Application of Kuz Ram Model to Minimize the Drilling and Blasting Operational Cost at RP3 Lafarge Limestone Quarry

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Abstract: ***This work presents the application of the Kuz Ram model to minimize the drilling and blasting operational costs at the Lafarge Limestone Quarry. The quarry faces challenges with rock fragment size distribution produced after primary blasting. The presence of boulders and toes requires a rock breaker or secondary fragmentation to reduce the broken materials to acceptable sizes further, thereby increasing the cost of production. Face mapping and Point Load Test (PLT) were used to characterize the rock at the RP3 Lafarge Limestone Quarry. The explosives parameters and blast design used in this study are the current parameters used at the RP3 Lafarge Limestone Quarry. The Kuz Ram model was applied in the actual parameters as a predictive model to analyze the results of blasting based on the parameters such as blasthole diameter, hole length, burden, spacing, sub drilling, charge length, blasted volume per hole,and powder factor. The Kuz Ram model results were compared to the results obtained from the Split Desktop image analysis. Significant differences in the distribution of rock fragment sizes were identified. Compared to the Kuz Ram prediction model, Split Desktop showed a more realistic size distribution in numerous blasts.The Kuz Ram model proposed by Cunningham (1983) was modified to meet the specifications of the RP3 Lafarge Limestone Quarry using the results obtained from Split Desktop image analysis software. The collar, alignment, hole depth and burden and spacing deviations were measured to evaluate the differences between the planned and the actual parameters at the RP3 Lafarge Limestone Quarry. The cost evaluation was also done in this study using the Kuz – Ram model to compare the planned, actual, and proposed parameters.***

Keywords: Kuz – Ram, Split Desktop, geometric blast design, secondary blasting, rock breaker

1. Introduction

Due to its direct impacts on the expenses of drilling and blasting, as well as the economics of subsequent operations such as loading, hauling, and crushing, the rock fragment size distribution after blasting is regarded as one of the most important production indices. In most circumstances, the Kuz-Ram model is used to make an empirical estimate of the predicted size distribution of blasted rock mass.This model combines rock properties, explosive properties, and blast design parameters in an empirical fragmentation model. The Kuz-Ram model is based on Cunningham's modifications to the Kuznetsov and Rosin-Rammler equations. Themean fragment size and the uniformity index are calculated using this method. The mean fragment size and uniformity index characterize the drill and blast design parameters, while the rock factor characterizes the rock properties. As a final consequence, it is feasible to predict blasted rock mass fragmentation. Equations for the mean fragment size,Kuznetsov, uniformity index, powder factor, volume of blasted material, and burden are listed below.

Mean fragment size:

$$Xm = AQ^{\frac{1}{6}}(\frac{115}{E})^{\frac{19}{30}}q^{-0.8} \qquad \text{Equation 1}$$

Where: **X**m is the mean fragment size (cm); **A** is the rock factor; **q** is the powder factor, kg/m3;
Q is the quantity of explosives per hole, kg; **E** is the relative weight strength of the explosive.

Adapted Kuznetsov:

$$R_x = \exp\left[-0.693\left(\frac{X}{X_m}\right)^n\right] \qquad \text{Equation 2}$$

Where **X** is the crusher grizzly and **n** uniformity index

Uniformity index:

$$n = (2.2 - \frac{14B}{d})\ (1- \frac{W}{B})\ [1 + (\frac{\frac{S}{B}-1}{2})]\frac{L}{H} \qquad \text{Equation 3}$$

Using Equation 3 proposed by Cunningham (1980), the standard deviation was derived in this study as follows:

$$n = (2.2 - \frac{14B}{d})\ (1- \frac{W}{B})\ [1 + (\frac{\frac{S}{B}-1}{2})]\frac{L}{H}$$

let $(2.2 - \frac{14B}{d}) * [1 + (\frac{\frac{S}{B}-1}{2})]\frac{L}{H}$ equal to **k**

$$n = (1- \frac{W}{B}) * k$$

$$n = (\frac{B-W}{B}) * k$$

$$W = B\ (1 - \frac{n}{k})$$

where **W** is the standard deviation of the drilling accuracy (m), and **L** is the charge length (m) including the sub-drilling, **B** burden (m), **S** spacing (m), **H** is the bench height (m), **d** the hole diameter (mm), and **n** is the uniformity index.

Rock factor:

$$A= 0.06(RMD + JF + RDI + HF) \qquad \text{Equation 4}$$

RMD is the rock mass description, **JF** is the joint factor, **RDI** is the rock density influence, and **HF** is the hardness factor. Equation 1 can be used to calculate the mean fragment size (**X**m) for a given powder factor. Making the power factor the subject of the formula gives:

$$q = \left[\frac{A}{X_m}Q^{\frac{1}{6}}(\frac{115}{E})^{\frac{19}{30}}\right]^{1.25} \qquad \text{Equation 5}$$

The powder factor required to achieve the desired mean fragment size can be calculated using Equation 5. On the other hand, the powder factor can also be calculated using the following formula based on the amount of explosives per hole and the volume of blasted material:

$$q = \frac{Q}{V} \quad \text{Equation 6}$$

Where **V** is the volume of blasted material given by:

$$V = B \times S \times H \quad \text{Equation 7}$$

Considering the spacing and burden ratio **S/B**, the burden can be evaluated as follow:

$$B = \sqrt{\frac{\frac{S}{B} X Q}{qH}} \quad \text{Equation 8}$$

Where **Q** is the amount of explosives per hole, **q** is the powder factor, and **H** is the bench heigh

Several researchers such as Temeng (2015), Kansake (2016), Gadikor (2018), Babaeianm (2019) and Tweneboah (2019), first applied and then modified the Kuz – Ram fragmentation model based on the image analysis on bench blasting to achieve the desired rock fragmentation and to optimize the cost related to the drilling and blasting operations and the subsequent processes (loading, hauling and crushing).

