Coal Operators' Conference

Faculty of Engineering and Information Sciences

2015

Monetary Savings Opportunities of Electronic Blast Initiation Systems

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MONETARY SAVINGS OPPORTUNITIES OF ELECTRONIC BLAST INITIATION SYSTEMS

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ABSTRACT: There are several blast initiation systems available on the market; these form a large component of the performance of each blast. Each available system has its own advantages and disadvantages which can affect the fragmentation of each blast, which in turn can affect downstream processes such as digging and hauling of material. This study was conducted to determine if there were monetary savings opportunities due to an increase in fragmentation (and hence downstream productivity) due to the use of an electronic blast initiation system over a pyrotechnic blast initiation system. It was completed using data collected from an open cut metallurgical coal mine in Queensland that agreed to be used as a case study. Statistical analysis of data was completed in order to identify if downstream productivity had increased, with the results from this being used to calculate potential savings opportunities. The results of this study suggest that there are increases in productivity during loading and hauling, which lead to significant savings opportunities when using an electronic blast initiation system.

INTRODUCTION

Most operating mines require a blasting system that is consistently capable of performing each required blast to specification. A large component of achieving this is the blast initiation system. Generally, blasts are initiated using a traditional pyrotechnic system; however these blasts are limited to the set of timings available for both surface connectors and downhole lines, and are also subject to the inherent inaccuracies of pyrotechnic elements (Combrinck and Strong, 2007). Due to these timing limitations and inaccuracies, blasthole interaction is often not at the optimal level to achieve the best fragmentation and, as a result of this, downstream processes such as digging productivity are negatively affected (Sullivan, 2003).In order to combat these issues with pyrotechnic systems, an electronic initiation system can be used. Electronic detonators have been in development for over four decades, yet have only been commercially acceptable within the last ten years. During this time, the benefits of them have become evident in both safety and productivity aspects of mines. From a safety perspective, the use of inert wires removes the inherent risk associated with pyrotechnic connections, while two way communications between a programming unit and each detonator aids in the identification of faults before they become a major event. Potential improvements to productivity stem from the increased control over blast induced forces in the strata that allow for better fragmentation which can decrease digging cycle times, and increases in loading fill factors (Cardu, 2013).

This project was completed using an open cut metallurgical coal mining site in Queensland as a case study site. The site had been using a pyrotechnic blast initiation system, using shock tube connectors. The price of metallurgical coal rose dramatically in 2011 (MCI, 2014), which provided larger revenue for the sites coal. Using this additional income, the site started investigating the use of a more expensive electronic blast initiation system. When the metallurgical coal price dropped in 2013 (MCI, 2014), many mine managers and accountants recommended reverting to the use of a pyrotechnic system as these systems are cheaper than electronic systems. Fortunately operations managers on site identified that there appeared to be an increase I productivity when using the electronic system. They thought that it could lead to savings in downstream processes, but these needed to be quantified in order to provide reason for the continued use of the electronic blast initiation system.

BLASTING CONCEPTS

Explosive detonation and rock interaction

When an explosive charge that is contained within a blasthole is detonated, there is a series of stress waves that move out radially, as well as the creation of gasses that are under extreme pressure. Primary breakage is due to the stress waves, with secondary breakage processes attributed to the gasses and indirect tensile stresses. The interaction between detonated explosives, and their associated breakage mechanisms, and a rock mass is a complex system that consists of three predominant zones. These

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zones, from the centre out, are: the crushed zone, cracked zone, and the radial fracture zone, as seen in Figure 1. The crushed zone is the region that immediately surrounds the Blasthole cavity. Blast induced stresses that exceed the Ultimate Compressive Strength (UCS) of the rock mass in this region are responsible for the intense crushing and pulverizing of the rock. The cracked zone is the area surrounding the blasthole, but outside the crushed zone. Blast induced stresses in this region are now below that of the rock mass UCS, although some crushing may occur in this region where the rock mass has inherent compressive weaknesses. The major characteristic breakage in this zone is due to elasto-plastic behavior of the rock mass, combined with rapidly expanding gasses creating cracks propagating outwards from the edge of the crushed zone.

