# Reducing Drill and Blast Cost through Blast Optimisation – A Case Study*

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Afum B. O. and Temeng V. A. (2015), "Reducing Drill and Blast Cost through Blast Optimisation – A Case Study", *Ghana Mining Journal*, Vol. 15, No. 2, pp. 50 - 57.

## Abstract

This paper studied the current cost trends associated with the drill and blast operations of Golden Star Resources, an open pit gold mine in Ghana, and further developed a suitable, cost-effective drill and blast geometric parameters for the mine. The study was conducted on three operational pits of the mine, namely Blocks A, B and C. The surface mine was challenged with high cost trends in its drilling and blasting operations. The current and two proposed sets of blast geometric parameters for each active pit, for ore and waste zones, were assessed with the Kuz-Ram fragmentation model. The estimated mean fragment size for the proposed blast parameters were within the desired fragment size range (25 – 65 cm) of the mine, and explosive energy was effectively utilised per *in-situ* material blasted. The estimated total volume of *in-situ* material blasted using the proposed blast parameters increased by 14.3 to 50.0% for ore zones and 12.5 to 50.0% for waste zones over current blast parameters. The estimated total drill and blast cost savings if the proposed blast parameters were adopted ranged from 5.3 to 12.2% for ore zones and 2.9 to 14.8% for waste zones.

**Keywords:** Burden, Spacing, Explosives density, Powder Factor, Cost saving

## 1 Introduction

The high cost of mining operations, as a results of global financial crises and fluctuations in the price of gold, compels technologists in the industry to search for innovative ways of reducing overall mining cost. The cost of drilling and blasting operations greatly contributes to the "high cost trends of the overall mining operations" (Anon., 2014; Anon., 2012, Palangio *et al.*, 2005 and Bozic, 1998). Drilling, one of the critical and important operations of every hard rock mine contributes about 15% of the overall mining cost in some mining operations (Gokhal, 2010).

Finding efficient methods of drilling and blasting that would significantly reduce the costs and improve productivity while maintaining fragmentation and wall control are technical areas that have well been researched (Anon., 2014; Gokhal, 2010; Olofsson, 1988). However, reducing cost through optimisation of drill and blast geometric parameters have barely been considered. Several factors affect the cost of fragmenting any piece of *in-situ* rock. These factors include but not limited to blast geometric parameters and pattern; explosive type, density and costs; labour; oversize (relative boulders), toes and geological nature of the formation.

The effective cost of poor blasting can be several times the cost of the blast itself as can be demonstrated in terms of fragmentation and environmental problems. Analysis of several operations suggests that although mine blasts generally fragment rock to be handled by the mining process, there is potential optimal fragmentation to improve the productivity and reduce cost of all downstream processes (Bozic, 1998). Optimising blast design parameters could reduce the drill and blast cost of a mine (Anon., 2014).

This research was conducted at Golden Star Resources, an open pit hard rock mine in Ghana. Drilling was conducted by the mine while total solution blasting services was sub-contracted to an explosive manufacturing and services company. The mine was experiencing high cost trends in its drilling and blasting operations. This paper studied the current cost trends associated with the drilling and blasting operations and further developed suitable cost-effective drill and blast geometric parameters for the mine. Three operational pits of the mine, namely Blocks A, B and C were considered for this study.

## 2 Materials and Methods Used

### 2.1 Kuz-Ram Fragmentation Model

Characteristics of blasted rock such as fragment size, volume and mass are fundamental variables affecting the economics of mining operations, and are in effect the basis for evaluating the quality of a blast (Bozic, 1998). In addition, computer-assisted photographic techniques for measuring the size distribution of actual blasts have been developed (Raitt *et al.,* 2013); this could also help evaluate the quality of a blast. The properties of fragmentation, such as size and shape, are very important information for the optimisation of production

**Manuscript received April 2, 2015*
*Revised version accepted August 3, 2015*

drilling and blasting operations. Size distribution is a critical component of managing any mining operation; from the drilling and blasting to the final product, the material size dictates all downstream operating costs (Palangio *et al.,* 2005).