Tosun (2014) and Gheibi et al. (2009) proposed the modified Kuz – Ram model that is similar to the origin Kuz – Ram but the Kuznetsov equation was modified by adding a land coefficient respectively 0.038 and 0.073 for Tosun (2014) and Gheibi et al. (2009) to the formula for the prediction of the mean fragment size.

Gadikor (2018) applied the modified Kuz – Ram model proposed by Gheibi et al. (2009) and compared the origin Kuz – Ram model. The modified Kuz – Ram model performed well compared to the original one. Abiodun (2021) proposed a new modification to the Kuz – Ram model using the mean fragment size predicted by the image analysis using data from the limestone quarry obtained from the research of Tosun (2014) and the iron mine from the study of Shad et al. (2018).

The goal of these several studies is to adapt the Kuz - Ram prediction model to the needs of mines and quarries. Because of the varying specifications of mines and quarries due to strains on the rock caused by progress drilling and blasting activities, the modified Kuz - Ram models are not identical. the generalization of the modified Kuz Ram model will require time and several measurements to come up with a common modified Kuz – Ram model that is going to be adapted to mines and quarries specifications as the geological conditions are being disturbed and changed by drilling and blasting activities.

In this study a simple method of modifying the Kuz – Ram model is proposed as well as a modified Kuz – Ram model adapted to the RP3 Lafarge limestone quarry specifications. However, the following layout was followed to meet the objectives of this study: materials and methods, data collection, data analysis and discussion, and conclusion and recommendations.

2. Materials and Methods

2.1 Materials

Data for this study were obtained from the RP3 Lafarge Limestone Quarry through field measurements. Below are the instruments used in this study work.

a) Drill and blast data from field studies at RP3 Lafarge Limestone Quarry;
b) MS Excel Software was used for the analysis of drilling and blasting performance;
c) Kuz-Ram Model and Splitdesktop Software were used for fragmentation analysis of blasting performance;
d) Geological compass for face mapping;
e) Dips software was used to evaluate the rock characterization (the dip, strike, and dip direction) and
f) GPS (global positioning system) was used to take locations where samples were taken.
g) Tape measure for the collar, hole depth and burden and spacing deviations
h) Drill machine for the alignment deviation

2.2 Methods

The data analysis in this study was analysed using the Kuz – Ram prediction model and the image analysis Split Desktop. Using the results of the fragmentation analysis from Split-Desktop as the baseline, the fragmentation prediction and image analysis were compared to determine the accuracy of the predictions made by the Kuz Ram model and to identify the gaps in the drilling and the blasting operations.

The comparison between Kuz – Ram model and Split Desktop image analysis was done using the statistical method regression analysis through MS Excel Software 2019.

A modified Kuz Ram model was calculated using the data acquired from the image analysis Split Desktop software with the help of MS Excel software 2019 to adapt the Kuz Ram model presented by Cunningham (1983) to the RP3 Lafarge Limestone Quarry parameters. The cost evaluation was done also using the Kuz – Ram model through MS Excel software 2019.

2.3 Split Desktop

In recent years, the image analysis technique has been used to predict rock fragmentation by blasting as a high-capability method in the mining industry. For example, researchers such as Babaeian (2019), Gadikor (2018)and Alireza (2017) used the Split Desktop image analyses software, and Hosseni and Namvar (2017) and Sereshki et al. (2016) used the Gold–size software to predict the rock fragment size distribution and blast blasting and develop new fragmentation model. Split-Desktop software is an image-processing program designed to calculate the size distribution of rock fragments by analyzing digital grayscale images. Split-Desktop software has five progressive steps for analyzing each photo, as follows: Scaling of the picture taken in the field,carrying out delineation of the fragments,Editing of the delineated fragments for obtaining accurate output, Determining the size distribution for the delineated fragments, andFinally, plotting the graph to display the size distribution outputs (Alireza, 2017).

3. Data Collection

Data on drilling, blasting and explosives parameters were obtained in this study through field measurements and reports after every blast. The geometric blast design parameters included blasthole diameter, burden, spacing, stemming, and hole length while blasting parameters included charge length, blasted volume of material, powder factor, explosive density, relative explosive strength, packing degree and type of explosives. Other parameters obtained were on the rock at the quarry.For the time allowed to undertake the study at the quarry, data on only **20** were obtained in two phases, of which data on 13 blasts were obtained in **Phase 1** while on 7 blasts were obtained in **Phase 2**.The tools used for measurements included a tape measure, the geological compass, a geological hammer and blast reports by blast operators after every blast. The data analysis in this study was done using the Kuz – Ram prediction model and the image analysis Split Desktop. Using the results of the fragmentation analysis from Split-Desktop as the baseline, the fragmentation prediction and image analysis were compared to determine the accuracy of the predictions made by the Kuz-Ram model and to identify the gaps in the drilling and the blasting operations. The comparison between the Kuz – Ram model and Split Desktop image analysis was done using the statistical method regression analysis through MS Excel Software 2019.In **Phase 2**, more data was acquired on rock characterization, hole deviations (that is, deviations of hole collaring point, hole alignment, hole trajectory and hole length), as well as burden and spacing deviations.

