6. New applications and training

Stockholm Conference Proceedings 2017, R. Holmberg et al
© 2017 European Federation of Explosives Engineers, ISBN 978-0-9550290-5-9

Utilisation of aerial drones to optimise blast and stockpile fragmentation

R. Tamir
Seekers Consulting West Palm Beach, FL, USA

M. Wagner & T. Palangio
WipWare Incorporated, 685 Bloem Street, North Bay, ON, Canada P1B 4Z5

J. Campbell
L'Hoist North America, 3700 Hulen St, Fort Worth, TX USA 76107

N. Dakers
LafargeHolcim – Bath Plant, Hwy 33 West, P.O. Box 160, Bath, ON K0H 1G0

ABSTRACT: This document introduces the use of drone generated aerial photography to collect and analyse fragmentation data for both muck piles and post crusher stockpiles in order to support the continuous improvement process. In tandem with photo analysis software, drone imaging gives mines and aggregate sites a fast, accurate and economical method of benchmarking and optimising the process of size reduction to specification.

1 INTRODUCTION

The introduction of the following methodology and technology is driven by the *mine to gate* continuous *improvement process*. The impact of ore size distribution along the process has been proven to be critical to quality as well as cost through the performance of all the components (loading, crushing, milling and kiln operations), ore yield and meeting the final product specification. Improvement is linked to maximizing utilisation of key components so mines and quarries strive to deliver ore to the point of entry in a state that would contribute as much as possible downstream. The higher the compatibility between the ore's controlled variables and the plant's requirements the better the productivity, cost and usually the quality of the final product. To overcome the fragmentation's high standard deviation and lack of compatibility 'that can't be avoided', plants compensate by implementing expensive processes solutions.

Our goal to produce the ideal feed requires we calibrate the pre-process handling of the ore - the blasts. Correlating between geology, blasting parameters such as pattern, timing, explosive load, hole information and measuring the results in place is key to that calibration.

The path to continuous improvement is:

- creating a 'situational awareness', a 360-degree picture of the parameters
- understanding the muck-pile, fragmentation, shape and density by zone location and the root cause for this occurrence
- making a change (decision)
- measuring the impact of the change and comparing it to a benchmark, and adjusting or pushing the performance envelope

Today, for the first time, we are able to see the blast fragmentation from overhead utilising aerial drone photography. Location-specific fragmentation data is one of the important building blocks in the process of putting together that 360-degree picture. With the advancement of UAS (Unmanned Aircraft System) technologies, operations are realising the benefits of new capabilities including aerial particle size analysis through photo analysis, using existing UAS photographs taken for surveying and 3-D profiling. Utilising this tool allows us to make changes that will help us in future blasts, and it can also allow us to react to the current conditions by adjusting the mucking plan.

This is a first step in creating a comprehensive tool that will assist us not just in understanding current blasting and stockpile feeding procedures, but also making real-time educated decisions based on fragmentation data and we have taken it.

2 EQUIPMENT SELECTION

It is important to familiarise yourself with the current technology available before investing in equipment. The following is a feature & specification based approach to equipment selection and will also include the equipment we selected for the purposes of this study.

Depending on your knowledge and skill with these technologies, there are three main components necessary to get started:

Figure 1. Typical drone and remote control.

– drone
– iOS mobile device with integrated cellular & GPS
– iOS fragmentation analysis application with integrated GIS and blast model

2.1 The drone

When selecting a drone for aerial fragmentation analysis, the primary focus should be on the quality of image samples it can collect.

The following components play a critical role in the UAV performance for this application.

Gimbal: Motorized pitch/roll/yaw that can point the camera straight downwards (perpendicular to the ground surface) is important to collect images with minimal distortion and perspective error, shock and vibration stabilisation is highly recommended, models without a gimbal should be avoided.

Camera: Digital CMOS camera with a large imager that can take 12 megapixel or higher resolution images is important. Cameras on most drones are optimised for video capability which is a nice feature but will not enhance the performance of this application.

Lens: A high speed (f2.8 or lower) fixed zoom lens with a view angle of less than 95 degrees is important to collect quality images in most daytime lighting conditions. Wide angle lenses with viewing angles exceeding 95 degrees should be avoided because the optical distortion may produce significant errors in analysis results.

Battery: Two smart batteries each capable of 25+ minutes of flight time is important. Batteries capable of expanded temperature operation are highly recommended.

Mechanical: A compact, robust construction, Quad rotor design capable of resisting wind speeds up to 10 metres a second is important. Models with more than four rotors may offer improved speed and increased payload capacity at the cost of size, weight, complexity and reduced battery life. Fixed wing drones may also be used however their increased take off/landing space requirement is a disadvantage and their superior speed and range offer no advantage for this application.

AI: Artificial intelligence in the form of autonomous decision making capabilities of a drone can have significant impact on its lifespan, most importantly automatic collision avoidance so if you tell your drone to navigate to a point and it flies directly towards a drill mast, telephone poll or a high wall it will automatically detect and navigate over, under or around any obstacles it detects with its three dedicated collision sensors, this is particularly useful in an environment that offers no soft surfaces. Other special intelligence features may exist such as 'orbit target', 'track object' and 'follow me' are also interesting but have limited use in this application.

GPS/GLONASS: Having a model with GPS and GLONASS is important especially in Northern latitudes. When a drone can access both satellite constellations it significantly improves satellite acquisition time and navigation accuracy. Some models offer DGPS (differential GPS) integration which if you have a DGPS benchmark available in your area can be further improve position accuracy especially elevation which is a real asset if you plan to use the acquired data for purposes such as volumetric calculations and/or surveying. Models with GPS only should be avoided.

Controller: 2.4 GHz ISM band radio control capable of 3+ kilometre operating range and have an iPad/iPhone holder complete with interface port are important. Models with built in display screens can be useful if they can still integrate with the iPad/iPhone but may reduce battery life, cost more and be redundant as the iPad/iPhone can fill this role. Models that do not have iPad/iPhone integration, and operate on non-ISM frequencies requiring special radio band licensing should be avoided unless you possess a valid commercial, police or military radio license that is valid in your area and have experience piloting a drone manually.

Case: Drones are relatively delicate and should be handled with care therefore a good quality carry case is highly recommended to contain backup batteries, propellers and other parts as well as keep your drone safe when in transit or not in use. Hard side cases offer the highest protection level at the expense of size and weight. For those looking for basic protection with less size and weight should consider a backpack style case.

Flight Planning Application: Most drones have advanced flight planning applications available at no additional cost that can help users easily layout and execute a flight mission even if they have never used a drone before. The application will typically undergo a pre-flight checklist to help identify risks such as restricted airspace, enforce maximum altitude compliance, give warnings if battery capacity is insufficient to complete the planned flight mission, and other factors that could result in loss or damage of the drone. These

Figure 2. Some drone carry-case options.

applications require a compatible mobile device (iPad/iPhone) and a data connection to the drone remote control to function properly.

The drone that we selected for this study was a DJI Phantom 4 Pro that meets all the important and many of the recommended characteristics mentioned above at a reasonable price (DJI Phantom 4 Pro $1,500USD as of May 2017, the case and supplementary battery was extra).