In recent years empirical methods for predicting the fragmentation from a given structural geology, rock type, explosive, and blast pattern have become better and more useful. It is good to recognise that there is currently no theory of fragmentation developed from first principles that can be used to accurately predict the fragmentation from blasting *in-situ* rock formations. Empirical prediction of expected fragmentation is most often done using the Kuz-Ram model. The basic strength of the model lies in its simplicity in terms of the ease of garnering input data, and in its direct linkage between blast design parameters and rock fragmentation (Cunningham, 2005). Using this approach, a rock factor that describes the nature and geology of the rock is calculated. A uniformity index is also obtained that characterises the explosive loading, the blast pattern type and dimensions. This allows a characteristic size and size distribution to be determined according to the Rosin-Rammler procedure. There are three key equations of the Kuz-Ram model (Cunningham, 2005):

Kuznetsov equation:

$$X_m = AK^{-0.8}Q^{1/16}(\text{RWS of Explosive/ RWS of ANFO})^{19/20} \quad (1)$$

where $X_m$ = mean particle size, cm; A = rock factor [varying between 0.8 and 22, depending on hardness and structure]; K = powder factor, kg explosive per cubic meter of rock; Q = mass of explosive in the hole, kg; and RWS = Relative Weight Strength.

Rosin-Rammler equation:

$$R_X = \exp[-0.693(x/x_m)^n] \quad (2)$$

where *Rx* = mass fraction retained on screen opening *x*; and *n* = uniformity index, usually between 0.7 and 2.

Uniformity equation:

$$n = \left(22 - \frac{14B}{d}\right).\sqrt{\frac{1+S/B}{2}}.\left(1 - \frac{W}{B}\right).\left(\text{abs}\left(\frac{BCL-CCL}{L}\right) + 0.1\right)^{0.1}.\frac{L}{H} \quad (3)$$

where B= burden, m; S = spacing, m; d= hole diameter, mm; W= standard deviation of drilling precision, m; L = charge length, m; BCL = bottom charge length, m; CCL = column charge length, m; and H= bench height, m.

## 2.2 Drill and Blast Parameters of the Mine

The mine currently operates three pits namely Block A, Block B and Block C. Current blast design data for the various pits including burden, spacing, blasthole diameter, bench height, sub-drill, stemming and drilling cost, were obtained from the mine. Due to several uncontrollable geological factors and the type of mineralised zones being mined, the mine has adopted different parameters for drilling and blasting the ore and waste zones of the pits. The staggered drilling pattern was generally used for all production blasting. The drill parameters used for the ore and waste zones in each operational pit of the mine are shown in Table 1.

Similarly, data on explosive consumption in the mine including the explosive type, Relative Explosives Energy (REE), explosive density and explosive cost (including initiation systems, bottom and column charges) were obtained from the explosive manufacturing and services company. The mine uses blend type of water resistant bulk explosive, made up of 20% Ammonium Nitrate Porous Prills (ANPP) and 80% Emulsion. Table 2 summarises the explosives data obtained for the research study.

**Table 1 Drill Parameters from the Mine**

| Parameter | Block A | | Block B | | Block C | |
|---|---|---|---|---|---|---|
| | Ore | Waste | Ore | Waste | Ore | Waste |
| Burden (B), m | 3.5 | 4 | 4 | 4 | 3.5 | 4 |
| Spacing (S), m | 3.5 | 4 | 4 | 5 | 3.5 | 4 |
| Hole Diameter (Φ), mm | 127 | 127 | 127 | 127 | 127 | 127 |
| Bench Height (H), m | 4 | 4 | 4.5 | 4.5 | 4.5 | 4.5 |
| Sub-drill (U), m | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Stemming (T), m | 2 | 2 | 2 | 2 | 2 | 2 |
| Drilling Cost (Dcpm), $/m | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |

**Table 2 Explosive Data used for this Study**

| Parameter | Value |
|---|---|
| Explosive Type | Blend (20% ANPP and 80% Emulsion) |
| Explosive Density ($kg/m^3$) | 0.00118 |
| Relative Explosives Energy, REE | 83.1 |
| Explosive Cost (\$/t) | 767.21 |
| Loading Density, Mc (kg/m) | 14.95 |
| Actual Powder Factor, PF ($kg/m^3$) | 0.76 |

The quality of the blast output using the current drill geometric parameters (Table 1) and the explosive data (Table 2) used by the mine was assessed with the Kuz-Ram fragmentation model. New sets of drill geometric parameters proposed for blasting the ore and waste zones in the three operational pits were also assessed with the Kuz-Ram model to estimate the quality of the blast output. The total costs per BCM of drilling and blasting using the mine's current drill and blast parameters and the two proposed sets of drill geometric parameters for blasting ore and waste zones in the active pits were also determined.