The zone of radial fracturing is the area surrounding the cracked zone. Although blast induced stresses are now not large enough to cause crushing of the rock, they still act to push the material radially out. This movement results in the rock mass being subject to tensile stresses that are tangential to the direction of stress wave propagation. As the tensile strength of rock is considerably lower than its UCS, these small tensile stresses are all that are required to further fractures that formed in the cracked zone (Fairhurst and Kutter, 1971).

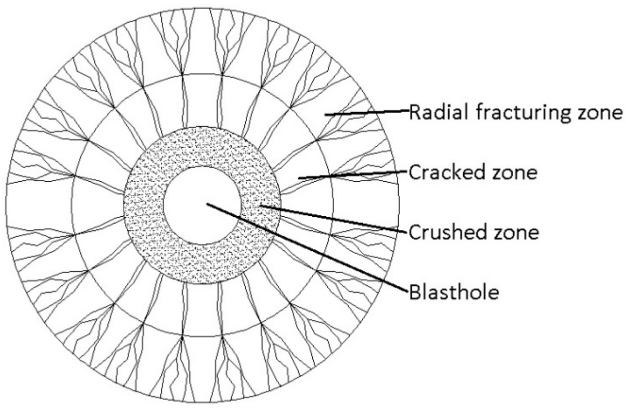

Figure 1: Zones of breakage around a blasthole

Blasthole interaction and timing

Blastholes breakage processes are able to interact in two predominant ways, these being between two or more holes in the same row (inter-hole), or between two or more holes that are in different rows that line up (inter-row). In order for blasts to fragment properly, a free-face must be available for material to move towards.

Interaction between blastholes can act to improve or hinder fragmentation of a blast as a whole. For optimal fragmentation results, the entire blast should be initiated on a hole-by-hole basis as seen in Figure 2. In doing this, the benefits of both inter-hole and inter-row interactions are exploited, as well a dynamic free face being provided to each blasthole by the blastholes before it (Orica, 2013).

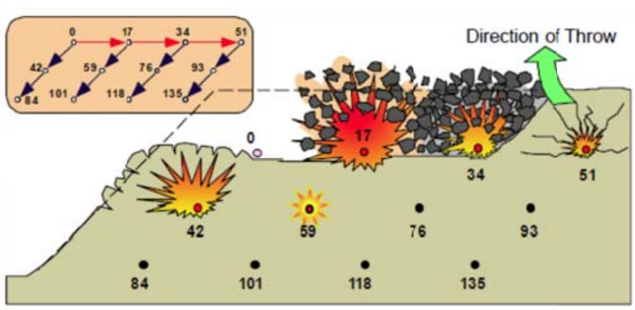

Figure 2: Multi-row blast initiated on a hole-by-hole basic (Orica, 2013)

Stagg and Nutting (1987) suggested that delays between 3-56 ms/m of burden or spacing were appropriate to achieve the desired fragmentation. This however does not specify what range the inter-hole and inter-row timing delays should be, providing an area for inaccuracy. Orica (1998) suggested separate ranges for inter-hole and inter-hole timings. These recommendations are 2-5 ms/m for inter-hole, and 10-25 ms/m for inter-row. The optimal timing for any given blast is the one that produces the best overall fragmentation that cannot be further improved without significantly increasing the powder factor.

Fragmentation, diggability and fill factors

The three statistical Key Performance Indicators (KPI) for this study (loads/operating hour involving loose Cubic Meters (LCM) and loading rate, and LCM and operating hours are each related to the fragmentation and fill factors. As rock is blasted in order to excavate it, it is broken down into smaller fragments. The more a material is broken down, the more fragmented it is. This means that as fragmentation increases, particle size decreases. It was thought that this decrease in particle size may do two things for the machines digging the material. The first is making it easier for the loaders bucket to penetrate into the material, increasing the rate at which loads can be completed, thus increasing the loads completed in each operating hour. The second is increasing the amount of material in the bucket as with smaller particles, there are fewer voids left in the bucket, thus increasing the fill factor which directly relates to LCM's per load.

It has been suggested by Cardu (2013) that when compared to a pyrotechnic initiation system, an electronic system can provide a decrease in mean particle size of 25 %. Similar work by Sullivan (2003) found that 11 % more material passed through the required passing size. Each of these studies show that using electronic detonators can increase the fragmentation of a blast. Martin and Miller (2007) took this analysis one step further and found that when using an electronic initiation system in a quarrying application, operating costs were decreased by 13 %, suggesting that savings opportunities exist in an operation when lauding and hauling rock material.

