SAG 2001

MINING AND MINERAL PROCESS ENGINEERING
UNIVERSITY OF BRITISH COLUMBIA
Vancouver, B. C., Canada

AUTOMATED ONLINE OPTICAL SIZING ANALYSIS

Norbert H. Maerz, Rock Mechanics and Explosives Research Center, University of Missouri-Rolla, MO, USA

ABSTRACT

Optical fragmentation sizing has been in widespread use for many years now. It is now being used in the explosives, mining, and materials handling industries for the purpose of evaluating the efficiency of the comminution process, whether by blasting, crushing, grinding, or inadvertently by materials handling processes.

On examination, there can be many inaccuracies with these methods, and the results do not always match screening results. Neitherless, there are many benefits to using optical sizing, as there is normally no feasible alternative to optical sizing. This paper discusses the limitations of such systems, the common errors that are made when implementing such systems, as well as the benefits and the proper way to use these systems, including some examples of applications.

INTRODUCTION

Optical sizing technology for measuring the size distribution of fragmented rock has been in widespread use for many years (Franklin et. al, 1996). The WipFrag fragmentation sizing systems was originally designed for measuring the size distribution of blasted rock, using a roving camera and operator assisted analysis (Figure 1), (Maerz et. al, 1987; Maerz et. al, 1996; Maerz, 1998). Using optical sizing technology, blasters could evaluate, reassess, and redesign their blasts, while understanding the effect of their design on their final product. In addition they could begin to quantitatively evaluate the effect of geological structure on their blasts. Although the accuracy of this method was low, subject to several types of measurement errors, this use of optical sizing technology has proven so successful because there was simply no alternative. Screening large masses of large rock pieces is prohibitively expensive.

More recently, optical sizing technology has been applied to processing operations such as crushing, grinding and screening operations (Figure 2), (Maerz, 1999; Maerz et. al, 1999; Maerz et. al, 2001). Using fixed cameras for example looking down on conveyor belts, many of the errors affecting accuracy can be eliminated or controlled and more accurate measurements can be made. Still some sampling type errors persist, and matching screening results is still difficult. The use of this technology is however becoming successful because again there is simply no alternative. Screening samples is simply to onerous to provide statistically significant data, and to make that data available in real time.

Figure 1: Image of a muck pile taken with a roving camera

Figure 2: Images rock on a conveyor belt

BENEFITS AND LIMITATIONS OF ONLINE OPTICAL SIZING SYSTEMS

Benefits Of Online Optical Sizing Systems

Crushing and grinding circuits can operate efficiently only when all of the input feed variables that affect the process are optimized. This includes feed size distributions, which in the past was virtually impossible to monitor. Feed sizes can be measured by screening, but the effort and time required to screen large quantities of large rocks is so great that it is rarely done, certainly not on an ongoing basis.

Optical sizing, using image-processing techniques has many advantages over the only other alternative, screening:

1. Measurement effort is independent of size. Large particles can be measured with no more effort than small particles.
2. Measurements are completely automated, devoid of any human subjectivity.
3. Measurements are quick, images can be analyzed and results reported in as little as one second per image.
4. Measurements are made with no disruption of production in any way, and the method is non-destructive in the case of fragile materials.
5. Because there are no marginal costs associated with taking extra measurements, large numbers of measurements can be made, and consequently measurements can be statistically more significant.
6. The cost of such systems are a fraction of the cost of automated mechanical screening systems, or the cost of lost production from inefficiencies or off-specification materials.

Limitations Of Online Optical Sizing Systems

At the same time, optical systems have limitations (Maerz and Zhou, 1998). They have been proported to suffer from a lack of accuracy, an inability to measure fines, and other associated errors. Errors in this context should not be thought of as mistakes but as a variability between the measured results and some “true” value. Often the true “size” is taken to be the screening results, although that may be debatable as well (Maerz and Luscher, 2000). These errors come from a variety of sources:

1. Errors related to the method of analysis of the images.
2. Errors related to sample presentation.
3. Errors related to the imaging process.
4. Errors related to the sampling process.

Errors related to the method of analysis of the images are ones caused by improper identification of blocks, and incorrect two to three dimensional transformation. These errors can be large for poorly designed imaging systems or when dealing with poor quality images. For well-designed imaging systems these errors should be relatively inconsequential.

