Mine Development Optimisation – An Evolutionary Process

J Kovacs[1]

ABSTRACT

Underground development drill and blast practices have generally remained unchanged for decades. Historically, development optimisation has focused mainly on the application of perimeter control products in order to reduce overbreak, and efficiencies in development cycle times to increase advance rates. In today's environment of ever increasing operating costs and lower ore grades, it has become even more critical to focus on the optimisation of drill and blast in development mining. It is a crucial component in ensuring mining schedules are maintained, but more importantly achieving the objective of getting to the orebody in the shortest possible time.

This paper will focus on the development optimisation process used in a trial at Xstrata's George Fisher Mine in North Queensland. Not only did the trial include the typical optimisation areas of charge loading practices, perimeter control methods, drill design standardisation and quality control processes, it also investigated the significance of delay accuracy with regards to perimeter control and drill design optimisation.

One of the key measures of the trial was a comparative analysis between baseline development and development with the staged introduction of optimisation elements using 3D photogrammetry as a validation tool. A detailed cost analysis between the various stages was also a key measurable of the trial.

The results of the work undertaken at George Fisher have shown that the accuracy of electronic detonators can produce significant benefits in development blasting. When combined with standard optimisation philosophies a substantial reduction in overbreak, ground support requirements and development cycle times can be achieved, whilst still being able to reduce the overall development operating costs.

INTRODUCTION

The George Fisher Mine is situated approximately 25 km north of Mt Isa, it is an underground silver, lead and zinc operation wholly owned by Glencore Xstrata PLC producing in excess of 3 Mt/a.

The mine is divided into two separate mining areas being George Fisher North and George Fisher South.

Both mining areas have dedicated development schedules with a North: South split of 66:34 for the scheduled development metres for 2013/2014. Development equipment consists of Tamrock Axera electric hydraulic jumbos, Atlas Copco 50D trucks and Elphinstone R2900 load-haul-dumps (LHD).

Mine development optimisation has become almost a mandatory exercise in the 21st century for most underground operations as a means of improving the efficiency and quality of development and importantly reducing the overall costs.

The cost of development in underground metalliferous mines has increased substantially to the point where adverse commodity prices can impact the sustainability of any operation, particularly those that are running with minimal margins.

Less than ideal results in fragmentation, overbreak, advance and profile integrity mean mining operations are bearing unnecessary costs in development that will impact on the mine schedule but more importantly the mine's sustainability. Sustainability in times of adverse commodity prices and a slowdown in economic activity will show that a mine has control over the mining cycle.

DEVELOPMENT OPTIMISATION PROJECT

George Fisher Management made the decision to undertake a development optimisation project to reduce the costs of development and to improve the standard of work practices and face compliance to both drill and charge designs.

The project heading was located on the 7L in the North Mine with the face to be developed a fresh air access designated as a profile D. The dimensions for this particular profile are a height of 5 m, a width of 5 m with the backs arched from shoulder to shoulder.

The rock mass in this area consist predominately of closely spaced shale beds dipping 65–70° to the west and calcite infill faults and shears. The rock mass is generally very poor mainly due to the strong fault and shear influence with rock quality designation (RQD) values ranging from zero per cent to 20 per cent.

1. Senior Technical Consultant, DynoConsult, 282 Paringa Road, Murarrie Qld 4172. Email: john.kovacs@ap.dynonobel.com

Previous development within this area resulted in poor perimeter control and overbreak making this an ideal area to show any benefits of optimisation elements, particularly in perimeter control.

The objectives of the project were to:

- measure and establish a benchmark for current practice
- improve the quality of the perimeter profile through optimised charging and the use of electronic detonators
- develop standardised optimal drill designs with reduced holes
- improve blast fragmentation and muck pile positioning through the flexibility and consistency of electronic timing
- reduce the costs and cycle times for the elements of development mining
- establish a standard of best practice.

The development optimisation project consisted of staged elements that were progressively introduced in a series of steps to highlight the immediate benefits introduced from the baseline benchmark.

The scopes of works undertaken were:

Step 1 Establish the benchmark of current practices with four faces drill and blasted.

Step 2 Fire four faces with revised perimeter charge design including inner easers.

Step 3 Fire four faces with perimeter holes initiated by electronic detonators.

Step 4 Fire four faces with full electronics based on current drill designs.

Step 5 Fire four faces with full electronics with redesigned drill and charge patterns.

