Modeling Vs. Monitoring Blast Movement: The Cost of Variation

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Abstract

In March of 2013, an undisclosed gold mine (MINE X), located in the Western United States, performed blast movement monitoring of three blasts occurring in one of two active pits. Blast Movement Monitors (BMMs) were placed in the bench before blasting, and located after the blast to determine vectors of movement. Using blast movement software, ore/waste boundaries were translated. These locations were compared to MINE X's standard ore translation procedure, which consisted of moving polygon boundaries by 17.5 feet (5.3 m) in the burden direction of the blast hole pattern. This translation amount, identified by MINE X as "average" motion, had been ascertained by performing a previous blast movement study.

This paper examines the economic impact of moving ore/waste boundaries to their positions as identified by direct measurement, as opposed to moving boundaries to a distance established by an average or modeled distance. The overall benefit to monitoring over modeling in two of these blasts was over $41,965. These blasts were monitored at a cost of $2,904. The return-on-investment for these blasts was 14.5. Although no ore was lost in the third blast due to movement, the benefit to monitoring was a reduction of 2,777 tons of dilution below economic cutoff grade.

The average horizontal movement observed in all data gathered was nearly consistent with the template established in 2009. However, each blast varied significantly from the model. Variance was also contained within each blast. The combination of the random movement observed in each blast and the variance of each blast from the template makes accurate modeling highly improbable as well as economically unsound.

Introduction

The MINE X gold district is located in the Western United States. For confidentiality reasons, the specific location and geology cannot be divulged. Gold mineralization chiefly occurs in narrow, rich vein systems that are related to multiple events. The area currently operated by the mine site has been actively mined since the 1800s, resulting in underground mining which previously targeted the narrow vein systems.

MINE X operates two open pits, which are extracting the low-grade halo surrounding the narrow veins. Three blasts were evaluated for this study in the southern end of the "A" pit on the 9,480 ft. elevation (9480 bench) (see Figure 2). This area is characterized by disseminated gold associated with phonolite and lamprophyre intrusives. Average grade in the study area is ~0.011 oz/ton (0.34375 g/tonne).

Previous Blast Movement Case Studies

To reduce ore loss and dilution and understand muck movement, MINE X implemented a blast movement study utilizing blast movement monitors (BMMs) in 2009. BMMs are electronic devices which are placed in the bench prior to blasting, and located after the blast to give movement vectors.

A three-month study utilizing BMMs was conducted in the “A” pit to study three shot types (production, rind, and burn). The goal of the study was determining a movement for ore that reduced overall dilution and ore loss. In 2009, management authorized only a pilot study and resources were unavailable for continuous monitoring after the BMM study.

Based on the results of the 2009 BMT control case, the implementation of shot movement was changed for each type of shot at MINE X. The results of the 2009 control case are shown in Figure 1 and Figure 3. Blast timing was dominantly 109 ms between rows, and 17 ms between holes in 2009, and this number has since been altered several times.

Prior to 2009, shot movement was measured by placing poly-pipe within production blasts. Poly-pipe studies have been shown to underestimate movement, as the results obtained reflect surface translation which can vary greatly from movement at depth (Thornton, 2009).

Control Case Formulated from 2009 Study

The following Standard Operating Procedure (SOP) was implemented at MINE X subsequent to the 2009 study. Hereafter, this SOP is referred to as the “Control Case”, as it represents the polygon translation that would have occurred if actual BMM measurements had not been made available.

Due to uncertainty in magnitude of movement, ore perimeters in burns and rinds did not have movement applied after the shot. Ore splits in burn and rind shots were only controlled parallel to shot direction.

An average shot movement of 17.5 feet (5.3 m) was applied to production blasts based on the mean horizontal movement of production blasts (Figure 3). The standard deviation of horizontal movement in the production blasts was 4.8 feet (1.5 m) based on 40 BMM observations.

