Blast Movement Modelling and Measurement

D La Rosa¹ and D Thornton²

ABSTRACT
Geologists use large data sets and spend many hours and much computing time modelling the distribution of minerals throughout a rock mass. Significant investments in drilling, assaying and quality assurance and quality control (QA/QC) are made before sophisticated geostatistical techniques are applied to the collected data. A large amount of research has been done in this field such that the ore control model is a reasonably accurate reflection of the mineral that is actually in the ground. However, after all this effort, the mining engineers then work just as diligently to blast the in situ rock mass to a particle size that can be efficiently handled and further reduced by downstream comminution processes. In open cut mines, this invariably requires large amounts of explosive energy that displaces the ore boundaries from where the geologists originally defined them. Failure to accurately account for blast movement will result in misclassification, whether that is ore to waste; low grade to high grade; sulfide to oxide; or other contaminates – collectively referred to as ore loss and dilution. The financial consequence of getting this wrong is substantial and not well quantified. This diminishes all of the good geological QA/QC done in defining the ore.

This paper discusses various technologies used to physically measure blast-induced orebody movement and the difficulties in modelling this with a purely theoretical approach. Rock mass structure, blast energy, design and timing contours all have significant and interrelated effects on blast movement vectors. Measured blast movement has a large variance due to the uncertainty of many of the controlling parameters – arguably dominated by the heterogeneous nature of the rock mass. Although there have been significant advances in blast movement modelling capability in recent years, this unpredictable blast movement limits their use in the context of production ore control. Certainly, without physical field measurements, accurate predictions of movement are near impossible.

Limitations of traditional surface markers in determining three-dimensional (3D) blast movement within the orebody are also reviewed, and advancements in accurately measuring these vectors within blasted ore discussed.

INTRODUCTION
Geologists and grade control engineers go to great lengths to model a resource so that the location and grade of the ore is as well defined as possible. Sample data from exploration core, in conjunction with advanced geostatistical techniques such as kriging (Krige, 1981) and sequential simulation; result in the best possible representations of the ore distribution in a deposit. These form the basis of prefeasibility studies, short- and long-term mine planning and daily production decisions.

In the majority of mining operations the first stage of comminution is by blasting and this allows the ore to be efficiently excavated and processed. Another effect is that the material being blasted will experience some movement, thereby causing an offset between the orebody and the resource model. Depending on the distribution of ore throughout the blast, failure to take this movement into account when excavating will have significant economic consequences in terms of ore loss and dilution. This paper describes the various measurement and modelling techniques employed to determine blast induced movement prior to excavation.

BLAST MOVEMENT MEASUREMENT
A number of sites and research institutions have used a range of measurement techniques with varying success. These can be categorised by the type of marker employed: passive visual ones such
as sand bags, chains and pipe; and remote detection systems such as blast movement monitors (Thornton, 2009) and magnetic markers that can be detected prior to excavation of the blasted ore.

**Visual markers**

Gilbride, Taylor and Zhang (1995) and Taylor *et al* (1996) trialled the use of marker bags at a number of open pit gold and silver mines in Nevada. These were surveyed as they were uncovered during excavation. While this measurement technique is simple, inexpensive and relatively accurate, typically less than 50 per cent of the bags were located (30 per cent for bags lower in the bench) and it took several days before all of the bags were uncovered. The measured 3D movement ranged from 3 m to 7.7 m.

A more common technique used in the gold industry is to drill additional holes within a blast and insert lengths of plastic pipe. As the pipes are exposed during the mining process their locations are surveyed, and if excavation of the bench is carried out in several passes (often referred to as flitches or split-benches), the survey process is repeated for each subsequent level. Figure 1 shows how a pipe typically presents itself during excavation.

Blast movement measurement using pipes has a number of limitations that are summarised below:

- Only provides horizontal (2D) movement vectors.
- Pipe only measures surface movement (where it protrudes from the muck pile) which can be significantly less than the bulk movement of the orebody and more variable. Even when the mining is done by a number of benches or flitches, the surface is not representative of the top flitch because that is typically the stemming zone of the blast where decreased horizontal displacement occurs.
- Long lengths of pipes can be difficult to handle, are time consuming to install, and introduce health and safety issues.
- Recovery of pipe is generally very poor. Seventy to 80 per cent detection is common for the muck pile surface but this reduces greatly for each subsequent bench in multipass operations, until very few (<10 per cent) are located from the lower portion of the bench. The surface movement is not representative of the bulk movement and where it is most important to get data, recovery is very poor. Pfeifenberger (2007) reported recoveries from between 0 - 70 per cent with typical results well below 50 per cent.
- If insufficient pipe is protruding from the bench before the blast, the heave of the muck pile can cover the tops of the pipes.
- It is difficult to remotely identify each pipe which can cause confusion when calculating movement vectors.
- Labour-intensive.
The major disadvantage of any visual marker method is that movement data is not available until after the surrounding ore has been excavated. Therefore, it does not allow for dig polygons to be adjusted prior to excavation – to some extent, a forensic investigation of ore loss and dilution.

