INTRODUCTION

While it seems deceptively simple, the process to produce rock is actually very complex and involved. This paper will demonstrate some simple methods to maximize fragmentation and productivity results. In addition, several methods to further refine the analysis will be introduced.

The Lafarge Ravena plant is using basic statistical analysis and digital fragmentation analysis to optimize fragmentation size and productivity.

Digital fragmentation analysis from blast photographs and video is becoming an essential tool to analyze blast results and determine the success of changes to blast design. This paper details ways to statistically relate the results of blast fragmentation analysis to changes in blasting parameters such as powder factor. Methods to integrate data into a single data pool using Excel spreadsheets to relate blasting parameters and fragmentation analysis to crusher productivity are described.

THE PROBLEM

Because of the unique nature of the blasting process, equally unique mining processes, and time inconsistencies between the results of each, the processes have not always been fully integrated. Both processes are statistical in nature and results are site-specific making integration of the separate modeling
processes difficult at best. In addition, the blasting and mining variables are interrelated and affect each other significantly with complex interactions.

The expansion and use of extensive blasting and production databases has been the first step in the integration. A statistical description and evaluation of significant blasting variables effecting the mining process is furthering the integration of the two processes while first principle modeling and development is proceeding. Below are some of the variables that enter into final productivity and product sizing.

Every mine is different and data is kept differently to describe the process and results. Product from a specific blast is not normally segregated in the operating data. What we are attempting to do in this paper is to describe a simple method to relate blasting parameters to product size and productivity in ways that can be related to all mines. In addition we will introduce some of the more advanced methods of analysis.
THE DATA

Every mine must keep blast records for regulatory purposes. A typical Lafarge blast report is shown below:

Dyno Nobel catalogs the blast reports in a database for retrieval in many forms of reports—a portion of one is shown below. The pertinent data can be taken from the blast reports if a database is not available.

<table>
<thead>
<tr>
<th>Quarry</th>
<th>Blast Date</th>
<th>QBench</th>
<th>Blast #</th>
<th>Tons</th>
<th>Hole Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravena</td>
<td>Aug 25, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>33-CM-10-2009</td>
<td>72505.26</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Aug 04, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>31-CM-09-2009</td>
<td>65869.32</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Jul 21, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>29-CM-08-2009</td>
<td>103096.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Jun 25, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>26-CM-07-2009</td>
<td>69026.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>May 20, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>19-CM-06-2009</td>
<td>88834.09</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Apr 09, 2009</td>
<td>Ravena: CM West</td>
<td>15CM-06-2009</td>
<td>97318</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Apr 02, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>13-09</td>
<td>99345.98</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Mar 25, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>11-09</td>
<td>70001.28</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Feb 26, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>07-09</td>
<td>62427.36</td>
<td>6.5</td>
</tr>
<tr>
<td>Ravena</td>
<td>Feb 11, 2009</td>
<td>Ravena: CM Main Pit</td>
<td>04-09</td>
<td>64265.34</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Lafarge retains productivity data in a database also. A portion of a monthly database is shown below. Most mines have a similar database but not always in this form. Many mines are keeping a variety of KPIs that can be helpful to the analysis.

The trick to combining the blasting and productivity data is to relate the blast to specific productivity data. In this example, the few Cement blasts in 2009 can be related to the day’s production after the blast. When there are more blasts in a month, it is possible to estimate an average monthly powder factor and relate that to monthly productivity.

An alternative method of establishing the relationship is to time specific crushing loads related to a blast. The procedure is illustrated in the referenced article The Powder Factor: More is not Necessarily Better. (1992).

Additional information on data can be found in “Tools to help Improve Operational Performance and Control Operating Costs-or Reducing the Guesstimation Factor (2007)“.
Blast Muckpile Fragmentation data can be acquired using digital photos and commercially available fragmentation analysis programs or with a very general manual method. An output of one of the commercially available fragmentation analysis programs is shown below. The data illustrated here is a merged analysis was from photos taken of areas in the blast muckpile. An alternate and more representative method is to take photos as the loads are dumped into the crusher.

A more general and manual alternative to commercial fragmentation analysis packages to analyze muck pile photos described in the paper A Blaster’s Tool to Measure Fragmentation (2008). Make no mistake the results of commercial photoanalysis are more accurate. Regardless the procedures and possibly the person taking photos are most important to both methods and should be constant for best results. It must also be noted that determining the percentage of fines is difficult with either of the photoanalysis methods.

In addition, the crusher manufacturers data can be utilized for additional guidance.
For the two examples (Cement and Aggregate) in this paper the data flow is as follows.