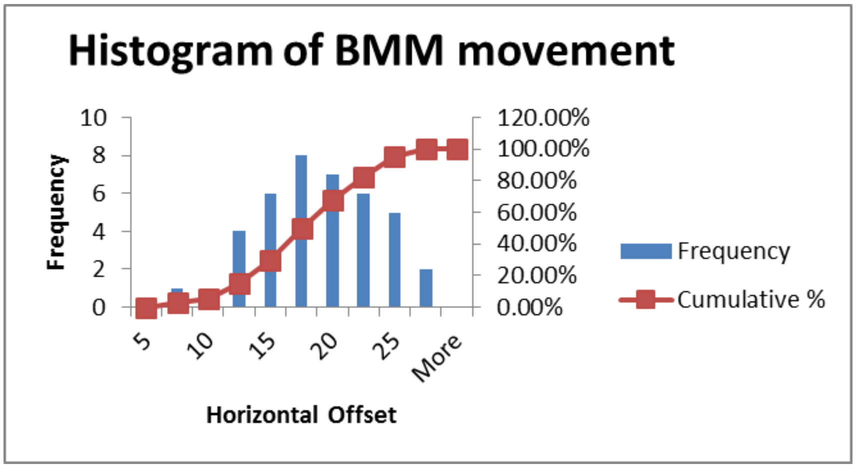

Figure 1. Histogram of 2009 BMM Movement Exhibiting Near-Gaussian Behavior

The lack of man power for an ongoing study combined with the low data variability (Coefficient of variation of 0.275) led MINE X to conclude that translating polygon boundaries by the average observed movement in production would reduce dilution and ore loss. MINE X concluded that the variance between the actual movement and the average movement in production blasts was a low risk to the operation, and that regular monitoring of blast movement was not practical. Additional blast movement studies would be completed if changes were implemented to the production blasting or the geologic conditions.

In 2013, MINE X initaited blast movement monitoring to review the SOP and complete additional blast movement studies based on a new open pit and changes to the blast timing and exposive products.

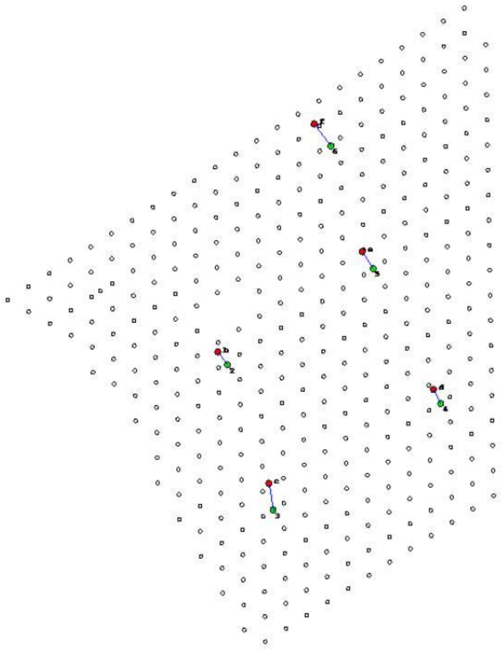

Figure 2. Plan View of 10145-78 (2009)

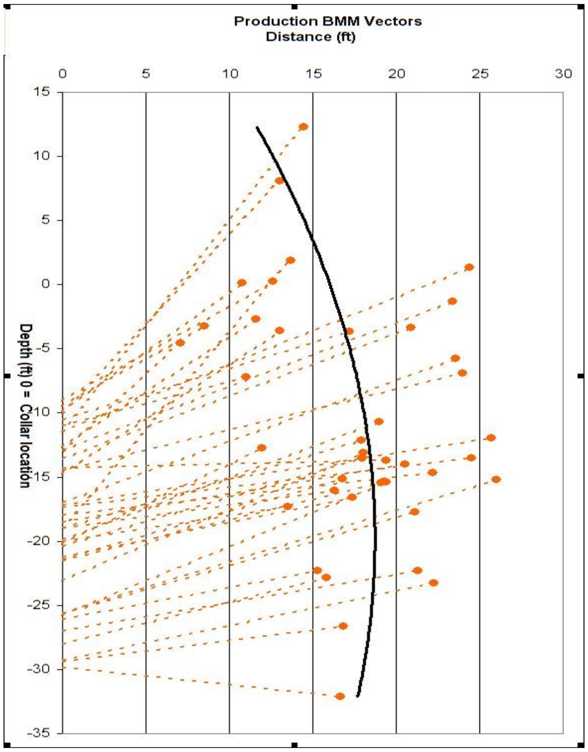

Figure 3. Cross-Sectional Graph of All Production Movement (2009)

Method

In order to evaluate movement with new timing and detonation systems (electronic caps), three blasts were selected. These blasts were nearly identical in their blast design. All were fired with a “V” type initiation, electronic caps, identical timing, hole depths, burden, spacing, powder factor, detonators, and in similar geology.

