Total Ore Processing Integration and Management

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Abstract

This report outlines the technical progress achieved for project DE-FC26-03NT41785 (Total Ore Processing Integration and Management) during the period 01 January through 31 March of 2006.

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Executive Summary

Work in Progress: Minntac Mine

Graphical analysis of drill monitor data moved from two-dimensional horizontal patterns to vertical variations in measured and calculated parameters. The rock quality index and the two dimensionless (π) indices developed by Kewen Yin of the University of Minnesota are used by Minntac Mine to design their blasts, but the drill monitor data from any given pattern is obviously not available for the design of that shot. Therefore, the blast results – which are difficult to quantify in a short time – must be back-analyzed for comparison with the drill monitor data to be useful for subsequent blast designs.

π_1 indicates the performance of the drill, while π_2 is a measure of the rock resistance to drilling. As would be expected, since a drill tends to perform better in rock that offers little resistance, π_1 and π_2 are strongly inversely correlated; the relationship is a power function rather than simply linear. Low values of each π index tend to be quantized, indicating that these two parameters may be most useful above certain minimum magnitudes.

Work in Progress: Hibtac Mine

Statistical examination of a data set from Hibtac Mine (Table 1) shows that incorporating information on the size distribution of material feeding from the crusher to the autogenous mills improves the predictive capability of the model somewhat (43% vs. 44% correlation coefficient), but a more important component is production data from preceding days (26% vs. 44% correlation coefficient), determined using exponentially weighted moving average predictive variables. This lag effect likely reflects the long and varied residence times of the different size fragments in the grinding mills. The rock sizes are also correlated with the geologic layers from which they originate. Additional predictive parameters include electric power drawn by the crusher and the inverse of the average grind index of the ore being milled.

Future Work

The project will end with the next quarter, so all ongoing analyses will be wrapped up by then.

Dissemination and Outreach

Mike Orobona of Hibtac Mine presented a paper at the Society of Economic Geologists' 2006 Conference, held in Keystone, Colorado on 14-16 May 2006. The title of the paper is "Exploring the Data – Adding Value with Non-traditional Geologic Initiatives on Minnesota's Mesabi Range," and the authors are M. J. T. Orobona, L. Gertsch, and J. W. Eloranta.

A paper is being planned for presentation at the 2007 Annual Meeting of SME in Denver.

Introduction

This eleventh quarterly report discusses the activities of the project team during the period 1 January through 31 March 2006.

Work in Progress

Minntac Mine

Graphical analysis of drill monitor data moved from two-dimensional horizontal patterns to vertical variations in measured and calculated parameters. The appendices show the charts for a typical shot at the Minntac Mine. These charts are also discussed below.

The rock quality index and the two dimensionless (π) indices developed by Kewen Yin of the University of Minnesota¹ are used by Minntac Mine to design their blasts, but the drill monitor data from any given pattern is obviously not available for the design of that shot. Therefore, the blast results – which are difficult to quantify in a short time – must be back-analyzed for comparison with the drill monitor data to be useful for subsequent blast designs. π_1 indicates the performance of the drill, while π_2 is a measure of the rock resistance to drilling:

$$\pi_1 = \frac{rNT}{F^2} \quad \pi_2 = \frac{uF}{NT}$$

Where u = penetration rate
 r = rock quality index
 N = rotation rate
 F = weight on bit (pulldown force)
 T = torque

As would be expected, since a drill tends to perform better in rock that offers little resistance, π_1 and π_2 are strongly inversely correlated (Figure 1). Note that the relationship is a power function rather than simply linear. Low values of each tend to be quantized, indicating that these two parameters may be most useful above certain minimum magnitudes. For this blast pattern, both minimum bounds appear to be approximately 1. The heavy concentration of data points in the mid-range prevents the bestfit line from being skewed by a faintly visible S-curve that deviates from the bestfit line in the extreme ends of the range.

The rock quality index could be set up as a function of the drilling parameters and the penetration rate directly, apparently avoiding more esoteric – and less quantitative – estimates:

$$r = \frac{\sqrt{NTF}}{u^{3/2}}$$

This would result in π_1 becoming:

$$\pi'_1 = \left(\frac{NT}{Fu} \right)^{1.5}$$

¹ Yin, K.T. and H.T. Liu, 2001. Using Information Extracted From Drill Data to Improve Blasting Design and Fragmentation. *Fragblast - The Int'l J for Blasting and Fragmentation*, Vol 5, No. 3 / Sept 2001, pp 157-179.