2.2 iOS mobile device with integrated cellular & GPS

You will need an iOS device with cellular radio to be used as your interface, remote view screen, processor and data hub connecting you and your flight plan to the drone, connecting the drone images to the fragmentation analysis software, and allowing you to analyse, archive and share results with your colleagues.

Although all iPhones natively have these capabilities, their small screen size is not as easy to work with which is why we selected the iPad Pro 9.7 inch with 4G LTE for several reasons:

– cellular connectivity (if available in your area) can greatly enhance the user experience
– only cellular equipped iPad models have an integrated GPS which is an important feature outside of this application to geotag manual image samples
– the smallest iPad Pro screen is nearly four times the view area of the largest iPhone screen making it easier in use
– the iPad Pro is compatible with the Apple pencil stylus further enhancing the user experience if manual editing is required

It is highly recommended to protect the iPad in a ruggedized/waterproof case when using it in the field. We selected the LifeProof Nuud for iPad Pro 9.7 inch which offers a good level of drop and moisture/debris protection to the device however special care should be taken to protect the bare screen from scratches while in use. (Apple iPad Pro 9.7 inch 256Gb WiFi + 4G LTE Space Grey $900 USD as of May 2017, the case and Apple Pencil for iPad Pro was extra).

2.3 iOS fragmentation analysis application with integrated GIS and blast model

The final component is specialised iOS software that can rapidly analyse particle size and shape distribution as well as detect dilution / contamination in blasted material from drone or ground level images taken with the mobile device camera. The application should be able to

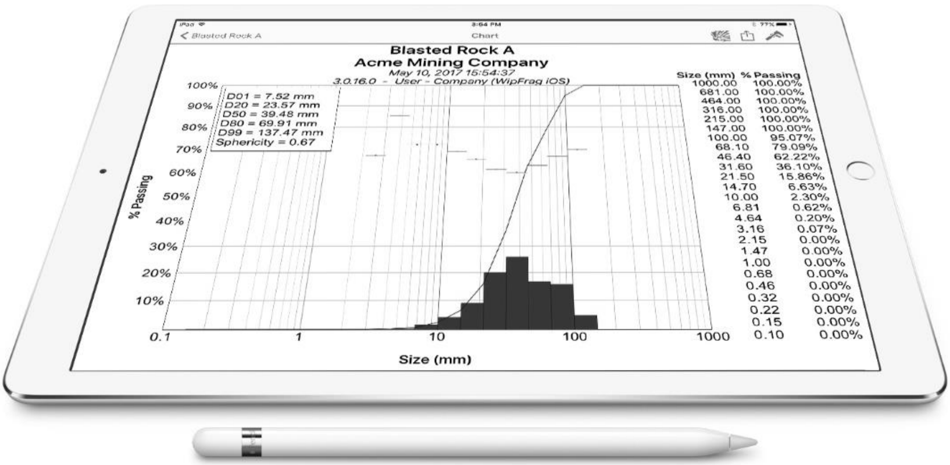

Figure 3. iPad Pro with stylus.

aggregate multiple data sources into a comprehensive report that can be viewed individually or as part of a unified heat mapped GIS (Geographic Information System) that quickly identifies problem areas and can be built on as a part of the continuous improvement strategy. The inclusion of a simple but effective KCO blast model is also important as it allows the model to self-validate so that historically difficult to acquire rock characteristics are more easily attained. This greatly enhances the accuracy of predicted fragmentation from various blast design scenarios based on historical performance.

The fragmentation analysis software that we selected for this study was WipFrag for iOS as its features, capabilities and price were without peer. More detail on this component will be described later on in this technical paper. WipFrag 3 for iOS permanent perpetual license $999 USD as of May 2017.

3 COLLECTING IMAGES AND FRAGMENTATION DATA

3.1 Drone configuration

With the rapid development of drone technologies capable of carrying more weight and flying longer, higher resolution mounted cameras and the opportunity to fly longer overlap patterns to achieve high quality orthomosaic (stitched) images allows for the detection of finer particle sizes, and more precise analysis of the material pile in general.

When selecting the drone used for collecting blast fragmentation data, it is important to note that the resolution of the camera in conjunction with the altitude of the drone will have impacts on the minimum particle sizes that can be delineated using photo analysis software. After identifying the limitations of both commercial and industrial-grade drones with various cameras, the following figure and formula will help identify the minimum/maximum particle sizes that can be analysed when flying over a blast pile.

Assuming a 45 degree camera field of view, the ratio of the flight altitude to the blast pile width is 1:2. Flying at 150 feet (45.72 meters) will get you an image analysis area of approximately 300 feet (91.44 meters).

In the case of the Lafarge Bath Quarry, the drone used was capable of taking an image with a resolution of 3992 pixels wide and 2242 pixels high. This translates into 9 megapixels.

By dividing the blast pile width by the pixel width, you are able to get an estimation of the minimum size that can easily be analysed with minimal manual editing inside of the photo analysis software. For the aforementioned figures, the software used was capable of comfortably analysing material sizes down to approximately 1.3527 inches (34.36 mm).

After attempting to fly the blast pile at Lafarge – Bath Quarry with a DJI Phantom 3 and DJI Phantom 4, it was determined that commercial grade drones are powerful enough to capture the images necessary for the fragmentation analysis;

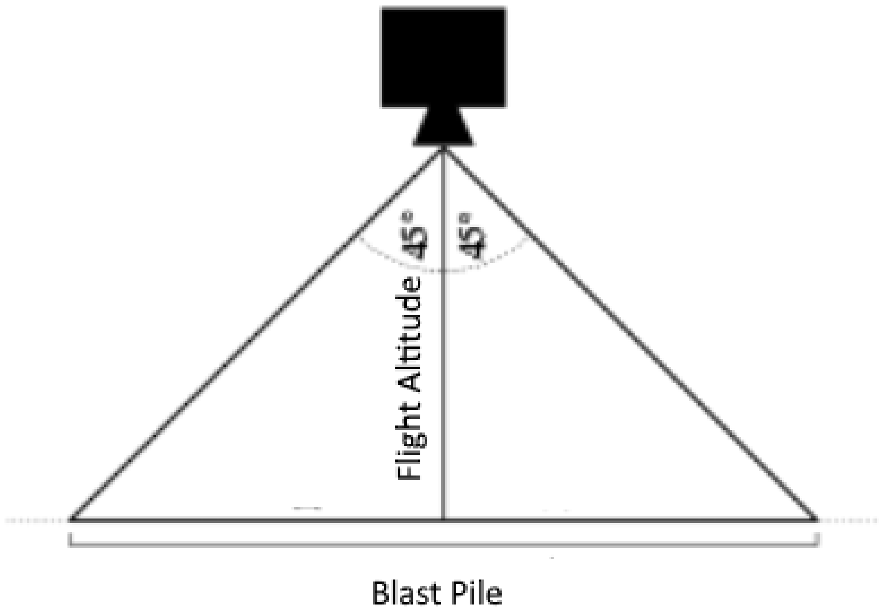

Figure 4. Camera with view angle.

Figure 5. Drone approaching muckpile.

Figure 6. 3D image of the blast pile used for fragmentation analysis.

however, it is recommended that using commercial drones in conjunction with orthomosaic software to stitch multiple images together will vastly increase the accuracy and minimum resolvable particle size. With the study, there was a minimum resolvable particle size of approximately 1 inch. In order to get down to the 3/8 inch key performance indicator that limestone and cement operations are interested in achieving, Orthomosaic images with 20% overlap will allow for sub-1/4 inch analysis results. Using a commercial grade drone is a very economical way for mining operations to get a good representation of the blast with the ability to make changes and track improvements in blasting performance.