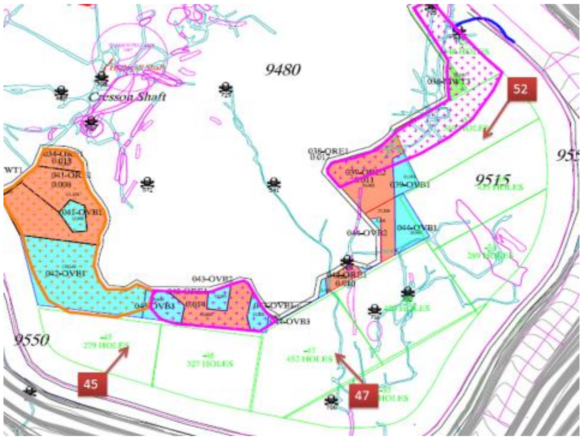

Figure 4. Map of Monitored Blasts

The following narrative describes the method for performing the cash flow analysis on the three blasts evaluated in this study.

In order to find the movement in each blast, BMMs coupled with BMM *Explorer* software produced by Blast Movement Technologies were utilized to perform translation of the ore/waste boundaries. This location is referred to as “actual location”. The “true location” of the ore/waste lines cannot be ascertained precisely, but use of this system is widely accepted as the most accurate method for performing blast movement monitoring and polygon translation.

Regardless of whether blast movement monitoring is performed, errors and inefficiencies can affect overall recovery. Some examples of these errors include:

- Assay sampling
- Geostatistical analysis for ore modeling
- Polygon creation
- Operators following dig lines
- Dispatch errors

Since these errors exist in the polygon control location as well as the actual location, it is assumed that these errors have no effect on the results of this study.

Identifying Ore Loss and Dilution

The actual polygon location was overlaid against polygons that were moved according to MINE X's control case (previously observed average motion) and two-dimensional differences (Blocks) were created. Then, those Blocks were identified as "ore loss" or "dilution" (no misclassification was present in these blasts) (see Figure 10).

Blocks defined as "ore loss" were zones that started in an ore polygon, but moved outside of the area that would have been sent to the valley leach fill (VLF) in the control case. Therefore, this material would have been transported to a waste dump.

Blocks defined as "dilution" were zones that were initially classified as waste (below cut-off grade) by the geology department, however these areas moved into a zone that would have been mined as ore and were sent to the VLF under MINE X's control case.

The Blocks were cut from the ore control (OC) model using the Interactive Planner Tool (IP Tool) in MineSight 3D. The OC model uses a known bench height and tonnage factor to calculate tonnages. Grades were calculated in each Block with this tool using ordinary Kriging of shake leach (SL) and fire assay (FA) from blasthole samples.

Additional Tonnage Processed

If the mine would process additional tonnage due to translating polygon boundaries, the additional cost of processing was subtracted from the benefit of monitoring. In cases where polygons reside completely in a blast, the dilution quantity is very close to the ore lost quantity, so the tonnage residing in a polygon pre-and-post blast is similar. However, in the case of a polygon residing along a back line, the polygon surface area stretches, which results in an additional area mined (see Figure 5, Figure 6, Figure 7, Figure 8). Note: in no case should a mine process more tonnage than originally planned due to blast movement monitoring. But, if blast movement is not monitored and the polygons are not translated, different tonnage may be processed.