However, this substitution does not work well. For one blast pattern the relationship is bilinear, with the knee at $\pi_1=2,500$ (Figure 2). The scale difference between π_1 and π'_1 in this

Figure 1. Pi-1 (drill performance) versus Pi-2 (rock resistance) for 20,812 monitor readings from the 234 holes of blast pattern 02136.

Figure 2. The original definition of π_1 versus the new definition (π'_1), for blast pattern 02136.

chart could be construed as due simply to differences in the units used (up to $\pi_1=2,500$), but Figures 4, 6, 8, and 10 show wide, often nonlinear variation in the relative values of π_1 and π'_1 .

Figures 3 through 10 are the same comparisons as shown in Figures 1 and 2, but for blast patterns 03004, 03022, 03023, and 03032. Here it is obvious that π_1 and its estimator, π'_1 , differ substantially in various ways for the different blast patterns. It is not clear just what these qualitative and quantitative differences indicate that would be useful to the goals of the TOPIM project.

Figure 3. Pi-1 (drill performance) versus Pi-2 (rock resistance) for 49,324 monitor readings from the 382 holes of blast pattern 03004.

Figure 4. The original definition of π_1 versus the new definition (π'_1), for blast pattern 03004. Several linear trends are visible in the lower-magnitude values.

Figure 5. Pi-1 (drill performance) versus Pi-2 (rock resistance) for 106,111 monitor readings from the 423 holes of blast pattern 03022.

Figure 6. The original definition of π_1 versus the new definition (π'_1), for blast pattern 03022. The amplitudes of these data are notably smaller than for the other patterns examined.

Figure 7. $\Pi\text{-}1$ (drill performance) versus $\Pi\text{-}2$ (rock resistance) for 30,289 monitor readings from the 257 holes of blast pattern 03023.

Figure 8. The original definition of π_1 versus the new definition (π'_1), for blast pattern 03023. The meaning of an apparent axis of symmetry in the data is not clear.

Figure 9. Pi-1 (drill performance) versus Pi-2 (rock resistance) for 30,447 monitor readings from the 84 holes of blast pattern 03032.

Figure 10. The original definition of π_1 versus the new definition (π'_1), for blast pattern 03032. Again, there is approximate symmetry apparent in the data.

In general, the three-dimensional variation of specific energy, rock quality, and the two Pi indices can be appreciated qualitatively by examination of Excel plots such as those shown in the appendices, but quantitative use of the information is more straightforward and flexible if the data is handled by commercially available orebody and mine modeling software, such as MineSight©. Such programs are designed to statistically analyze non-independent data in three dimensions and incorporate the results in mine plans. It is likely that more mine employees would have sufficient previous training to use programs like Excel©, with the appropriate macro programs added, than that they would have had training in using MineSight©. Those with the appropriate mine modeling training, however, would make much more effective use of their time.

Hibtac Mine

Statistical examination of a data set from Hibtac Mine (Table 1) shows that incorporating information on the size distribution of material feeding from the crusher to the autogenous mills improves the predictive capability of the model somewhat (43% vs. 44% correlation coefficient), but a more important component is production data from preceding days (26% vs. 44% correlation coefficient), determined using exponentially weighted moving average predictive variables. This lag effect likely reflects the long and varied residence times of the different size fragments in the grinding mills. The rock sizes are also correlated with the geologic layers from which they originate. Additional predictive parameters include electric power drawn by the crusher and the inverse of the average grind index of the ore being milled.

Table 1. Stepwise linear regression analysis of a dataset from the Hibtac Mine and mill.