BLASTING TECHNOLOGIES USED

Bulk explosives and primers

There are several variations of bulk explosive that can be used to load blastholes. The most common bulk explosive used in the mining industry is Ammonium Nitrate Fuel Oil (ANFO), although each product has situations where they are more suitable over other options (University of Queensland, 1996). Nielson and Kristiansen (1996) suggest that when selecting a bulk explosive for a blast, it is desirable to use the explosive which has the highest velocity of detonation to provide the highest fragmentation, provided the powder factor is not changing. However, financial analysis may show that this is not the most optimum explosive for the blast.

Although bulk explosives provide the energy required to induce rock breakage, they are not sensitive enough to be initiated by detonation cord or a detonator alone. In order to initiate bulk explosives, a primer is used. Primers are a packaged source of high explosive that can be initiated by a detonator, and provide sufficient energy and shock to initiate a bulk explosive (Coundouris and Scott, 2009). The optimum bulk explosive and primer were selected for each blast at the case study site during the period from which data was used. For each blast examined for this study, a site sensitized emulsion, and identical primers were used.

Detonation system

Before the case study site started trialing electronic blast initiation systems, they were using a shock tube initiated pyrotechnic delay system. Central to both pyrotechnic and electronic systems are the detonators that are used in blastholes. Figure 3 shows the internal structure of the two types of detonators used at the case study site during the trial period.

Though both types of detonators will provide the energy required to initiate the primer, and hence the bulk explosive, there is one fundamental difference that provides the basis for this study. This difference is how the timing delay is achieved within each detonator. The shock tube initiated detonators that form the centre of a pyrotechnic initiation system use a pyrotechnic element that burns at a certain rate to provide the timing delay. This timing method has inaccuracies of up to 1.0 %, meaning that detonators may not detonate at the exact timing delay required. The electronic detonators that form the centre of an electronic initiation system have an internal digital delay timer. This timing method reduces timing inaccuracies to 0.1 %, meaning there is less difference between the design delay time, and the actual delay time. This increase in accuracy of timing means that when using an electronic system, the timing of the blast will be more accurate, which should lead to an increase in fragmentation. Another way that electronic initiation systems achieve increased fragmentation is through the available range of timing delays. Pyrotechnic systems are only available at set delay times for detonators and downhole connectors; electronic detonators however can be individually programmed exactly to any value between 0 - 15,000 ms (Cardu and Giraudi, 2013).

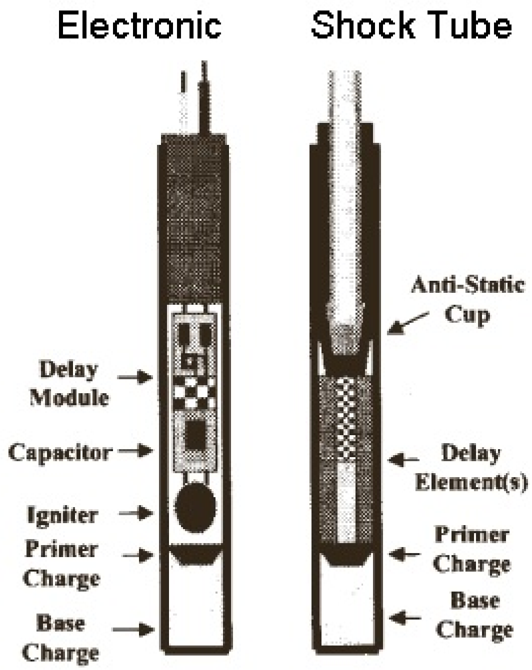

Figure 3: Detonators used on-site during the trial period (adapted from Coundouris and Scott, 2009)

COMPARISON CALCULATIONS

Data collection

Initially, pairs of blasts were to be identified that were in either adjacent blocks in the same strip, or the same block location in adjacent strips as shown in Figure 4. This would have ensured that geological differences were minimal in order to retain some level of consistency for the comparison.