## 3 Results and Discussion

### 3.1 Optimisation of the Drill and Blast Parameters for the Mine

Drilling and blasting operations of the mine were closely studied to identify alternative geometric parameters for blasting based on the Kuz-Ram fragmentation model that reduces the total cost of blasting. Other technical parameters that would significantly reduce costs and improve productivity, whilst maintaining the desired rock fragmentation and wall control were also considered.

To assess the blast performance and further generate appropriate sets of geometric parameters for drilling and blasting in a surface mine, it is recommended to use the Kuz-Ram fragmentation model which is the best estimator (Cunningham, 1983; 1987; 2005) of geometric parameters. It is also a tool for examining how different parameters could influence blast performance. The major factors for selecting the optimum and appropriate set of geometric drill and blast parameters of a mine include the total cost/BCM blasted, and the desired mean fragmentation size. The mine is committed to achieving a mean fragment size of 45 cm.

The effect of changes in the current drill and blast parameters on fragmentation are presented in Tables 3 to 5. The two new sets of drill and blast parameters (Proposal 1 and Proposal 2) used for blasting both ore and waste zones in the three different pits are also shown in Tables 3 to 5. For each proposal, the explosive type and density; REE, and loading density were the same as those currently used by the Mine.

### 3.2 Drill and Blast Cost Evaluation

The drilling and blasting performance in terms of the total cost per BCM using the current drill and blast data compared to the proposed drill and blast geometric parameters for blasting ore and waste zones in the various operational pits (Block A, Block B, and Block C) are shown in Figs. 1 to 3 respectively.