Primary crusher throughput							
Without Size Data				With Size Data			
R-squared 13%		R-squared 43%		R-squared 26%		R-squared 44%	
		With EWMA				With EWMA	
ActSiO2		ActSiO2		ActSiO2		ActSiO2	
Ave Temp	▲	Ave Temp	▲	Ave Temp		Ave Temp	
BIB	△	BIB		BIB	▲	BIB	▲
Grind Index 1	▼	Grind Index 1		Grind Index 1	▼	Grind Index 1	▼
PCAT		PCAT		PCAT		PCAT	
PSiO2		PSiO2		PSiO2		PSiO2	
PSmallAct	▽	PSmallAct	▼	PSmallAct	▼	PSmallAct	▽
PSmallPred	▲	PSmallPred		PSmallPred	▲	PSmallPred	
surge Tons	▼	surge Tons		surge Tons		surge Tons	△
T1	▲	T1		T1		T1	
T2		T2		T2		T2	
T3		T3		T3	▼	T3	▼
T4		T4		T4		T4	
		GTPTPred				GTPTPred	
		PC1Amps	▲			PC1Amps	▲
		PC1AT				PC1AT	
		PC1Shift				PC1Shift	
		PC2Amps				PC2Amps	
		PC2AT				PC2AT	
		PC2Shift				PC2Shift	
		PCATPred	▼			PCATPred	▼
		PCrushPred	▲			PCrushPred	▲
				S10	▲	S10	
				S2		S2	
				S24		S24	
				S4	▼	S4	
				S48		S48	▽
				S8		S8	
				S810		S810	
				SM2		SM2	

Legend

▲	Strong positive influence
▼	Strong negative influence
△	Positive influence
▽	Negative influence

Future Work

The upcoming quarter will be concerned with wrapping up the work in progress, such as the detailed statistical analyses, and writing a final report.

Dissemination and Outreach

Mike Orobona of Hibtac Mine presented a paper at the Society of Economic Geologists' 2006 Conference, held in Keystone, Colorado on 14-16 May 2006. The title of the paper is "Exploring the Data – Adding Value with Non-traditional Geologic Initiatives on Minnesota's Mesabi Range," and the authors are M. J. T. Orobona, L. Gertsch, and J. W. Eloranta.

A paper is being planned for presentation at the 2007 Annual Meeting of SME in Denver.

Appendix: Vertical Variation in Drilling Specific Energy for Pattern 02136

Pattern 02136, Specific Energy, Surface to 5 ft Depth (approximate borehole locations)

Pattern 02136, Specific Energy, 5 to 10 ft Depth (approximate borehole locations)

Pattern 02136, Specific Energy, 10 to 15 ft Depth (approximate borehole locations)

Pattern 02136, Specific Energy, 15 to 20 ft Depth (approximate borehole locations)

Pattern 02136, Specific Energy, 20 to 25 ft Depth (approximate borehole locations)

Pattern 02136, Specific Energy, 25 to 30 ft Depth (approximate borehole locations)

Appendix: Vertical Variation in Drill Rock Quality for Pattern 02136

Pattern 02136, Rock Quality, Surface to 5 ft Depth (approximate borehole locations)

Pattern 02136, Rock Quality, 5 to 10 ft Depth (approximate borehole locations)

Pattern 02136, Rock Quality, 10 to 15 ft Depth (approximate borehole locations)

Pattern 02136, Rock Quality, 15 to 20 ft Depth (approximate borehole locations)

Pattern 02136, Rock Quality, 20 to 25 ft Depth (approximate borehole locations)

Pattern 02136, Rock Quality, 25 to 30 ft Depth (approximate borehole locations)

Appendix: Vertical Variation in Pi-1 (Drill Performance) for Pattern 02136

Pattern 02136, Pi-1, Surface to 5 ft Depth (approximate borehole locations)

Pattern 02136, Pi-1, 5 to 10 ft Depth (approximate borehole locations)

Pattern 02136, Pi-1, 10 to 15 ft Depth (approximate borehole locations)

Pattern 02136, Pi-1, 15 to 20 ft Depth (approximate borehole locations)

Pattern 02136, Pi-1, 20 to 25 ft Depth (approximate borehole locations)

Pattern 02136, Pi-1, 25 to 30 ft Depth (approximate borehole locations)

Appendix: Vertical Variation in Pi-2 (Rock Resistance) for Pattern 02136

Pattern 02136, Pi-2, Surface to 5 ft Depth (approximate borehole locations)

Pattern 02136, Pi-2, 5 to 10 ft Depth (approximate borehole locations)

Pattern 02136, Pi-2, 10 to 15 ft Depth (approximate borehole locations)

Pattern 02136, Pi-2, 15 to 20 ft Depth (approximate borehole locations)

Pattern 02136, Pi-2, 20 to 25 ft Depth (approximate borehole locations)

Pattern 02136, Pi-2, 25 to 30 ft Depth (approximate borehole locations)