Errors related to sample presentation relate to the lay of the individual blocks, especially if anisotropic. Since blocks tend to lay flat, imaging systems will tend to measure the average of the intermediate and long diameters, while screening will tend to focus exclusively on the intermediate axis. Blocks tend to be partially overlapped, and so imaging systems need to use algorithms of geometric probability to “unfold” or reconstruct a true distribution. Again, in a well-designed imaging system, these errors should be relatively inconsequential.

Errors related to the imaging process are concerned with all the technical aspects of imaging. There is variability in the sensor of a CCD camera, which guarantees that two pictures of the same scene are never identical. Variability in lighting will cause different measurement results. Perspective errors in the image will result in measurement errors. Perhaps the most significant is the scale of the image. Setting the size of the image imposes a sampling window on the process (relatively large rocks are excluded from the image, and relatively small rocks are too small to be resolved in the image. Thus there is a “bandpass filtering” effect, and the measurement result is significantly affected by the size of the image (Santemarina et. al, 1996). While these errors loom large when using the roving camera approach, the use of optical sizing systems online reduces these dramatically. On a conveyor belt for example, the camera is set up so there is no perspective error, lighting is held constant, and the scale of the image can be set to both be constant, and to include the largest sample.

Errors related the sampling process allude to the fact that not all fragments of rock can be sampled, so errors occur when the rocks that are sampled are not representative. In the roving camera approach, where to point the camera is an issue, because that is a human decision. In online monitoring, this is not an issue, because all the rock is automatically paraded past the camera. A second issue is that of missing fines. Fines fall in and behind coarser blocks, so optical systems inevitably miss fines, and tend to make measurement errors on the large side, i.e. measurements larger than screening. In online situations, the degree of settling of fines is some constant, and consequently in many situations, calibration may be used to compensate for missing fines. Where calibration should be used or not used is an issue that depends on many factors, and is further discussed below

Rationalization of Benefits and Limitations Of Online Systems

Given the fact that there really is no alternative to online optical sizing systems, we must live with the limitations of these systems. Experience has shown that even if these systems cannot do everything demanded of them, they are significantly reliable and accurate enough to provide valuable insight and feedback to a processing loop.

Experience has also shown that proper implementation and use of the systems is important, as well as proper training of operators.

Experience has also shown that while proper expectations lead to profitable outcomes, unrealistic expectations lead to disappointment.

Figure 3: Minus ½” crusher run product from on an aggregate quarry belt

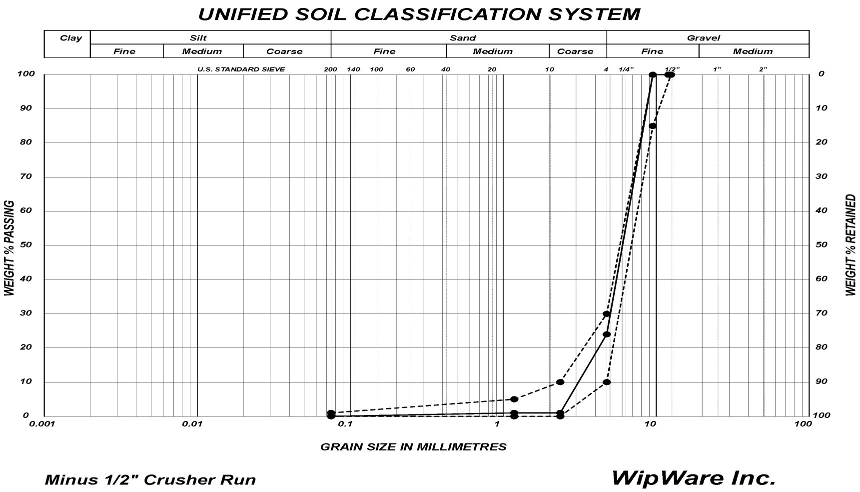

Figure 4: Screening results of minus ½" crusher run product (solid line) with superimposed specification limits (dotted line).

