Utilizing Continuous Photo Analysis of Fragmentation as a Blast / Crush Improvement Tool

Abstract

The paper will demonstrate how automated fragmentation photo analysis is being used at the Lafarge North America, Ravena NY quarry as part of an ongoing drill, blast and primary crushing continuous improvement process. Using on-line fragmentation photo analysis systems at both the primary crusher feed point and crusher discharge belt, data is collected to: benchmark the drill/blast process; monitor the work being done by the primary crusher; measure gradation changes in the crusher feed resulting from changes in drill/blast and measure the subsequent changes in further size reduction done by the primary crusher.

Explanation will be given to: the ongoing drill, blast and primary crusher continuous improvement process; the objectives and methodology for their refinement; determination of the benchmarks for the drill/blast fragmentation based on crusher type and operational settings; the guidelines and rationale used for choosing methods, techniques and equipment for data collection; and finally benefits realized from the implementation of the on-line photo analysis system.

Discussion will be given to how the data is systematically organized and correlated not only to compare to benchmarks and measure improvement but to build a high level of understanding that ultimately supports decisions for improvement.

The paper will provide templates presenting data at different steps of the process and a template for the dashboard that is the decision supporting information

Introduction

Lafarge Ravena NY Quarry is part of Lafarge North America's Cement Division. It is a surface open pit operation that supplies aggregate and cement feedstock to the Lafarge Ravena NY Cement facility. The quarry has one primary crusher (Superior MK-II 54-75 Gyratory Crusher). The blasted rock crushed at the primary is conveyed across the road to supply the cement plant and aggregate producer.

The Lafarge Ravena NY quarry mines four (4) benches. In order of their elevation from highest to lowest in the pit they are: the Becraft, the New Scotland, the Aggregate (AGG) and the Coeymans Manlius (CM). Of these 4 benches only three (3) have value. Each are drilled, blasted and crushed separately. The Becraft bench is shortest and the smallest amount of the useable reserves. 100% of the AGG bench is drilled, blasted, crushed and sent across the road for cement production and use by the aggregate producer. Approximately 20% of the total amount of the crushed aggregate is used by Lafarge in the cement process. 100 % of the CM Bench is drilled, blasted, crushed and sent across the road for feedstock to the cement plant.

The goal for the quarry is to produce the lowest cost possible, in-spec product to its customers, the cement plant and aggregate producer.

The quarry has utilized a continuous improvement process for over 6 years[1]. Over this period of time several key management and metric systems have been implemented to support this effort including a Logimine On-line Mining System[2] and the Geo-Instruments Jean Lutz Drill Monitoring System. In July of 2010, the Lafarge Ravena Quarry installed the WipWare Reflex and Solo Fragmentation Analysis Systems[3] to push the continuous improvement process even further.

The automated fragmentation photo analysis systems support the continuous improvement process as a drill/blast performance measurement improvement tool.

Continuous Improvement Process

The continuous improvement process in place at the Lafarge Ravena quarry revolves about the Observe, Orient, Decide, Act[4] (OODA) loop (Figure 1). Success in this loop is a decision to act that is based on a clear understanding of the key factors that can effect improvement. Four basic steps[5] are necessary to build this understanding for the decision to act. They are:
   1.) Raw data acquisition (collect the data).
   2.) Processing the data (put data in an understandable form).
   3.) Evaluate and analyze the data (give meaning to the data - build knowledge).
   4.) Synthesize and visualize the data (give greater situational meaning to the data build understanding).
For blast/crush improvement this same OODA loop approach was applied through the utilization of the automated fragmentation analysis systems.

Raw Data is continually acquired from the automated fragmentation photo analysis systems and downloaded to a master database; it is then processed, analyzed and uploaded to the dashboard (Appendix A). The dashboard displays the performance of each blast, provides information on the controllable factors and presents a basis for decision making. As a change is implemented, resultant data is acquired by the system, processed, analyzed, and appears on the dashboard ready for the cycle to begin again.

