Improving the Productivities of Surface Coal Mines in Australia

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ABSTRACT This paper presents four case studies from surface coal mines in Australia. The first case study is from a coal mine where a dragline operates in 1 km long strips. The site requested an optimisation study to improve the muckpile profile for their cast blasts. Cast percentage, muckpile profile, fragmentation, and easy access for dragline entry into the strip following a blast were some of the Key Performance Indicators (KPI). In case study 2, dozers were used to move the blasted overburden material to the spoil instead of truck/shovel fleet. An optimum profile was required for the dozers for this low-cost mining operation. In case study 3, blast-generated fume (NOx) which is toxic and highly visible is minimised. The fourth case study summarises a vibration project at a large open cut coal mine where planned blast polygons were close to the residential property. These case studies have their own Key Performance Indicators (KPIs). It is shown that these KPIs were delivered successfully which allowed sites to improve their productivities while maintaining the Licence to Operate and preserving the mine reputation.

1 INTRODUCTION

Australia is the fourth largest coal producer and the largest coal exporter in the world. Metallurgical (coking) and thermal (steaming) coal productions in 2016-2017 were approximately 196 Mt and 253 Mt respectively (Thurtell, 2017). Slow growth is expected in the next five year period (see Figures 1-2).

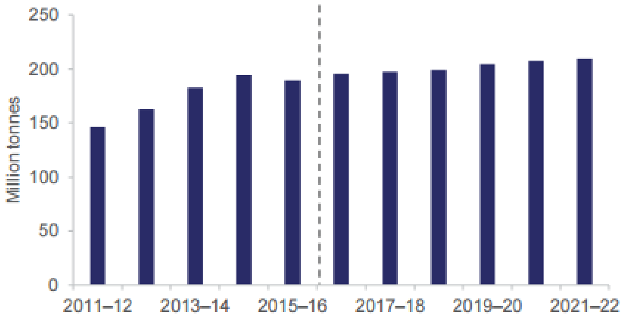

Figure 1. Australia’s metallurgical coal output (Thurtell, 2017).

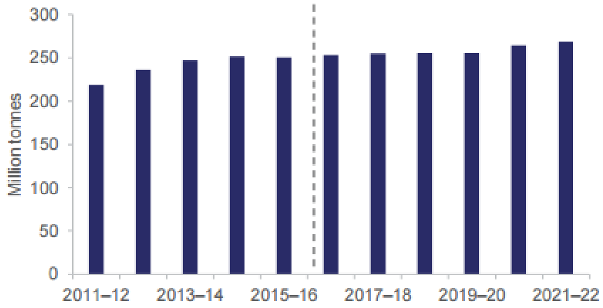

Figure 2. Australia's thermal coal output (Thurtell, 2017).

The mining methods used in open cut coal strip mining in most major coal producing countries have been well established and fairly consistent over the past few decades. These general mining practices have been described by Kukla et al. (1993) and Aspinall et al. (1993). In most cases, the overburden and coal cannot be excavated without prior blasting operations.

Technological advancements especially in drill&blast and load&haul (mainly larger mining equipment) have made surface coal mining today more productive than it has ever been. This paper focuses on only drill&blast related advances. Major drill and blast methods used in Australia were summarised in the next section.

This paper presents several case studies in which improving mining productivity was vital to the success while maintaining Licence to Operate at the mines.

2 BACKGROUND

The use of cast (throw) blasting involves a substantial proportion of the overburden material thrown or cast directly into a final spoil position by the blast. This practice effectively utilises the explosive energy to perform two functions, namely fragmentation of the rock for subsequent excavation as well as the direct excavation of a proportion of the rock without the need for mechanical handling afterwards. Most commonly around 15-30% of overburden material can be moved in this way, leading to a correspondingly reduced amount of waste to be moved by the mine fleet. Overviews of throw blasting practices and the effects of blast variables have been discussed by Sengstock and Kennedy (1995), Chiappetta and Postupak (1995), Workman (1998), Kanchibotla and Scott (1999), Brent and Noy (2006), Esen and Nagarajan (2015). One of the main drawbacks of the cast blast is the coal loss. To minimise the coal loss, baby-deck cast blasts (with traditional and dynamic buffer) have been employed in Australia with mixed success to date (Kanchibotla and Scott, 1999; Kanchibotla, Laing and Grouhel, 2006; Goswami et al., 2008).