4 THE PHOTO ANALYSIS PROCESS

Sizing analysis of muck piles has been done for many years. A detailed review of this method is given by John A. Franklin, and Takis Katsabanis. (Measurement of Blast Fragmentation, Fragblast Workshop, 1996).

The photo analysis process involves capturing images of the fragmented rock in question and uploading these images into the fragmentation analysis software. Orthomosaic imaging software allows for an overlay scale to be placed anywhere in the image after the flight takes place. This scale is used as a reference inside of the image, and is crucial for the analysis to take place.

The photo analysis software's automatic edge detection parameters delineate the particles within the image based on the defined edges of the particles. In the case of this technical paper, it took approximately ten seconds to run the analysis, and approximately seven minutes of manual edits to these images to ensure an accurate analysis.

After editing, the software outputs the particle sizing data into a percent-passing format for up to 17 customizable size classes.

Unlike traditional photo analysis methods where an employee walks to a blast pile, places a measurement device in the blast pile's area of interest and captures images standing perpendicular to the material, drone imaging allows for the user to capture aerial images of the same pile, and use orthomosaic imaging to

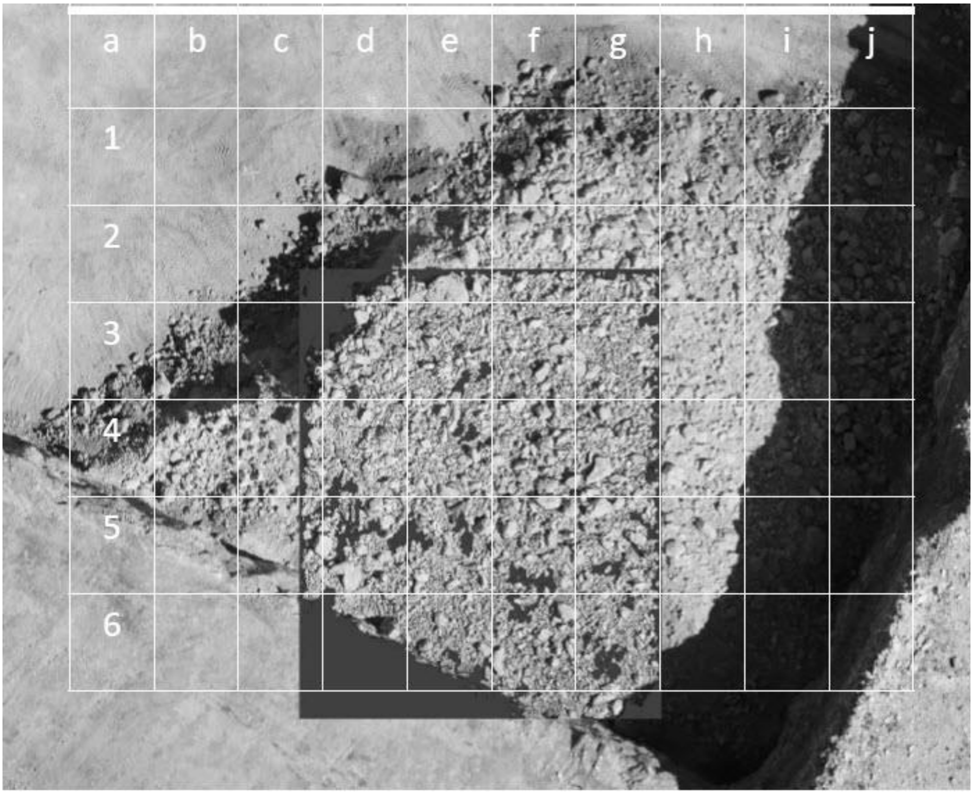

Figure 7. Grid overlay used to identify specific areas in the blast that need attention. The fragmentation ‘nets’ can also be seen.

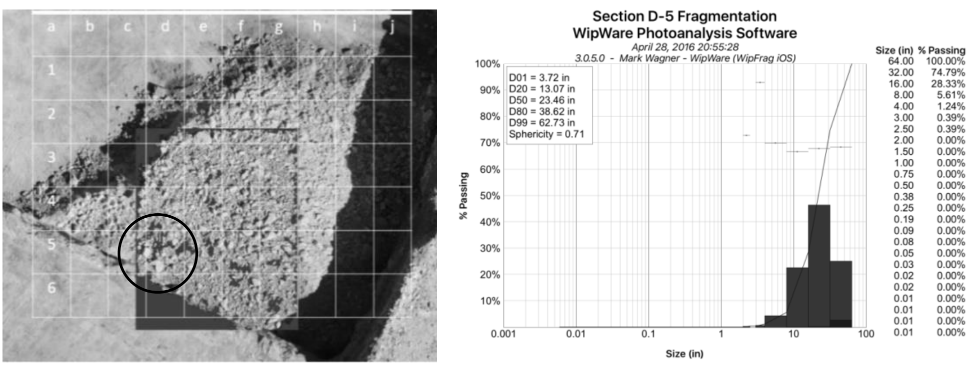

Figure 8. Section D5 identifies a coarser section of the blast, and its associated distribution curve.

automatically set the scale inside of the image. It should be noted that the drone flights were controlled from approximately 150 feet away from the blast piles, further confirming that this method of collecting particle sizing is much safer than other methods that require manually placing scales on the pile in question.

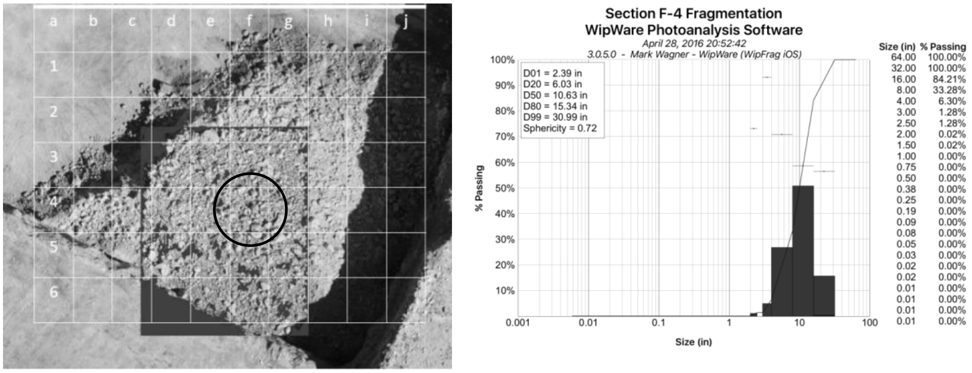

Figure 9. Section F4 identifies a finer portion of the blast and its associated distribution curve.

4.1 Blast pile benchmarking and optimisation

Having the fragmentation of the entire blast pile allows an operation to begin benchmarking procedures in the hopes of finding ways to improve performance. To break down blast performance for each shot, the authors found that it is advantageous to implement a grid overlay when completing the analysis of blasted material. By doing so, the interested parties will be able to identify the following:

– what specific zone of the blast provided acceptable fragmentation, and how can we reproduce these results?
– where are the problem areas inside of the blast, and what caused these areas to be coarser? (Stemming, initiation, hole spacing, etc.)