Figure 1: OODA

(The OODA loop)

Raw Data Acquisition

The data collection process begins with the recording of pertinent blast information from each blast. This includes rock type, pattern and area, timing and opening, bench height, tonnage, the quantity and types of explosives that are used as well as the cost of drilling and blasting.

The next stage of data collection is the acquisition of the fragmentation gradation of each blast. Lafarge Ravena utilizes a two stage automated fragmentation photo analysis system that captures images of loads as they are dumped into the primary crusher as well as when the material exits the crusher on the conveyor.

Crusher Input Data

When the material is dumped into the crusher by 100 ton haul trucks, a series of images of each load are automatically captured. Of the series, two (2) of the images are utilized by the system to calculate the fragmentation for that load. The remaining images are discarded to ensure that only images of the material are processed. The number of samples for each blast can range from 600 to 2600 samples per blast depending upon the size of the blast and the percentage of the muck pile being sent directly to the crusher from the muck pile. Data is disregarded when material is being sent to the crusher from the stockpile due to the fact that there may be material from multiple blasts stockpiled.

The system exports a daily report including a chart of the overall gradation curve for that day as well as a CSV file with time stamps and gradation percentages for each load dumped into the crusher. The crusher operator logs the load counts, any down time and the blast/muck pile from which the load was dug. This seeming redundancy is important to ensure that the automated system is working properly and ensures that erroneous or

missed data does not go unnoticed. Accurate reporting of changes in the digging location is required by the crusher operator to enable sorting of the fragmentation data into separate blasts.

Another important piece of data that is acquired from the automated fragmentation photo analysis system is the actual hours of crushing. This is based upon the time stamps recorded by the system for each load. This provides accurate tracking of the loads per hour to the crusher. Assuming an average tonnage per haul truck load, a reasonable estimate of the tons per hour to the crusher is calculated. It also enables quantitative recording of production from each blast.

Conveyor Output Data:
As material exits the crusher it is discharged onto a conveyor belt where a second camera is mounted. This camera captures images of the belt feed at a rate of one image every fifteen seconds which translates to about 18 samples per load or between five thousand and twenty thousand samples per blast depending upon the blast size and again the percentage of material crushed directly from the muck pile, assuming and average load of 89 st (81 tonnes) and average feed rate of 1267 st/hr (1150 tonnes/hr).

The automated system exports a daily report including an overall gradation chart and CSV file including time stamps and gradation percentages. It is worth noting that the output system automatically detects when material is on the belt so that no empty belt images are recorded. Utilizing the time stamps for each sample it is possible obtain the black belt time for the duration of the crushing day.

Processing the Raw Data
The next step in the information hierarchy is data processing with the goal of putting the data into a workable form. At this stage vast amounts of raw data are recorded in master databases that sort the data by blast. The fragmentation production data is processed daily and loaded onto a dashboard for each rock type. New blasts are added as they occur.

Blasting Performance Dashboard
The Blasting Performance Dashboard (Appendix A) represents the evaluation and analysis of the processed data and is the tool utilized to draw conclusions and ultimately direct decisions for furthering process improvement. It consists of several comparative charts that relate the analyzed data from each blast of the same rock type to one another. Detailed information about the fragmentation, downstream contributing factors and an overall blast rating are given on the left side of the dashboard. The Controllable Factors that affect the blasting performance are recorded in the charts on the right portraying visually the changes made from blast to blast. Tracking these changes along with the changes in blast performance is of pivotal importance as a blast/crush improvement tool. The goal is to improve control over the blast performance and to maximize the downstream contribution of each blast.

Blast Contribution Rating System

In the quarry fragmentation has a direct impact upon in-pit productivity as well as downstream on the crushing and grinding cycle[6]. Therefore drilling and blasting must be recognized as the first step in the size reduction process. With this in mind, consideration to the fragmentation of each blast is of great importance and is the first of three factors used for quantifying the effectiveness of each blast. The rating system (appendix B) also enables the comparison of the blast/crush operation on a blast by blast basis.