The baby-deck is a small deck of explosive just above the coal that fires on a separate delay, conventionally 50-100 ms, after the main column of explosive in the throw blast. In addition to baby-decking, a large buffer of material is constructed in front of the coal to protect it from movement during the blast (see Figure 3). At most mines, first three rows are usually baby-decked in a cast blast. Some sites apply baby-decking technique for all rows.

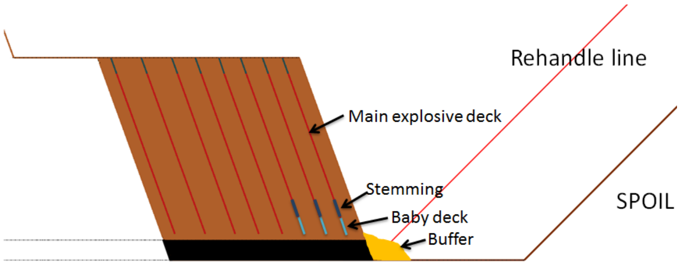

Figure 3. Baby deck cast blast.

Dynamic buffering can be applied by firing the face row of the cast blast. Once face row settles in front of the coal which may take sevaral seconds, the main shot is fired after that. This technique appears to be an effective method for reducing coal loss and eliminating the additional buffering by trucks and dozers. It is considered as more advanced version of the traditional baby deck cast blasting.

Orica's mining method of Stratablast^{TM} has been described by Goswami and Brent (2006). It is essentially a technique of implementing multiple different blast types within a single drill, blast and excavation cycle. The method combines a throw blast with one or more stand-up blasts in a single event. The throw portions of the blasts are fired before the stand-up portions, with a separation in time in the range of 500 to 10,000 ms. This "inter-blast" delay is dictated by rock properties and the time required for the throw blast layer to fall in place. These separate sub-blasts in several layers are each loaded to a particular powder factor, separated by a column of stemming and fired on quite different initiation sequences and inter-hole delays from each other. Goswami et al (2015) showed that this technique provides effective coal protection and streamlines the mining (mine planning and resource management). It also improves the dragline and drill&blast productivities.

In a multi-seam case, through-seam blasting method is favorable especially when coal dips or seams are separated by a few to several metres. The larger number of mining cycles becomes costly if conventional drill&blast method is carried out. In addition, mining equipments often have problems when the coal seams are steeper than 10%. Thin coal seams with thickness of approximately 200mm can be recoved using this technique (Nagarajan et al, 2015).

Electronic blasting systems and higher energetic bulk explosive products are some of the key technology enablers in achieving better blast outcomes while conducting above blast types (cast, stratablast and through-seam). Smart blast designs using these products with more innovative charging and firing configurations help improve productivity and result in better muckpile shapes suiting to the operational needs.

Regarding the environmental impacts, the use of advanced vibration and airblast models while conducting the blast designs help mines maintaining their Licence to Operate (LTO). Better explosive selection and application minimise toxic bast-generated fumes which again help miners keeping their LTO.

3 CASE STUDY 1

The first case study is from a coal mine in Australia where a dragline (Marion 8050) operates in 60m wide and 1km long strips. Dragline dig methods used at the mine site vary from traditional key-low wall combinations, high wall chopping and extended bench according with spoil profile balance and a planned dragline productivity of 2,000 m^3/h.

The primary goal of this site is to reduce the cost of production due to the coal price drop (a few years ago) and high ash content (i.e. low coal recovery). To achieve this, the site needed to optimise their muckpile profile for more efficient dragline operation as well as achieve well-fragmented muckpile for the dragline by improving the drill and blast designs.

Typical overburden height ranges from 30m to 50m (see Figure 4). Typical cast blast volumes are approximately 2.2 million m^3. Overburden is typically weathered interbedded sandstone overlying sandstone/siltstone layers. Hard band (carbonaceous siltstone) exists above 6.5-7.0m thick coal seam.

Figure 4. Cast blast.