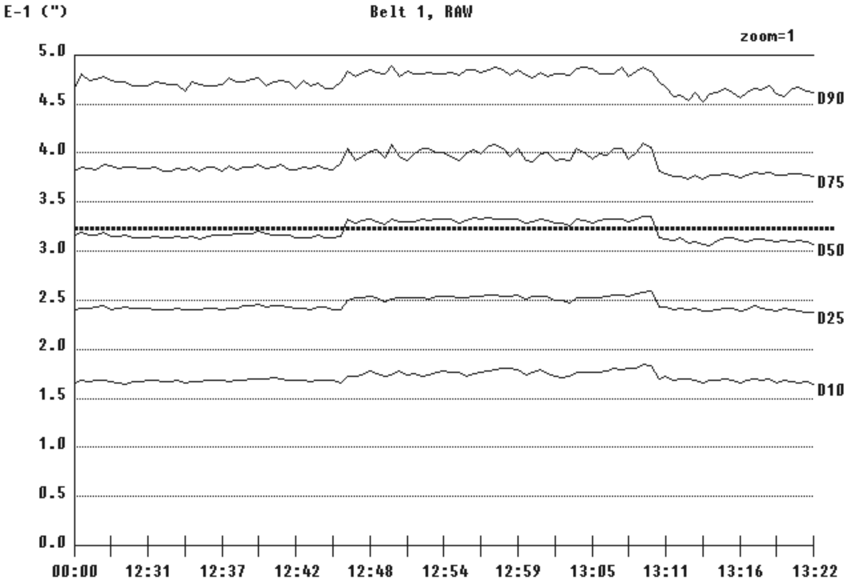

Figure 5: Time based graph of minus ½" crusher run product (Dotted line is upper limit on D50, for alarm condition).

USE OF ONLINE OPTICAL SIZING SYSTEMS

Specification vs. Process Control

There are two reasons why size distributions might be measured. One is to see if the product meets a size distribution specification, and the other is to determine if over time, the size distribution of the product is changing, as a feedback for process control.

As an example the crusher run product of Figure 3 might have a specification given by the limits in Figure 4. The specification is very tight, and given this distribution with the appropriate tweaking and perhaps calibration (see below), specifications could be tested using optical imaging systems. However, as the distributions get more difficult from an optical imaging viewpoint, the accuracy of optical systems, especially in the area of fines may not be adequate. Modern processing equipment can under some circumstances produce more uniformity that can be measured, assuming there are no equipment problems, and the feed material remains constant.

On the other hand if a screen producing this material broke, or if the plates on a crusher experience excessive wear, the result could be measured quite easily by an optical processing system focusing on a single parameter, the variability of which can be measured with great precision (see below).

Accuracy vs. Precision

Accuracy and precision are two quite different things. Inherently optical imaging systems tend to be high precision, low accuracy.

As illustrated in Figure 6, the accuracy of a measurement can be thought of as how close to a "true" value it lies, while precision is a measure of the variability of the measurement.

In the case of optically determined size distributions if the goal is to do specifications, accuracy would be more important, whereas if the goal is to do process control, precision is more important.

For a number of reasons, optical sizing systems are more precise rather than more accurate. First optical systems are not as accurate as might be wished because the "true" values that they are being compared against are screening results, which as mentioned earlier, measures

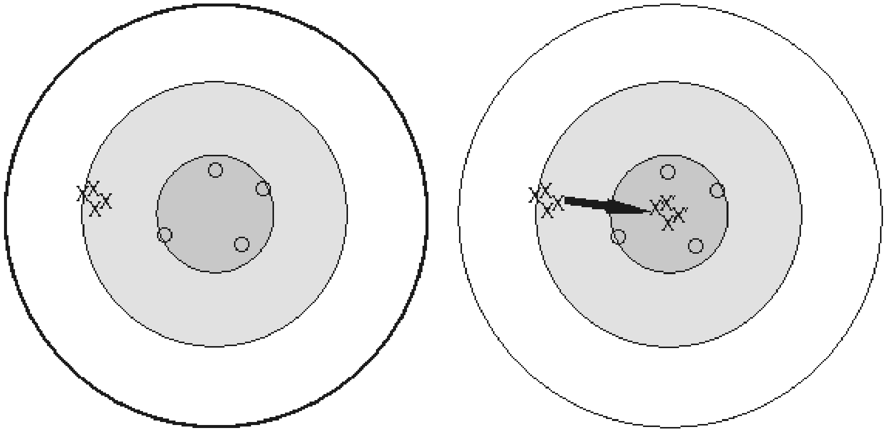

Figure 6 (Left): The difference between accuracy and precision illustrated by a “bulls eye” target. The four o’s are more accurate, while the four x’s are more precise. (Right): Adding a “calibration to improve the accuracy of the x’s.

intermediate diameters rather than an average of the long and intermediate diameters.