Table 1: Designed parameters at RP3 Lafarge Limestone quarry

Designed Parameters	Patter 1	Patter 2
Hole Diameter (mm)	102	115
Explosive Density (grams/cc)	1.15	1.15
Packing Degree	98	98
Rock Density (g/cc)	2.56	2.56
Bench Height (m)	10	10
Hole Angle (0 = vertical)	0	0
Stem Length (m)	2.5	2.5
Subdrill (m)	0	0
Hole Length (m)	10	10
Charge Length (m)	7.5	7.5
Loading Density (kg/m)	9.20	11.71
Charge Weight (kg) per hole	69.03	87.75
Burden (m)	3	3.2
Spacing (m)	3.5	3.7
Spacing Burden ratio	1.15	1.15
Volume Shot per Hole (bcm)	105	118.4
Mass shot per hole (ton)	268.8	303
Powder Factor (kg/bcm)	0.66	0.74
Powder Factor (kg/ton)	0.26	0.29

Table 2 gives the rock properties at RP3 Lafarge Limestone Quarry.

Table 2: Rock properties

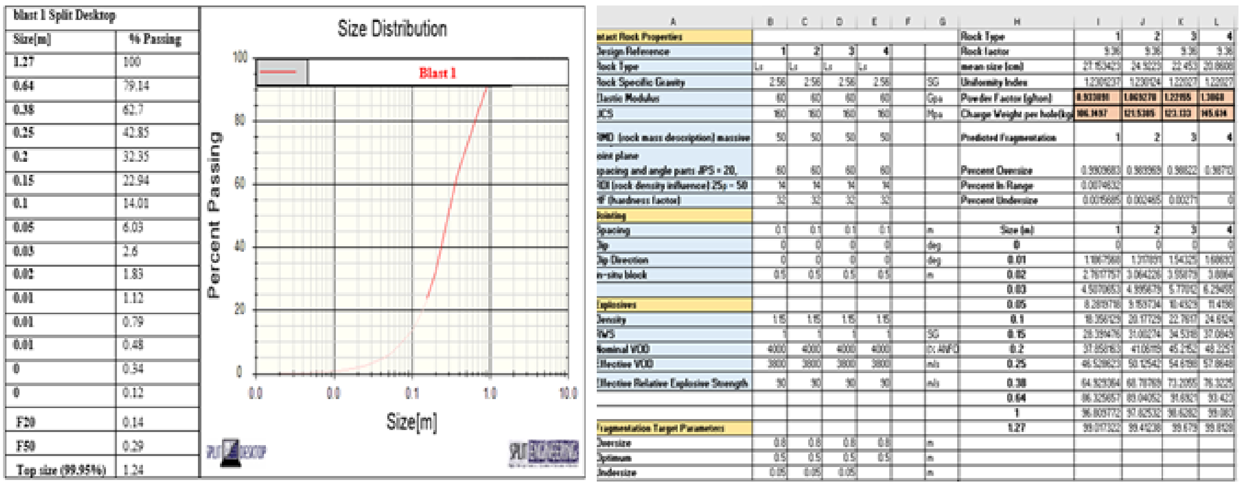
RMD (rock mass description) 50	10 = rock powdery or friable
	JF = vertical joints
	50 = massive rock
Joint Factor JF = JPS + JPA JF = 20 + 40 JF = 60	JPA = 10 (S_j < 0.1m)
	JPA = 20 (0.1 < S_j <x_0)
	JPS= 50 (S_j >x_0)
	JPA = 20 (dip out of face)
	JPA = 30 (strike perpendicular to the face)
	JPA =40 (dip into the face)
HF (hardness factor)	E/3 E < 50 GPa
	$\frac{\sigma c}{5}$ E > 50 GPa
RDI (rock density influence) = 25*2.56 – 50 = 14	RDI = 25ρ – 50

On average, the uniaxial compressive strength (UCS) and the rock factor (A) were 145 Mpa and 9.2.

4. Data Analysis and Discussion

Results and discussions are presented in this section of the study. 20 blats were collected in this study,11 blasts in phase 13 and 7 basts in phase 2 were used in the first phase of this study comparing the results obtained from Kuz Ram and Split Desktop as shown in table 8, figures 2 and 3

Table 3: Kuz – Ram model



blast 1 Split Desktop	
Size[m]	% Passing
1.27	100
0.64	79.14
0.38	62.7
0.25	42.85
0.2	32.35
0.15	22.94
0.1	14.01
0.05	6.03
0.03	2.6
0.02	1.83
0.01	1.12
0.01	0.79
0.01	0.48
0	0.34
0	0.12
F20	0.14
F50	0.29
Top size (99.95%)	1.24

Figure 1: Split Desktop

The observed results obtained by Slit Desktop image analysis compared to the predicted results obtained by the Kuz – Ram prediction model using the regression analysis show that the correlation between the observed and predicted results is good. However, the prediction of boulders by Kuz – Ram was different from the results obtained using Split Desktop; tables4 and 5 give the example of the regression analysis done for the 11 blasts.In addition, the mean fragment size and uniformity index correlated poorly with the Kuz – Ram model results and the image analysis Split Desktop.