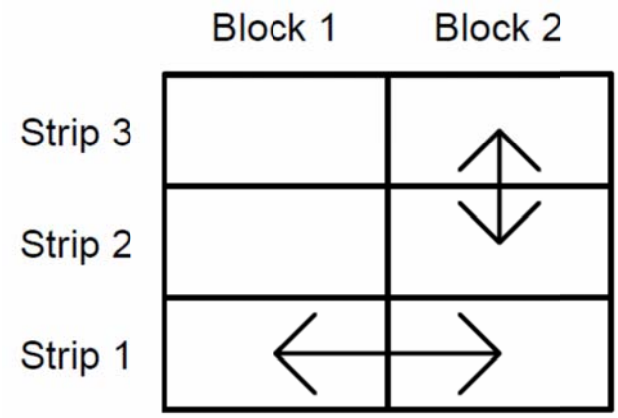

Figure 4: Ideal blast locations for comparison

Due to the guidelines on-site as to which initiation system to use for each blast, no such pairs could be identified. In the absence of such pairs, an alternative approach was implemented. This approach saw blasts with complete sets of dig data that were initiated using either of the two systems during the trial period (January 2012 – December 2013) being compared. These blasts were identified through the case study sites internal reporting software. Once these blasts had been found, the reporting software was then used to access dig data. The dig data reports contained the following information:

- Date of shift;
- Night/day shift;
- Loader, loader availability, loader utilization;
- Shift operating hours;
- Shift operating delays and standby times;
- Scheduled and unscheduled time losses;
- Volume of overburden moved in shift; and
- Number of loads completed in shift.

This data was extracted and record for each of the three excavation fleets used on-site for both pyrotechnically and electronically initiated blasts. These are 30 m^3 loaders with three pass matched trucks, 34 m^3 loaders with three pass matched trucks, and 60 m^3 loaders with two pass matched trucks. This created six sets of data, which were then normalized in order to remove any errors from loaders occasionally working on the border between two blasts on the same shift, resulting in material being moved that was not to be included in the analysis.

Data analysis and KPI calculations

Equations 1, 2 and 3 shows how the three KPI's of the study were calculated. Once these values had been worked out for all data points, a strict outlier removal was conducted. A data point was considered an outlier if it was outside the range defined by Equation 4.

$$\frac{Truck\ loads}{Operating\ hours\ on\ shift} = \frac{Loads}{Operating\ hour} \tag{1}$$

$$\frac{Volume\ of\ overburden\ moved\ on\ shift}{Truck\ loads\ on\ shift} = \frac{LCM}{Load} \tag{2}$$

$$\frac{(Loads/Operating\ hour)\ on\ shift}{(LCM/Load)\ \ on\ shift} = \frac{LCM}{Operating\ hour} \tag{3}$$

$$X < Q1 - (1.5 * IQR)\ Or\ X > Q3 + (1.5 * IQR) \tag{4}$$

Where:

- X is the data point in question;
- Q1 is the first quartile of the data set;
- Q3 is the third quartile of the data set; and
- IQR is the interquartile range (i.e. Q3-Q1)

Once outliers were removed, key statistical values for each data set were calculated, these were the minimum, median, maximum, average and variance.

AU$/LCM calculations

Equations 5, 6 and 7 were used to calculate the total cost of loading and hauling one LCM of overburden. These calculations were completed using operating costs that were supplied by the case study site which can be seen in Table 1.

$$\frac{Loader\ hourly\ operating\ cost\ (AU\$/hour)}{Average\ \ LCM/operating\ hour} = Loader\ \frac{AU\$}{LCM} \tag{5}$$

$$\frac{Truck\ hourly\ operating\ cost\ (AU\$/hour)/average\ truck\ loads\ per\ hour}{Average\ \ LCM/load} \tag{6}$$

$$= Trucking \frac{AU\$}{LCM}$$

$$(Loader\ AU\$/LCM) + (Trucking\ AU\$/LCM) = Total \frac{AU\$}{LCM} \quad (7)$$

These calculations done for each of the six data sets, provide costs for each loader fleet for both pyrotechnical and electronic blasts. Equation 8 shows how the difference between these two costs provides the savings the result from the use of an electronic system.

$$\left(Electronic \frac{AU\$}{LCM}\right) - \left(Pyrotechnic \frac{AU\$}{LCM}\right) = \frac{AU\$\ savings}{LCM} \quad (8)$$

Table 1: Operating costs of on-site equipment

	30 m^3 fleet	34 m^3 fleet	60 m^3 fleet
Loader op. cost (AU$/op. hour)	1099.00	973.00	746.00
Truck op. cost (AU$/op. hour)	288.00	374.00	374.00