PHOTOGRAMMETRIC ANALYSIS

Photogrammetry is the science of using sets of 2D images to create accurate 3D models (Birch, 2008). This requires capturing 16 images of a heading taken at four different orientations from four distinct station setups. Adam's software identifies and generates relative points throughout the 16 images and processes a digital terrain model (DTM) with a visual 3D image.

The main field components of the system are a single camera mounted on a custom panoramic camera mount and three LED lamps as seen in Figure 1. They provide even illumination with soft shadows and are the same colour as daylight to aid geological identification.

Adam Technology's digital photogrammetric tool 3DM Analyst Mine Mapping Suite™ was used to validate any improvements during each step. The photography was conducted shortly after completion of the mucking cycle and before the mechanical scaling/ground support cycle.

VALIDATION AND ANALYSIS

A number of standard methods were used to validate results, these being:

- direct measurements – advance, butts and fragmentation
- comparisons – from stage to stage
- digital and photogrammetric imaging
- cost analysis – what cost benefits were delivered to the operations
- feedback – whether it's better or worse, quicker or slower.

Adam 3DM Analyst™ was used to calculate volumes of post fired faces in each of the project stages.

Survey was present to conduct the mandatory face pickups as well as the pickups for the control points marked out for geo-referencing the photogrammetry process.

The DXF (design files) received from the survey department were imported into 3DM Analyst so that the as-built DTM could be laid over the design profile DTM for comparison and calculation.

Volumes were calculated in 1 m sections to determine conformance to design and give an average for overbreak/underbreak as shown in Table 1.

TABLE 1
Volume calculations.

Stage	Design volume	Average volume	Difference	% Overbreak
1	23.24	29.25	6.01	25
2	23.24	27.28	4.04	17.4
3	23.24	25.74	2.5	10.8
4	23.24	24.28	1.04	4.5
5	23.24	24.98	1.74	7.5

FIG 1 – Camera/mount and underground field kit in operation (images courtesy of Adam Technology).

The ability to view and compare both DTM's from any viewpoint shown in Figure 2 also gave invaluable feedback on non-conformance and what was needed to improve results to mining personnel, including drillers and charge crews.

Stage 1 – benchmark

Stage 1 was to establish the benchmark of current practices with four faces drill and blasted.

Like all mines, both the jumbo operators and charge-up personnel at George Fisher have individual work methods and styles that are unique to each other.

Jumbo operators differ in the drill pattern and number of holes drilled and the type of burn/cut used. Each of the four faces drilled in this stage were different to each other with an average of 59 holes drilled per face and a chargeable length of holes of 4 m.

There were two variants of burn/cuts used, one being an exposed four reamer post hole burn/cut, the other a site specific 3 reamer cut in a triangular pattern without a shot hole as shown in Figure 3.

Charge-up personnel also had individual preferences for timing using long period (LP) delays and charging with an average of 320 kg of bulk emulsion used at a set density rate of 1.0 g/cc; this included approximately 30 kg of emulsion used to prime the system. Charge up crew deliver the bulk emulsion with a DynoMiner Profile™ mated to a Normet carrier to charge the face drill holes. The unit consists of a 1.8 t emulsion tank with two trace chemical tanks.

Perimeter holes, when decoupled charged, were from grade line to grade line. Two different delays were used with the perimeter holes in the walls fired first followed by the back perimeter holes.

Post fired faces indicated less than satisfactory advance with average butts of around 400 mm with minimal to no half barrel marks around the perimeter indicating a fully coupled charge as shown in Figure 4.

Inspections were conducted after the mucking cycle and revealed faces that were dished out (concaved) with an average of 750 mm protrusion of rock from the knee holes to the lifters. This made mucking out to the floor difficult and without a square face; hand bogging was required to expose the butts in the lifters. To square off the face, shorter holes are required in the concaved area, thus resulting in less than maximum advance in the following cut.

Volume calculations were conducted on the four faces fired with an average overbreak of 25 per cent to the mine design.

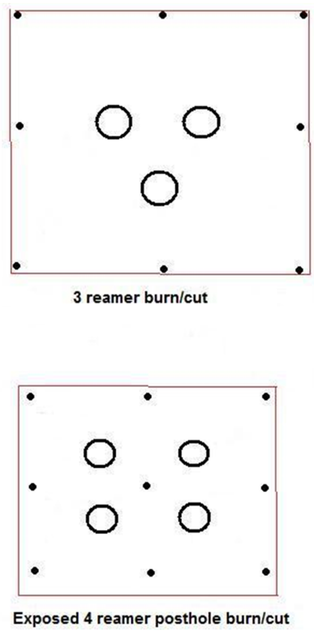

FIG 3 – Baseline variants of burn/cuts used.