Table 1 shows the three (3) factors of contribution used along with their assigned weight. Based upon these three factors a rating is assigned to each blast on a scale of one to ten.

Table 1: Blast Contribution Rating Factors

Blast Contribution Rating Factors	Weight
Fragmentation (D80)	40%
Tons/Hour to the crusher	40%
Drill and Blast cost ($/Ton)	20%

Fragmentation (D80)

The fragmentation for each blast is rated based upon the screen size for which 80 percent of the material passes (D80). The D80 for each load is reported from the automated analysis system, and an average D80 size is calculated as loads are brought to the crusher until digging of the muck pile is complete. The fragmentation photo analysis system records the fragmentation distribution of each load based upon the percent of the area that each block within the image occupies. Since the image size of the sample photos remains the same an average of all loads to the crusher from a blast will yield a result comparable to a cumulative gradation of the muck pile, assuming that the truck load tonnages remain consistent.

Tons/hr

The tons per hour to the crusher is the key indicator for the effectiveness of the fragmentation and muck pile profile being that it is a function of not only the loading time at the muck pile, but also the time it takes for the crusher to do its work. Pushing the capacity of the crusher to its maximum is critical in order to maximize production and provides the initial means for quantifying the impact of fragmentation down stream. If digging conditions such as a tight pile inhibit maximum crusher feed it is reflected in a reduction of the tons per hour to the crusher and an increase to black belt time.
The tons per hour for each blast are the sum of the total tons crushed per actual crushing hour (excluding downtime) for the duration of the blast and are calculated from the time stamps for each load recorded.

Drill and Blast Cost

The drill and blast cost is the total invoiced blasting cost plus the drilling cost estimated at 3.90 USD divided by the tonnage of the blast. It is important to include both drilling

and blasting cost since changes made to one effects the other. Figure 2 is taken directly from the dashboard and depicts ten CM (Coeymans Manlius) blasts and actual ratings.

Figure 2: Blast Contribution Rating
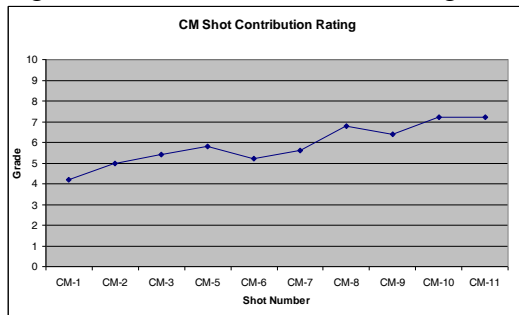
Based upon the contribution rating of a particular blast adjustments to the contributing factors for the next blast may be made in order to get the desired result. If for instance greater production rates are required, a blast design that will yield the desired fragmentation can be chosen.

Percent Passing By Blast

On the left side of the dashboard directly below the blast contribution rating is a chart titled CM Percent Passing By Blast (Figure 3). This chart gives the overall fragmentation gradation curves for each blast. The overall gradation of each blast is important to take into consideration due to size requirements downstream. The screen size in inches is plotted on a logarithmic scale on the x-axis and percent passing on the y-axis.

Figure 3: Percent Passing by Blast
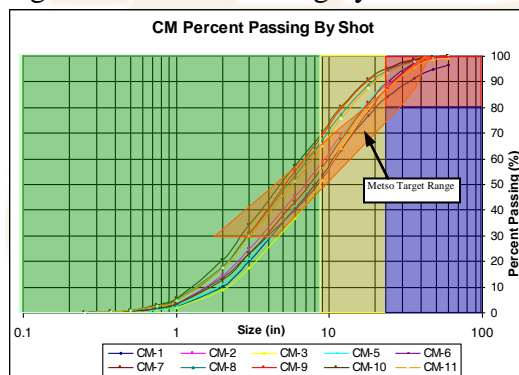
There are several size ranges identified with separate colors to indicate areas of interest.