Three different grid areas in the blast pile image were identified as having fine, mid-sized or coarse material when visually inspecting the orthomosaic image generated by the drone. Once identified, these areas were analysed inside of photo analysis software to get size distributions.

In addition to testing these three areas of the blast pile separately, the particle sizing results can also be merged to help get the ‘full picture’ look at the blast pile fragmentation and a comparison against future blasts. Using the primary crusher specifications as a guideline, zones can then be created inside the analysis results to track improvements and optimise material size being fed into the crusher. In this case, we identified the grey area as a ‘no-work zone’ (to the left and centre), where the primary crusher does not need to actually crush this material; a pale grey ‘crush zone’ (on the right) where the primary crusher begins actively breaking down material, and a darker grey ‘danger zone’ (top right on graph in Figure 10) where oversize material is getting into the primary crusher.

4.2 Utilising the data

At this stage we are ready to integrate this data to the CI process. After the initial task of photographing the pile and the shot has been completed and fragmentation analyses has been completed we go to the next phase – setting the data in a format that allows better understanding and correlation to upstream impacting factors and downstream impacted factors. Those could be an issue to deal with or an opportunity to grasp. After we have completed this step we can seek actions.

There are several steps in this process.

4.2.1 Reference grid

Setting a reference grid covering as much of the pile as possible in order to reference and collect all of the anomalies and seemingly inconsequential data.

4.2.2 Visual review

Visually reviewing the pile for anomalies in shape and fragmentation. In Figure 12, two anomalies were spotted, a high ridge (larger oval shape) and a peek (smaller shape). Those anomalies represent a higher density zone in the pile that might contain larger material. This event should launch an RCA that when reviewed with the shot and drill report can produce action items.

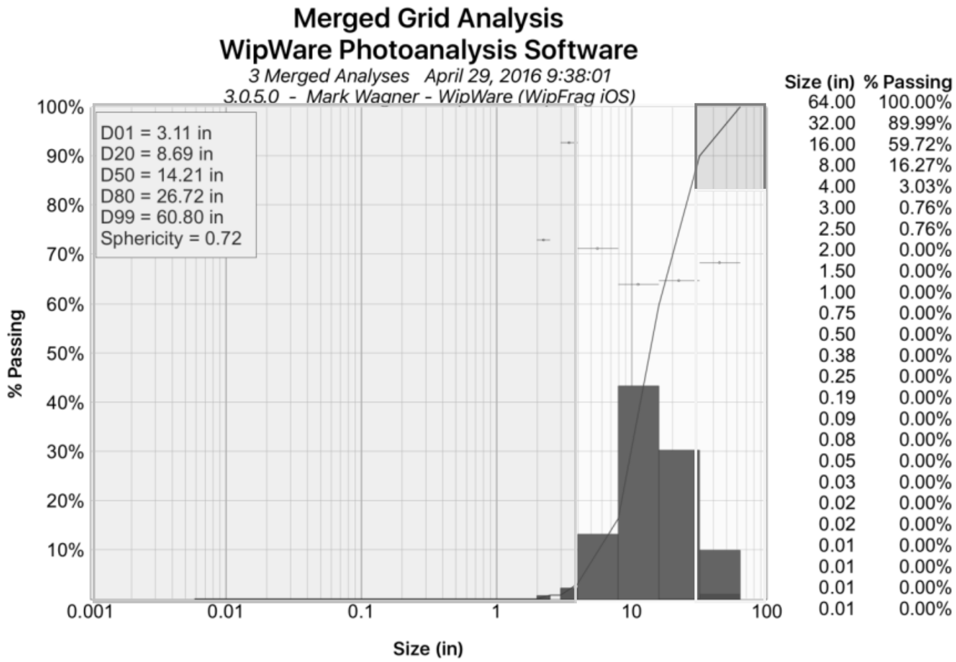

Figure 10. Merged grid analysis results can be used to benchmark where the operation is in terms of ideal fragmentation, and will allow operations to see improvements on future blasts.

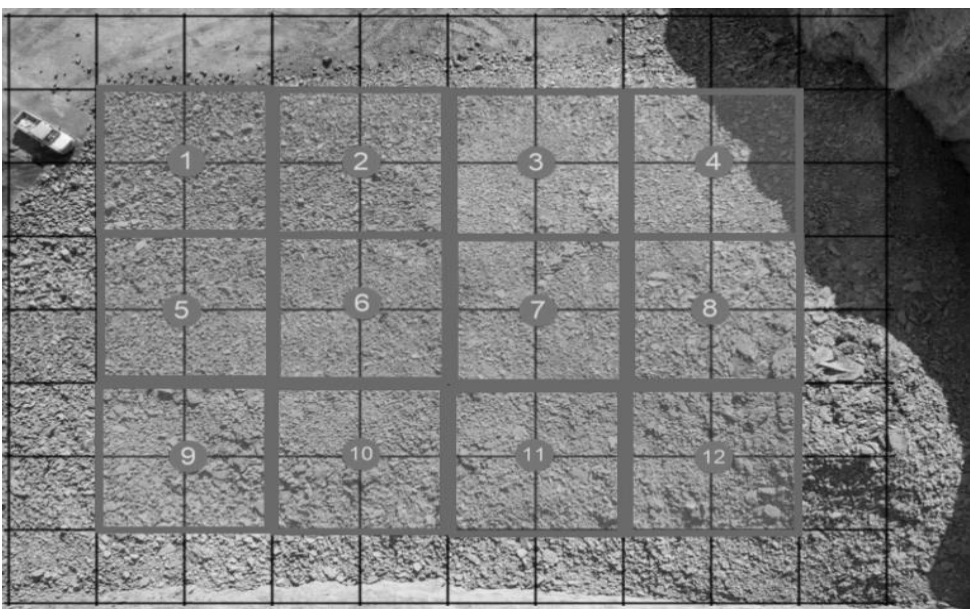

Figure 11. Setting up a grid pattern is crucial in being able to reference where the coarser and finer fragmentation came from when blasted.

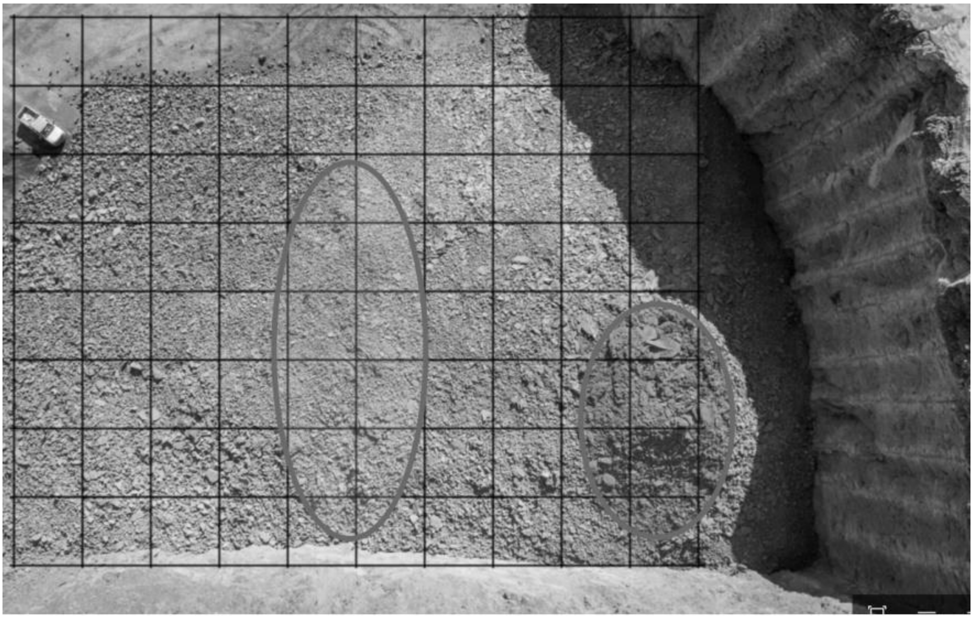

Figure 12. By studying the drone image, the user can identify peaks (red) and ridges (yellow) in the blast.