Table 4: Rock fragment size distribution analysis Blast 1

Blast 1			
Size (m)	Kuz – Ram(%)	Split Desktop (%)	Predicted Y(%)
0	0	0.48	2.63853
0.01	1.147913	1.12	3.288919
0.02	2.690671	1.83	4.010444
0.03	4.40974	2.6	4.792943
0.05	8.146997	6.03	8.278622
0.1	18.1891	14.01	16.38816
0.15	28.24787	22.94	25.46312
0.2	37.76658	32.35	35.02587
0.25	46.50058	42.85	45.69632
0.38	65.05458	62.7	65.86854
0.64	86.56116	79.14	82.57541
1.27	99.08639	100	103.774

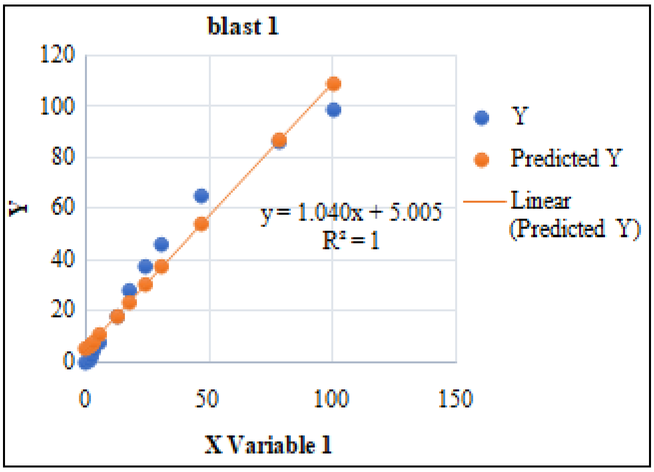


Figure 2: Blast analysis blast 1

Table 5: Regression statistics Blast 1

Regression Statistics	
Multiple R	0.997295
R Square	0.994598
Adjusted R Square	0.994058
Standard Error	2.667071
Observations	12

5. Modified KUZ – RAM Model

The results obtained using the first 11 blasts presented a significant difference between Kuz ram and Split Desktop to adapt the Kuz Ram model to the quarry specifications;a modified Kuz Ram model was proposed in this study. In total, 20 blasts were collected, but only 15 blasts were considered in the modification of Kuz Ram using MS Excel software 2019 based on the data acquired using Split Desktop. In addition, there were several measurement problems in the remaining five blasts in terms of images captured after blasting.

Cunningham's (1983) mean fragment size formula equation 1 was used to find the modified Kuz Ram

$$Xm = AQ^{\frac{1}{6}}\left(\frac{115}{E}\right)^{\frac{19}{30}}q^{-0.8}$$

Were A is defined in equation 4
It was assumed that 0.06 is a constant = c, (RMD + RDI + JF +HF) = Z and $Q^{\frac{1}{6}}\left(\frac{115}{E}\right)^{\frac{19}{30}}q^{-0.8}$ = Y
the for formula will be Xm = c*Z*Y and the unknown constant
$c = \frac{Xm}{Z*Y}$ (land coefficient)Equation 1
with the help of MS Excel software, the land coefficient was found equal to 0.078, and the modified Kuz – Ram model can be written as:

$$Xm = 0.078\ (RMD + RDI + JF + HF)\ Q^{\frac{1}{6}}\left(\frac{115}{E}\right)^{\frac{19}{30}}q^{-0.8}$$ Equation 2

5.1 Application of the Modified Kuz Ram Model

The modified Kuz Ram model was applied to predict the mean fragmentation size, the 80% and 100 % of material passing through the grizzly using the designed parameters of the quarry. As shown in table 17, the results are quick good according to the quarry objectives of having at least 97% of materials passing through the grizzly. However, there is a need of improving.

Table 6: Performance of the modified Kuz Ram model on the designed parameters at RP3 Lafarge Limestone quarry

Pattern 1				Pattern 2			
n	Xm (cm)	P80 (%)	P100(%)	n	Xm(cm)	P80(%)	P100(%)
1.3	43	89	94	1.3	38	92	96

5.2 Redesigning of Blast Design

The redesigning of the blast design was done using the Kuz – Ram model using the equation 1

$$Xm = AQ^{\frac{1}{6}}\left(\frac{115}{E}\right)^{\frac{19}{30}}q^{-0.8}$$

Equation 1 can be used to calculate the mean fragmentation size (Xm) for a given powder factor. Making the power factor the subject of the formula gives:

$$q = \left[\frac{A}{X_m}Q^{\frac{1}{6}}\left(\frac{115}{E}\right)^{\frac{19}{30}}\right]^{1.25} \qquad \text{Equation 3}$$

The equation can also calculate the power factor required to yield the desired mean fragmentation size.Using the modified Kuz – Ram model proposed in this study Equation 11.