Red and Blue Zones**:**
The red and blue areas indicate the size range that Lafarge Ravena desires to eliminate. Both manufacturer specification and recorded data indicates that material larger than 24 inches (61 cm) reduces productivity at the crusher.

Yellow Zone**:**
The yellow area indicates sizes between nine (22.9cm) and twenty four inches (61cm). This is the primary work zone of for size reduction by the crusher. The operational goal is to push the top size of the muck pile fragmentation down into this area.

Green Zone:
The green zone indicates fragmentation sizes of less than nine inches (22.9cm). The material in this zone will pass through the primary with the least amount of crushing. Maximization of the amount of material in this zone without producing excessive fines will increase production, reduce work done by the primary crusher and decrease the wear on the crusher components and to those downstream.

Orange Envelope:
The orange envelope represents the target range for material fed to the primary crusher based upon the model and settings (Superior MK-II 54-75 Gyratory Crusher: 1.26 inch stroke, 6 3/4 inch closed side and 8 in open side setting). Material within this zone ensures optimum crusher productivity as defined by the manufacturer METSO.

Tons per Hour and Percent Passing

Muck pile fragmentation and profile are key contributing factors to load/haul cycle times in that they affect dig ability, loading time and downstream crusher productivity. Figure 4 is a chart taken from the dashboard that tracks the tons per hour to the crusher as well as the percent passing of the material through various screen sizes (in inches).

By achieving finer fragmentation it is reasonable to conclude that the tons per hour will increase. Basic statistical analysis of the data shows that the T/hr to the crusher is a linear function of the D80 size. It is understood however and should be noted that at some point finer fragmentation could reduce the T/hr reflecting the dig ability.

Figure 4: Tons per Hr v. Percent Passing
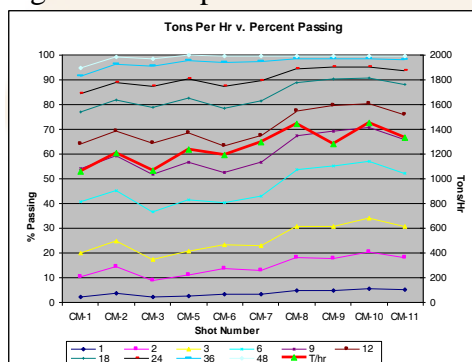
This chart shows the change in tons per hour to the crusher as well as the changes in the overall fragmentation from blast to blast.

Top Size Material

It is important to quantify the amount of material over 24 inches (61 cm) not only by the total percentage of the blast but also the frequency that this material is fed to the crusher. Large amounts of material greater than the desired top size sent to the crusher at one time slows crushing and limits overall productivity. Utilizing the data from the automated system the percent of material over 24 inches (61cm) for each load is tracked throughout the duration of digging each blast. The homogeneity and the distribution of this larger material throughout the muck pile becomes obvious in the moving average trend graph (figure 5).

Figure 5: Trend of Plus 24" (61cm) by Load
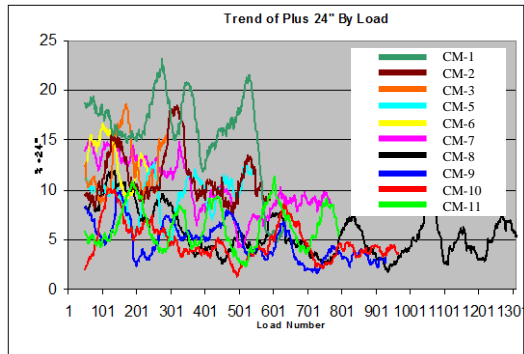
Controllable Blast Factors

Relating the controllable parameters of blast design to the effectiveness of each blast is important to determining the effect each has on the resultant blast. Monitoring changes in the controllable blast design parameters and resulting fragmentation builds a history of contribution of each. From here changes based upon facts can be made to future blast designs.