Secondly, the aforementioned inherent problem of missing fines dictates that imaging systems have measurement errors that typically result in overestimating sizes.

On the other hand, optical imaging systems have high precision because of the high volume of measurements possible.

Calibration

If the precision is high and the error that limits accuracy is systematic then it stands to reason that calibration can be used to improve the apparent accuracy. In our analogy of Figure 6, a calibration is used to adjust the measured values to give them more apparent accuracy.

Calibration of rock sizing distributions is primarily an exercise of compensation for the missing fines. Figure 7 shows the results of such a calibration. In order for this calibration to be useful we need high precision and systematic error. We have already established that there is high precision in optical sizing systems.

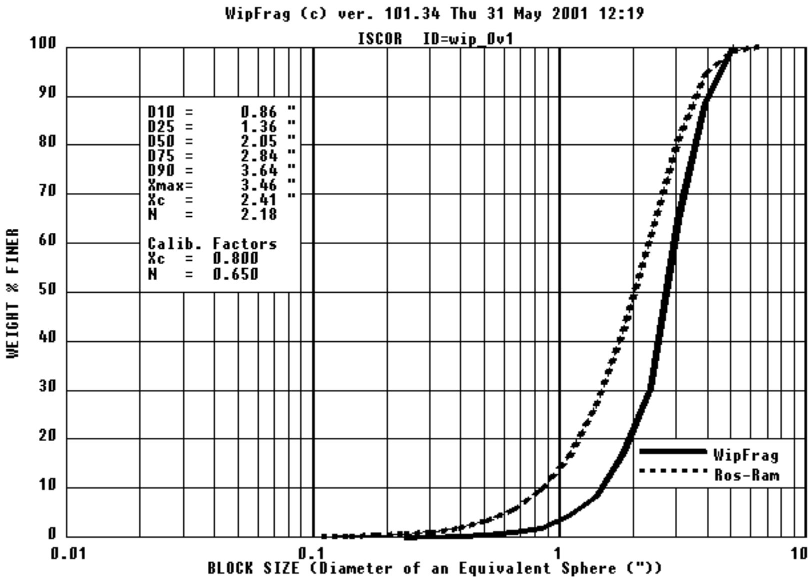

Figure 7: Calibrated (dashed line) and un-calibrated (solid line) measurement results.

In an online measuring application the error, (due to missing fines) is systematic. It is because small pieces cannot be resolved in the image and they fall in and behind the larger pieces. The number of missing fines tend to be constant because in the first case the position of the camera is fixed, so the resolution stays fixed, and in the second case, at a given position along the belt, all the material has undergone the same amount of transport and vibration, and has been loaded in the same manner, so we would expect the number of pieces that have fallen in and behind larger pieces to be constant as well.

But while calibration will get a more accurate appearing number, the following must be considered: There is no increase in precision, and there actually may be a loss of data. Figure 7 shows an example of such calibration and 2 issues become clear. First, the calibrated line is a smooth, continuous function, and so will not reflect the subtleties of deviation from a smooth continuous curve. Secondly, and perhaps more importantly, in this example, virtually no pieces at the 0.8” size range are actually seen (un-calibrated), and so the calibrated result, which shows about 10% in this range, is not a measurement, but is inferred only.

Interfacing

Since optical sizing systems are normally stand alone devices, interfacing with control systems becomes an issue. How this is handled depends largely on the sophistication of the control system. Optical systems can be used very simply to ring alarms, or to feed data to the control system at various levels of sophistication:

1. The simplest approach is to visually monitor the graph on the screen, and or the data file that is generated. This is the simplest approach if for instance daily summaries are all that is needed.

2. This simplest real time approach, used when dealing with control systems that are not highly automated is to use logic built into the imaging system to determine alarm conditions and, using TTL (transistor-transistor logic) outputs, ring an alarm. Using TTL I/O allows only 2 states per physical channel, on and off, so while an alarm condition can be triggered, the details of the condition causing the alarm will not be available.