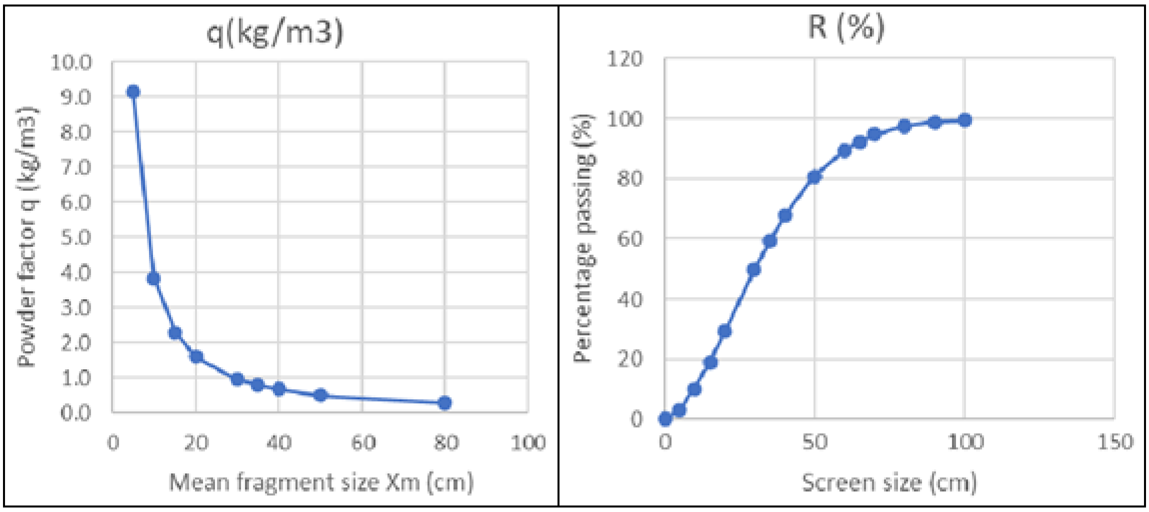
$$A = 0.078(RMD + RDI + JF + HF)$$

Using the designed parameters used at the RP3 Lafarge Limestone quarry, calculating the powder factor required to yield desired mean fragment size was done using different mean fragment sizes as shown in the table7 for the hole diameter of 102, 114, and 115 mm.

In yellow are parameters that produce the best results in mean fragment size, powder factor, and percentage passing, as shown in table 7. Figures 4 and 5 give the relations between powder factor and mean fragment size and the mean fragment size and percentage passing.

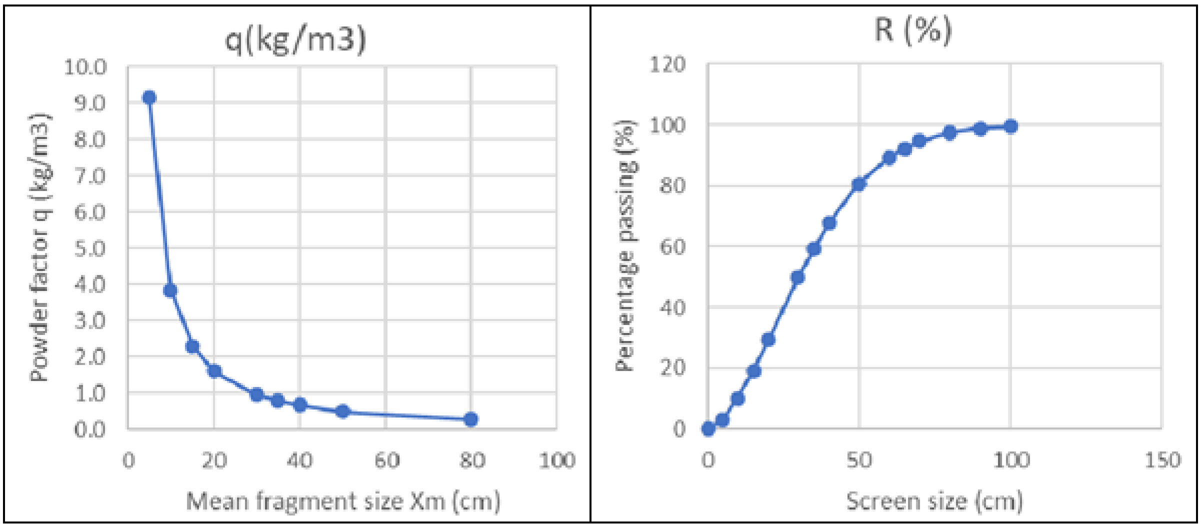
Table 7: Relation between mean fragment size, powder factor, and percentage passing for 102 mm and 114 mm and 155 mm hole diameter

D = 102 mm					D = 114 mm and 115 mm				
Xm (cm)	Q	q(kg/m3)	n	R	Xm (cm)	Q	q(kg/m3)	n	R
5	69	8.7	1.6	100	5	87.8	9.1	1.7	100
10	69	3.7	1.6	100	10	87.8	3.8	1.7	100
15	69	2.2	1.6	100	15	87.8	2.3	1.7	100
20	69	1.5	1.6	100	20	87.8	1.6	1.7	100
30	69	0.9	1.6	99	30	87.8	1.0	1.7	99
35	69	0.8	1.6	98	35	87.8	0.8	1.7	98
40	69	0.6	1.6	95	40	87.8	0.7	1.7	96
50	69	0.5	1.6	88	50	87.8	0.5	1.7	89