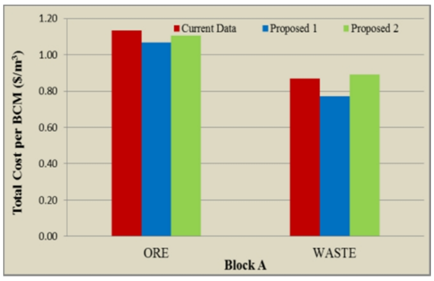


**Fig. 1 Total Cost per BCM of Drilling and Blasting in Block A Pit**

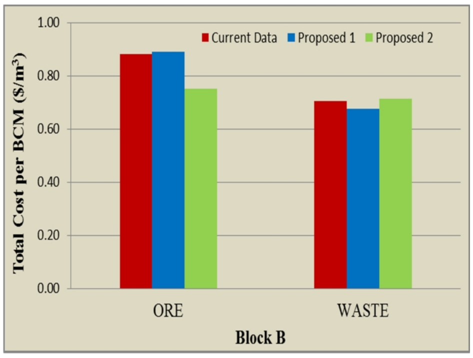


**Fig. 2 Total Cost per BCM of Drilling and Blasting in Block B Pit**

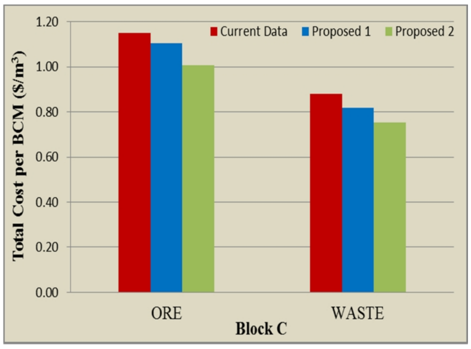


**Fig. 3 Total Cost per BCM of Drilling and Blasting in Block C Pit**

**Table 3 Evaluation of Drilling and Blasting for Block A**

| Parameter | Ore Zone | | | Waste Zone | | |
|---|---|---|---|---|---|---|
| | Current Data | Proposal 1 | Proposal 2 | Current Data | Proposal 1 | Proposal 2 |
| Burden (m) | 3.5 | 3.5 | 3.5 | 4 | 4 | 4 |
| Spacing (m) | 3.5 | 3.5 | 3.5 | 4 | 4.5 | 4 |
| Hole Diameter (mm) | 127 | 127 | 127 | 127 | 127 | 127 |
| Bench Height (m) | 4 | 5 | 6 | 4 | 4 | 5 |
| Sub-drill (m) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Stemming (m) | 2 | 2.5 | 2.5 | 2 | 2 | 2 |
| Explosive Type | Blend | Blend | Blend | Blend | Blend | Blend |
| Explosive Density (kg/m$^3$) | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 |
| Relative Explosives Energy | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 |
| Drilling Cost ($/m) | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Explosive Cost ($/t) | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 |
| Loading Density (kg/m) | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 |
| Charge Length (m) | 2.5 | 3.0 | 4.0 | 2.5 | 2.5 | 3.5 |
| Mass per Hole (kg) | 37.38 | 44.86 | 59.82 | 37.38 | 37.38 | 52.34 |
| Mass above Grade (kg) | 29.91 | 37.38 | 52.34 | 29.91 | 29.91 | 44.86 |
| Technical Powder Factor | 0.61 | 0.61 | 0.71 | 0.47 | 0.42 | 0.56 |
| Actual Powder Factor | 0.76 | 0.73 | 0.81 | 0.58 | 0.52 | 0.65 |
| Mean Size (cm) | 27.06 | 27.44 | 24.77 | 33.50 | 36.81 | 29.70 |
| BCM per Hole (m$^3$) | 49 | 61.25 | 73.5 | 64.00 | 72.00 | 80.00 |
| | | | | | | |
| Explosives Cost per Hole ($) | 28.68 | 34.42 | 45.89 | 28.68 | 28.68 | 40.15 |
| Initiation Cost per Hole ($) | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 |
| Drilling Cost per Hole ($) | 18.95 | 23.16 | 27.37 | 18.95 | 18.95 | 23.16 |
| Total Cost per Hole ($) | 55.58 | 65.52 | 81.21 | 55.58 | 55.58 | 71.26 |
| | | | | | | |
| Explosives Cost per BCM ($/m$^3$) | 0.59 | 0.56 | 0.62 | 0.45 | 0.40 | 0.50 |
| Initiation Cost per BCM ($/m$^3$) | 0.16 | 0.13 | 0.11 | 0.12 | 0.11 | 0.10 |
| Drilling Cost per BCM ($/m$^3$) | 0.39 | 0.38 | 0.37 | 0.30 | 0.26 | 0.29 |
| | | | | | | |
| **Total Cost per BCM ($/m$^3$)** | **1.13** | **1.07** | **1.10** | **0.87** | **0.77** | **0.89** |

### 3.2.1 Performance of Block A Pit

It is observed in Table 3 and Fig. 1 that by adopting Proposal 1 as an alternative for ore zones in Block A, the Powder Factor (PF) would reduce fairly from 0.76 to 0.73 kg/m$^3$, the mean fragment size increases slightly from 27.06 to 27.44 cm, and the total cost per BCM of drilling and blasting would reduce from \$1.13/m$^3$ to \$1.07/m$^3$. The fragmented BCM per blasthole would considerably increase by 25%, an added advantage for the mine.

Similarly, in blasting the waste zone of Block A pit (Table 3 and Fig. 1), the set of drill and blast geometric parameters for Proposal 1 give a better alternative to the current practice. If the mine is to adopt Proposal 1 for blasting the waste zones in Block A pit, the PF would reduce from 0.58 to 0.52 kg/m$^3$, the mean rock fragment size would increase from 33.5 cm to 36.8 cm and the total cost per BCM of drilling and blasting would reduce from \$ 0.87/m$^3$ to \$ 0.77/m$^3$. The blasted BCM per blasthole using the proposed alternative geometric parameters for the waste zones of Block A pit would increase by 12.5%.