**Remote markers**

Gilbride, Taylor and Zhang (1995) trialled the use of magnetic markers in conjunction with a magnetic gradiometer to determine their applicability as a blast movement measurement system. The targets were reported to have been detected at reasonable depths but disadvantages included:

- restricted to operations not susceptible to equipment damage from the metallic targets (such as crushers),
- only one magnetic target can be placed in each hole, and
- adequate horizontal distance between adjacent markers is required to allow proper detection of each one.

The early magnetometer research carried out by Gilbride, Taylor and Zhang (1995) was evidently continued and Harris, Mousset-Jones and Daemen (1999, 2001) reported on a system using a caesium vapour magnetometer and GPS receiver to locate the pre- and post-blast positions of magnetic targets distributed throughout a blast. They reported that horizontal rock movement could be measured with an accuracy of ±1 m and vertical movement to an accuracy of ±1.2 m, to a depth of 18 m below the surface.

La Rosa et al (2007) described the use of radio frequency ID (RFID) tags as an ore movement tool at a South American mine. Ruggedised RFID tags were installed into the stemming columns of blastholes in the orebody and their preblast location logged. As passive RFID tags can only be detected from around a metre, one of the detection antennae was installed at the discharge of the primary crusher to detect the tags as they passed by. The logged detection time allowed the tag to be associated with a dispatch truck dump event, and therefore to the dig coordinates of the excavator when the truck was being loaded. While this technique relies heavily on the accuracy of the GPS receivers on the excavator and the trigonometric algorithms employed to determine the bucket location, this case study showed movements in the order of 20 m. Limitations of this technique include:

- More than one bucket load of broken rock is required to fill a haul truck, so there are several possible dig locations to choose. This introduces a large error to the post-blast location.
- In a similar manner to visual markers, RFID tags can only be used to determine ore loss and dilution after they’ve been excavated, reducing their usefulness as a grade control tool.
- Any marker installed in the stemming could be ejected from the blasthole and even if this did not occur, near-surface movement is not representative of the bulk movement.

Research at the University of Queensland resulted in the development of an active movement marker (Adam and Thornton, 2004; Thornton, Sprott and Brunton, 2005; Thornton, 2009) and subsequent commercialisation under license by Blast Movement Technologies (BMT). The BMM® system comprises directional transmitters that are installed in the blast prior to blasting, which are located after the blast by specialised hardware. The system accuracy in the horizontal and vertical orientations is proportional to depth but is generally in the order of 0.1 to 0.2 m. The BMM®s can be detected to a depth of around 25 m after blasting, prior to excavation. The 3D movement vectors obtained can then be applied to the ore block boundaries by the system software with results typically available within one to two hours after the blast. Recent improvements in the system architecture allow up to four BMM®s to be placed in a hole, or for BMM®s to be placed in closer proximity in neighbouring holes, creating further opportunities to extend the understanding of the finer details of blast dynamics. Figure 2 shows a BMM® being activated before being inserted into a blasthole. With a battery life of more than 12 hours, and detection rates of about 90 per cent, the BMM® system is an effective and practical grade control tool that can be used on a regular basis by ore control personnel.

**Summary**

Of the two marker types, visual and remote, the latter provide the only practical way to measure blast movement and take this into account when managing ore loss and dilution in a mining operation. As part of a carefully controlled experiment, visual markers can be used to define blast movement but are not ideal for use as a grade control tool. Of course, the Holy Grail in grade control is to accurately know where the ore is going to move even before blasting and the next section of this paper deals with modelling.
BLAST MODELLING

The application of explosive energy to the orebody is an integral and vital part of all hard rock mining operations. This reduces and loosens the in situ blocks of the rock mass, making them amenable to excavation and downstream processing, such as crushing and grinding. Obeying Newton’s Second Law of Motion (Newton, 1687), this invariably results in movement of the rock mass. As each blasthole wall is subjected to pressures of several gigapascals, movement is hardly surprising. In some operations this is perceived to be a ‘bad thing’ for the purposes of grade control, but this is only true when it’s unmeasured and/or chaotic, causing the misclassification of different mineral zones, such as ore and waste, or sulfide and oxide material.