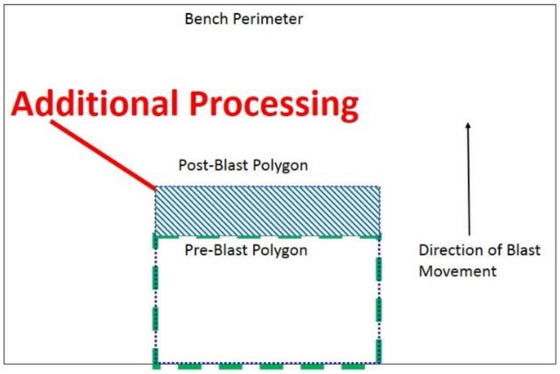

Figure 5. Plan View Additional Processing

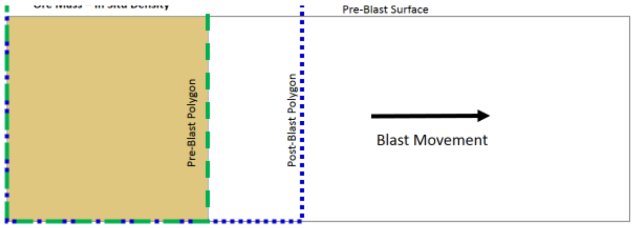

Figure 6. Cross-Sectional View Additional Processing Explained A

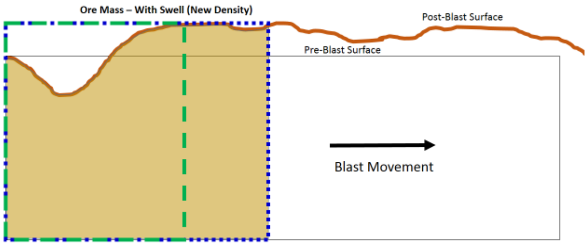

Figure 7. Cross Sectional View Additional Processing Explained B

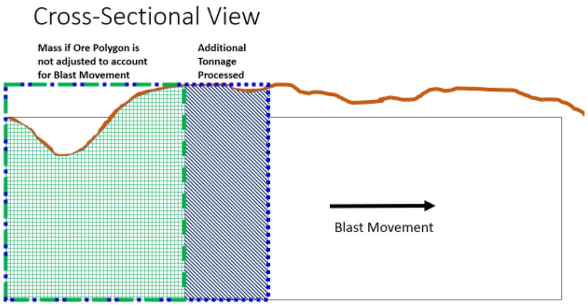

Figure 8. Cross Sectional View Additional Processing Explained C

Cash Flow Method

The following assumptions have been made with respect to the economic calculations:

- Bench Height - 35 ft (10.7 m).
- AU Recovery - 100%
    - 100% recovery is assumed when using "SLEXT" grades (see below for explanation)
- The grade used for these calculations are identified by MINE X as "SLEXT" or "cyanide leach extraction" grades.
- Gold Price - 1600 USD/oz ($51.44/g)
- Processing Ore cost - $4.82

Each blast is different, and the requirements to obtain sufficient data to accurately adjust polygon locations vary from blast-to-blast. The following assumptions regarding the costs associated with monitoring were used to anticipate the cost outlay by MINE X to monitor a similar blast in the future, as well as to perform the cash flow analysis contained in this report:

- Cost per hour for geologist = $50.00
- Cost per BMM used, including drilling to mid-bench - $338
- Each blast requires that one geologist devotes two hours to monitoring.

Table 1. Monitoring Cost for 9480-52

9480-52			
Monitoring cost	Units	Cost per	Total
BMMs	4	$ 338	$ 1,352
Labor (hr)	2	$ 50	$ 100
			$ 1,452

Table 3. Monitoring Cost for 9480-45

9480-45			
Monitoring cost	Units	Cost per	Total
BMMs	2	$ 338	$ 676
Labor (hr)	2	$ 50	$ 100
			$ 776

Table 2. Monitoring Cost for 9480-47

9480-47			
Monitoring cost	Units	Cost per	Total
BMMs	4	$ 338	$ 1,352
Labor (hr)	2	$ 50	$ 100
			$ 1,452

In each Cash Flow Analysis, gold contained in ore loss is assigned a positive value, while gold in dilution is assigned a negative value (any gold contained in dilution will be realized, while gold in ore loss will be shipped to the waste dump). Additionally, the cost to monitor is a negative value, along with additional tonnage processing costs. Therefore, any benefit to monitoring over the control case (using average movement) is shown as a positive number. If there is no economic benefit to monitoring, the net benefit will appear as a negative number (see Table 8).

Movement Results

Of the three blasts evaluated, all varied greatly from each other in magnitude of displacement. Blast 9480-52 moved approximately 13 feet at the mid-bench level, while 9480-45 and 9480-47 moved on average between 23 and 26 feet (Table 9). It is not known why 9480-52 moved so much less than the other blasts, but **this illustrates the problems associated with modeling blast movement**. The variability in a single blast can exceed +/- 50% of the mean (La Rosa, 2011). However, blasts will nearly always vary from a model as the model is based on average data, which is the case in the three blasts evaluated in this study.

As Figure 9 illustrates, the average displacement for the individual blasts varies greatly from the template created in 2009, as shown by the dashed “trend” lines. Note that there is also significant variation within the individual blasts. However, if statistics are done on all of the combined data (Table 4), the overall average horizontal movement from these blasts is close to the 2009 template (17.9 ft vs 17.5 ft). Some of the movement vectors are from above the powder column where the horizontal displacement is known to decrease (Thornton, 2009) and if these data are removed then the average is 20.1 ft, which is slightly higher than the 2009 template.