If the mine adopts Proposal 1 as an alternative for blasting both ore and waste zones in Block A pit (Table 3), the total amount of money it could save for the current drill and blast operational cost is modelled against the total *in-situ* volume of material (BCM) blasted at any given time and shown in Fig. 4.

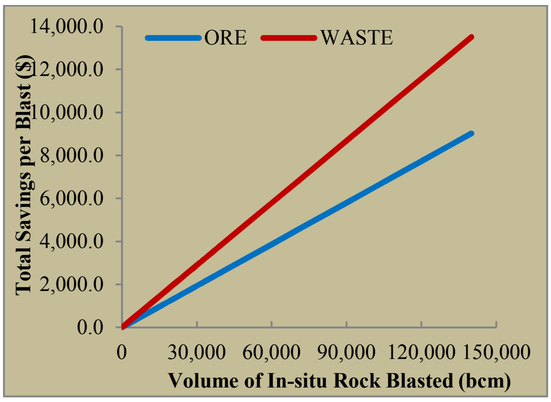


**Fig. 4 Total Cost Savings using Optimised Parameters for Blasting in Block A Pit**

**Table 4 Evaluation of Drilling and Blasting for Block B**

| Parameter | Ore Zone | | | Waste Zone | | |
|---|---|---|---|---|---|---|
| | Current Data | Proposal 1 | Proposal 2 | Current Data | Proposal 1 | Proposal 2 |
| Burden (m) | 4 | 4 | 4.5 | 4 | 4 | 4 |
| Spacing (m) | 4 | 4 | 4 | 5 | 5 | 5 |
| Hole Diameter (mm) | 127 | 127 | 127 | 127 | 127 | 127 |
| Bench Height (m) | 4.5 | 5 | 6 | 4.5 | 6 | 5 |
| Sub-drill (m) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Stemming (m) | 2 | 2 | 2.5 | 2 | 2.5 | 2 |
| Explosive Type | Blend | Blend | Blend | Blend | Blend | Blend |
| Explosive Density (kg/m$^3$) | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 |
| Relative Explosives Energy | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 |
| Drilling Cost ($/m) | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Explosive Cost ($/t) | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 |
| Loading Density (kg/m) | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 |
| Charge Length (m) | 3.0 | 3.5 | 4.0 | 3.0 | 4.0 | 3.5 |
| Mass per Hole (kg) | 44.86 | 52.34 | 59.82 | 44.86 | 59.82 | 52.34 |
| Mass above Grade (kg) | 37.38 | 44.86 | 52.34 | 37.38 | 52.34 | 44.86 |
| Technical Powder Factor | 0.52 | 0.56 | 0.48 | 0.42 | 0.44 | 0.45 |
| Actual Powder Factor | 0.62 | 0.65 | 0.55 | 0.50 | 0.50 | 0.52 |
| Mean Size (cm) | 31.23 | 29.70 | 33.70 | 37.33 | 36.67 | 35.50 |
| BCM per Hole (m$^3$) | 72 | 80 | 108 | 90.00 | 120.00 | 100.00 |
| | | | | | | |
| Explosives Cost per Hole ($) | 34.42 | 40.15 | 45.89 | 34.42 | 45.89 | 40.15 |
| Initiation Cost per Hole ($) | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 |
| Drilling Cost per Hole ($) | 21.05 | 23.155 | 27.365 | 21.05 | 27.365 | 23.155 |
| Total Cost per Hole ($) | 63.42 | 71.26 | 81.21 | 63.42 | 81.21 | 71.26 |
| | | | | | | |
| Explosives Cost per BCM ($/m$^3$) | 0.48 | 0.50 | 0.42 | 0.38 | 0.38 | 0.40 |
| Initiation Cost per BCM ($/m$^3$) | 0.11 | 0.10 | 0.07 | 0.09 | 0.07 | 0.08 |
| Drilling Cost per BCM ($/m$^3$) | 0.29 | 0.29 | 0.25 | 0.23 | 0.23 | 0.23 |
| | | | | | | |
| **Total Cost per BCM ($/m$^3$)** | **0.88** | **0.89** | **0.75** | **0.70** | **0.68** | **0.71** |

### 3.2.2 Performance of Block B Pit

As depicted in Table 4 and Fig. 2, the set of drill and blast parameters for Proposal 2 with the lowest blasting cost per BCM is a better alternative for drilling and blasting in the ore zones of Block B pit. To achieve this, the burden should be increased from 4.0 to 4.5 m, the bench height should be increased from 4.5 to 6.0 m (thus mining should be conducted in two flitches), the stemming height should be increased from 2.0 to 2.5 m and the PF should be reduced from 0.62 to 0.55 kg/m$^3$.