In its intact and undisturbed state, a rock mass can be represented as a 3D matrix of blocks of varying shape and size, with a range of mechanical properties. To attempt to model the result of blasting on the rock mass, the properties of the explosive, rock and boundary conditions of the blast need to be well understood. Figure 3 shows this schematically. For the purposes of this paper, only ore movement prediction, as it relates to grade control, will be considered.
Model inputs

Explosive characteristics

The energy released by the explosive in the blasthole can be partitioned into two components: shock and gas energy (Persson, Holmberg and Lee, 1993). The shock energy is created as the detonation front travels up the blasthole at hypersonic velocity, i.e. the velocity of detonation, crushing the rock around the blasthole, and causing cracks to extend outward from it. The expanding gases that follow the detonation then enter these cracks, further extending them and doing work on the broken and intact blocks of the rock mass. This is repeated many times throughout the blast as each hole detonates in turn, interacting with its neighbouring holes. As was mentioned previously, the result of this energy is to break the rock and set it in motion.

To be able to model the contribution of explosive energy to the blast results, its energy content needs to be known accurately, and how this energy is converted into the shock and gas partitions. This also needs to take into account the efficiency of the explosive reaction, and whether it has been affected by contaminants such as water or suboptimal quality control. Bulk blasting agents are non-ideal explosives and many factors (beyond the scope of this paper) will affect their performance.

Blast design

The blast design governs how the explosive energy is distributed spatially and temporally. The pattern (e.g. bench height, burden, spacing, charge length, stemming length and material, hole length and diameter) controls the former, and the timing between each individual blasthole controls the latter. There is a complex interaction between the two because the volume of rock being subjected to the explosive energy, changes dynamically throughout the blast, as the rock moves due to the forces imparted on it. Generally speaking, in the body of the blast (i.e. away from the edges of the blast) the rock mass moves approximately perpendicular to the timing contours of the blasthole initiation time. This is illustrated in collected data (Figure 4).

![FIG 4 - Blast movement vectors relative to timing contours.](image)

A difficult variable to quantify is the confinement of the explosive contributed by the stemming of the explosive. The expanding detonation gases are meant to be contained by the stemming material above the explosive charge. The longer the stemming column, the better the confinement, however,
this also limits the explosive energy available to the rock towards the collar of the blasthole. Quite often this means that some explosive gases will vent to the atmosphere when the stemming is ejected and this reduces the amount of time that the gases can do work on the newly fractured rock mass. This is an important factor in any muck pile model, as it is these gases that impart the bulk of the velocity onto the broken ore and therefore determine their final resting position.

**Rock mass properties**

The rock mass is defined by its structural (e.g., block size and inter-block joint roughness, aperture and filling) and mechanical properties (e.g., compressive and tensile strength, Young’s modulus and Poisson’s ratio). Due to the randomness intrinsic to any orebody, these can never be truly fully measured and only be described as statistical distributions based on the limited observations that can be made. The ability to take abundant measurements is restricted due to the fact that for standard production blasts only a small portion of the rock mass is exposed and available for measurement. For example, a 200 m × 100 m × 10 m blast with a clean front face will have a 22 000 m² exposed surface for its 200 000 m³ volume. If the average block was 0.5 m³ in volume and cubic in shape (0.8 m × 0.8 m × 0.8 m) only nine per cent would be available for measurement. As the block size reduces, so too does this proportion.

**Boundary conditions**

The final input into any blast model will be the boundary conditions of the blast. These have a large influence on the movement close to the boundary and the shape of the final blasted muck pile. For a blast with a clean face and appropriate timing, the movement will be predominately horizontal. If the free face of the blast is not entirely unconfined, the lower part of the bench will be buffered by the material in front of it while the rock from the upper part of the bench will be free to flow over the top of it.

**Existing models**

Blast models can be segregated into several categories, however the two predictions that are of major interest are run-of-mine (ROM) fragmentation and muck pile movement vectors. These can be empirical or mechanistic, but more often than not utilise a hybrid approach of the two modelling techniques to take into account the fact that not all input variables are known well enough to deal with in a purely numerical fashion. This is by no means an exhaustive review, merely a broad overview of modelling directions over the past 20 years.