Cast blast design parameters for the benchmark blast are as follows:

- hole diameter : 251mm
- # of rows: 8
- burden : 7.5 m (face row burden: 7.1m)
- spacing : 14 m
- blasthole angle : 15 degrees
- average hole depth : 36 m
- design powder factor: 0.49 kg/m^3
- stemming length: 6 m
- main bulk explosive: Heavy ANFO in dry holes and pumped emulsion in wet holes
- Loading time: up to 3 weeks using a single MMU
- Coal buffered with coal rejects
- full strip fired using non-electric system.

During the benchmarking phase, a detailed Quality Assurance/Quality Control (QA/QC) process was established which included the definition of the top of coal layer in the design allowing backfill and redrills. This process showed that all blastholes did not meet the required tolerance (backfill and redrill).

The implementation of this QA/QC process ensured improved control of blasthole depths and associated stand off coal. This process made sure that muckpile is well-fragmented (especially above the coal seam where the overlying rock is hard). All holes were checked during loading and the design stemming lengths were achieved. Crushed aggregate was used as backfilling/stemming material. Two MMU’s were used after the benchmarking to minimise the loading time. Aquacharge (more water resistant heavy ANFO) was used in water-saturated ground to manage the post-blast fume.

In addition to QA/QC improvements, a few design modifications were made including:

- spacing: 13 m
- burden for the first two rows: 5.5-6.0 m, the rest is 7.5 m
- stemming length: 5 m
- electronic timing to achive 20-50 ms/m burden relief
- control row timing reduced for improved cast percentage.

By implementing the QA/QC and blast design changes; the following outcomes were obtained: an increased cast of 4% (from 21.1% to 25.1%) and an improved muckpile profile (Figure 5) that reduced rehandle significantly (from 45% to 30%) and improved dragline rate of advance. Although benchmark and current dragline productivity rates (bcm/h) were similar, reduced rehandle and dozer requirement for preparation work the new post blast muckpile profile delivered an improved faster advance rate along strip with the full strip of coal being uncovered approximately two weeks ahead of schedule. The designs also catered the dragline entry requirements to minimise the lost time for the dragline (i.e. dozer preparation work for the entry area).

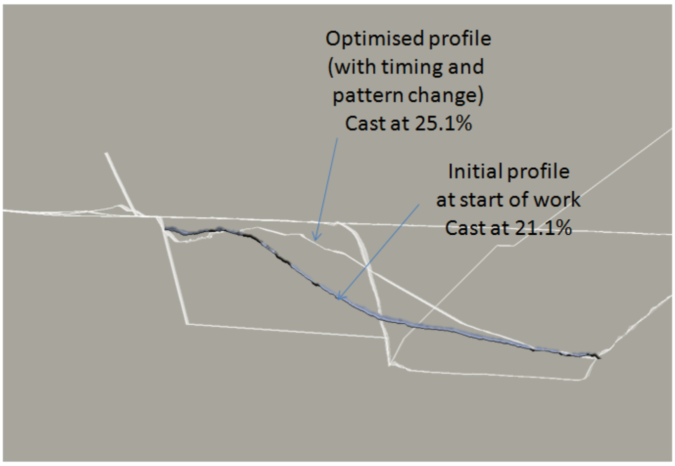

Figure 5. Benchmark and optimised muckpile profiles.

4 CASE STUDY 2

This case study is from a Queensland open cut coal mine which utilises excavators, loaders, dozers and trucks to mine the coal. Only 25% of the overburden is blasted with the remainder being free-dig material. The blasted portion of the overburden rock is fresh mudstone/siltstone which is relatively competent rock that definitely requires blasting. As with the previous case, the site required to reduce their cost of mining so they set up a project team to optimise the use of dozers (instead of truck/shovel) by investigating changes in blast designs to deliver a change in the post blast muckpile shape. To achieve this goal, the post blast muckpile shape needed to have an increased cast into the void and achieve higher dozer productivity, improving the advance along strip and the rate of coal being uncovered.