**Ravena, NY Cement Rock**

- **Blast Muck** → **Loader** → **Haul**
- **Crusher** → **Stockpile** → **Belt**

**Ravena, NY Aggregate Rock**

- **Blast Muck** → **Loader** → **Haul**
- **Crusher** → **Stockpile** → **Belt**
A SIMPLE METHOD TO RELATE PRODUCT SIZE AND PRODUCTIVITY TO BLASTING PARAMETERS

Below is data taken from the above reports to illustrate a simple analysis of the method to relate the different parameters. All data is from the Ravena Plant in 2009. Normally, the mean size is used and not the minimum but the Ravena crusher does not scalp fines and fines are a significant percentage of the final product. Fines can slow a crusher as easily as oversize. Video analysis of blasts do not discriminate fines though it is possible in other configurations. A sieve analysis of a Ravena blast prior to the study indicated a high fines percentage. In the case of Cement fines are an essential part of the product.

<table>
<thead>
<tr>
<th>BLAST DATE</th>
<th>POWDER FACTOR TONS/LB</th>
<th>TONS CRUSHED</th>
<th>HOURS CRUSHED</th>
<th>PRODUCTIVITY TONS/HOUR</th>
<th>WHIPFRAG MINIMUM SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-Feb</td>
<td>1.71</td>
<td>50357</td>
<td>56</td>
<td>899.2</td>
<td></td>
</tr>
<tr>
<td>26-Feb</td>
<td>1.87</td>
<td>63304</td>
<td>63</td>
<td>1004.8</td>
<td></td>
</tr>
<tr>
<td>25-Mar</td>
<td>1.73</td>
<td>45625</td>
<td>53</td>
<td>860.8</td>
<td></td>
</tr>
<tr>
<td>2-Apr</td>
<td>2.36</td>
<td>33929</td>
<td>38</td>
<td>892.9</td>
<td>0.3050</td>
</tr>
<tr>
<td>9-Apr</td>
<td>2.02</td>
<td>91349</td>
<td>88</td>
<td>1038.1</td>
<td>0.4440</td>
</tr>
<tr>
<td>20-May</td>
<td>1.67</td>
<td>82768</td>
<td>105</td>
<td>788.3</td>
<td>0.2610</td>
</tr>
<tr>
<td>25-Jun</td>
<td>2.15</td>
<td>82232</td>
<td>86</td>
<td>956.2</td>
<td>0.2770</td>
</tr>
<tr>
<td>21-Jul</td>
<td>1.74</td>
<td>77857</td>
<td>80</td>
<td>973.2</td>
<td>0.3200</td>
</tr>
<tr>
<td>4-Aug</td>
<td>1.47</td>
<td>52143</td>
<td>58</td>
<td>899.0</td>
<td>0.1180</td>
</tr>
</tbody>
</table>

From the above data, simple graphs of the relationships can be made as shown below. Below is the relationship between crusher productivity (tons per operating hour) and powder factor (tons/lb explosive). While the product in this example is cement feed and productivity should be maximized, when sized aggregate is produced, productivity should be analyzed based upon the size preferred. See previous 2007 study “Aggregate Size Optimisation Program at the Lafarge Marblehead Plant”.

![Graph of CRUSHER PRODUCTIVITY vs POWDER FACTOR TONS/LB]

\[ R^2 = 0.2717 \]
The relationship indicates that fines are slowing the crusher at the lower powder factors (more lbs of explosive per ton of rock) and also at the higher powder factors with oversize. The optimum powder factor for crusher productivity appears to be at 2.0 to 2.1 tons/lb.

Basically the same relationship was found in a previous study done in 2007 “Factors Driving Continuous Blasting Improvement at the Lafarge Ravena Plant” using monthly data. Charts from that study are shown below.

The relationship between powder factor and minimum block size is shown below. It is basically a linear relationship. It can be refined by using the techniques described in a previous 2007 study “Aggregate Size Optimisation Program at the Lafarge Marblehead Plant” to separate the relationship by pattern area or burden and spacing. Because of the limited data and closeness of the pattern areas, this was not attempted in this example.
The relationship between minimum and mean block size and crusher productivity is indicated below – again indicating that both fines and oversize affect crusher productivity.

Below is a similar analysis for the aggregate production at the Ravena Plant. Note this time the maximum and minimum sizes are used for correlation. Mean size is shown also as a reference.