The mean rock fragment size is estimated as 33.7 cm. By adopting this proposed alternative for blasting the ore zones of Block B pit, the total cost per BCM would decrease from \$0.88/m$^3$ to \$0.75/m$^3$ while the volume of *in-situ* rock fragmented would increase from 72 to 108 BCM, an increment of 50%.

As presented in Table 4 and Fig. 2, by adopting the set of parameters for Proposal 1 as a better alternative for drilling and blasting the waste zones of Block B pit, the total cost per BCM would decrease from \$0.70/m$^3$ to \$0.68/m$^3$. The bench height would also need to be increased from 4.5 to 6.0 m, the stemming height increased from 2.0 to 2.5 m and the PF kept constant (0.50 kg/m$^3$). The mean rock fragment size would reduce to 36.7 cm, and volume of *in-situ* waste fragmented would increase from 90 to 120 m$^3$, constituting 33% increment.

The total cost savings in drilling and blasting ore and waste zones in Block B pit using Proposal 1 (in Table 4) respectively is modelled and shown in Fig. 5.

**Table 5 Evaluation of Drilling and Blasting for Block C**

| Parameter | Ore Zone | | | Waste Zone | | |
|---|---|---|---|---|---|---|
| | Current Data | Proposal 1 | Proposal 2 | Current Data | Proposal 1 | Proposal 2 |
| Burden (m) | 3.5 | 3.5 | 4 | 4 | 4 | 4 |
| Spacing (m) | 3.5 | 3.5 | 3.5 | 4 | 4 | 4.5 |
| Hole Diameter (mm) | 127 | 127 | 127 | 127 | 127 | 127 |
| Bench Height (m) | 4.5 | 6 | 4.5 | 4.5 | 5 | 6 |
| Sub-drill (m) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Stemming (m) | 2 | 2.5 | 2 | 2 | 2.5 | 2.5 |
| Explosive Type | Blend | Blend | Blend | Blend | Blend | Blend |
| Explosive Density (kg/m$^3$) | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 | 0.00118 |
| Relative Explosives Energy | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 |
| Drilling Cost ($/m) | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 | 4.21 |
| Explosive Cost ($/t) | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 | 767.21 |
| Loading Density (kg/m) | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 |
| Charge Length (m) | 3.0 | 4.0 | 3.0 | 3.0 | 3.0 | 4.0 |
| Mass per Hole (kg) | 44.86 | 59.82 | 44.86 | 44.86 | 44.86 | 59.82 |
| Mass above Grade (kg) | 37.38 | 52.34 | 37.38 | 37.38 | 37.38 | 52.34 |
| Technical Powder Factor | 0.68 | 0.71 | 0.59 | 0.52 | 0.47 | 0.48 |
| Actual Powder Factor | 0.81 | 0.81 | 0.71 | 0.62 | 0.56 | 0.55 |
| Mean Size (cm) | 25.22 | 24.77 | 28.06 | 31.23 | 33.97 | 33.70 |
| BCM per Hole (m$^3$) | 55.13 | 73.50 | 63.00 | 72.00 | 80.00 | 108.00 |
| | | | | | | |
| Explosives Cost per Hole ($) | 34.42 | 45.89 | 34.42 | 34.42 | 34.42 | 45.89 |
| Initiation Cost per Hole ($) | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 | 7.95 |
| Drilling Cost per Hole ($) | 21.05 | 27.37 | 21.05 | 21.05 | 23.16 | 27.37 |
| Total Cost per Hole ($) | 63.42 | 81.21 | 63.42 | 63.42 | 65.52 | 81.21 |
| | | | | | | |
| Explosives Cost per BCM ($/m$^3$) | 0.62 | 0.62 | 0.55 | 0.48 | 0.43 | 0.42 |
| Initiation Cost per BCM ($/m$^3$) | 0.14 | 0.11 | 0.13 | 0.11 | 0.10 | 0.07 |
| Drilling Cost per BCM ($/m$^3$) | 0.38 | 0.37 | 0.33 | 0.29 | 0.29 | 0.25 |
| | | | | | | |
| **Total Cost per BCM ($/m$^3$)** | **1.15** | **1.10** | **1.01** | **0.88** | **0.82** | **0.75** |