Since the late 1980s there have been several research projects with muck pile shape and blast movement modelling objectives. Yang and Kavetsky (1990) presented a two-dimensional (2D) kinematic model to predict the final muck pile shape for bench blasts with a single free face. The model used both empirical and numerical techniques to predict muck pile shape but did not output individual block vectors. Two-dimensional cross-sections through the muck pile had a similar shape to those in the field and an example of the output from their model is shown in Figure 5.

![FIG 5](image) - Model results from Yang and Kavetsky (1990).
Preece, Burchell and Scovira (1993) took advantage of increases in computing power and developed a 2D model that represented the rock mass as circles. These circles were acted upon by the explosive in the blasthole and their trajectory and final position defined the final muck pile. This simplification of the rock mass – representing the rock as a matrix of balls connected to each other with a dampened spring – has been used in several projects and is necessary if the computation is to run in a reasonable time. This model too showed reasonable results in predicting muck pile shape. Figure 6 shows the model calculations over four time increments.

More recently, a large collaborative research project known as the hybrid stress blasting model (HSBM) has been funded by a consortium of explosive and equipment suppliers, and major mining houses (Furteny, Cundall and Chitombo, 2009). The HSBM is a modelling framework that incorporates ideal and non-ideal explosives detonation codes and geomechanical rock mass models. The ultimate aim of the project is to develop a practical, fundamental model of the blasting process in rock. Small-scale experiments show promise for this approach; however, there is still some way to go before a full production shot could be simulated and the model output used for grade control.

One of the main drawbacks of previous numeric models has been the sheer number of particles and computational power required to process them in order to obtain a result with a resolution that is suitable for practical applications. Tordoir et al. (2009) have taken an approach to modelling that makes use of dedicated physics processor units found in widely available high end video graphics cards. This approach discretises the blast volume into cubes and then assigns initial conditions for each based on the energy distribution throughout the blast, in conjunction with the timing contours. These blocks are then passed to the physics engine which deals with the block trajectories and collisions, and generates the resultant muck pile. Figure 7 shows the 3D representation of the blast with blocks still in flight.

Since the model tracks blocks from their starting location to their final resting position, and each block can be assigned with material properties, this framework has been developed with grade control in mind.

Tordoir presented two case studies where model results were compared with BMM® results from actual field trials. The first was a 68 000 m³ production trim blast with four BMM®s installed. The powder factor (defined as the mass of explosives per cubic metre of rock) was 1.2 kg/m³. The comparison between the predicted and actual movement were good with an average variance of...
0.8 m in the horizontal plane and 1.5 m in the vertical. The variance in the 3D movement was 1.0 m with a standard deviation of 0.3 m.

The second case study was a 125 000 m³ production blast with eight BMM®s installed and a designed powder factor of 1.7 kg/m³. The result of this comparison showed a mean horizontal variance of 7.7 m, vertical variance of 2.8 m and 3D movement variance of 7.7 m with a standard deviation of 7.0 m.

Due to hardware and software limitations, 2 m × 2 m × 2 m cubic blocks were used for these simulations. The first case study shows that it is possible to get reasonable results from a modelling approach; however, the second case study highlights that significant error can still occur. The mention of these results is not in any way meant to denigrate the development of this model. The approach taken, using physics processor units to overcome computational constraints, will allow the user to get a general idea of movement vectors throughout a blast volume. This is beneficial for blast design purposes but to rely entirely on modelled movement for ore control can have significant negative economic consequences, as will be discussed in the following section of this paper.

Summary
There are two aspects that determine the accuracy of a model; firstly the accuracy of the mathematical algorithms that comprise the model, and secondly the precision with which the inputs can be defined. Even with a perfect numerical blast model, attempts to predict the response of a rock mass to blasting will only be as accurate as its inputs — explosive energy characteristics and distribution, rock mass structure and strength, and boundary conditions. Quite often ‘fudge-factors’ are introduced to models to deal with these unknowns, making mechanistic, numerical models more like empirical models.

While some rock mass parameters can be measured from the exposed faces of the blast volume only a small proportion will be exposed on a typical blast. Even then, structural mapping and mechanical testing for every blast would be impractical on an operating mine site. The errors in the model’s algorithms along with the uncertainty in the model inputs will be reflected in the output of the model and even small errors in predicted movement will result in a large penalty due to ore loss and dilution.

MODEL VERSUS MEASURE
Background
Once it is acknowledged that blasting induces movement to the rock mass and that ignoring it will result in large sums of lost revenue, there are very few alternatives to directly measure movement for the purposes of grade control. In practice, there is very little scope to reduce the movement for a particular rock mass because the primary objective of blasting is to fragment it so it can be excavated efficiently.