3. A more sophisticated approach is to use 4-20 mA current loop outputs. This has the advantage of being able to transmit quantitative data to the control system, thereby offloading the decision making process on alarm conditions and process control to the control system. As this is an analog signal, the values of only one parameter per physical channel can be used.

4. A yet more sophisticated approach is to use digital communication in the form of RS232 (serial) transmission. This format allows transmission of all data available, with no significant limitations.

5. The most sophisticated approach is an integrated fully networked approach. Here the control system can get data upon demand, and specify which data is required. Additionally, it is possible to change sampling frequencies, and processing parameters on the fly.

Only one of these approaches needs to be implemented. It would be unusual to use two or more methods of interfacing.

Recommended Use of Data

When using optical sizing systems the aforementioned issues need to be addressed:

1. Is this a process control or specification application? The probability of successful implementation depends on realistic goals.

2. Will calibration be required? In the case of specification work the answer is yes. In the case of process control the answer is that calibration is usually not required, unless the size measurements are to be used in a model that is based on sizes determined by screening.

3. Which type of interface will be used between the optical sizing system and the control system? Will a simple alarm condition be enough? How much data will be required?

Another issue is how the data will be used:

1. Are there firm limits on any particular parameters that require shutdown or adjustment of process? Are these limits known beforehand?

2. Are individual data points used, or are moving averages implemented to remove the ability of individual anomalous data points to affect process control?

3. Should limits on particular parameters be determined by establishing baseline values over a given period during which time the process has been operating at an acceptable level of efficiency?

4. Should measurements be calibrated and fed into a historical predictive model or should outcomes be correlated directly to raw measurement results?

5. Should decisions be made by deterministic algorithms or should neural networks or some other method of artificial intelligence be used to establish cause and effect.

Finer Blast Fragmentation

Larfarge Canada, Exshaw Alberta conducted a study to reduce the fragmentation size (Ethier et al., 1999; Figure 8). The purpose of the study was to design and conduct blasts to reduce the fragmentation size by 50% and prove the benefit in terms of reduced costs.

