Pattern Expansion Optimization Model Based on Fragmentation Analysis With Drone Technology

Francisco Sena Leite, O-Pitblast, Lda.
Vinicius Miranda, O-Pitblast, Lda.
Thomas Palangio, Wipware Inc.

Abstract

With an increasing pressure to find efficiencies in the mining industry, operations are looking for continuous improvement tools to validate blasting procedures, a crucial and often overlooked area of the process. Using case studies completed at both small and large-scale mining operations, this technical paper proposes a practical methodology for pattern expansion studies, taking into account terrain parameters, rock quality and explosive strength. This technical paper will use a series of tools geared towards an economical continuous improvement procedure, using UAV particle size analysis to optimize blasting based on “generalized reduced gradient” for non-linear problems, with cost savings being the main objective. For the validation of this methodology, one scenario was created based on the operation’s budget: an economical continuous improvement plan that relied on manual data collection methods in order to baseline and optimize procedures.

Introduction

Mining production cycle is represented by two main stages: rock breakage and material handling. Rock breakage process, among others, is dependent on drilling and blasting. In general, boreholes are drilled by mobile rotary percussion drills (Figure 1), along/over the area to be excavated, for the positioning of explosive agents (mainly ammonium-nitrate based) (Hartman, 1992). When the explosive is detonated, high compressive/tensile waves travels through the rock mass followed by high pressure gases. The combination of these two last situations, reduces the rock mass to fragments capable to be hauled economically.

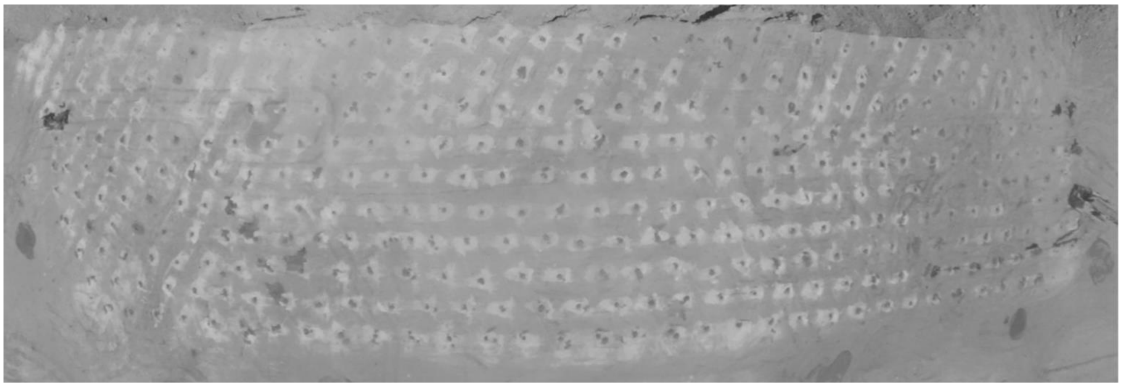

Figure 1. Blast Pattern Drone Control

All modern industries, including mining companies, chase the best operation process in order to reduce the overall cost and, consequently, increment the profit. In general, mining operation costs are defined by crushing and milling cost, load and haul cost and drilling and blasting cost (Figure 2). The overall cost is the result of the combination of each individual cost and, being the drilling and blasting process the initial chain link of the operation, has a great impact on the final score. This document is focused on the optimization of blasting performance in order to obtain a desired result at a minimum cost possible.