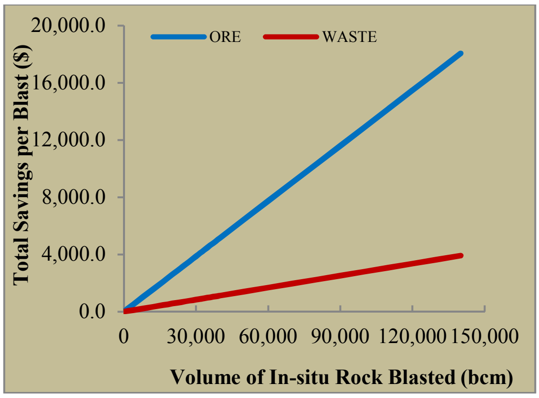


**Fig. 5 Total Cost Savings using Optimised Parameters for Blasting in Block B Pit**

### 3.2.3 Performance of Block C Pit

When drilling and blasting the ore zones in Block C pit, Proposal 2 gives better alternative set of drill and blast parameters with the minimum total cost per BCM of ore blasted. It is observed in Table 5 and Fig. 3 that, if all the drill and blast parameters are maintained but the burden is increased from 3.5 to 4.0 m, the PF would decrease from 0.81 to 0.71 kg/m$^3$ and the mean fragmented rock size would increase from 25.2 to 28.1 cm. This fragmented size is within the desired mean fragmentation size of 45.0 cm for the mine. The volume of *in-situ* ore fragmented would increase from 55.1 to 63.0 m$^3$ while the total cost would decrease from $1.15/m$^3$ to $1.01/m$^3$, about 12.2% cost reduction.

In Fig. 3, it is observed that, in drilling and blasting the waste zone of Block C pit, drill and blast parameters for Proposal 2 give better alternative to the current drill and blast geometric parameters. As shown in Table 5, if the spacing is increased from 4.0 to 4.5 m, the bench height increased from 4.5 to 6.0 m and the stemming height increased from 2.0 to 2.5 m, the PF would decrease from 0.62 to 0.55 kg/m$^3$. Also, the mean fragment size would be approx. 33.7 cm. The blast performance in terms of the BCM blasted per hole would increase from 72 to 108 m$^3$, an increment of 50%. The total cost per BCM blasted when Proposal 2 is adopted as a better alternative for blasting waste zones in Block C pit would decrease from $0.88/m$^3$ to $0.75/m$^3$, about 14.8% reduction in the drilling and blasting cost.

The cost savings in drilling and blasting ore and waste zones in Block C pit using Proposal 2 (Table 5) is modelled and shown in Fig. 6.

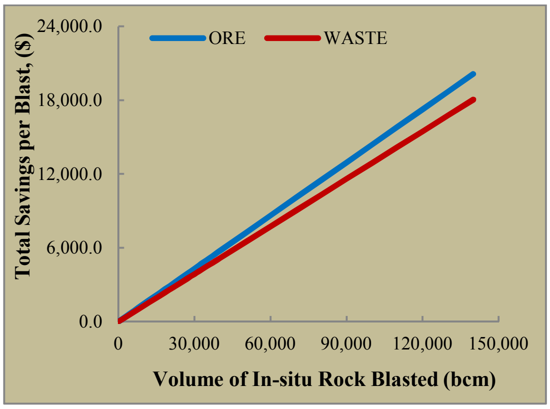


**Fig. 6 Total Cost Savings using Optimised Parameters for Blasting in Block C Pit**

## 4 Conclusions and Recommendations

### 4.1 Conclusions

Several factors including on-bench geometric parameters, technical explosive data and desired fragmentation sizes influence the cost trends in the drilling and blasting operations of a mine. The Kuz-Ram fragmentation model was used as a tool for experimenting with various blast geometric parameters to improve on drill and blast performance of the mine. The blast performance was measured in terms of the Powder Factor (PF), the mean fragment size and the volume of blasted material per blasthole in three (3) operational pits of the mine (Block A, Block B and Block C). The total cost of drilling and blasting in the three pits and the cost savings from the proposed blast parameters over the mine's current parameters for ore and waste zones were assessed.