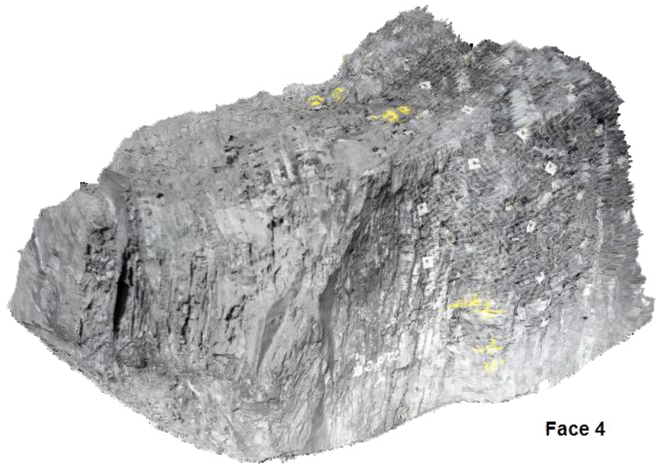

FIG 4 – Photogrammetry pickup of benchmark face.

The percentage in overbreak translates to an increase in load and haulage of material, the mucking cycle time as well as the scaling/ground support cycle time.

The increased cycle times greatly impact the schedule as well as the overall cost per metre to the business.

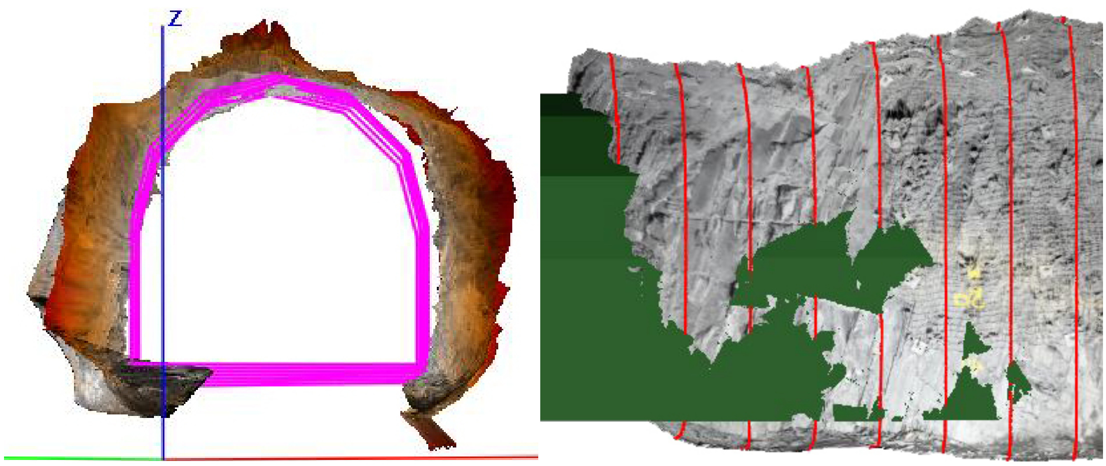

FIG 2 – As-built comparisons to design.

Stage 2 – revised perimeter charge

The focus for Stage 2 was to improve the profile integrity of the perimeter of the drive by ensuring a de-coupled charge of 2 kg per perimeter hole with the density lowered from the original 1.1 g/cc to a 0.85 g/cc.

Stage 2 was to fire four faces with revised perimeter charge design including inner easers. Timing of the perimeter holes was also changed from the benchmark practice of two different delays to all fired on one delay.

In poor ground conditions, the shock energy of a hole fired will further damage exposed ground fired by the preceding detonator when using two delays. This effect is further exacerbated when pyrotechnic scatter of the detonators is taken into account.

Good perimeter control in underground development is essential to minimise back breakage, overbreak and preserve the contour of the designed profile especially in poor ground conditions.

The benefits of good perimeter control translate to decreased cycle times in scaling, ground support, load and haul. Decreased cycle times result in productivity gains in the development schedule and importantly reduce the overall cost per metre of development.

Perimeter holes, if charged correctly, will more often than not reveal the accuracy of drilling by leaving visible half barrel markings, the post fired perimeter holes. The half barrel markings will indicate the standard of drilling ie holes drilled parallel to each other and those holes drilled at the correct direction and grade as per design.