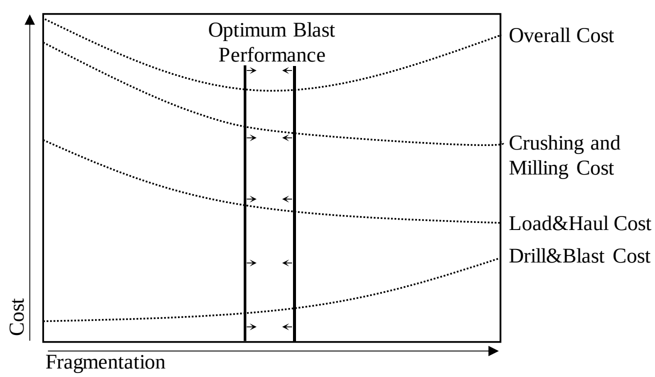

Figure 2. Mining cost relation (adapted from Efficient Blasting Techniques, (Floyd, 2000)

Rock Fragmentation

Fragmentation process

The objective of a blast is to fragment and displace the rock. In fact, this stage can have great impacts on load, haul, crushing and milling. With the constant need to reduce costs and comminution optimization, several models were created to estimate and control, or even more accurate, to guide the drilling and blasting operation. Nowadays the most applied model is Kuz-Ram (Cunningham, 2005) and is used by the authors of this document. To understand a fragmentation model is important to know the fragmentation process of a rock. A rock when submitted to a certain state of pressure is more resistant by compression than when submitted to a tensile strength (Persson, Holmberg, & Lee, 1994). When an explosive shock wave hits the borehole walls applies a compressive strength deforming the rock in a perpendicular direction. If this compressive strength is higher than the compressive resistance of the rock mass, this will be pulverized/fragmented (borehole hydrodynamic and plastic zone), in the other case, fractures (weak cracks or fissures) will be generated resulted by the lateral deformation of the rock (borehole semi-plastic zone). When the compressive wave hits a free face, will be reflected as a tensile wave, deforming the rock perpendicularly to its direction in the same moment that gases at high pressure and temperature start expanding from the borehole center, acting like a wedge in the generated fractures. The combination of these two last points generates the fragmentation and movement of the material (Sanchidrián & Muñiz, 2000).

Fragmentation prediction

To predict the degree of fragmentation prior to a blast, between others, a world-wide (well-known) fragmentation model is proposed by Cunningham, 2005– The Kuz-Ram Fragmentation model. The ease application of Kuz-Ram model makes it one of the most used prediction models (Cunningham, 2005). This Model is based in three main equations:

Kuznetsov Equation (Equation 1), presented by Kuznetsov, determines the blast fragments mean particle size based on explosives quantities, blasted volumes, explosive strength and a Rock Factor.

$$\boldsymbol{x_m = AK^{-0,8}Q^{1/6}\left(\frac{115}{RWS_{ANFO}}\right)^{19/20}} \quad \textbf{Equation 1}$$

Where X_m= Medium size of fragments (cm); A= Rock factor; K = Powder factor (kg/m3); Q= Explosive per hole (kg); 115 = Relative Weight Strength (RWS) of TNT compared to ANFO; RWS_{ANFO}= Relative Weight Strength (RWS) of the used explosive compared to ANFO.

Rosin-Ramler Equation (Equation 2), represents the size distributions of fragmented rock. It is precise on representing particles between 10 mm/0,39 in and 1000 mm/39,37 in (Catasús, 2004, p. 80).

$$\boldsymbol{P(x) = 1 - e^{-0,693\left(\frac{X}{X_m}\right)^n}} \quad \textbf{Equation 2}$$

Where P= Mass fraction passed on a screen opening x, n = Uniformity Index

Uniformity index equation, determines a constant that represent the uniformity of blasted fragments based on the design parameters indicated in Equation 3.

$$\boldsymbol{n = \left(2,2 - \frac{14B}{d}\right) \times \sqrt{\frac{1+\frac{S}{B}}{2}} \times \left(1 - \frac{W}{B}\right) \times \left(\left|\frac{h_f - h_c}{L}\right| + 0,1\right)^{0,1} \times \frac{L}{H}} \quad \textbf{Equation 3}$$

Where B = Burden (m), S= Spacing (m), d = Drill diameter (mm), W = Standard deviation of drilling precision (m), h_f = Bottom charge length (m), h_c = Column charge length (m), L = Charge Length (m), H = Bench height (m).