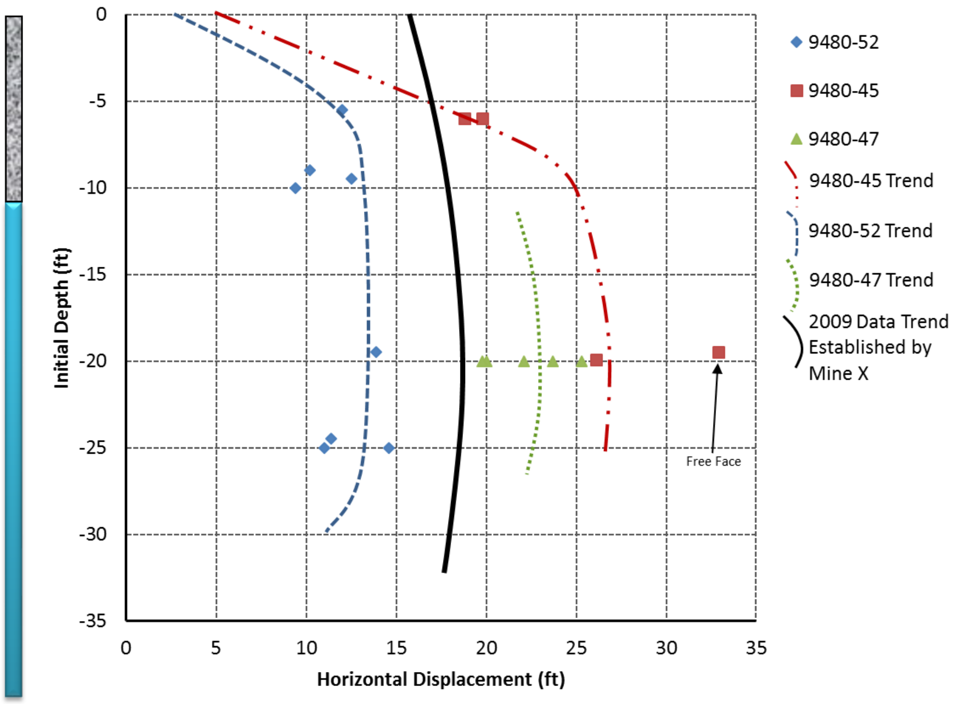

Figure 9. Horizontal Movement Vs. Depth (Trend lines are not mathematical)

Table 4. Summary of All Movement

	All BMMs Included		Removing BMMs Above Powder Column	
	(ft)	(m)	(ft)	(m)
Avg. Horizontal Movement:	17.9	5.4	20.1	6.1
Avg. Vertical Movement:	6.3	1.9	5.6	1.7
Avg. 3D Movement:	19.2	5.9	20.9	6.4
Max Horizontal	32.9	10.0	32.9	10.0
Min Horizontal	9.4	2.9	11.0	3.4
	All BMMs Included		**Free Face BMM Removed**	
	(ft)	(m)	(ft)	(m)
Standard Deviation	6.5	2.0	5.6	1.7

Cash Flow Analysis Results

The following is a summary of the cash flow analysis performed on each blast in the methods described. “Block ID” in each Ore Loss and Dilution table refers to the Blocks identified in each plan view image.