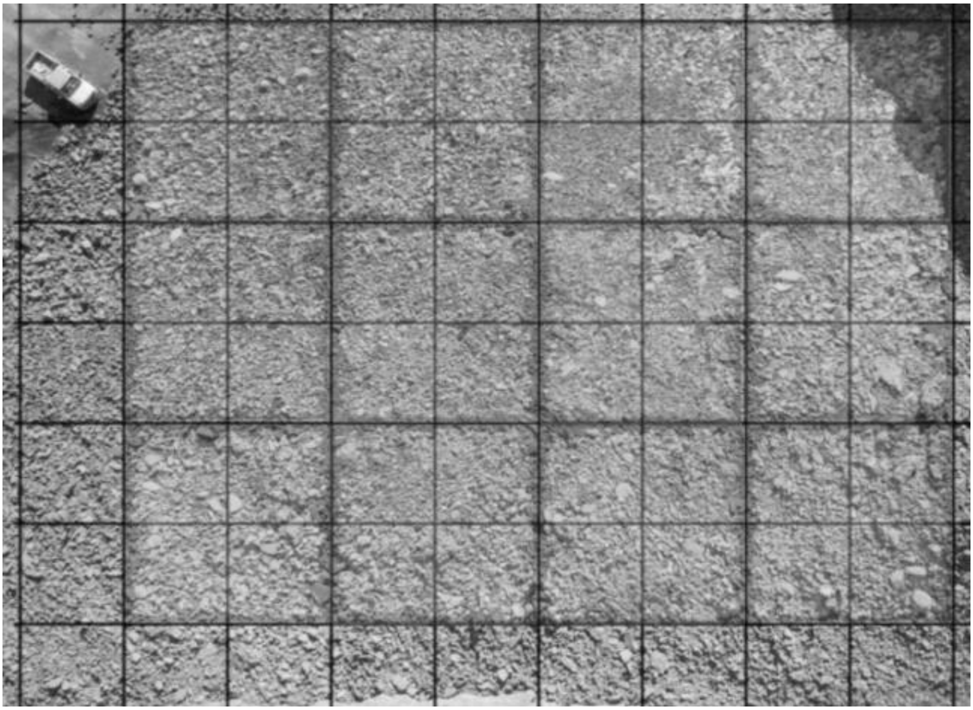

Figure 13. Fragmentation grids can be colour coated based on sizes, and can identify areas in the pit that showed finer and coarser fragmentation.

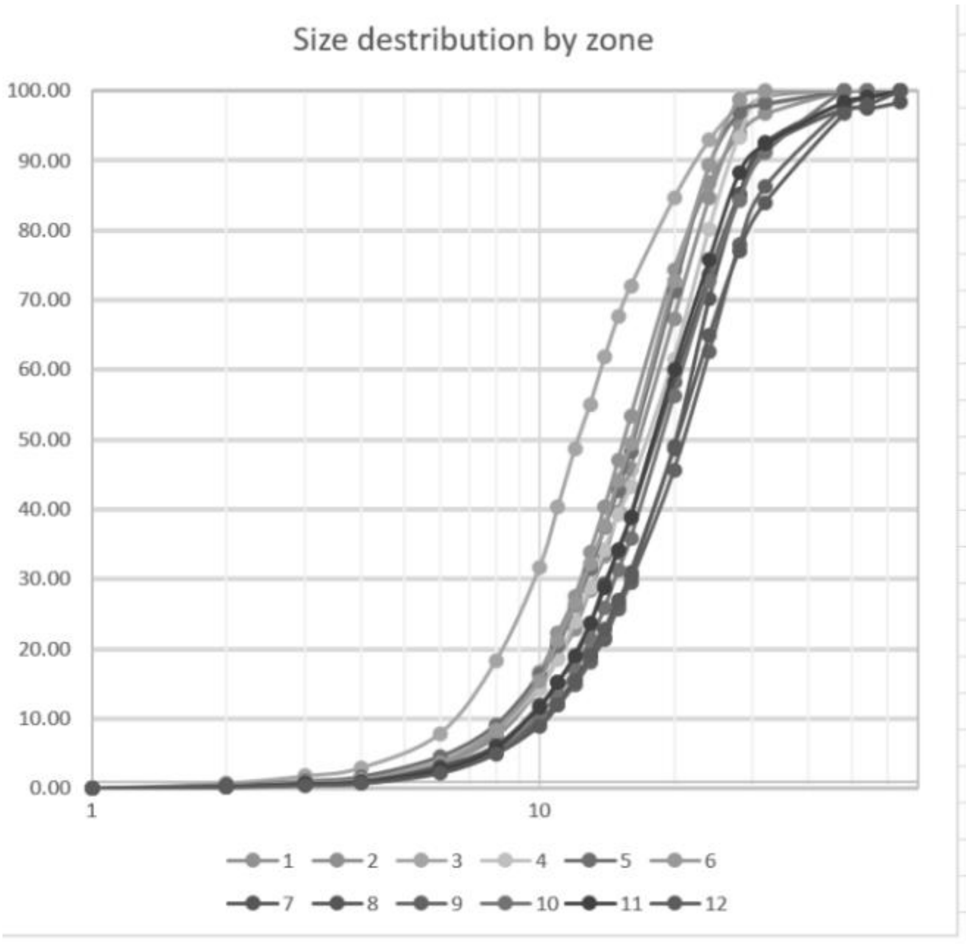

Figure 14. Distribution curves from the twelve separate zones for quick identification of outliers.

In Figure 13 a quick view of the picture will assist in identifying fragmentation anomalies by highlighting the very large size rock in light grey. This will assist in focusing on problematic areas.

4.2.3 Size distribution analysis

Analysing the fragmentation of each zone separately and looking for both the individual zone analyses and the combined fragmentation curve (see Figure 14).

Comparing the pile fragmentation to the BlastCast model, the more accurate we become utilising the model the greater our confidence in its results, allowing us to use it as a planning tool (scenario-builder, see Figure 15).

Defining the primary crusher benchmarks (in this case a APPH1615 Hazemag Primary impactor). This crusher is a no bypass machine closed to 2 inch (see Figure 16).

4.2.4 Overlay primary crusher benchmark and analysis

Overlay the primary crusher benchmark information over the zones fragmentation analyses: this crusher top-size intake is 36 inch. The secondary Canica VIS crusher top size is 2 inch (50.8 mm), therefore the working zone of this crusher is between 36 inch (914.4 mm) and 2 inch (50.8 mm). (See Figure 17).