Fragmentation analysis

Fragmentation analysis process (on field)

When referring to blast optimization one of the main key factors are fragmentation results. Fast and precise measurements are crucial for an accurate and effective continuous improvements on this field (Maerz N. H., 1990). In the present research was used a fragmentation analysis system (Wipfrag) for particle size detection. The system uses an automatic algorithm transforming an image into a binary image, identify individual particles and create a border line around each element. This methodology includes several Edge Detection Variables (EDV) like the use of thresholding and gradient operators in order to delineate the blocks before calculating its area and size (Figure 3) (Maerz, Palangio, & Franklin, 1996).

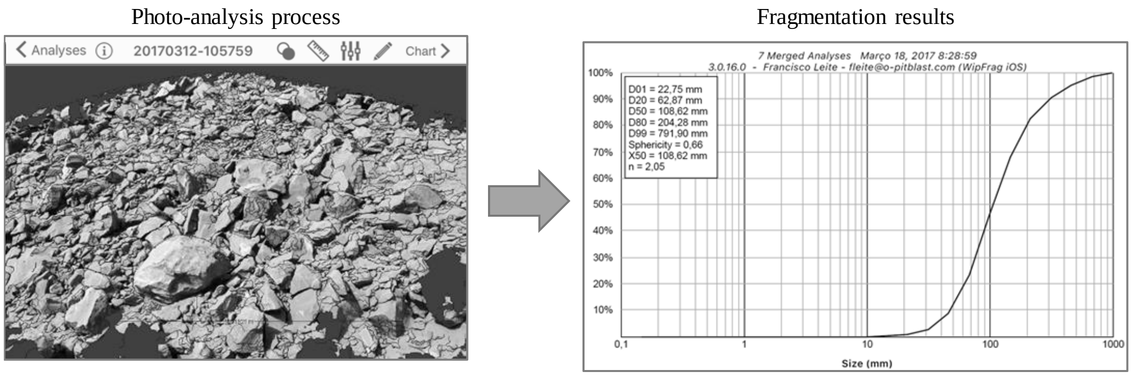

Figure 3. Image process and size distribution

Drone Technology

A drone, also known as UAV (Unmanned Aerial Vehicle) is an aerial vehicle non crewed developed, firstly, for army and military purposes. In the last years, these vehicles gain a popularity in other areas like communication, sports, agriculture, remote sensing, pests control, mining (Rathore & Kumar, 2015). In mining, drone technology reduces the manual effort and risks in survey procedures, mapping, misfires inspection, machinery tracking, structures inspections and dilution control. In the case of the present document, UAVs are playing an important role on fragmentation analysis reducing the risk associated with muckpile inspection, saving great amounts of time collecting fragment samples.

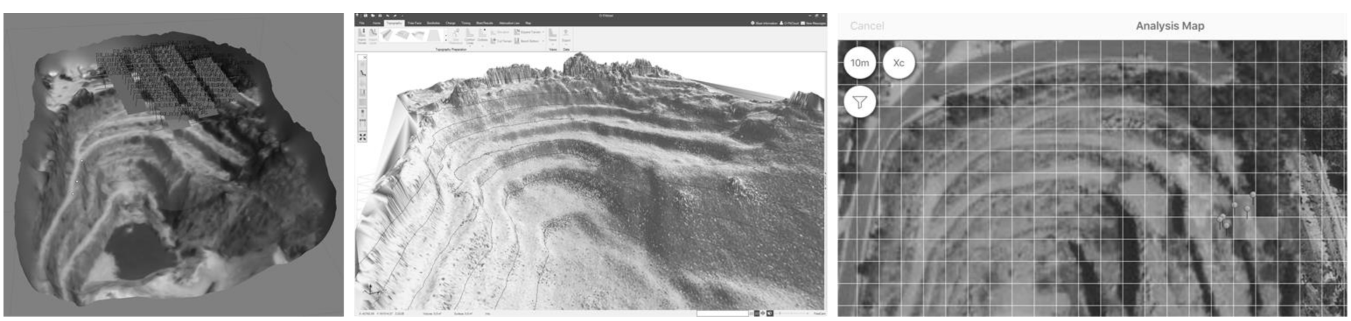

Figure 4. Drone Topography Control

Mathematical Optimization

The objective of a mathematical model is to represent mathematically an abstract problem found on the nature. A mathematical problem, to be interpreted and solved, needs to involve three elements (Tormos & Lova, 2003):