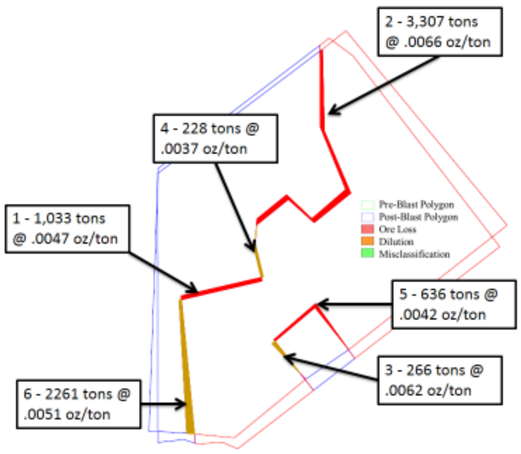

Figure 10. 9480-47 Ore Loss and Dilution Blocks

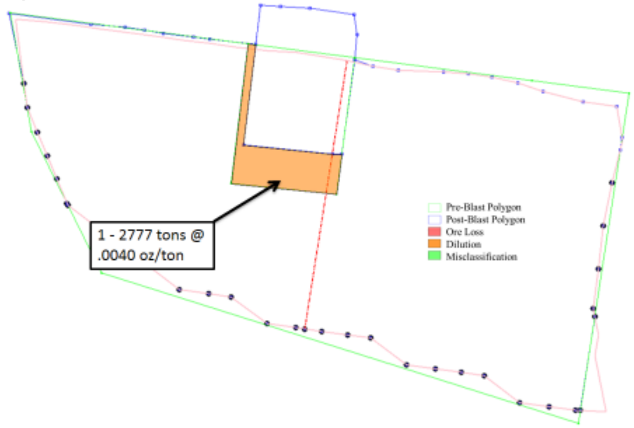

Figure 11. 9480-45 Ore Loss and Dilution Blocks

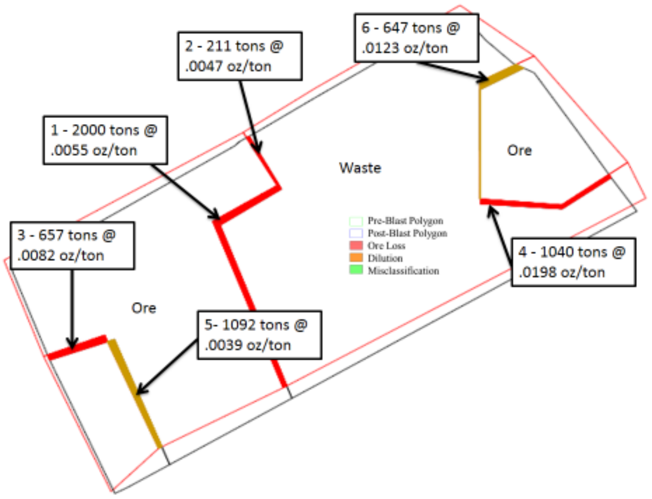

Figure 12. 9480-52 Ore Loss and Dilution Blocks

As the previous figures illustrate, variation exists between the control case and actual observed movement in each blast. The actual movement vectors observed are detailed in Table 9.

Table 5. 9480-47 Ore Loss and Dilution

Blast #	**9480-47**		Ore Loss			Dilution Contribution		
Block ID	Tons	AU Grade (oz/st)	Ore Loss (t)	AU Loss (oz)	AU Loss (USD)	Dilution (t)	AU From Dilution (oz)	AU From Dilution (USD)
1	1033	0.0047	1033	4.9	$ 7,768		0.0	$ -
2	3307	0.0066	3307	21.8	$ 34,922		0.0	$ -
3	266	0.0062	266	1.6	$ 2,639		0.0	$ -
4	228	0.0037	0	0.0	$ -	228	0.8	$ 1,350
5	636	0.0042	0	0.0	$ -	636	2.7	$ 4,274
6	2261	0.0051	0	0.0	$ -	2261	11.5	$ 18,450
Total	**7731**		**4606**	**28.3**	**$ 45,329**	**3125**	**15.0**	**$ 24,073**

Table 6. 9480-45 Ore Loss and Dilution

Blast #	**9480-45**		Ore Loss			Dilution Contribution		
Block ID	Tons	AU Grade (oz/st)	Ore Loss (t)	AU Loss (oz)	AU Loss (USD)	Dilution (t)	AU From Dilution (oz)	AU From Dilution (USD)
1	2777	0.0040	0	0.0	$ -	2777	11.1	$ 17,773
2				0.0	$ -	0	0.0	$ -
Total	**2777**		**0**	**0.0**	**$ -**	**2777**	**11.1**	**$ 17,773**

Table 7. 9480-52 Ore Loss and Dilution

Blast #	**9480-52**		Ore Loss			Dilution Contribution		
Block ID	Tons	AU Grade (oz/st)	Ore Loss (t)	AU Loss (oz)	AU Loss (USD)	Dilution (t)	AU From Dilution (oz)	AU From Dilution (USD)
1	2000	0.0055	2000	11.0	$ 17,600	0	0.0	$ -
2	211	0.0047	211	1.0	$ 1,587	0	0.0	$ -
3	657	0.0082	657	5.4	$ 8,620	0	0.0	$ -
4	1040	0.0198	1040	20.6	$ 32,947	0	0.0	$ -
5	1092	0.0039	0	0.0	$ -	1092	4.3	$ 6,814
6	647	0.0123	0	0.0	$ -	647	8.0	$ 12,733
Total	**5647**		**3908**	**38.0**	**$ 60,754**	**1739**	**12.2**	**$ 19,547**

In the case of 9480-45, the only polygon present was on the free face (see Figure 11). Most likely, given MINE X’s control case, no ore would have been lost along the leading edge as the front dig line would have been moved forward to account for movement in the face. However, the back and sides of the polygon would not have been translated according to actual movement, which would induce dilution of 2,777 tons.

As Table 6 demonstrates, this single polygon was kriged slightly above cutoff grade and the induced dilution contributed $17,773 to the revenue recovered in that blast. In Table 8, it appears that it was not economic to monitor this blast. However, in reality, the dilution induced by blast movement was 2,777 tons of material below economic cutoff. These economic calculations are strictly based on processing costs provided by Mine X, and do not consider net present value (NPV) or internal-rate-of-return (IRR) in the cost-benefit. Therefore, there is certainly value to Mine X in preventing the dilution in this blast from reaching the VLF, but that value is more difficult to determine than the simple calculations in this study examines.