(a) Mean fragment size (b) Percentage passing

Figure 4: Desired powder factor for 102 mm



(a) Mean fragment size for 114 and 115 mm. (b) Percentage passing for 114 and 115 mm

Figure 5: Desired powder factor

The powder factor required to yield desired mean fragment size was equal to 0.9kg/m3 for the hole diameter of 102 mm and 1kg/m3 for the hole diameter of 114 mm and 115 mm, which yield 99% of material passing through the crusher gape as presented in tables and figure

After getting the required powder factor that yields the desired mean fragment size, the Burden and spacing were redesigned based on the powder factor using equation 9.

$$B = \sqrt{\frac{1.15Q}{qH}}$$

Table 8 gives the redesigned parameters using Kuz – Ram model

Table 8: Redesigned Parameters

Pattern	Pattern 1 (D = 102 mm)	Pattern 2 (D = 114 mm and 115 mm)
Burden (m)	2.9	3.1
Spacing (m)	3.3	3.6

6. Cost Evaluation

The cost was evaluated in this study using mathematics formulas with the help of MS Excel software 2019 to compare the designed, actual, and proposed costs.

$$C_T(\$/m^3) = \frac{(C_{DR} * L_H + \frac{\pi D^2 \rho p}{4000*100} * L_c * C_{Ex} + C_B + C_{DTH} + C_{STL})}{B * S * L_H}$$

Equation 4

$$C_T(\$/ton) = \frac{(C_{DR} * L_H + \frac{\pi D^2 \rho p}{4000*100} * L_c * C_{Ex} + C_B + C_{DTH} + C_{STL})}{B * S * L_H * d}$$

Equation 5

Where C_T is the total cost, C_{DR} drilling cost, C_{BL} is the blasting cost, C_{Acc} is the cost of accessories, C_B is the cost of a booster, C_{DTH} is the cost of non-electric down the hole, C_{STL} is the cost of the surface lines L_H is the hole length, L_c is the charge length, C_{Ex} is the cost of the explosives, D is the hole diameter, ρ density of explosives, and p is the packing degree.

Table 9 gives prices of drilling, explosives, and accessories.

Table 9: Prices of drilling, explosives, and accessories

Drilling cost ($/m)	5.85
Cost of explosive($/kg)	0.81
DTH 500ms 15 mtrs ($)	3.8
DTH 500ms 21mtrs ($)	5
STL 0ms, 17ms, 25ms,42ms,6.0 mtrs ($)	1.85
Booster 150g ($)	2.5
Booster 400g ($)	4.5

Considering 20 blasts the tables give the costs of the design, actual and proposed blast design divided into two groups according to the bit size used as shown in tables 10 and 11 and figure 7.

Table 10: Cost evaluation using 102 mm bit size

D = 102mm				
	Planned	Actual (B = 3, S= 3.5)	Actual (B = 2, S=2.5)	Proposed
Cost ($/kg)	1.2	1.9	3	1.3
Cost($/ton)	0.47	0.74	1.19	0.51

Table 11: Cost evaluation using 115 mm and 114 mm bit sizes

D = 115mm and 114mm			
	Planned	Actual	Proposed
Cost ($/kg)	1.2	1.6	1.3
Cost($/ton)	0.47	0.62	0.51

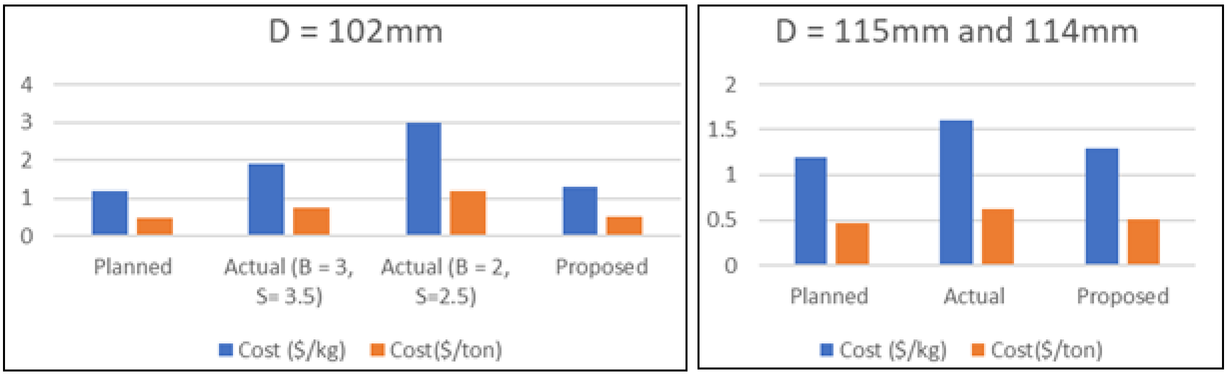


Figure 3: Cost evaluation

7. Conclusions and Recommendations

7.1 Conclusion

According to the findings of the study, it can be concluded that:

1) The Kuz – Ram model in its original form proposed by Cumminghan (1983) can be applied only when the assumed rock mass is intact
2) The Kuz-Ram model has been successfully modified and applied at the RP3 Lafarge Limestone Quarry.
3) The measurements of drilling and blasting operations using a tape measure revealed many errors in drilling and blasting operations in terms of hole drilling pattern quality and blasting parameters:
   Deviations in the collar placement, blast hole depth, burden and spacing were significant. These deviations exceeded the permissible limits of the quarry. The deviations were average 0.19 m (27.8%) against the acceptable limits of 0.15 m for collar placement, 0.9 m (17%) against 0.5 m for blast hole depth, 0.115 m (11.5%) against 0 m for burden and spacing, and, these deviations could be attributed to operational errors in the field and equipment.
4) Blast assessment using the Kuz-Ram fragmentation model on the blasting practices using the existing blast pattern of 3.2 m × 3.7 m for the hole diameter of 114 mm and 115 mm and 3 m x 3 m for the hole diameter of 102 mm shows that the fragmentation is good, giving a yield of about 95% of the blasted material passing through the grizzly. On the other hand, the new blast pattern of 2 m x 2.5 m for the hole diameter of 102 mm shows that the fragmentation is better with a yield of about 98% of blasted material passing through the grizzly. These values meet the optimum fragment sizes of 1 m for the existing blast design and 0.6 for the new blast design for the quarry.

Analysis of the fragmentation based on image analysis using the Split Desktop Software on blasts resulting from the blast pattern, 3.2 m × 3.7 for the hole diameter of 114 mm and 3 m x 3 m for the hole diameter of 102 mm shows that only about 80 % of the muck pile meets the 1 m maximum fragment size requirement of the quarry.

The results of the new blast pattern of 2 m x 2.5 for the hole diameter of 102 mm showed about 92 % of the material met the 0.6 m maximum fragment size required for the mobile crusher used when the primary crusher was down.

This implied about 20% of the blast material was oversize (boulders) for the prevailing blast patterns while only 8% for the new blast pattern quired secondary blasting. This could be attributed to operational errors in the field, the drilling process and also the rock mass condition then, which was highly fractured and had a portion of clay from bench 1 to bench 5, and the stress caused by the drilling and blasting operations where the drilling and blasting operations were being undertaken.

5) The significant deviations in the drill design geometric parameters (collar placement, blast hole depth, burden and spacing) and rock characteristics appeared to be the main reasons for poor fragmentation at RP3 Lafarge Limestone Quarry, which resulted in boulders, toes, uneven floors in the quarry, and consumption of the explosives more than planned. These may have subsequently led to the excessive cost of primary blasting and also led to secondary blasting of the boulders to achieve the required mill throughput.
6) The parameters such as rock conditions and hole deviations have a significant impact on the efficacy of the Kuz – Ram model because the model does not take into consideration the hole deviations such as the collar, depth, burden and spacing and does not also consider the progressive rock destabilization (fracture formation or increasing weakness) with an increase in drilling and blasting activities.
7) The modified Kuz – Ram model proposed in this study can also be applied when the assumed rock mass is not intact because it was designed according to the prevailing rock mass condition of the quarry. The model thus also considers the progressive rock destabilization with the increase of drilling and blasting activities that cause fractures in the rock mass which weaken it. Hole deviations (excluding trajectory deviation).

7.2 Recommendations

From the above conclusions, the following are recommended:

1) Regarding the application of the proposed blast designsfor the Pattern 1 (D = 102, B = 2.9 m and S = 3.3 m) and Pattern, 2 (D = 114 mm and 115 mm, B = 3.1 m and S = 3.6 m);
   <u>Pattern 1</u> can be used mostly on benches 1 to 5 of the quarry because of therock masscondition in those particular areas of the quarry. In these benches, the rock is highly fractured and contains some portion of clay. This rock condition is also due to the increase of drilling and blasting activities in the quarry; and proposed <u>Patterns 1 and 2 can be used</u> for the remaining parts of the quarry and benches where the rock is not highly fractured but disturbed by the increase of drilling and blasting activities.
2) To achieve the desired fragmentation, the powder factor that should be used for Pattern 1 has been determined to be 0.9 kg/m^3 and for Pattern 2 should be 1 kg/m^3.
3) Carryout rock characterization in the parts of the quarry where drilling and blasting are being undertaken to assess the effect they may be having on drilling and blasting results; measure hole deviations (Collaring, Alignment, Trajectory and Length) to determine their magnitudes and the likely effect they have on the blasting results, and use the parameters to adjust the Kuz – Ram model accordingly for better rock fragment size prediction.
4) Observe and examine the drilling and blasting procedures, patterns and practices in relation to plans to determine their effect on rock fragmentation and adjust them to conform to the planned parameters.
5) The drillers and the blasters should be trained on drilling and blasting principles so that they are made aware of the ramifications of their mistakes on the overall mining performance.

References

[1] Abiodun, 2021. A new modification to the Kuz-Ram model using the fragment size predicted by image analysis. International Journal of Rock Mechanics and Mining.https://www.researchgate.net/publication/348193068 [Accessed 27 April 2021]

[2] Ablebits,2018.About us - Ablebits.com. [Online] Available at: https://www.ablebits.com [Accessed 27 April 2021]

[3] Adebola, J.2016. Rock Fragmentation Prediction using Kuz-Ram Model. Journal of Environment and Earth Science, pp. 2224-3216. https://www.iiste.org/Journals/index.php/JEES/article/download/30610/31442

[4] Agyei, G. and Owusu-Tweneboah, M. 2019. A Comparative Analysis of Rock Fragmentation using Blast Prediction Results. Tarkwa: Ghana Mining Journal. https://gmj.umat.edu.gh/ojs/index.php/gmj/article/view/443

[5] Alireza, T.2017. Analysis of blasted rocks fragmentation using digital image processing (case study: limestone quarry of Abyek Cement Company). International Journal of Geo-Engineering, Volume 8, p. 11. https://www.researchgate.net/publication/319273881

[6] Babaeian, 2018. A new framework for evaluation of rock fragmentation in open-pit mines. Journal of Rock Mechanics and Geotechnical Engineering, pp. 325 – 336. https://doi.org/10.1016/J.JRMGE.2018.11.006

[7] Balasubramanian, A.2017. Rock blasting for mining. ResearchGate, pp. 1-23.