- Decision variables;
- Restrictions or decision parameters;
- Objective function.

The first objective is to define the involved decision variables, for example, in blasting optimization problems, these variables can be *burden*, s*pacing*, *diameter*, *bench high* and other design parameters. The restriction would be empirical ranges of blasting design parameters and the desired results from a blast, fragmentation size limits in this case. Related with the objective function, is imperative to define the objective of the problem (Taha, 2008), in this case is to obtain the desired results at the lowest cost possible – this will be the objective function.

Pattern Expansion Procedure and Results

Pattern expansion is one of the key factors on drill blast cost savings. This procedure can bring high benefits to a mine operation, however, it needs to be simulated and predicted in a blast simulator in order to avoid field issues like secondary blasting, overbreak, toe and poor fragmentation. Even with the computer simulation approved, the field work must be staged in a way that every change is sufficient small to sidestep any operation problem, allowing a sufficient cost saving. For this study was used an optimization module present in a blast design software in order to calibrate the fragmentation prediction model and estimate the best design parameters.

Blast Design and Actual Results

In general, when a blast engineer intends to optimize a blast, there's a phase of data collecting to define the initial stage and calibrate the prediction models. For the present study, the initial design parameters are presented on Table 1.

Table 1. Initial blast design parameters

Parameter	Value
Burden	3,0 m
Spacing	3,5 m
Diameter	102,0 mm
Stemming	2,8 mm
Subdrilling	1,2 m
Bench High	10 m
Powder Factor	0,77 kg/m3

As referred, is imperative to analyze and measure the results for the actual blast design. There are several solutions in the market directed for different types of operations and by authors experience, is important to affirm that these kinds of optimization procedure are available to each one.

Small/Medium Operations – Fragmentation control with drone technologies

A relatively recent methodology appeared to obtain fragmentation information with a drone flight. In the presented study was used a DJI Phantom 4® and a flight plan was estimated by the DroneDeploy® app. The process is defined in the following steps:

- Define the area to be analyzed;
- Define ground sampling distance and respective height;
- Define the photo overlay (80% in the current study);
- Adjust all the above parameters to overtake drone’s battery limitations.

The result from the drone flight will be a series of georeferenced photos (drone’s GNSS receiver precision) which should be processed in a photogrammetry analysis software in order to generate a scaled orthophoto (.tiff). In the market, there are several free and payed solutions, Agisoft Photoscan®, Pix4Dmapper® and MicMac® are some examples.

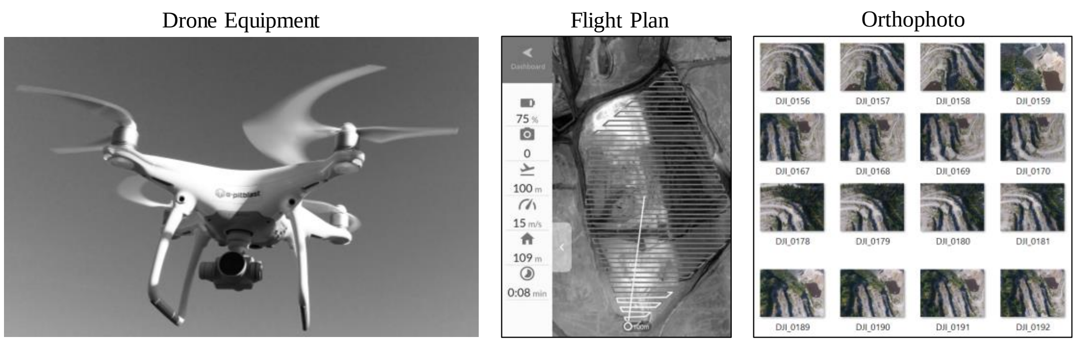

Figure 5. Drone Technology for Fragmentation Analysis

The ortophoto is imported into the software (Wipfrag) and a fragmentation analysis is performed (Figure 6).