The BMM® System mentioned previously, has its roots in 2001 when Placer Dome tendered a research project to develop a system for routinely measuring 3D blast movement and develop a predictive muck pile movement model. Muck pile models had been attempted by several researchers up until that time but with limited success and it was thought that this was at least partly because
there had never been a practical method to collect sufficient 3D blast movement data to enable accurate muck pile models to be developed and calibrated.

The University of Queensland’s proposal was not accepted by Placer Dome but independent development was conducted regardless. The first commercial application of this prototype BMM® System was at a Placer Dome mine in 2003 where blasting of an entire bench was monitored over a one-month period. It was envisaged that an outcome from the project would be a template of blast movement derived from data obtained from several similar blasts, which would then be used to predict muck pile movement for similar blasts in the future. It quickly became apparent that a simple model was not going to be a cost-effective solution because the large variation in the blast-induced movement (eg 5 m - 15 m at mid-bench depth, away from any edge-affects) meant that the predicted movement would regularly miss the ore boundary by several metres. Therefore, a simple model is not the optimal solution for minimising ore loss and dilution, even with gold at only US$350 per ounce. The results of this project are summarised by Thornton, Sprott and Brunton (2005).

After the outcomes of the 2003 project, Placer Dome funded a three-year research project with the primary objectives being to develop the prototype monitor suitable for site use, develop a blast movement model and apply the movement data to ore control. After the first year, 35 blasts at seven sites had been monitored with 375 BMM®s. This extensive data set reinforced the outcome from the first trial in 2003:

- blast movement is highly variable with a seemingly large random (ie unpredictable) component,
- it was not feasible to produce a muck pile movement model with sufficient accuracy for grade control, and
- direct measurement of blast movement is more cost-effective than modelling.

The focus of the remaining research switched from muck pile modelling to defining post-blast ore locations. Barrick Gold took over Placer Dome soon after and not only agreed with this approach, but went one step further by requesting practical tools that sites could use day-to-day.

Good models, in any discipline, can be very useful tools but the user must understand their limitations for their particular application. A model does not have to be overly sophisticated to be useful. On the contrary, a technically ultimate model would have very limited use for a production environment if its computational run-time was measured in days. Uses of muck pile movement models include:

- Education – to gain an understanding of blast dynamics; to visualise how the rock is moving in various parts of the muck pile.
- Research – field testing is more expensive and sometimes difficult so models can be used to conduct computer-based experiments to short-list a manageable set of scenarios to test in the field.
- Approximate solutions – not all problems need highly accurate results. For example, during the feasibility study of a new operation, an estimation of blast movement to the nearest metre would probably be sufficient, but not accurate enough for production grade control.
- Supplemental measurements – if there is no measured data for some reason, then a good estimate is better than nothing at all. It is not feasible to measure every point in a blast and BMT currently uses simple models to interpolate between measured points – a better model or more movement vectors would result in more accurate interpolation.

Analysis of blast movement

Figure 8 shows an example of the measured variation in horizontal displacement from a number of blasts at the same operation. The blasts were separated by time and one set had a slightly higher powder factor than the other but were from the same region of the pit. The measurements shown are only those from the body of the blast, ie any measurements that may have been affected by boundary conditions have been removed. This highlights the variations in movement that can be obtained for similar conditions.

Figure 9 shows the results from a project that was done specifically to understand blast movement dynamics. Most of the patterns were designed for consistent movement (large, echelon-initiated blasts) and BMM®s were strategically located to achieve various objectives, one of which was minimising the influence of variations in parameters such as depth, rock mass, initiation and edge effects. The data was then further filtered to remove erroneous or unrepresentative data. In summary,
these were well controlled tests to compare blast movement but once again, there is significant variation in the results that cannot be attributed to any measured parameters.

At this time, there is no blast movement model that is as accurate as monitoring blast movement and there may never be such a model. The main reasons for this are:

- blast movement is highly variable with a large random component – typically at least ±50 per cent of the mean horizontal displacement; and
- of the many factors that affect blast movement, some can be controlled and measured, but the rock mass has a large influence and its properties can never be completely accurately defined.
Simple cost-benefit analysis

The choice of whether to model or measure blast movement should be based on the net benefit and a basic cost-benefit analysis is reasonably straightforward. For grade control, the accuracy of defining the post-blast ore location determines the ore loss and dilution. There is no disputing the fact that modelling is the easy option and sometimes it is perceived to be cheaper, but is this really the case when less accurate modelling is likely to result in greater ore loss and dilution when compared to direct measurement?