### AGGREGATE

<table>
<thead>
<tr>
<th>BLAST DATE</th>
<th>POWDER FACTOR</th>
<th>TONS CRUSHED</th>
<th>HOURS CRUSHED</th>
<th>PRODUCTIVITY TONS/HOUR</th>
<th>WHIPFRAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-Apr</td>
<td>1.81</td>
<td>94196</td>
<td>112</td>
<td>841.04</td>
<td>27.8000</td>
</tr>
<tr>
<td>2-Jun</td>
<td>1.69</td>
<td>56518</td>
<td>64</td>
<td>883.09</td>
<td>26.5800</td>
</tr>
<tr>
<td>16-Jun</td>
<td>2.17</td>
<td>44286</td>
<td>49</td>
<td>903.80</td>
<td>45.3040</td>
</tr>
<tr>
<td>24-Jun</td>
<td>1.94</td>
<td>22929</td>
<td>28</td>
<td>818.89</td>
<td>22.8980</td>
</tr>
<tr>
<td>6-Jul</td>
<td>1.92</td>
<td>130268</td>
<td>146</td>
<td>892.25</td>
<td>29.5350</td>
</tr>
<tr>
<td>5-Aug</td>
<td>2.08</td>
<td>119911</td>
<td>126</td>
<td>951.67</td>
<td>29.5890</td>
</tr>
</tbody>
</table>
Again the powder factors for aggregate should be adjusted to take into account the productivity and costs to produce the aggregate size required. See the referenced paper “The Enterprise Solution to Integrating Blasting Into the Mining Process (2008)”. Below illustrates that powder factors most likely can be increased for aggregate production – more tons per lb of explosive. While not possible presently at Ravena, the monthly-scaled production of sized aggregate can be related to powder factors for a better estimate. Again, this is a reality that most mines find in trying to relate blasting to mining production but the efforts to quantify can be very rewarding. Efforts may also indicate other data that is more important.

In addition, a comparison of the blast fragmentation distribution with the crusher belt fragmentation distribution is helpful to determine blast efficiency.

A more complete analysis of many of the factors affecting Ravena productivity can be found in the paper “Factors Driving Continuous Blasting Improvement at the Lafarge Ravena Plant (2007)”, a productivity improvement study that utilized “lean thinking” principles is described in the referenced paper “Missouri Quarry Productivity Improvement – Casework (2009)”
ADVANCED METHODS OF ANALYSIS

Several enhancements to the simple methods described above can refine the analysis for further gain and are summarized below.

MULTIVARIABLE NON-LINEAR REGRESSION ANALYSIS

Crusher productivity is a function not only of blasting parameters but also mine operating parameters such as number of trucks, volume, seasonality, and other factors.

Two studies are referenced which illustrate the method – “A Statistical Approach to Integrating Blasting Into the Mining Process (2007)” and “Factors Driving Continuous Blasting Improvement at the Lafarge Ravenna Plant (2007)”. The use of these techniques has proven to substantially improve operating results.

“LEAN THINKING” ANALYSIS

Before base lining is started, a value map is built and “Lean Thinking” principles are applied to identify all areas of improvement. Lean Thinking is quite simple: you define value in terms of what your customer wants; you map how that value flows to the customer; and then you ensure the process is as efficient as possible by making it as cost effective and quick as possible. It examines subjects such as productivity, operational effectiveness, operational efficiency, waste elimination; and profitability - words and phrases that many people understand but which can mean very different things in different contexts. Operational effectiveness is about adapting, achieving and extending best practices and lean thinking -- it’s running the same race faster.

You make the process more cost efficient by eliminating waste. ‘Waste’ is defined as any part of your process that does not add value. Wastes in “lean thinking” are categorized into 7 different types:

Overproducing (producing too much or producing it before it is needed), Waiting (idle time that causes workflow to stop), Over processing (processing things that the customer does not want), Inventory (Excess stock of anything), Motion (typically more walking, reaching or bending than is necessary), Defects or Correction (this is what most people thing of as waste (i.e. scrap) but the knock on costs of disruption caused by rework need to be taken into account as well), Transport (Many things, including people, are moved too many times or too far).

When you can work out where these wastes are and eliminate them then the impacts can be invariably huge.

A full description of “lean thinking” is in the reference “Missouri Quarry Productivity Improvement – Casework (2009)”. 
CUMULATIVE SUM ANALYSIS

Cumulative sum (CUSUM) statistical process control methods have been used in
many industries to monitor quality control results. CUSUM charts are a method to
determine when small changes in data indicate a major change in results.

While CUSUM charts do not directly give causal information about productivity
changes, they can be used with other techniques to determine why change is
occurring. In particular, CUSUM charts of the main blast variables affecting
productivity can be married with the results to help explain changes. The ability of
CUSUM charts to highlight the timing of changes is important when changes are
made. CUSUM charts are easy to implement and the visual results are helpful to
interpret changes. See the paper “CUSUM for the Control of Vibration and Air
Blast (2009)” for details of this method. An example using productivity is included
in the paper.

PRINCIPAL COMPONENT ANALYSIS

In blasting many variables are highly correlated (powder factor, pattern area,
 explosive weight and density, hole size, etc.) and principal component analysis
can combine these variables into a more concise form to solve problems relating
to specific goals such as mining productivity, environmental concerns and
highlight the effects of major changes.

Principal component analysis has been successfully adapted to many industries
to create summary information. The summary information concisely expresses
the status of a process from the diverse data that best expresses the result or a
specific outcome. The principal component analysis method creates an overall
measure, which is a refined dashboard type of performance measurement using
statistical data compression techniques.

See The Use of Principal Component Analysis to Integrate Blasting Into the
Mining Process (2009)
ACKNOWLEDGEMENTS

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(Email one of the authors from the title page to receive copies of any of the references)


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