[8] BME, 2010. blast design methods. Lusaka: BME

[9] Borana, 2018. Image Processing Analysis of Blast Fragmentation: A Case Study of Sandstone Mining Area of Jodhpur. International Journal of Research in Advent Technology, pp. 2321-9637. https://www.researchgate.net/publication/328638051
[10] Cunningham, C., 2005. The Kuz-Ram fragmentation model – 20 years on. Brighton Conference Proceedings 2, African Explosives Limited, Modderfontein, South Africa, pp. 201 – 210. https://www.smctesting.com/documents/mine-to-mill/The%20kuz%20ram%20fragmentation%20model%2020%20years%20on.pdf
[11] Eshun, P.2016. Drill and Blast Performance Evaluation at the Obra Pit of Chirano Gold Mines Ltd, Ghana. Ghana Mining Journal, pp. 28 – 35. https://www.ajol.info/index.php/gm/article/view/149645
[12] Gadikor, J. 2018. optimization of drilling and blasting practices at a western us open-pit copper mine. Montana: Montana Tech Library. https://digitalcommons.mtech.edu/cgi/viewcontent.cgi?article=1159&context=grad_rsch
[13] Gheibie, S., 2009. Modified Kuz—Ram fragmentation model and its use at the Sungun Copper Mine. International Journal of Rock Mechanics & Mining Sciences, p. 967–973.https://www.sciencedirect.com/science/article/pii/S1365160909000811
[14] Hekmat, A. 2018. Prediction of Rock Fragmentation Based on a Modified Kuz-Ram Model. Switzerland, Springer Nature Switzerland AG 2019, pp. 69 - 79.http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S2225-62532021000300004
[15] Kangwa S. and Sinkala T. (2003). "Hole Deviation in Mining Operations: types, sources and effects". The Journal of Explosives Engineering. May/June. Pp 6 – 14. https://www.researchgate.net/publication/289833523
[16] Kansake, B. A., Temeng, V. A. and Afum, B. O. (2016), "Comparative Analysis of Rock Fragmentation Models – A Case Study", 4th UMaT Biennial International Mining and Mineral Conference, pp. MP 1 – 11.https://www.researchgate.net/publication/307594360
[17] Kiril, 2021. corporate finance institute. [Online] Available at: https://corporatefinanceinstitute.com [Accessed 4 May 2021].
[18] Mills, J.2000. A Technical Discussion of Mining Operations in the Lime and Cement Industries of Zambia and Malawi. Nottingham: Nottingham ePrints.
[19] Ouchterlony F and Sanchidrián J.A. 2019. A review of the development of better prediction equations for blast fragmentation. Journal of Rock Mechanics and Geotechnical Engineering, Volume 11, pp. 1094 - 1109.https://www.sciencedirect.com/science/article/pii/S1674775518305614
[20] Ouchterlony, 2017. A Distribution-Free Description of Fragmentation by Blasting Based on Dimensional Analysis. Rock Mech Rock Eng, p. 781 – 806.https://link.springer.com/article/10.1007/s00603-016-1131-9
[21] Owusu-Tweneboah, G. 2019. A Comparative Analysis of Rock Fragmentation using Blast prediction results. Ghana Mining Journal, Volume 19, pp. 49 - 58. https://www.ajol.info/index.php/gm/article/view/189574
[22] Petrowski, 2022. Hole deviation. Kuala Lumpur, Offshore conference ASIA.
[23] Sharma, P.2011. Characteristics of Rock and Geology influence Surface, UG and Tunnel Rock Blasting Results. s.l.: Partha Das Sharma. https://miningandblasting.wordpress.com/2011/03/11/
[24] Siinkala T. 2019. Drilling and Blasting Basics. Lecture Powerpoint Presentation. University of Zambia, Lusaka, Zambia.
[25] Sinkala T. 2019. Drilling and Blasting Basics, Module 1 drilling techniques. Lecture Powerpoint Presentation, University of Zambia, Lusaka, Zambia.
[26] Sinkala T. 2020. Bench blasting basics. Lecture Powerpoint Presentation, University of Zambia, Lusaka, Zambia.
[27] Sinkala T.2020. Hole deviations in mining operations, how to measure them, and their economic consequences. Lecture Powerpoint Presentation, University of Zambia, Lusaka, Zambia.
[28] Temeng, B. 2015. Reducing Drill and Blast Cost through Blast Optimisation. Ghana Mining Journal, Volume 15, pp. 50 - 57.https://www.ajol.info/index.php/gm/article/view/127930
[29] Tosun, A. 2014. Development of the kuz-Ram model to blasting in a limestone quarry. de Gruyter, p. 477 – 48. https://www.researchgate.net/publication/272537516