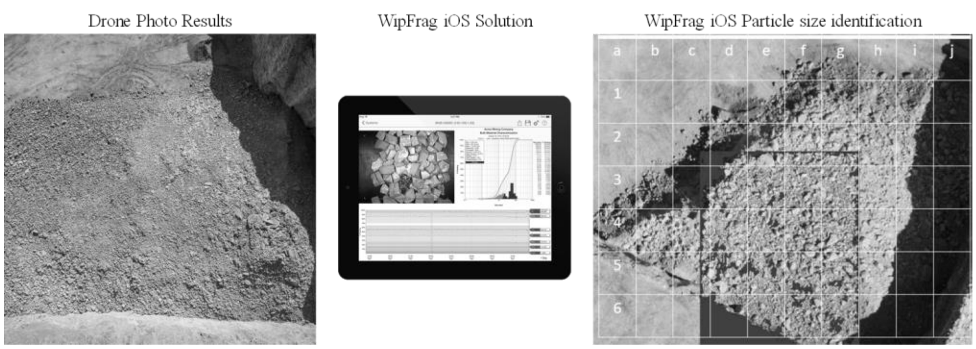

Figure 6. Fragmentation Analysis

Calibrating Rock Factor

Is imperative to have an actual prediction model before simulating any change on design parameters. For that reason, is important to have the Kuz-Ram’s Rock factor calibrated. In the Table 2 is presented the initial state of rock calibration factor, predicted and actual fragmentation. Several blasts were analyzed in order to find the most accurate rock factor. For the calibration process was used the referred GRG non-linear programming optimization methodology. The process to calibrate the rock factor/rock influence constant, analyses the predicted and measured X20, X50, X80 and X90 (Figure 3) to obtain a perfect match between the two fragmentation curves. The process is described on the Figure 7.

Table 2. Rock factor calibration process

	Initial Parameters	Rock Factor Cal. STG 1	Rock Factor Cal. STG 2	Rock Factor Cal. STG 3
Diameter	102,0 mm	102,0 mm	102,0 mm	102,0 mm
Bench High	10,0 m	10,0 m	10,0 m	10,0 m
Burden	3,0 m	3,0 m	3,0 m	3,0 m
Spacing	3,5 m	3,5 m	3,5 m	3,5 m
Subdrilling	1,2 m	1,2 m	1,2 m	1,2 m
Stemming	2,8 m	2,8 m	2,8 m	2,8 m
(KR Adjusted) X20	91,0 m	97,0 m	102,0 m	106,0 m
(KR Adjusted) X50	190,0 m	204,0 m	213,0 m	224,0 m
(KR Adjusted) X80	330,0 m	353,0 m	369,0 m	390,0 m
(KR Adjusted) X90	416,0 m	446,0 m	466,0 m	493,0 m
(Photo-Analysis) X20	109,90 mm	114,00 mm	117,80 mm	115,30 mm
(Photo-Analysis) X50	209,60 mm	220,70 mm	225,80 mm	235,90 mm
(Photo-Analysis) X80	347,70 mm	364,50 mm	384,10 mm	399,50 mm
(Photo-Analysis) X90	433,70 mm	457,10 mm	480,70 mm	506,10 mm
Rock Factor Cal.	7	7,5	7,83	8,14