The current total cost of drilling and blasting in the mine ranges from \$0.88/BCM to \$1.15/BCM for ore zones and \$0.70/BCM to \$0.88/BCM for waste zones. The estimated total volume of *in-situ* material blasted using the proposed parameters increases by 14.3 to 50.0% for ore zones and 12.5 to 50.0% for waste zones. Moreover, the estimated total drill and blast cost savings from the study ranged from 5.3 to 12.2% for ore zones and 2.9 to 14.8% for waste zones.

The estimated PF of all the proposed set of drill and blast parameters were comparatively lower than the current PF used in the mine with the exception of blasting waste zones in Block B pit, where the estimated PF was 0.01 kg/m$^3$ higher than the current practice. The estimated mean rock fragment sizes of all the proposed alternatives were significantly less than the desired mean fragment size of 45.0 cm, and there was effective utilisation of explosive energy per *in-situ* material blasted.

The total cost savings in adopting the proposed drill and blast parameters for drilling and blasting *in-situ* formations in each operational pit of the mine have been modelled.

### 4.2 Recommendations

The mine should consider adopting the proposed optimised parameters to reduce its high drill and blast costs trends. The mine should undertake a pilot study by using these proposed parameters in its three operational pits for a period of one month. Environmental impact prediction studies should be conducted on the use of the proposed optimised parameters. Also, environmental impact assessment of ground vibration, air blast or air overpressures, fly rock and noise should be monitored during the pilot project when the proposed drill and blast parameters are being explored.

## References


Anon., (2014), "Reducing the Cost of Drill and Blast through Blast Design Optimisation: Case Study at North parkes Open Cut Mine, Australia", *Orica Limited Group*, Australia, pp. 1-2.

Bozic B. (1998), "Control of Fragmentation by Blasting", *Rudarsko-geoloiko-nafini zbornik*, Vol. 10, pp. 49-57.

Cunningham, C. V. B. (2005), "The Kuz-Ram Fragmentation Model – 20 Years On", *Brighton Conference Proceedings 2005,* R. Holmberg *et al.* (ed), European Federation of Explosives Engineers, pp. 201-210.

Cunningham, C. V. B. (1987), "Fragmentation Estimations and The Kuz–Ram Model – four years on", *Proceedings of Second International Symposium on Rock Fragmentation by Blasting*, Fourney W. (ed.), Keystone, Colorado, pp. 475-487.

Cunningham, C. V. B. (1983), "The Kuz–Ram Model for Prediction of Fragmentation from Blasting", *Proceedings of First International Symposium on Rock Fragmentation by Blasting,* Holmberg R. & Rustan A. (eds), Luleå, pp. 439-454.

Gokhal, V. B. (2010), *Rotary Drilling and Blasting in Large Surface Mines*, CRC Press, 748 pp.

ICMM, (2012), "Trends in the Mining and Metals Industry", *Mining's Contribution to Sustainable Development,* International Council on Mining and Metals, London, United Kingdom, 16 pp.

Olofsson, S. O. (1988), *Applied Explosives Technology for Construction and Mining*, Nora Boktryckeri AB, Sweden, 315 pp.

Palangio, T. W., Palangio T. C., and Maerz N. (2005), "Advanced Automatic Optical Blast Fragmentation Sizing and Tracking", *Brighton Conference Proceedings 2005,* R. Holmberg *et al.* (ed)*,* European Federation of Explosives Engineers, pp. 259-267.

Raitt, G. D., McClure, R. and Workman, L. (2013), "Lesson 3 – Drilling and Blasting", *http://www.pitandquarry.com/lesson-3-drilling-and-blasting/*, Accessed: April 15, 2014.

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