Table 8. Cash Flow Summary

Blast	Ore Loss (tons)	Ore Loss ($)	Dilution (tons)	Gold Contained in Dilution ($)	Additional Processing (tons)*	Additional Processing ($)*	Monitoring Cost ($)	Net BMM Benefit ($)	Net BMM Benefit in Scenarios ($)*
9480-47	4,606	45,329	3,125	24,073	(1,481)	(7,138)	(1,452)	12,665	20,262
9480-45	0	0	2,777	17,773	(2,777)	(13,385)	(776)	(5,164)	(5,164)
9480-52	3,908	60,754	1,739	19,547	(2,169)	(10,455)	(1,452)	29,300	38,928

* Negative=Cost Positive=Savings

Scenario Cash Flow Analysis

Examination of the grades in the previous tables indicates that some areas labeled “dilution” are above ore cutoff. This can occur when **a higher grade assay inflates the models expectations** or when an ore cut becomes too small to be feasibly mined without incurring neighboring waste. The ore control model may indicate that the small “dilution” cut is ore grade, however, unacceptable amounts of waste would need to be taken in order to feasibly mine that cut.

In order to examine the cash flow impact if these anomalies had not been present, a scenario was created whereby the dilution grade (if it exceeded the ore cutoff grade of 0.005 oz/ston) was changed to the mineralized waste cutoff grade of 0.003 oz/ston. The scenario results are listed in *Net BMM Benefit in Scenarios ($)** contained in Table 8 (note 9480-45 did not change in the scenario).

Analysis of Results

The benefits of accounting for blast movement have been documented and published (Fitzgerald, et al, 2011), but the costs of implementing models are rarely examined in the author’s experience. For these blasts, the mid-bench variation was in excess of 58% of the mean (see Figure 9).

Based on known movement dynamics, some variation is deterministic (not random), such as the difference between movement in the stemming zone vs. the powder column zone, free face vs. buffered fronts, and backline vs. body areas. But, there will always be random movement within these individual zones. The data shown in Figure 9 and Table 9 demonstrates significant variation between similar blasts and within these blasts. This could be attributed to varying energy concentrations resulting from differing powder quantities, uncontrollable variation in the rockmass (Thornton, 2002), or a number of other factors.

Therefore, the random variation in each blast occurs in the ‘bulge’ or leading edge of the movement (see Figure 9), which occurs at MINE X between 10-25 feet in depth. It is this variance that requires multiple monitoring points in each blast to ascertain movement in areas of concern. This insures that ore/waste boundaries and ore/ore boundaries are moved to their correct post-blast locations. As in other statistical processes, decreasing the distance between the monitored location and the location of concern increases confidence and reliability in the data gathered. In other words, translating polygon vertices based on data gathered in zones where deterministic variability exists, or translating vertices in similar zones based on data gathered far away from the point of concern decreases the confidence in the translation. Research is ongoing to determine optimum distances and monitoring densities for blast movement.

The consequence of the variability between the template and blasts 9480-47 and 9480-52 totaled $41,965. As the scenario demonstrates, these same three blasts could have easily resulted in losses of $59,189 (see Table 8).

Conclusions

All three of these blasts were monitored on the same bench, in the same pit, with the same timing and caps, and in similar geological types. Although every blast is different, variation exhibited when all designed variables are held constant can still have serious financial consequences for mining operations. Even though the overall average measured movement in this study (17.9 ft) was close to the 2009 study results (17.5 ft), it is important to note that each blast varied significantly from the mean. The consequence of this variance is that no blast moves according to a template, even when all controllable attributes are held constant. Even if the overall movement in a blast were to move according to the template, the random variance within a single blast is such that individual points will not actually move according to the modeled displacement.

If a movement template or model is to be used rather than continuous monitoring, the risks associated with these templates should be examined and evaluated. In this case, the benefits of direct monitoring were far in excess of the costs. The return on investment (ROI) for blasts 9480-47 and 9480-52 was 14.5 in the actual situation and 20.4 in the scenario presented. The cost of the observed variation reached $5,209 per foot from the control case and could have easily resulted in losses of $6,920 per foot (see Table 10).