The charging unit has the capability to string load (decoupled charge) any hole through the retraction rate of the charge hose driven by a set of motorised wheels. Hose retraction enables charge rates as low as 0.70 kg/m or 48 per cent charge volume of hole.

The density of bulk emulsion can be varied between 0.80–1.2 g/cc by simply adjusting the trace chemical ratios. The advantage of variable density, as well as string loading functions, is that the explosive product can be varied according to ground conditions.

In extremely poor ground conditions both the density and charge rate of emulsion are lowered to ideally minimise potential blast damage to the surrounding rock outside the perimeter envelope.

There were improvements in the profile integrity of all four faces with noticable half barrel markings as well as a 20 per cent decrease in the quantity of emulsion used from baseline practice as shown in Figure 5.

Volume calculations of the post fired faces of stage 2 showed an immediate reduction in overbreak from the benchmark 25 per cent to an average of 17.4 per cent.

Stage 3 – perimeter holes initiated with electronic detonators

Along with the revised perimeter charging of stage 2, this stage incorporated the use of SmartShot™ electronic detonators to initiate all of the perimeter holes. All of the perimeter holes were timed at 6500 ms (LP16) (Dyno Nobel, 2009). Stage 3 was to fire four faces with perimeter holes initiated by electronic detonators.

FIG 5 – Photogrammetry pickup of revised perimeter charge.

There has always been an assumption in mining circles regarding the effect of the pyrotechnic scatter of LPs on controlling smooth blasting practices of perimeter holes.

LP16 detonators tested have revealed a scatter range between ±150 ms in contrast to a SmartShot™ electronic detonator which has a range of ±1 ms.

Post fired inspections of the four faces revealed significant improvements in profile integrity with predominant half barrel markings noted as shown in Figure 6.

The blasts showed that perimeter holes fired with electronic detonators timed on one delay with practically no scatter result in clean breakage from the surrounding rock mass with less damage outside of the perimeter envelope. This was also confirmed by the jumbo operators who scaled and ground supported the post fired faces.

The predominant half barrels also led to some of the jumbo operators inspecting post fired faces as their drill standards were now the show piece and as a result drill standards for perimeter holes improved substantially.

Perimeter holes fired with electronics showed significant improvement in the reduction of overbreak from the benchmark of 25 per cent to 10.8 per cent.

Feedback from a couple of the jumbo operators cited the main benefits being the reduced time taken to both scale and install the ground support.

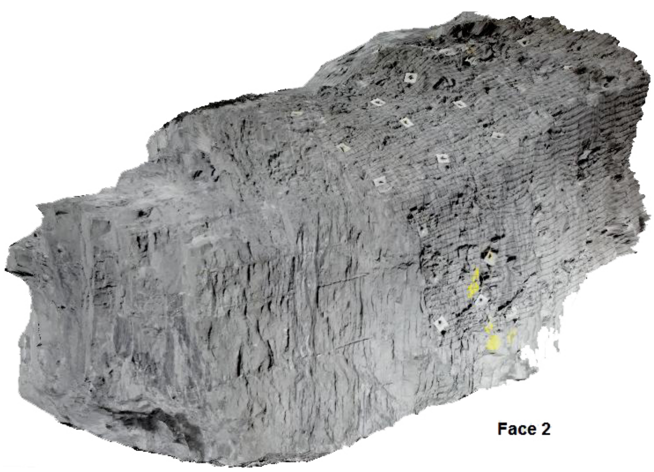

FIG 6 – Photogrammetry pickup of perimeter holes initiated with electronic detonators.

Stage 4 – full face electronic detonators used in benchmark drill standard

This fourth stage incorporated the full use of electronic detonators in the face which were timed as per the nominal LP timings that would have been used. Stage 4 was to fire four faces with only electronic detonators based on current drill designs.

The results were very encouraging with continued half barrel markings of perimeter holes and a reduction in the length of butts as shown in Figure 7.

FIG 7 – Photogrammetry pickup of full face electronics.

One of the benefits of electronic detonators from the safety standpoint is that faulty detonators can be identified during the testing stage and the detonator can be replaced prior to blasting, ensuring full firing of drilled holes.

The combination of underground bulk emulsion which has the characteristic of high shock energy and electronics with almost zero scatter, resulted in improved advance and improved fragmentation of the muck pile. Drill inaccuracy had less impact on face advance under this charging regime.