Figure 10 is a fictitious, but realistic, example of the zones of ore loss and dilution for a typical echelon blast. There is a mix of isolated and contiguous ore blocks with both NS and EW mineralisation, the movement is 4 m at 140° and the resulting ore loss and dilution is 24 per cent of each. Table 1 only deals with ore loss for simplicity as the cost of dilution is site-specific. There will be a certain error between what the model predicts as movement and what is actually measured and this will depend on the model and blasting conditions. Note that greater movement will likely result in a large absolute error. Table 1 computes the value of ore lost by using a model compared to measurement for errors of 1 m, 2 m and 4 m. These errors are independent of the movement depicted in Figure 10, ie it is not suggesting that a model would predict zero movement in this case but a range of errors are presented to extrapolate to blasts with larger powder factors.

Tordoir’s model is the only one in the literature that quantifies prediction errors. In one blast, the average error compared to BMM’s is about 1 m, which would result in US$175 882 worth of gold

![Movement 4 m @ 140 deg](image)

**FIG 10** - Example of the potential zones of ore loss and dilution for a typical echelon blast.

**TABLE 1**

The value of lost gold and zinc for various model errors.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price (US$)</th>
<th>Grade</th>
<th>Error of model relative to measurement</th>
<th>Ore loss (%)</th>
<th>Ore loss (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>$ 1500/oz</td>
<td>1.8 g/t</td>
<td>4 m</td>
<td>24%</td>
<td>$680 657</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 m</td>
<td>12%</td>
<td>$347 952</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 m</td>
<td>6%</td>
<td>$175 882</td>
</tr>
<tr>
<td>Zinc</td>
<td>$ 2340/t</td>
<td>9%</td>
<td>4 m</td>
<td>24%</td>
<td>$2 064 153</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 m</td>
<td>12%</td>
<td>$1 055 194</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 m</td>
<td>6%</td>
<td>$533 377</td>
</tr>
</tbody>
</table>
lost and more than US$2 M worth of zinc. In the second test blast, the error between model and measurement is about 7 m, which would result in the loss of about US$1.2 M worth of gold and about US$3.6 M worth of zinc. Taylor and Firth (2003); Thornton, Sprott and Brunton (2005), and more recently Fitzgerald et al (2011), all reported potential ore loss expressed as percentages and/or dollar values of similar magnitudes. These numbers almost seem too large to be true but before they are dismissed, consider that work has been done at several sites that blast with very high powder factors to achieve good fragmentation. The rock in the body of these blasts moved in excess of 20 m on average – and considerably more at times – and this is similar to the scenario that Tordior modelled. Compare these to the cost of monitoring blast movement that is approximately US$2000. The reality is that minimising ore loss and dilution is critical to every mine’s bottom line. Even if a model could get within 0.5 m of actual, it would not be more cost effective than measurement for most operations.

CONCLUSIONS

Ore block movement is intrinsic to any mining operation and this must be taken into account accurately for effective grade control. This can either be measured directly with physical markers embedded in the blast, or predicted using modelling techniques. Visual markers such as pipes have a number of limitations in achieving accurate movement vectors, one being the assumption that surface movement is not necessarily representative of the movement within the bulk of the shot. Remotely detectable markers that can be inserted into the blast volume provide much more valuable 3D vector information that can be used to precisely move dig polygons, even in multipass operations.

Some movement models developed to date may give reasonable indications of blast movement vectors, and in the absence of any physical measurement provide a ‘better than nothing’ solution. However, sparse, uncertain input data to the models and non-ideal algorithms will always result in some error in the output. Errors of even a few metres can have significant economic consequences in terms of ore loss, especially with commodity prices at all-time highs. Models are potentially useful for such things as training and non-critical tasks but their inaccuracy when compared to direct measurement means they are not the optimum solution for grade control.

Hard-rock mines do not mine from their resource model because it is not accurate enough, yet there seems to be a desire in some quarters to adjust ore boundaries after blasting according to a model or movement template. A template will apply an average movement derived from monitoring a few blasts and assume that these will be applicable across the entire gamut of conditions found across a particular blast domain.

There is an increasing awareness of the magnitude and variation of blast movement and its economic implications. Since practical methods are now available to routinely measure blast movement, there is a compelling case for all mines to include blast movement measurement into their grade control procedures.

REFERENCES