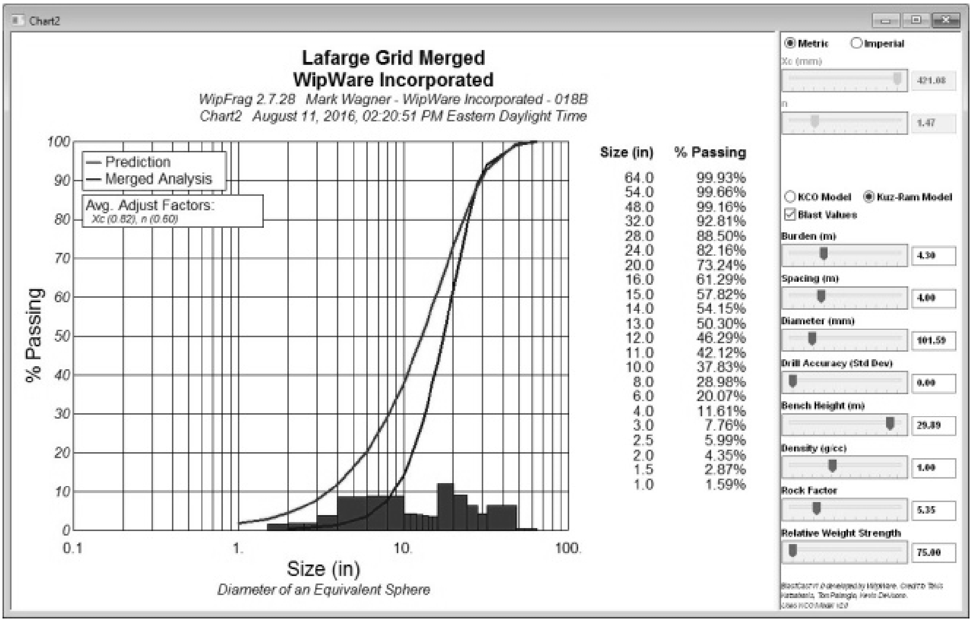

Figure 15. Blast Prediction models will allow users to tweak procedures in order to achieve fragmentation within the desired crusher specifications.

Crusher Specifications

Model	Capacity Tons/Hour (Tonnes)	Power Requirements Hp (Kw)	Inlet Size in. (mm) (H x W)	Maximum Feed Size in. (mm)	Rotor Size in. (mm) (D x W)	Weight Lb. (Kg)
APPH-1010	125 (115)	150 (115)	35 x 40 (890 x 1020)	20 (500)	40 x 40 (1000 x 1000)	28,000 (12,725)
APPH-1013	175 (160)	200 (150)	35 x 54 (890 x 1360)	20 (500)	40 x 52 (1000 x 1340)	34,100 (15,500)
APPH-1313	250 (230)	250 (185)	43 x 54 (1092 x 1360)	25 (635)	52 x 52 (1340 x 1340)	42,300 (19,200)
APPH-1315	350 (320)	400 (300)	43 x 60 (1092 x 1360)	25 (635)	52 x 59 (1340 x 1500)	46,000 (20,900)
APPH-1320	450 (400)	500 (375)	43 x 80 (1092 x 2030)	25 (635)	52 x 79 (1340 x 2000)	58,600 (26,600)
APPH-1515	400 (360)	500 (375)	47 x 60 (1092 x 1360)	32 (812)	59 x 59 (1500 x 1500)	49,200 (22,300)
APPH-1615	450 (400)	500 (375)	47 x 60 (1092 x 1360)	36 (915)	64 x 59 (1600 x 1500)	59,600 (27,090)
APPH-1620	600 (550)	600 (450)	50 x 80 (1270 x 2030)	36 (915)	64 x 79 (1600 x 2000)	77,100 (35,045)
APPH-1622	650 (600)	700 (525)	50 x 89 (1270 x 2270)	36 (915)	64 x 88 (1600 x 2200)	82,600 (37,545)
APPH-1630	800 (730)	800 (600)	50 x 119 (1270 x 3020)	36 (915)	64 x 118 (1600 x 3000)	104,700 (47,590)

Figure 16. Crusher manufacturer specifications are readily available and can be used to determine the upper and lower envelopes.

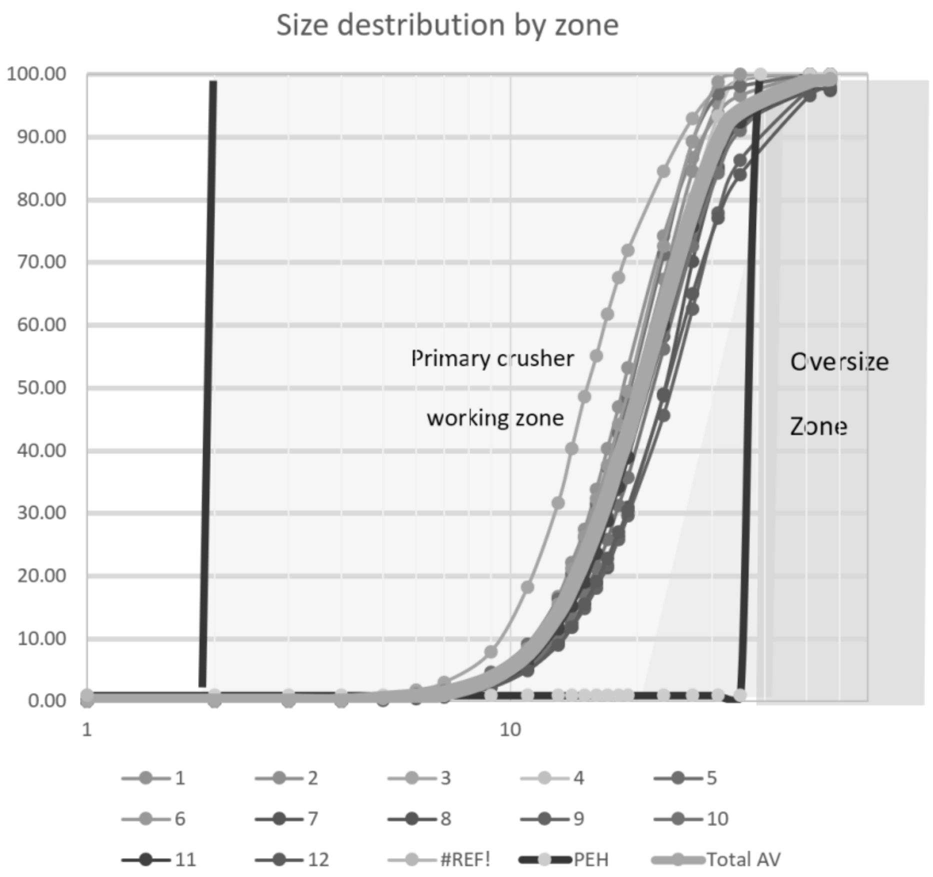

Figure 17. Overlaying the crusher 'work zones' allows users to identify undesirable blast fragmentation.

4.2.5 Fragmentation compatibility map

Creating a fragmentation compatibility map by zone to show the correlation between the primary crusher capacity and the shot outcome. In this case we used 10 inch (254 mm) and 1 inch (50.8 mm) as the bottom size.