There were further reductions in overbreak averaging 4.5 per cent from the benchmark of 25 per cent with jumbo operators continuing to take greater care in drill accuracy of the perimeter holes.

The reduction in overbreak had contributed to the quickest mucking and ground support cycle times since the project began. This has resulted in an extra face taken for the week.

Stage 5 – full electronics with redesigned drill and charge pattern

Stage 5 involved the firing of four faces with electronic detonators and redesigned drill and charge patterns.

This final stage was the combination of the improved elements of stages 2 to 4 with a redesign of the drill and charge pattern. Drill accuracy was of great importance with particular emphasis placed on the initial burn/cut and perimeter holes.

As shown in Figure 8, the design incorporated 53 drill holes with a shadowed four reamer post hole burn/cut selected as it is a proven choice for performance in varied ground conditions.

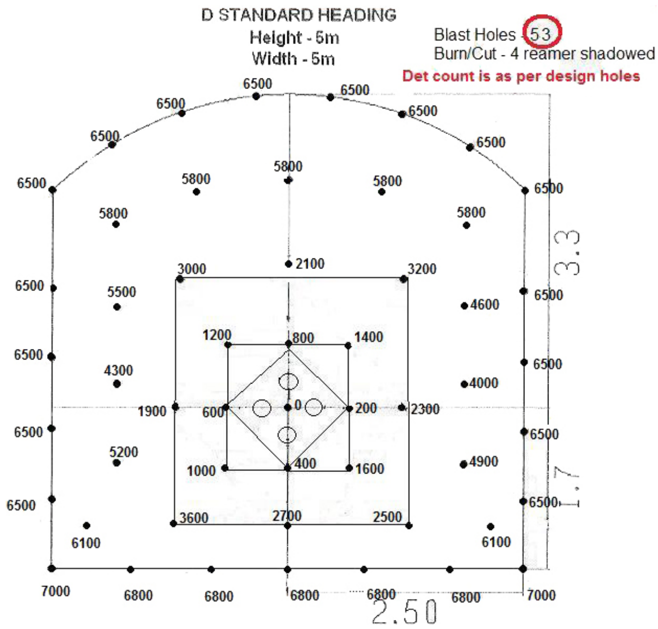

FIG 8 – Redesigned drill and timing design for profile D.

The initial easer holes were timed at a faster rate to ensure maximum throw from the initial void. Timing was conservative in that it was faster than for traditional LPs but with enough delay from set holes such as easers, box holes to the outer diamond then to the outer box holes to ensure non-confinement.

Charge criteria consisted of a density setting of 0.85 g/cc with a fully coupled charge rate of 4 kg per hole and a decoupled charge rate of 2 kg per hole.

Post fired inspections of the stage 5 headings revealed good fragmentation with an average size of around 150 mm as shown in Figure 9. Consistent half barrel markings around the perimeter confirmed the benefits of both precision initiation and good charging practices in maintaining the perimeter contour as shown in Figure 10.

Muck pile shape was considerably flatter with dirt thrown 10 m further than normal. There was also dirt a third of the way up the face rilling down at an angle of approximately 30°.

The 7L LHD operator reported improved ease in mucking as a result of fragmentation and throw of dirt down the drive.

There were very few butts with those that were evident only approximately 50 mm deep. This was more apparent after mandatory face prepping where butts are identified and circled with white paint as shown in Figure 9.

Faces were inspected post mucking/prescaling; all were clean and squared off from top to bottom with no visible dishing.

Overbreak for the final stage averaged at 7.5 per cent, still a significant improvement from the benchmark average and a contributing factor in improving the cycle times of the elements of development.

RESULTS

The development optimisation project delivered a number of benefits to the George Fisher Mine with the following findings:

- A substantial improvement in the quality/integrity of the perimeter profile with the detonators timed on one delay.