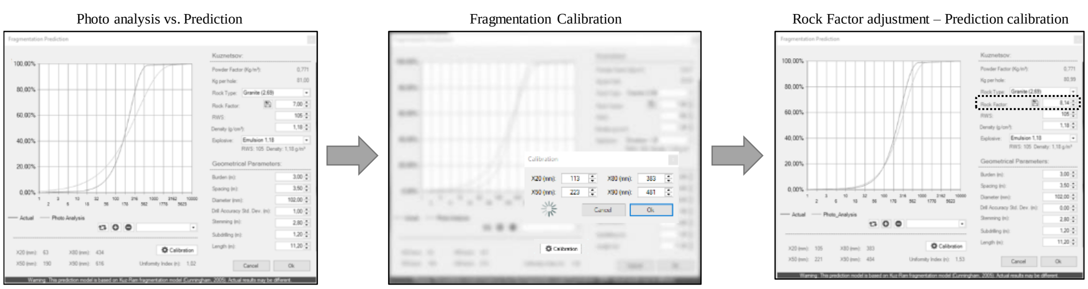

Figure 7. Rock Factor Calibration Process (O-Pitblast system)

Building Optimization Module

To obtain the optimum blast design parameters it is necessary to build a non-linear problem. In other words, define the dependent variables, empirical restrictions and fragmentation demands (90% under 700 mm/27,56 in, in this case). In Figure 8 is represented the model variables/restrictions and are shown the initial and final/optimized parameters.

This first approach needs to be treated, as any other non-linear problem (with its own limitations), considering that this solution can be an optimum local instead of a globlal one (Miranda, Leite, & Frank, Blast Pattern Expansion - A numerical Approach, 2017). To avoid any kind of issue the authors defined a field application procedure.

The idea behind the pattern expansion field is to avoid excessive deviations at the same time. Controllable changes were applied at any improvement stage and detailed fragmentation analysis were performed in order to control the blast results. The pattern was expanded until the fragmentation limit was reached. On Table 3 the reader can analyze the evolution of each stage in terms of changes and results.

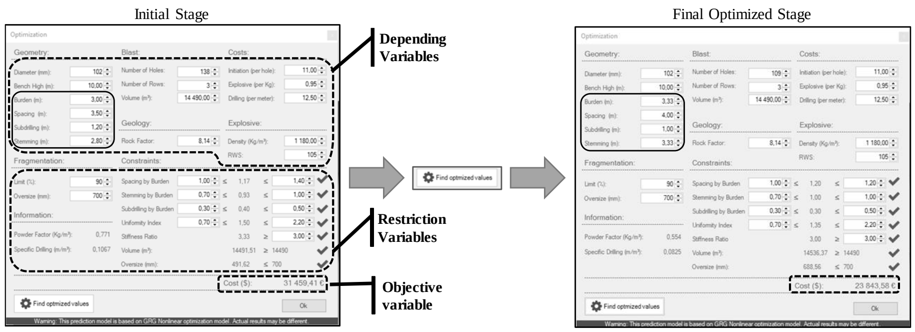

Figure 8. Optimization Module

Table 3. Pattern expansion evolutionary stages

	Initial Stage	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Diameter (mm)	102 mm	102 mm	102 mm	102 mm	102 mm	102 mm
Bench High (m)	10,0 m	10,0 m	10,0 m	10,0 m	10,0 m	10,0 m
Burden (m)	3,0 m	3,1 m	3,1 m	3,2 m	3,3 m	3,3 m
Spacing (m)	3,5 m	3,6 m	3,7 m	3,8 m	3,9 m	4,0 m
Subdrilling (m)	1,2 m	1,2 m	1,1 m	1,1 m	1,0 m	1,0 m
Stemming (m)	2,8 m	2,9 m	3,0 m	3,1 m	3,2 m	3,3 m
(KR Adjusted) X20	105,0 mm	109,0 mm	113,0 mm	117,0 mm	121,0 mm	125,0 mm
(KR Adjusted) X50	221,0 mm	233,0 mm	245,0 mm	257,0 mm	270,0 mm	283,0 mm
(KR Adjusted) X80	383,0 mm	409,0 mm	433,0 mm	461,0 mm	488,0 mm	520,0 mm
(KR Adjusted) X90	484,0 mm	519,0 mm	552,0 mm	591,0 mm	629,0 mm	689,0 mm
(Photo-Analysis) X20	124,50 mm	134,70 m	151,80 mm	171,20 mm	223,90 mm	N/A
(Photo-Analysis) X50	240,10 mm	275,80 m	303,40 mm	327,10 mm	352,60 mm	N/A
(Photo-Analysis) X80	398,10 mm	449,90 m	480,30 mm	517,80 mm	543,10 mm	N/A
(Photo-Analysis) X90	501,50 mm	541,90 m	604,40 mm	653,80 mm	714,80 mm	N/A