The right hand side of the Dashboard consists of six charts that compare the controllable blast design factors. Each variable is charted along with the overall percent passing nine (9) inches (22.9cm) and the overall percent of material greater than nine inches (22.9cm) for each blast- nine inches (22.9cm) being the largest fragment size that would pass through the primary crusher's open side setting without need for size reduction. The seeming redundancy in the nine inch (22.9 cm) sizes graphed is useful because it allows, at quick glance, an assessment of the fragmentation based upon the size of the gap between the two lines. The six controllable blast design variables are as follows:

Cost/Ton

This cost consists of the invoiced blasting cost and estimated drilling expense per short ton of rock from each blast. Relating the drill and blast cost to the target fragmentation size is important in order to gage the effect of this upstream process cost on the productivity at the primary crusher.

Figure 6: Cost/Ton
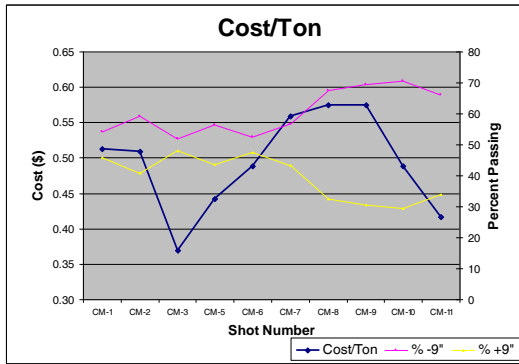
Energy Factor

The energy factor for each blast is calculated using the total energy of explosives loaded and the total volume blasted. This factor fluctuates due to changes in the type of explosives loaded as well as the pattern and bench height. It is representative of the average explosive energy used per volume of rock. Note: Lafarge Ravena currently utilizes a consistent hole diameter for every production blast.
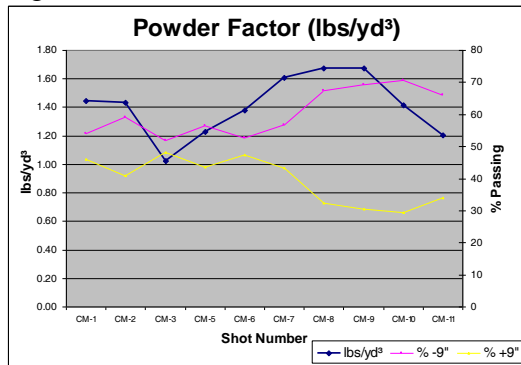
Figure 7: Energy Factor
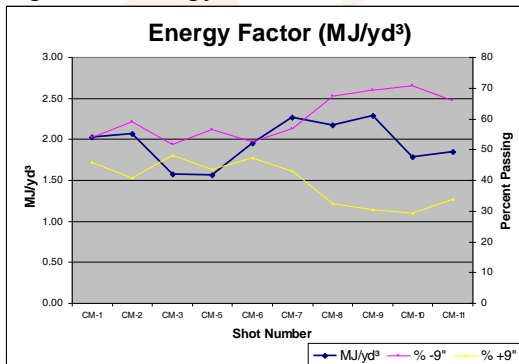
Powder Factor

The powder factor is calculated using the total weight of explosives loaded and the total surveyed volume of rock blasted. Notice that the energy and powder factors differ. This is due to differing densities between explosive products.

Figure 8: Powder Factor

Powder Factor (lbs/yd³)

Distribution Factor

The distribution factor is representative of the number of holes per area of bench blasted and correlates with the pattern for each blast. It is an overall factor that takes into consideration the holes that are out of pattern, and likewise gages the average distribution of holes throughout the entire blast - the closer to a factor of one, the better the explosive distribution.