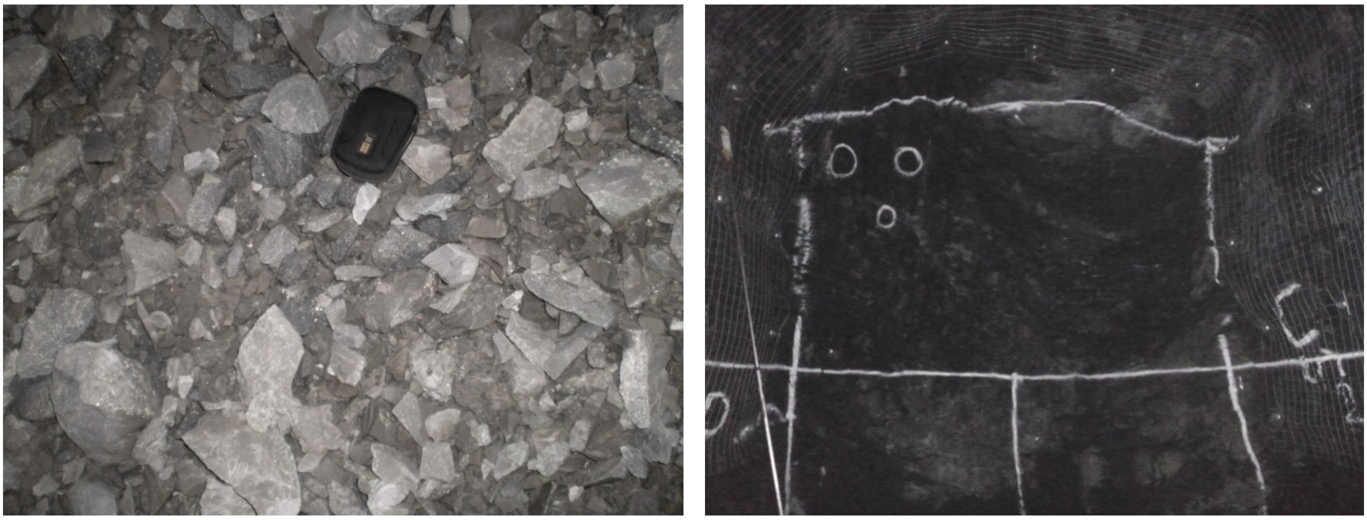

FIG 9 – Fragmentation and butt identification.

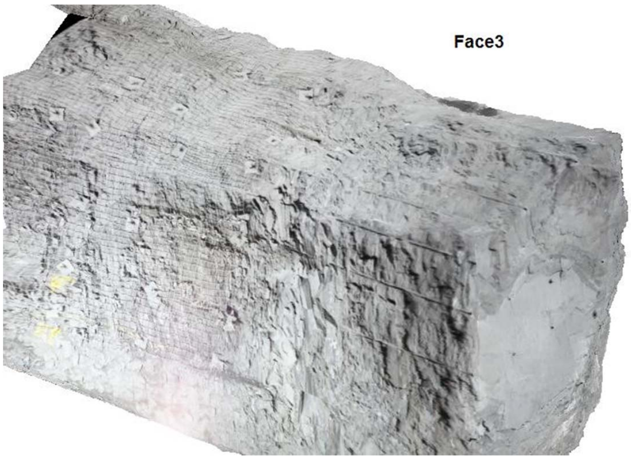

FIG 10 – Pickup of full face in Stage 5 with redesigned drill and charge pattern.

- Half barrel markings became noticeable when string loading perimeter holes.
- Predominant half barrel markings were evident from Stages 3–5.
- Overbreak was reduced from 25 per cent to 7.5 per cent.
- Scaling and ground support cycle times were reduced.
- A 20 per cent reduction in bulk emulsion used for charging.
- A 13.5 per cent improvement in the development cycle time.
- A reduction of six face holes against the average of 59 face holes improved the cycle time as well as long-term metres gained. The shadowed four reamer burn/cut proved to be effective in the varied ground conditions encountered.
- A noticeable increase in advance when using precision timing with reduced/minimal butts.
- A significant improvement in the standard of drilling which increased conformance to design. Visible half barrel markings had the effect of putting operators on notice regarding their drilling skills.
- Elimination of face dishing when using precision timing with bulk emulsion.
- Precision timing improved fragmentation and muck pile shape, decreasing mucking cycle times and increasing productivity.
- Considerable savings in overall development costs.

CONCLUSION

To remain competitive and sustainable in an environment of cost pressure and economic volatility, underground operators need to regularly take stock of their development processes by optimising core elements.

This will ensure sustainability in both adverse and favourable global markets but more importantly help the business to evolve to best practices that capture the benefits that otherwise would have been wasted.

The findings of the optimisation project were presented to George Fisher Management and as a result the decision was made to implement those optimised elements. This is testimony to the commitment of the mine in ensuring best practice, reducing the cost per metre of development and improving its sustainability in today's volatile environment.

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