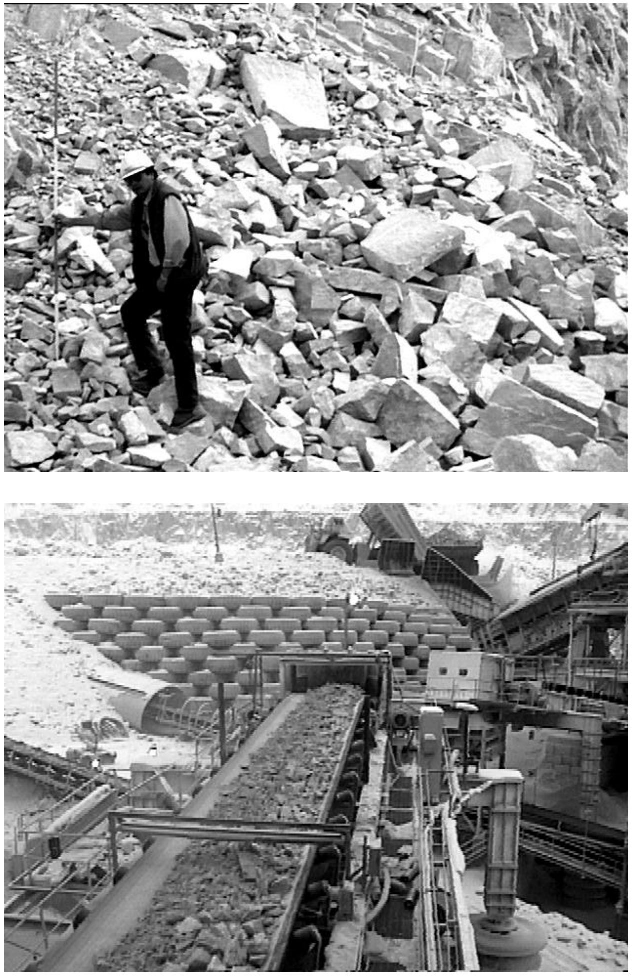

Figure 8. **Fragmentation analysis at Lafarge, Exshaw Alberta.**

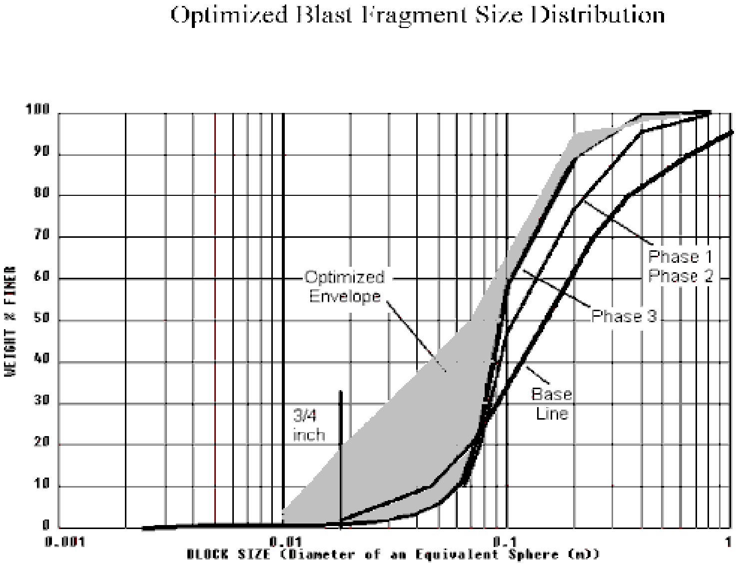

Figure 9. Optimal size distribution targets (Ethier et al., 1999).

In this project, size measurements were taken on the muckpile, on the primary crusher dump, and a conveyor after the primary crusher. The study was able to conclude that improved fragmentation reduced mechanical down time, improved crusher throughput and decreased power consumption savings in the crusher circuit.

Elliott et al (1999) concluded that:

§ Subdrill from previous shots was responsible for much of the oversize generated in later blasts.

§ Cross drill bits produced less hole deviation than ballistic-type button bits.

§ A new blast design with 102mm blastholes could produce finer, more uniform fragmentation.

§ This better fragmentation resulted in savings in mechanical down time (easier digging and improved tire life on loaders).

§ Better fragmentation improved crusher throughput by 16% and power consumption savings by 30%

§ The new blast design eliminated complaints from neighbors by lowering vibration levels.

§ The lower charge weight per hole caused less damage to the final walls and improved safety.

Tracking Hardness and Size

Highland Valley Copper, of Logan Lake, B. C., Canada, use on-line monitoring of ore sizes and combining it with ore hardness tracking to predict autogenous grinding mill performance (Simkus and Dance, 1998; Figure 10).

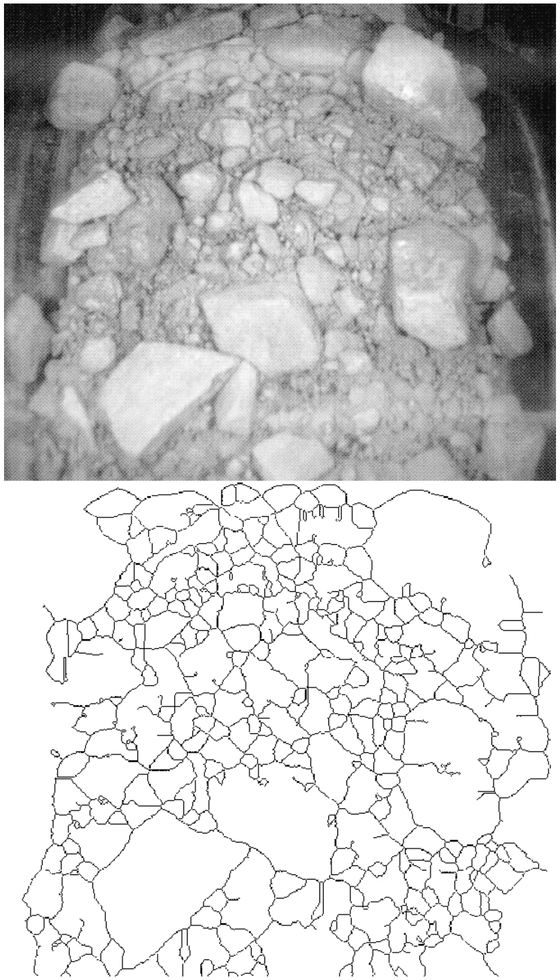

Figure 10. Typical Highland Valley copper image of ore free falling off the end of a transfer chute, and the WipFrag generated block outlines (Simkus and Dance, 1998).