At the time of the project, the site had no records of cast blasting. The optimum cast blast design was implemented using a blast design software. Pre-blast survey (face points, crest, toe), top of coal and drill surface points were imported and front row holes were positioned according to the surveyed face profile. Average face angle was 58.2±4.7 degrees. This face angle was very shallow for the cast blasting application. The site was using a drilling contractor to drill 165mm diameter holes. These drills were able to drill at a maximum of 10 degrees. The heavy burdens resulting from these drills and face angle constraints were expected to limit the cast results.

First cast blast with 259 holes was designed at a powder factor of 0.40 kg/m^3 (spacing:7m; burden: 3.5-6m) with a blast volume of approximately 162,000 bcm. All holes were designed at 10 degrees. Average hole length was 17m. An electronic blasting system was utilised to achieve the required timing and burden relief (20-40 ms/m).

The blast delivered excellent fragmentation and dozers performed well (Figure 6). Dozing productivity was difficult to quantify but operator feedback indicates that the improved muckpile looseness was giving the dozer “an easier push” and the muckpile profile was more suited to the dozing.

The cast analysis based on post-blast survey data showed that average post blast cast was 11.1%. Furthermore, the centre of prime block had moved 11.1m. Figure 7 shows one of the cast x-sections.

Figure 6. Dozer productivity.

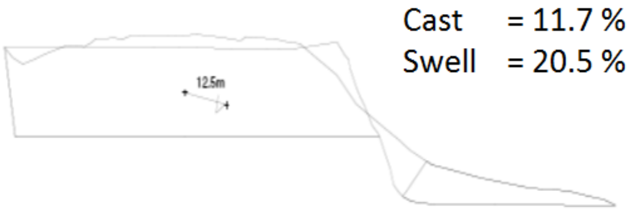

Figure 7. An example cast x-section.

The site implemented these changes which resulted in the increased use of dozers in pushing blasted material to final position. A comparison to the previous truck and shovel operation showed that the site was achieving significant cost savings from cast shots excavated by dozers. This method has been adopted at this site with cast percentage and centre of mass movement results varying from 10.1 to 13.2% and 10.1-13.5m, respectively. Due to the operational issues, hole diameter was not changed.

5 CASE STUDY 3

This case study is an extension of Case 1 which focuses on the blast-generated fume (NOx). The benchmark study identified fume levels of 2-4 (yellow/orange colour) as shown in Figure 8. The definition of a fume event is an event that generates the visible (and toxic) nitrogen dioxide that moves outside the standard blast exclusion zone. Fume is generated as a result of a non-ideal explosive reaction. The causes of the non-ideal explosive reaction are many and variable. The readers are referred to Queensland Guidance Note (2011) and Henley et al (2012) for the causes/mitigations as well as fume levels (0-5).

Figure 8. Blast-genarated fume.

The benchmark study showed the primary causes of the fume events at site were: incorrect bulk type choice in water-saturated ground and long sleeping times. As explained in Case study 1, Aquacharge was used in water-saturated ground and all wet holes were loaded with pumped emulsion. In addition, sleep time was reduced by introducing the second MMU which allowed two weeks of loading time in total (i.e. one week less). A post blast fume assessment was made after the changes and the fume levels were found to drop to 0 (grey colour) which indicated successful results in NOx fume mitigation.

6 CASE STUDY 4

This case study summarises a vibration project at a coal mine. Planned blast polygons at one zone of the pit were close (min of 450m) to a residential property; therefore, there was a need to model the blast vibrations more accurately. An empirical site law was used by the site for predicting the vibration with limited success. The model was not predicting reliably due to variable geology and close distances. Therefore, the site requested more reliable model and making sure that the vibration results meet the local standard requirements. Australian Standard (AS2187.2) requirements are: <5mm/s for the 95% of the blasts and 5-10mm/s range for 5% of the blasts per year.

The site wanted to mine the coal close to the residential area and still achieve the 1850 bcm/hr budget dig rate when mining through this area of the pit.

Esen and Arana (2015) developed an advanced vibration model based on the Monte Carlo approach which included as input to the model: measured waveforms; a single hole site law; ground p-wave velocity; and spatial and temporal aspects of a blast design. Using a measured single hole vibration signature (seed wave), we can simulate a production blast as a phase delayed sequence of spatially separated single holes. The seed wave encodes much of the geological and geometric complexities present in the real world. The Monte Carlo approach involves evaluating multiple simulations of a blast taking into account uncertainty or variability in the input. The effectiveness of such advanced vibration models in simulating production blast vibration attenuation and Peak Particle Velocity (PPV) prediction at sensitive locations have been shown by Blair (2007) and Yang et al. (2009).