Discussion

The use of technology to support mining daily tasks is performing an important role in terms of safety and production. The gathering process of field samples with drones, opened a completely new horizon on the fragmentation analysis procedures. Muckpile inspection is associated with several safety issues like gas presence (after blast), twisted ankles and hand injuries.

Fragmentation is one of the primordial blast quality feedbacks. Having a fast, accurate, easy system is half way to a constant measure of blast results – WipFrag software proved to be a very useful tool to calculate fragmentation.

In terms of mining cost optimization, a blast continuous improvement should be a constant practice since it affects all the consequent stage of mineral processing. With O-Pitblast's blast optimization algorithm was possible to reduce 229.361,00 \$ in 605.307,7 m^3/791712.58 yd^3 of rock (Figure 9 and Figure 10). The optimization process, operation and field practices demonstrated that a careful analysis must be done in order to match the mathematical optimization and nature behavior to obtain the best and desired results.

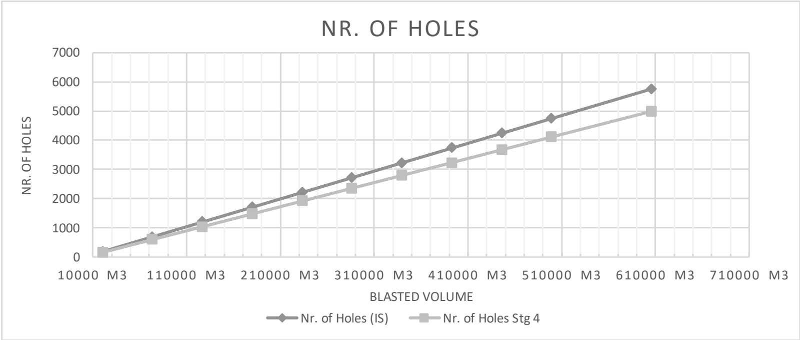

Figure 9. Drilled holes

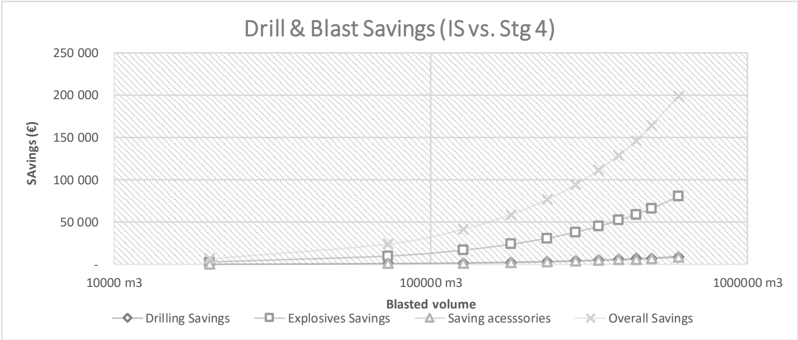

Figure 10. Drill and Blast Savings

Acknowledgements
We would like to gratefully thank to EXPLOG CEO, José Ismael Prado Neto for the opportunity given to carry out this project in Maracatu Quarry (Recife, Brazil). Mining Engineers José Guedes (Madalena Quarry Manager) and João Fernandes (Madalena Quarry Engineer) are acknowledge for the test phase opportunities on Madalena Quarry (V. N. Gaia, Porto, Portugal). We would like to thank the Oporto University - Engineering Faculty (Mining Department - FEUP), specially to Engineer Alexandre Leite and Engineer José Soeiro de Carvalho. Also Engineer Bento Martins and Raquel Sobral (Geomatic and Mining Engineers) for the outstanding support in the drone equipment control and georeference field procedures.