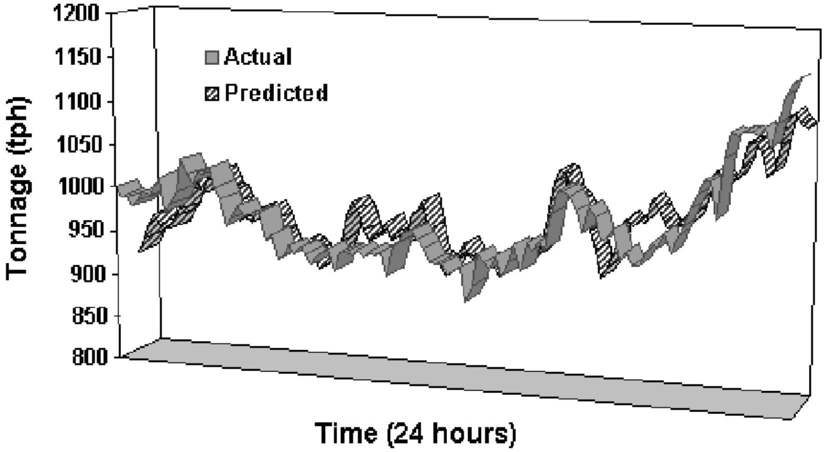

Figure 11. Comparison of predicted (modeled) vs. actual mill throughput based on input parameters of size and hardness (Simkus and Dance, 1998).

Initially sizing was measured on 2 grinding lines. Twenty images per line are analyzed every five minutes, and the combined results are sent to the control system via RS232 feed.

The WipFrag output is used as a control signal (Simkus and Dance, 1998). Uncalibrated data is used and the control system responds to changes in the distribution.

Figure 11 shows the correlation between the actual SAG mill throughput and the throughput predicted by the model that was developed based on feed size as measured by WipFrag and feed hardness. Highland Valley Copper is claiming a 10% increase in mill productivity as a result of controlling feeds based on size and hardness.

Highland Valley Copper has more recently upgraded its capabilities to 5 cameras on five milling lines. A second system has been added on 4 crushers in the pit, as Highland Valley Copper realized the importance of the primary crushers in adding value to the feed mill (Dance, 2001).

Improving Grinding Efficiency

COREM is in the process of investigating grinding productivity and efficiency at the Kiena and Louvicourt Mines in Quebec, Canada (Bouajila et al., 2000; Figure 12-14).

Figure 12: COREM imaging setup. Picture courtesy of COREM.

Figure 13: COREM ore.

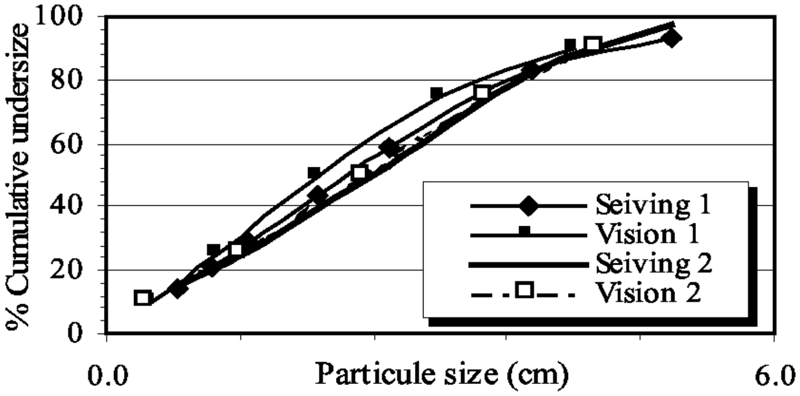

Figure 14: Comparsion of ore size curves (Bouajila et al., 2000).

In this study COREM concluded that the extraction of size indicators is now possible, and that the obtained measurements are now acceptable. They found a negative correlation between size (D_{90}) and energy consumption, although they also indicated that single point descriptors were inadequate. They further found that in the case of fully autogenous mills, a minimum of coarse rock is needed to prevent slowdown of throughput.

CONCLUSIONS

The use of optical image analysis systems such as WipFrag have been well established by now. These systems although they have inherent limitations which makes it difficult to match screening results, however can be very useful if used as a process control instrument, focusing on very small changes in measured sizes.