Seven seed holes were fired using the electronic blasting system. Seven monitors were used between the blast area and the property including one monitor at the residential property.

P-wave velocity was calculated based on the arrival time of the waveform at each of the vibration monitors and the vibration path length difference between the monitors. The local p-wave ground velocity was determined as 4322±295 m/s. This value was rather high when it is compared to other site's data (usually 1500-3000m/s). Figure 9 shows the PPV vs scaled distance for the seed wave data.

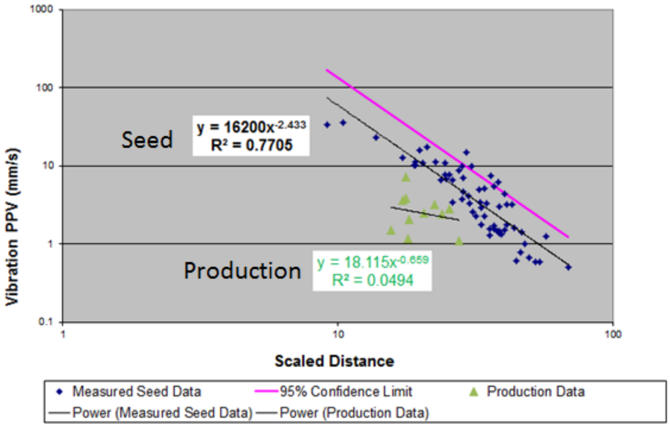

Figure 9. PPV versus Scaled Distance relationships for the seed wave and production blast data.

11 large production blasts were monitored. Closer to the residential area (<700 m), electronic blasting system was preferred instead of a shock tube system. Average hole length was in the range of 13-16m depending on the topography. 200mm hole diameter was preferred in this area. 300-450 kg ANFO was loaded per hole depending on the hole length.

The advanced vibration model was calibrated using two production blasts. Figure 10 shows the comparison of the measured and predicted waveforms (peak vector sum). It is shown that waveforms look similar.

Figure 11 shows that measured and prediction PPVs were reasonably close. There was only one measured value above 5mm/s (less than 10mm/s) which still met the target of 10mm/s (max allowed PPV). Following this blast, delay timings and firing directions were changed after a detailed modelling work. These changes resulted in lower measured PPV (2.11 mm/s at 456m from the monitoring station).