References

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Appendix

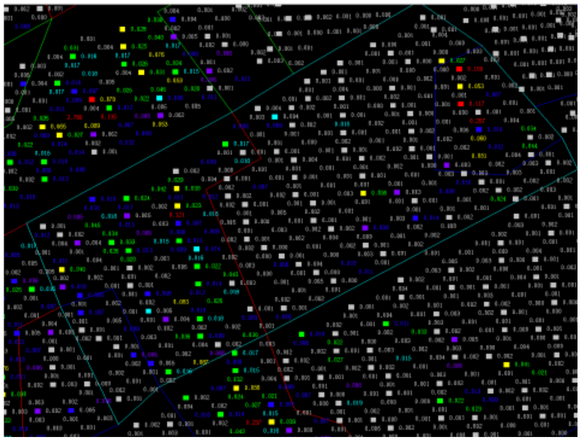

Figure 13. 9480-52 SLEXT Grades

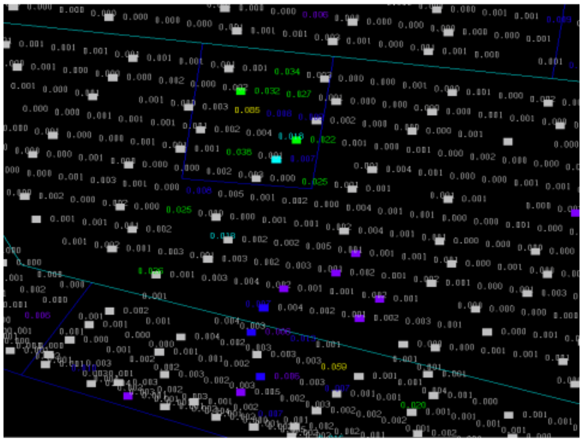

Figure 14. 9480-45 SLEXT Grades

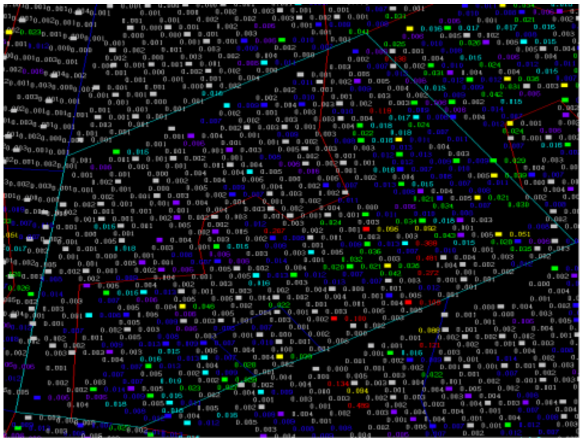

Figure 15. 9480-47 SLEXT Grades

Table 9. Summary of All Observations (in feet)

Blast Number	BMM-Color	Installed Depth	Horizontal Movement	Vertical Movement	Heave	3D Movement
9480-52	1-O	25	14.6	4.9	5.6	15.4
9480-52	2-Y	10	9.4	2.6	4.5	9.7
9480-52	3-O	25	11	3.7	15.5	11.7
9480-52	4-Y	9	10.2	13.4	14.7	16.8
9480-52	5-O	19.5	13.9	6	13	15.1
9480-52	6-O	5.5	12	8.2	8.1	14.5
9480-52	7-O	24.5	11.4	1.1	0	11.5
9480-52	8-Y	9.5	12.5	2.7	1.5	12.8
Blast Number	**BMM-Color**	**Installed Depth**	**Horizontal Movement**	**Vertical Movement**	**Heave**	**3D Movement**
9480-45	1-G	19.9	26.1	8.3	10.1	27.4
9480-45	2-Y	6	18.8	10.9	9.6	21.8
9480-45	3-R	19.5	32.9	8.1	-0.2	33.9
9480-45	4-O	6	19.8	7.2	6.2	21.1
Blast Number	**BMM-Color**	**Installed Depth**	**Horizontal Movement**	**Vertical Movement**	**Heave**	**3D Movement**
9480-47	1-O	20	20	3.6	9.7	20.3
9480-47	2-Y	20	19.8	7.8	13.2	21.3
9480-47	3-Y	20	23.7	5.2	10.5	24.3
9480-47	4-O	20	22.1	4.3	11.2	22.5
9480-47	5-O	20	25.3	8.7	11	26.7

Table 10. Cost of Variation

Blast	Actual Average Horizontal Movement (ft)	Assumed Average Horizontal Movement (ft)	Difference (ft)	Cost of Variation	Cost per foot
9480-47	22.2	17.5	4.7	$12,665	$2,706
9480-52	11.9	17.5	(5.6)	$29,300	$5,209
Scenario 9480-47	22.2	17.5	4.7	$20,262	$4,329
Scenario 9480-52	11.9	17.5	(5.6)	$38,928	$6,920