Proper use of these systems involves first an understanding of the limitations of the system, then understanding how best to make use of the size data generated in each particular application. Realistic expectations lead to profitable outcomes, unrealistic expectations lead to disappointment.

REFERENCES

Bouajila, A., Bartolacci, G., Koch, N., Cayouette, J., and Cote C., 2000. Toward the Improvement of Primary Grinding Productivity and Energy Investigation Consumption Efficiency. **Mine to Mill 2000,** Finland, 5pp.

Dance, A., 2001. The Importance of Primary Crushing in Mill Feed Size Optimization. To be presented, **SAG 2001**, 13 pp.

Elliott, R., Ethier, R. and Levaque, J., 1999. Lafarge Exshaw finer fragmentation study. **Proc. 25th Ann. Conf. On Explosives and Blasting Technique**, Nashville, Tennessee, USA, Vol.II, 1999, pp. 333-354.

Ethier, R., Levaque, J.-G., and Wilson, M., 1999. Achieving Finer Fragmentation and Proving the Cost Benefits. **Fragblast 1999**. Johannesburg, South Africa, Institute of Mining and Metallurgy, pp 99-102.

Franklin, J. A., Kemeny, J. M., and Girdner, K. K., 1996. Evolution of Measuring Systems: A Review. **Proceedings of the FRAGBLAST 5 Workshop on Measurement of Blast Fragmentation,** Montreal, Quebec, Canada. Franklin, J. A, and Katsabanis, T., (ed.). A. A. Balkema, 1996, pp. 47-52.

Maerz, N. H., 1998. Aggregate Sizing and Shape Determination Using Digital Image Processing. **Center For Aggregates Research (ICAR) Sixth Annual Symposium Proceedings,** 1998, pp. 195-203.

REFERENCES (CONTINUED)

______, 1999. Online Fragmentation analysis: Achievements in the mining industry**. Center For Aggregates Research (ICAR) Seventh Annual Symposium Proceedings**, Austin Texas, April 19-21, pp. C1-1-1 to B1-1-10.

Maerz, N. H., Franklin, J. A., and Coursen, D. L., 1987. Fragmentation Measurement for Experimental Blasting in Virginia. **S.E.E., Proc. 3rd. Mini-Symposium on Explosives and Blasting Research**, pp. 56-70.

Maerz, N. H., and Luscher, M., 2000. Measurement of flat and elongation of coarse aggregate using digital image processing**. Presented at the, Transportation Research Board 80th Annual Meeting**, Jan. 7-11 2001, 13 pp.

Maerz, N. H., Palangio, T. C., and Franklin, J. A., 1996. WipFrag Image Based Granulometry System. **Proceedings of the FRAGBLAST 5 Workshop on Measurement of Blast Fragmentation**, Montreal, Quebec, Canada. Franklin, J. A, and Katsabanis, T., (ed.). A. A. Balkema, pp. 91-99.

Maerz, N. H., and Palangio, T. C., 1999. WipFrag System II - Online Fragmentation Analysis. **FRAGBLAST 6, Sixth International Symposium For Rock Fragmentation By Blasting, Johannesburg**, South Africa, Aug. 8-12 1999, pp. 111-115.

______, 2000. Online Fragmentation Analysis For Grinding and Crushing control. **Control 2000 Symposium**, 2000 SME Annual Meeting, March 1, 2000, Salt Lake City, Utah, SME, pp. 109-116.

Maerz, N. H., and Zhou, W., 1998. Optical digital fragmentation measuring systems - inherent sources of error**. FRAGBLAST, The International Journal for Blasting and Fragmentation,** Vol. 2, No. 4, pp. 415-431.

Santamarina, J. C., Morley, M., Franklin, J. A., and Wang, D. S. 1996. Development and testing of a zooming technique for fragmentation. **Proceedings of the FRAGBLAST 5 Workshop on Measurement of Blast Fragmentation,** Montreal, Quebec, Canada, 23-24 Aug. 1996, pp. 133-139.

Simkus R., and Dance A. 1998. Tracking Hardness and Size: Measuring and Monitoring ROM Ore Properties at Highland Valley Copper. **Proceedings Mine to Mill 1998 Conference. Australasian Institute of Mining and Metallurgy: Melbourne**, 1998, pp. 113 -119.