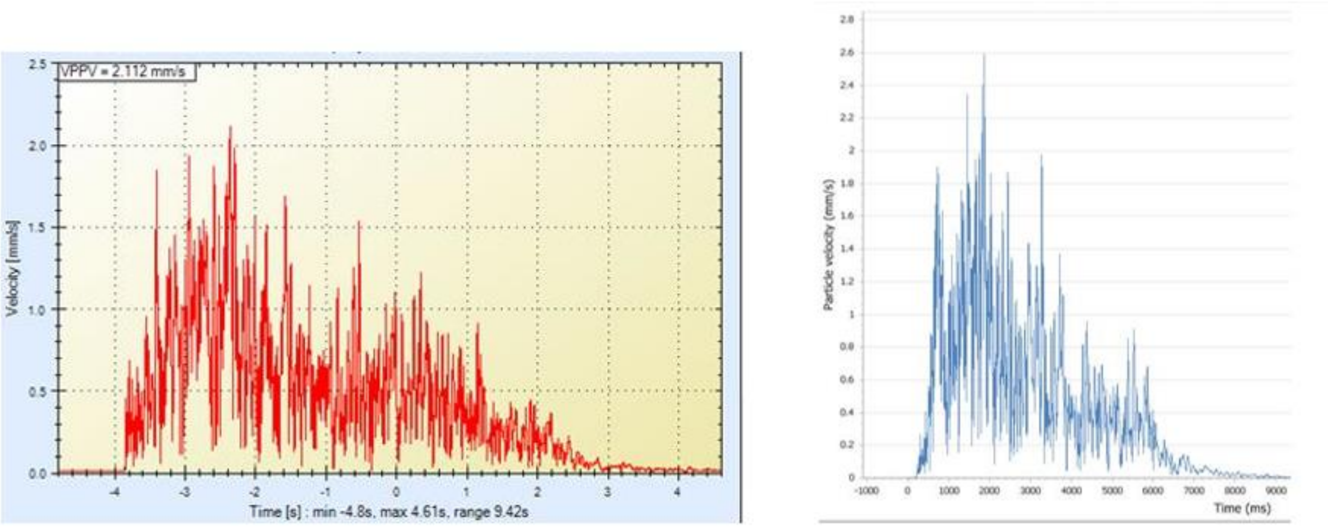

Figure 10. Comparison of the measured (top) and predicted (bottom) waveforms.

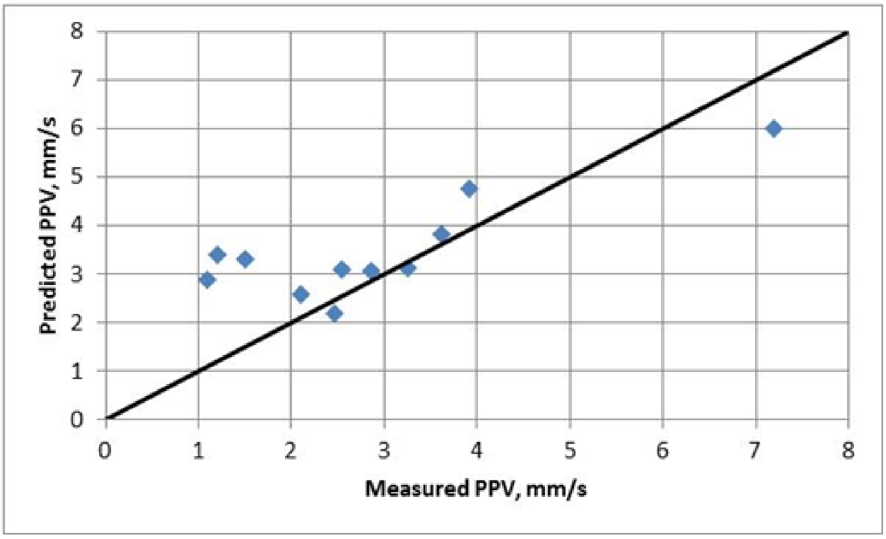

Figure 11. Comparison of the measured and predicted PPVs.

Some of the key findings were:

- As shown in Figure 8, traditional site law cannot be used to predict the vibration accurately due to its poor correlation coefficient.
- Advanced vibration model was reasonably good in predicting the PPV. It was shown to be an excellent tool for managing the risks.
- The site did not have to deck the blasts.
- Electronic timing helped with the flexible timing choices.
- Average dig rate was calculated as 1872 bcm/h with a standard deviation of 172 bcm/h. Average dig rate was slightly above the target dig rate of 1850 bcm/h.
- Vibration model helped the site to extract the coal in this part of the pit while maintaining Licence to Operate.

7 CONCLUSIONS

Four case studies were presented in this paper. Two of the case studies presented the productivity improvements at the dragline and dozer operations which improved the efficiencies at the mine sites and reduced the total mining cost. Optimisation projects were shown to deliver the much needed results at these two sites which were seeking to reduce the total mining cost. In the second case study, it was shown that dozing was much cheaper than truck/shovel and the success in the early stages of the drill and blast project resulted in the acceptance of the dozing over truck/shovel.

The third and fouth case studies showed the importance of the environmental impacts for maintaining the Licence to Operate (LTO). It is possible to minimise or completely elimate the blast generated fume by understanding the root causes and taking necessary actions to fix it. This requires a team work at sites. The sites should get an independent specialist support in these projects when risks are identified.

The fourth case study showed that the site can mine the coal which is close to the residental property without exceeding the vibration limits. Advanced vibration model and electronic blasting system were the main technology enablers in achiving the successful outcomes and managing the risks. The value of these projects is significant in that it allows the mining of the resources while maintaining the LTO. The vibration models were shown to be an excellent tool for managing the risks and achiving the confidence. The sites should identify the risks at the early stages of the project and develop a study by including external specialists to manage the identified risks.