References

Bhandari, S. (1997). *Engineering Rock Blasting Operations.* Rotterdam Brookfield: A.A.Balkema.

Catasús, P. S. (2004). *Análisis Experimental de la Fragmentación, Vibraciones y Movimiento de la Roca en Voladuras a Cielo Abierto.* Madrid: Escuela Técnica Superior de Ingenieros de Minas.

Cunningham, C. (2005). The Kuz-Ram fragmentation model - 20 yeasrs on. *Brighton Conference Proceedings.* European Federation of Explosives Engineers.

Floyd, J. (2000). *Efficient Blasting Techniques.* Blast Dynamics.

Hartman, H. L. (1992). *SME Mining Engineering Handbook.* Society for Mining, Metallurgy, and Exploration.

Hillier, F., & Lieberman, G. (2010). *Introduction to Operations Research.* New York: McGraw-Hill.

Hustrulid, W. (1999). *Blast Principles for Open Pit Mining.* Rotterdam Brookfield: A.A.Balkema.

Jimeno, C. L., Jimeno, E. L., & Carcedo, F. J. (1995). *Drilling and Blasting of Rocks.* Rotterdam Brookfield: A.A.Balkema.

Konya, C. J., & Walter, E. J. (1990). *Surface Blast Design.* Englewood Cliffs: Prentice Hall.

Maerz, N. H. (1990). *Photoanalysis of Rock Fabric.* University of Waterloo: Dep. of Earth Sciences.

Maerz, N. H., Palangio, T. C., & Franklin, J. A. (1996). WipFrag Image Based Grannulometry System. *Fragblast - 5 Workshop on Measurement of Blast Fragmentation , Montreal, Quebec, Canada*.

Miranda, V., Leite, F., & Frank, G. (2017). Blast Pattern Expansion - A numerical Approach. *European Federation of Explosives Engineers - 9th World Conference - Stockholm*.

Miranda, V., Leite, F., Jesus, C., & Sobral, R. (2017). A new Approach to 3D Modeling of Blast Free Faces. *International Society of Explosives Engineers - 43rd Annual Conference on Explosives & Blasting Technique - Orlando, Florida, USA.*

Miranda, V., Leite, F., Jesus, C., & Sobral, R. (2017). A New Blast Vibrations Analysis Methodology. *International Society of Explosives Engineers - 43rd Annual Conference on Explosives & Blasting Technique - Orlando, Florida, USA.*

Palangio, T. (2009). Digital Image Analysis. *The Journal of Explosives Engineers*, 8-16.

Persson, P.-A., Holmberg, R., & Lee, J. (1994). *Rock Blasting and Explosives Engineering.* Boca Raton, FL: CRC Press.

Rathore, I., & Kumar, N. P. (2015). Unlocking the Potentialities of UAVs in Mining and its Implications. *International Journal of Innovative Research in Science,*, 852-855.

Sanchidrián, J. A., & Muñiz, E. (2000). *Curso de Tecnología de Explosivos.* Madrid: Fundación Gomez Pardo - Universidade Politécnica de Madrid (Escuela Técnica Superior de Ingenieros de Minas).

Taha, H. A. (2008). *Operations Research.* Brasil: Pearson Prentice Hall.

Tormos, P., & Lova, R. A. (2003). *Investigación Operativa para Ingenieros.* Valencia: Universidade Politécnica de Valencia.