4.2.6 Shot report review

Reviewing the shot report correlation to the fragmentation by zone outcome.

4.2.7 Secondary crusher run size distribution

Utilising an automated conveyor belt particle sizing system installed post primary crusher, we obtain the crusher run size distribution and correlate it to the secondary crusher benchmarks (Canica 3000 HD DD).

By compiling the data from three major phases of the mining process we can see the contribution each phase makes. (See Figure 18).

Complementing the data are the benchmarking and scenario building tools such as the plant optimisation tools (in this case AggFlow and BlastCast). (See Figure 19.)

The next step after data is collected, analysed and put in the proper dashboard-like template is to use it in the continuous improvement process driving conclusions and creating action items (and updating KPI). On top of that we can validate our assumptions and guidelines by looking at the trends. As this data is continuous and

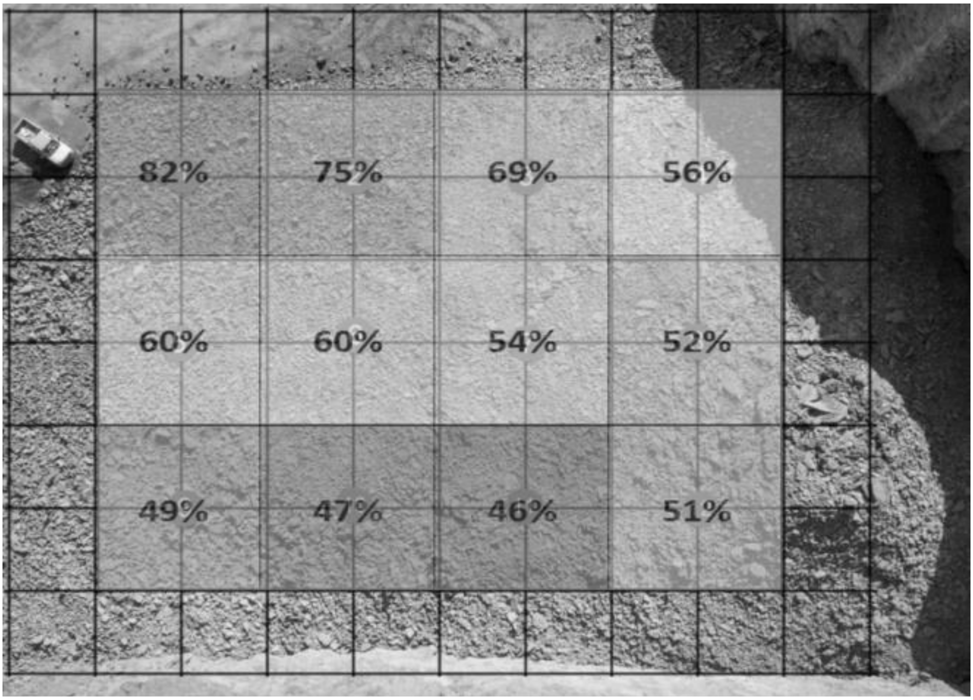

Figure 18. The compatibility zones allow users to identify what material is best suited for the crusher specifications.

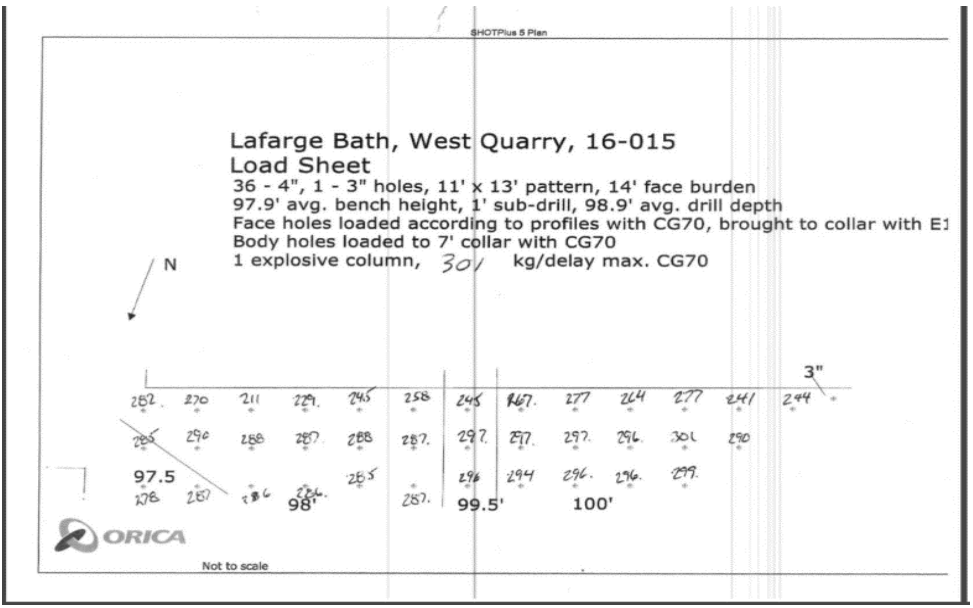

Figure 19. A shot report allows the user to identify potential issues with the blast as they relate to the compatibility zones.

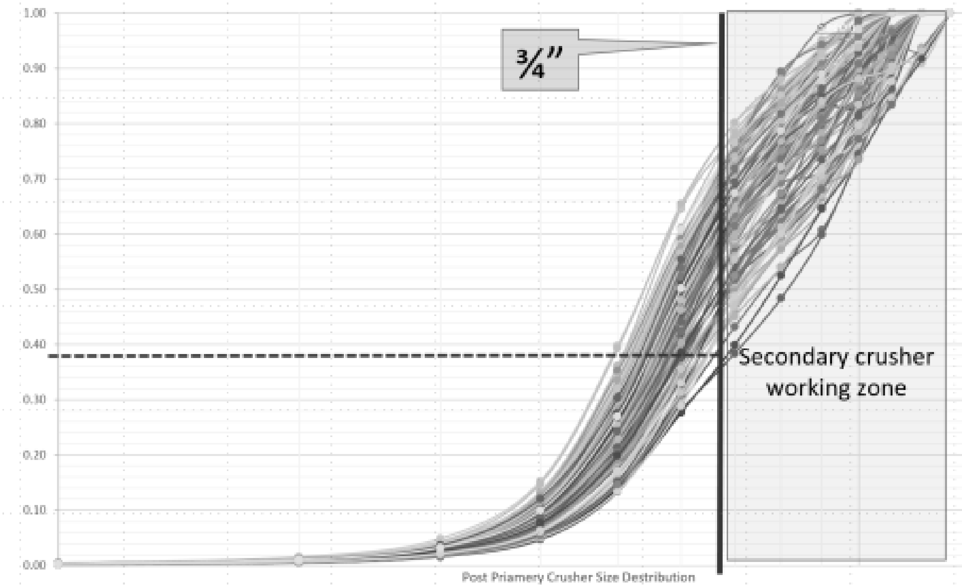

Figure 20. Tracking particle sizes as they pertain to the secondary crusher specifications.