REFERENCES

Aspinall, TO, Isles, PT, Davidson, CW, Davies, AL, Hagan, TN, McManus, DA and Smith, GH, 1993. Strip Mining, in *Australasian Coal Mining Practice*, eds: Hargraves AJ and Martin CH, pp 203-224, AusIMM: Illawarra, Australia.

Blair, D. P, 2007. Non-linear superposition models of blast vibration. *Int. Journal of Rock Mechanics and Mining Science*.

Brent, G, Noy, M, 2006. Throw blasting analysis. *Proc. 8th Int. Symposium on Rock Fragmentation by Blasting, Fragblast-8*, Chile, pp. 255-261.

Chiappetta, R.F, Postupak, C, 1995. An update on causes and recommendations for controlling coal damage when blasting overburden, *Proc. EXPLO '95 Conference,* Brisbane, 345-360.

Esen, S, Nagarajan, M., 2015. Muckpile Shaping for Draglines and Dozers at Surface Coal Mines. *Fragblast-11: 11th International Symposium on Rock Fragmentation by Blasting*, Sydney Australia, pp 409-416.

Esen, S, Arana, C, 2015. *Orica Internal Report* (unpublished).

Goswami, T, Brent, G.F., 2006. Stratablast- A New Mining Method, *Proc.32nd Int. Conf. on Expl. and Blasting Technique*, Dallas, USA. (ISEE: Cleveland).

Goswami, T, Brent, G.F., Hain, L., 2008. Reducing coal damage and loss with a new blasting technology, *Proc. 34th Int. Conf. on Expl. and Blasting Technique,* Dallas, ISEE.

Goswami, T., Martin, E, Rothery, M, Genge, D, 2015. A Holistic approach to managing blast outcomes. *Fragblast 11*. Sydney, Australia. 645-653.

Henley, K., Botttomley, L, Medusalec M., 2012. Mitigation and Management of Blast Generated Fume in Eastern Australia. *Proc. of 38th ISEE Annual Conference On Explosives and Blasting Technique*, Nashville, TN.

Kanchibotla, S., Scott, A., 1999. Study of the influence of buffering on coal edge loss and dilution from cast blasting, *FRAGBLAST-Int. J. for Blasting and Fragmentation*: 3 (4) 365-375.

Kanchibotla, S., Laing, T., Grouhel. P., 2006. Reducing Coal Loss During Cast Blasting at Rix's Creek Mine, *Proc. International Society of Explosives Engineers*, Dallas, USA.

Kukla, GT, Buffier, MJ, Balks, RJ and Farnell, GK, 1993. Open Pit Operation, in *Australasian Coal Mining Practice*, eds: Hargraves AJ and Martin CH, pp 225-237, AusIMM: Illawarra, Australia.

Nagarajan M, Green, A, Brown, P, Dare-Bryan, P, 2015. Managing Coal Loss Using Blast Models and Field Measurement. *Fragblast-11: 11th International Symposium on Rock Fragmentation by Blasting*, Sydney Australia, pp 429-436.

Queensland Guidance Note, 2011. *Management of oxides of nitrogen in open cut blasting*. https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0010/212500/qld-guidance-note-20-mgmt-oxides-nitrogen.pdf.

Sengstock, GW, Kennedy, BJ, 1995. Australian Open Cut Coal Mine Blasting Practices and Trends, in *Proc. 21st Ann. Conf. on Explosives and Blasting Technique*, pp136-152 (International Society of Explosives Engineers: Nashville, USA).

Thurtell, 2017. *Resources and energy quarterly*. www.industry.gov.au/oce.

Yang, R., Scovira, D. S., Patterson, N.J., 2009. An integrated approach of signature hole vibration monitoring for quarry vibration control. *Fragblast 9*, Spain.

Workman, JL, 1998. An Economic Analysis of Cast Blasting compared to other Stripping Alternatives, in *Proc. 24th Ann. Conf. on Explosives and Blasting Technique*, pp587-604, (International Society of Explosives Engineers: New Orleans, USA).