Figure 8: Distribution Factor

Distribution Factor

Distribution Factor= 1-(#holes/ft²)
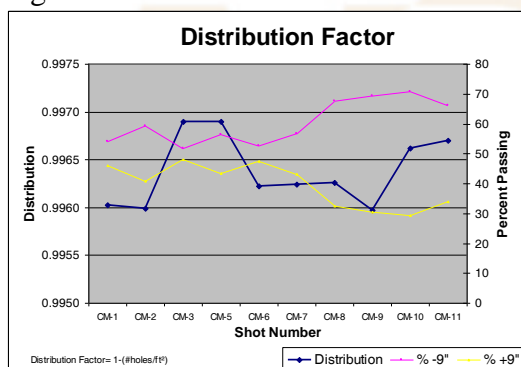
Timing Factor

Differing timing scenarios yield differing results. The timing factor is a representation of the delay interval used between the detonation of consecutively initiated blast holes in a row and the spacing between the consecutively initiated blast holes in the same row.
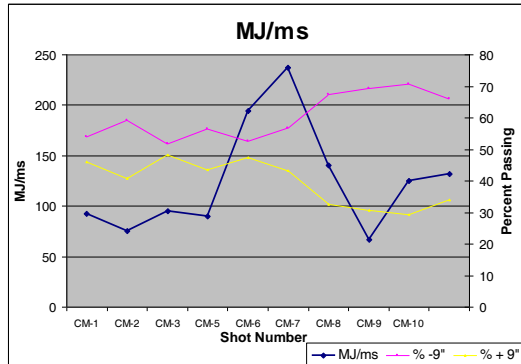
Figure 9: Timing factor

Timing (ms/ft of Spacing)
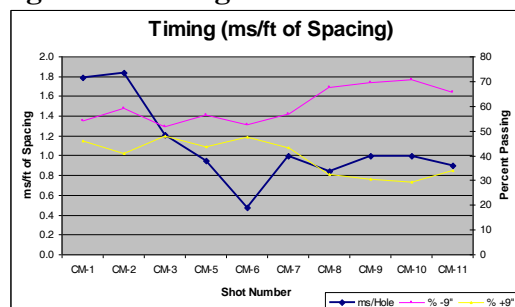
Power Factor

The power factor is a representation of the amount of explosive energy delivered per ms of delay time. It is calculated using the total explosive energy delivered and the total duration time for the complete blast.

Figure 10: Power Factor (MJ/ms)

The Automated Fragmentation Photo Analysis System – Cost / Benefit Analysis

Continuous measurement and monitoring of the fragmentation of each blast are the obvious benefits that automated fragmentation photo analysis systems provide. However, the benefits that provide true value for implementation of such systems are only realized when the systematic organization, correlation and utilization of the data they collect is used to benchmark blast performance, measure productivity improvements and build an understanding of the important controllable blast design factors to support decisions for furthering process improvements.

Conclusions: Making Informed Decisions

Size distribution is a critical component of managing any mining operation. From the drill and blasting to the final product, the materials size directly affects downstream costs[6]. At the Lafarge Ravena Quarry, the automated photo analysis system has been found to be a useful tool for monitoring and collecting raw data that is utilized to measure drill blast improvements and further enrich its continuous improvement process. It is the processing, evaluation and analysis of the data collected by the automated photo analysis system and its representation on the Blasting Performance Dashboard that truly provides the understanding necessary for making informed decisions regarding improving final product costs. Although the data analysis program at the Lafarge Ravena Quarry has the flexibility to evolve utilizing even more data as it becomes available and enables further maximization of blasting performance, it should be noted that it is site specific. Any other quarry site or mining operation deciding to implement such a program will need to develop its own unique program to analyze data collected by the automated fragmentation system, use it to build an understanding and ultimately gain control over the effectiveness of each of their blasts.

Some examples of the measured gains achieved at the Lafarge Ravena Quarry using the automated photo analysis system as a blast/crush improvement tool are as follows:

1.) 20 % increase in crusher productivity. 12 % reduction in crushed product cost per ton. In spite of 16% increase in Drill and Blast cost.
2.) 20% increase in crusher productivity. 12 % reduction in crushed product cost per ton. No change in drill and blast cost.
3.) 12.5 % increase in crusher productivity, 14 % reduction in crushed cost per ton. In spite of 16 % reduction in Drill and Blast cost.