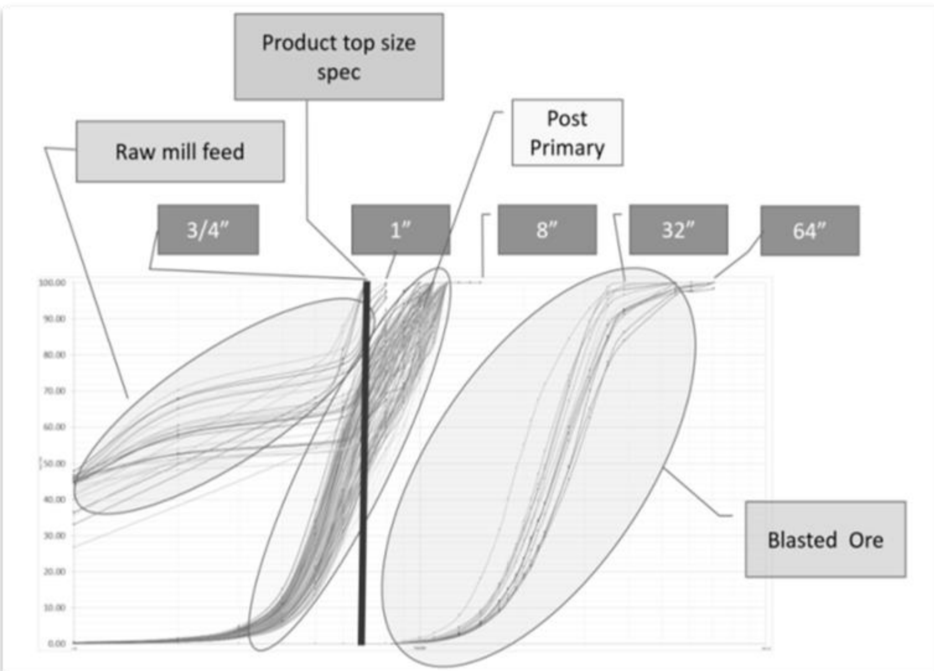

Figure 21. By comparing the fragmentation data from the blasting and crushing zones tracked, we can begin to identify the contribution that each phase makes.

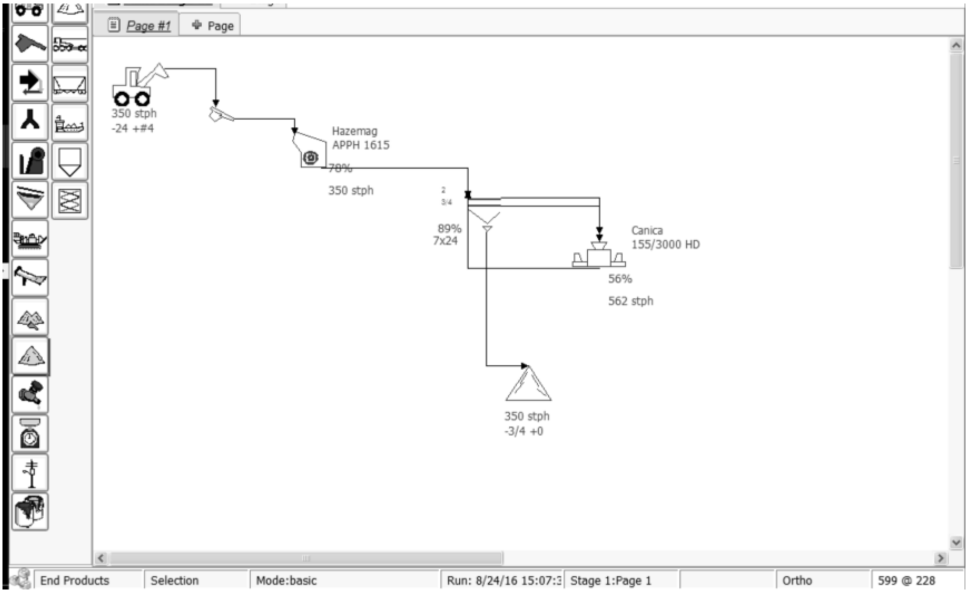

Figure 22 Scenario building software is used to tie in the data and allow for a continuous improvement loop.

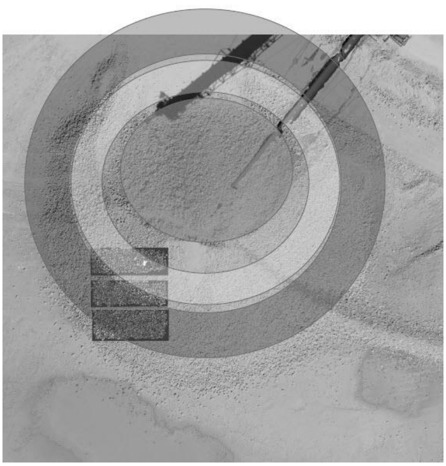

Figure 23. Stockpile segregation can now be quantified, and the data collected can be used to forecast what material will be feeding the kiln.

automatically generated we can take actions as we go along (changing drill patterns and crusher settings). The opportunities that arise range from what can we do better on the upstream to meet the targets or can we improve on the downstream side and gain a bigger advantage (if by better fragmentation at the blast we are able to achieve better raw-mill feed size distribution that will allow to reduce costs significantly).

4.2.8 Managing stockpile segregation

In addition to the advantages this technology brings to the pit and crushing operations the drone imaging techniques can capture and present stockpile fragmentation, assist in understanding the segregation in the pile and mitigating its effect. By separating the stockpile into three distinct zones, operations can use the fragmentation data collected to forecast ideal feed blend and burn rate settings prior to the material entering the kiln.

An example of how drone imaging can be used to improve performance is with the material size in the ‘outer-zone’ as seen in Figure 8. Now when an operation wants to start pushing outside material through the process, they can optimize kiln settings based on the image analysis data collected.

5 CONCLUSIONS

Our ability to attribute fragmentation to a location at the muck-pile allows us to better understand the variables contributing to the outcome. The correlation between the shot parameters, geology and fragmentation helps differentiate between cause and effect and allows an operation to:

- set better goals
- reproduce what worked well
- improve what did not yield expected results

Since the ‘penny is not always under the light’, the more detailed the picture, a fragmentation analysis of each grid block, the better the understanding we have. This will give us a wide spectrum of data. We look for the best result, the worst result and the deviation from our standard. The plant’s ideal in-coming material for maximising both productivity and yield in this case is material above 3/8 inch and below 12 inch. In cement, the raw mills need a consistent feed (varies based on operation) to reduce standard deviation. The grid location knowledge provides the blaster the ability to relate material size to specific areas in the blast, allowing subsequent blasts to be optimised in line with the operation’s goals.

In the case of monitoring the product piles, we work very hard to get the ideal fragmentation curve so we can supply a consistent feed to the mills and the kilns. However, building a stockpile comes with a price; the segregation impacts both the mill and kiln productivity, energy use and product quality. Monitoring the different segregated ‘rings’ in the pile helps us find the best solution for the consistent feed method by understanding what the segregation looks like and its associated boundaries as it relates to fragmentation.

6 ACKNOWLEDGMENTS

The authors of this paper would like to acknowledge and thank the following companies for their contribution to this paper: L’Hoist – Clifton Quarry for allowing the drone trial to occur and taking the time to facilitate the first portion of this study; Lafarge Bath Cement Plant for hosting and participating in the case study; Texas Drone Professionals for the excellent quality images and services; WipWare Incorporated for providing the fragmentation analysis data for this project.

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