasting requirements are the combination of activity
costs and managing them in order to minimise the overall production costs. This does not
mean that reducing any particular parameter in exclusion will necessarily result in
lowering overall costs. It should be understood that the effectiveness of the blast does not
necessarily increase with a reduction in blasting costs as some changes can be counter
productive.

4.4 Cost model for specific blasts

A reduction in the pattern size reduces the volume per blasthole and gives better
explosive distribution and generally produces less oversize material. Increases in the cost
per tonne for initiation, drilling and labour arise from the lower volume per blasthole and
will result in a higher total cost per tonne of rock.

Figure 7 shows the key blasting cost drivers at GGM. The influence of the blast results is
critical for continuous improvements on site. The cost of replacing a single damaged
Terex tyre due to poor running ground or sharp rocks at the loading face is a higher cost
than to blast five blastholes at 10 m depth. In most operations, explosives supplies are
always contractual, government or environmentally constrained for safety reasons. The
quality of explosives, including in-hole density and sensitivity must be maintained for
good blast performance and this becomes one of the key blasting cost drivers.

Figure 7: Total blasting Costs Model GGM
As with most operations, labour costs make up a significant proportion of the total cost of breaking rock. It is therefore necessary that productivity is maximised and labour is fully utilised. Blasting requires suitably qualified and experienced personnel and should not be treated as a training ground.

Eliminating ore loss and preventing dilution at GGM can prove difficult particularly along the highwall as blasting techniques do conflict with geotechnical consideration.

5. CONCLUSION

The process of optimising blasting must be done in a controlled manner so that the influence of changes on blast performance can be measured and evaluated. It is most important that changes are made independent of other variables and that thorough analyses of the total cost and the performance of blasts are undertaken to enable any benefits to be identified and quantified. It should be acknowledged that even minor fine tuning of blast geometry to suit changing operating conditions in multi-pit operations has a significant impact on blasting economics.

In addition to blast cost savings there are a number of issues that need to be addressed to significantly improve the efficiency of downstream activities. These include:

1. Fragmentation measurements are required so that the effect of blast performance on loading efficiency and fragmentation can be tracked.
2. On-bench quality control checks to achieve design and required Drill & Blast results
3. The relationship between blasting, crushing and grinding performance is vital for the operations.
4. Drill and Blast Engineers, shot firers and drill supervisors all need high levels of training.
5. Operations team need to understand and support to achieve the necessary quality.

ACKNOWLEDGEMENTS

This paper describes economics associated with blasting by Alistides Ndibalema employed as Mining Engineer and is presented with the permission of Geita Gold Mine. The author would like to thank Geita Gold Mine’s management for their permission to present this paper and also thank the members of the Mining Department at Geita who contributed to the preparation of this paper.
REFERENCES


2 APPENDICES

Appendix 1: Cost Reports

![Blasting Cost Trend Graph]

[Graph showing the Blasting Cost Trend with axes for Total Blasted BCM on the y-axis and Month on the x-axis, with cost levels indicated for each month from January 2006 to December 2006.]