These accomplishments do not take into consideration the savings on manpower and equipment usage. As the methods and tools described in this paper evolve, they will undoubtedly deliver even greater value.

Appendix A:

Blasting Performance Dashboard
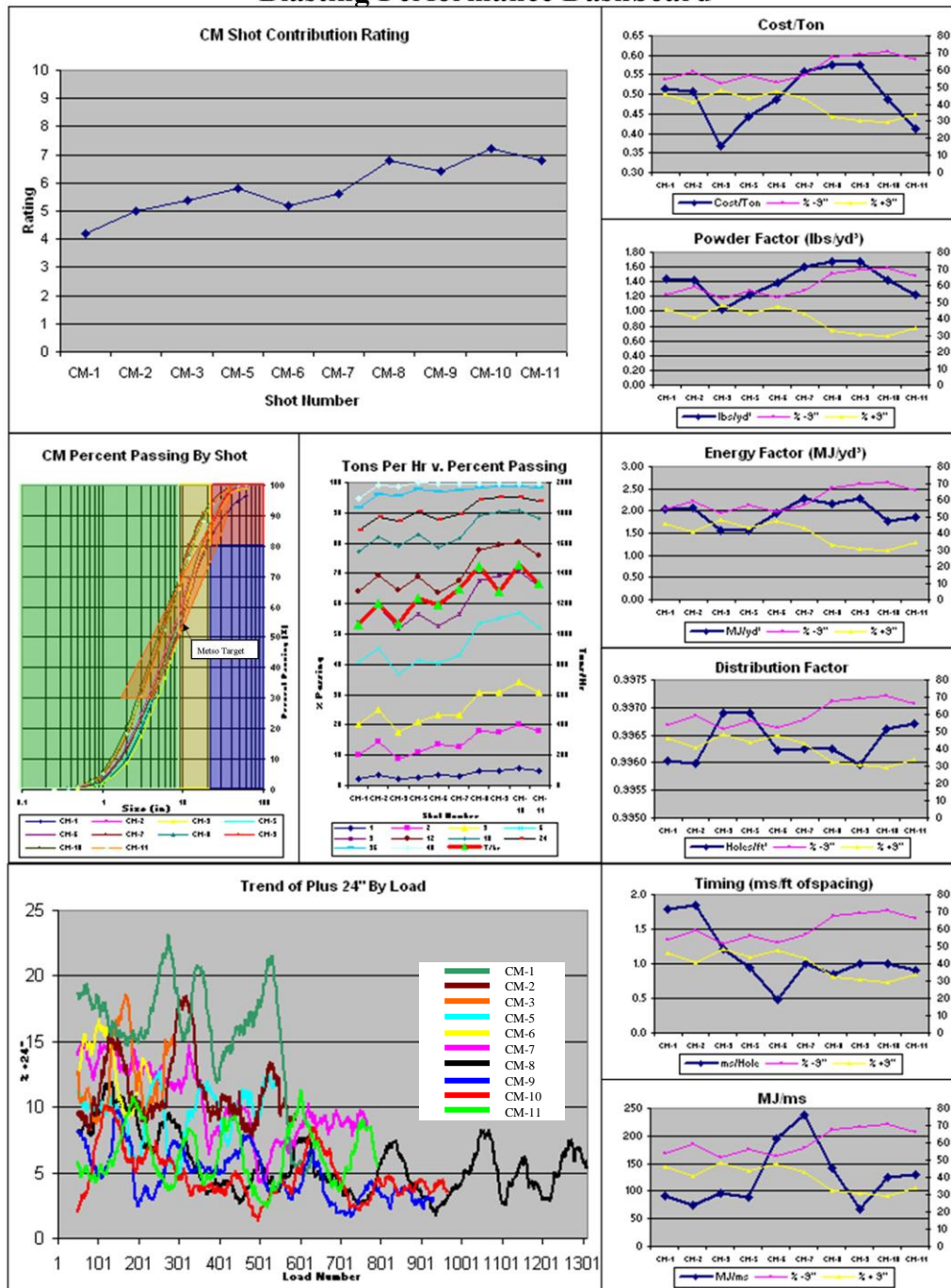
Appendix B:

Shot Contribution Rating System

Tons Per Hour		Weight 0.4	Total Blasting Cost/T	0.2	Size (in) for which 80% passe	0.4	
>2000	11		<.28	11	<8"	11	
1850-1999	10		.28-.31	10	8-9.99"	10	
1700-1849	9		.34-.37	9	10-11.99"	9	
1550-1699	8		.38-.41	8	12-13.99"	8	
1400-1549	7		.42-.45	7	14-15.99"	7	
1250-1399	6		.46-.49	6	16-17.99"	6	
1100-1249	5		.50-.53	5	18-19.99"	5	
950-1099	4		.54-.57	4	20-21.99"	4	
800-949	3		.58-.61	3	22-23.99"	3	
650-799	2		.62-.65	2	24-25.99"	2	
<650	1		>.65	1	>26	1	

Shot #	Grade		T/hr	Cost/Ton	Size
CM-1	4.2		1057.1	0.51	20.53
CM-2	5		1205.7	0.51	17.96
CM-3	5.4		1070.3	0.37	19.21
CM-5	5.8		1237.7	0.44	17.66
CM-6	5.2		1195.9	0.49	19.66
CM-7	5.6		1295.1	0.56	17.64
CM-8	6.8		1445.7	0.57	13.63
CM-9	6.4		1282.6	0.57	12.82
CM-10	7.2		1453.8	0.49	12.43
CM-11	6.8		1336.3	0.41	14.18
CM-12	0				

CM Shot Contribution Rating
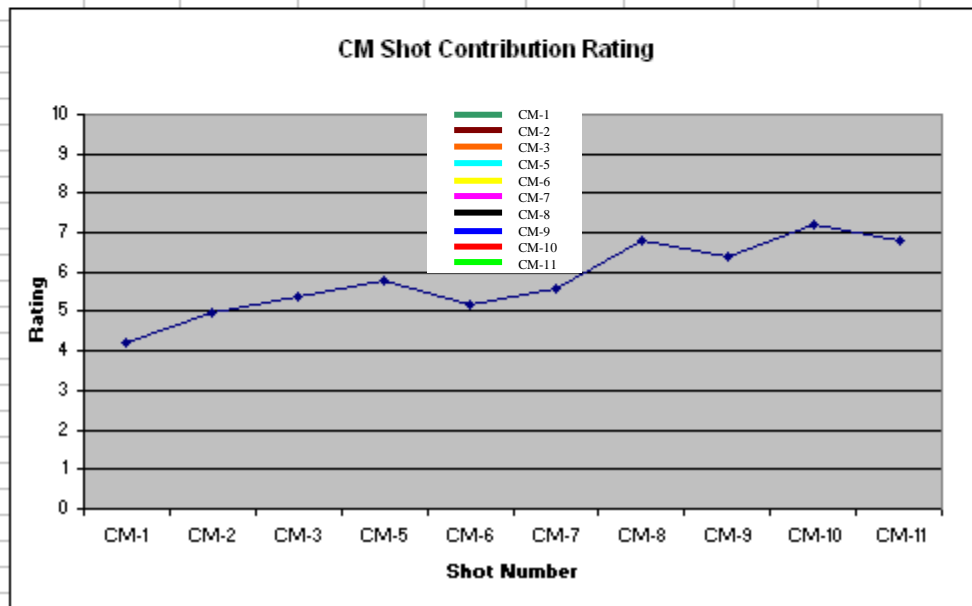
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