Savings opportunities calculations

Once savings possible for each LCM moved were calculated, a calculation was required to identify if these savings were enough to offset the additional upfront cost of using an electronic initiation system. In order to do this, a conceptual blast was designed that resembled a typical overburden shot at the case study site. This conceptual shot had the following parameters:

- 478 holes;
- Three detonators/hole;
- 34 m average hole length;
- 270 mm hole diameter;
- 8.6 m burden;
- 10.7 m spacing; and
- 1.7 million LCM

Using this information, and the values in Table 2, two factors could be calculated: the additional cost for using an electronic initiation system, and the total savings for the blast for each loader fleet. Equation 9 shows how the savings for the blast were calculated for each of the three loader fleets.

$$\frac{AU\$\ savings}{LCM} * Blast\ volume = Total\ AU\$\ savings\ for\ blast \quad (9)$$

For the conceptual blast, it is assumed that all loading practices remain the same, and the time spent to load is the same, meaning that the only difference in cost is that of the detonators and associated connections for each initiation system. It is important to note that the values in Table 2 include the detonator and associated surface connections for each detonator in the blast.

Table 2: Cost of implementing each initiation system

Electronic system (AU$/detonator)	Pyrotechnic system (AU$/detonator)
44.31	25.12

Equation 10 was used to calculate the total cost for each initiation system if it were to be used on the conceptual blast. Once total initiation costs were calculated, the difference in initiation costs were calculated using Equation 11. This represents the additional cost due to using an electronic initiation system. Once the additional cost for using an electronic system was identified, Equation 12 was used to identify the net savings opportunity for the conceptual blast.

$$Total\ initiation\ cost = Number\ of\ holes * Detonators\ per\ hole * Cost\ per\ detonator \tag{10}$$

$$Difference\ in\ inititation\ cost = Cost\ for\ electronic\ initiation - Cost\ for\ pyrotechnic\ initiation \tag{11}$$

$$Net\ savings = Total\ savings\ for\ blast - Additional\ electronic\ cost \tag{12}$$

RESULTS

Statistical Results

Each loading fleet has two data sets, one for blasts initiated using a pyrotechnic system, and one for blasts initiated using an electronic system. Each of these data sets has three KPI's analysed, providing nine groups of data for comparison. It can be seen in Tables 3, 4 and 5 that every data comparison pair, the average values for electronic blasts are higher. This shows that there is an increase in fragmentation, providing increases in diggability which results in higher downstream productivity. It is worth noting that for a large portion of the data comparison pairs that the variance is lower, meaning that these higher values are being achieved more consistently. For the pairs where the electronic blasts have higher variance, the minimum and maximum are both higher than that of the pyrotechnic blasts, meaning that they are digging at less consistent rates, but are still outperforming the pyrotechnic blasts.

Table 3: Key statistical results for 30 m^3 loader fleet

	Loads/op. hour		LCM/load		LCM/op. hour	
	Av.	Var.	Av.	Var.	Av.	Var.
Pyro.	22.72	21.53	89.79	0.07	2,042	167,690
Elec.	23.61	2.69	90.61	0.19	2,140	24,211

Table 4: Key statistical results for 34 m^3 loader fleet

	Loads/op. hour		LCM/load		LCM/op. hour	
	Av.	Var.	Av.	Var.	Av.	Var.
Pyro.	18.87	2.66	103.63	73.44	1953	50,073
Elec.	20.58	4.29	109.10	102.01	2,240	73,690

Table 5: Key statistical results for 60 m^3 loader fleet

	Loads/op. hour		LCM/load		LCM/op. hour	
	Av.	Var.	Av.	Var.	Av.	Var.
Pyro.	30.52	10.37	121.58	19.27	3,745	126,522
Elec.	30.83	11.83	130.69	15.76	3,998	103,961

AU$/LCM results

Figure 5 shows that due to the increase in fragmentation, and hence downstream productivity, there are savings available, on an AU$/LCM basis, through the use of an electronic blast initiation system.

Savings results

The difference in cost to load the conceptual blast with an electronic initiation system was calculated to be AU$27,524. It can be seen in Table 6 that even with the additional cost of using an electronic system, substantial savings opportunities are available for each loader fleet and associated trucks.

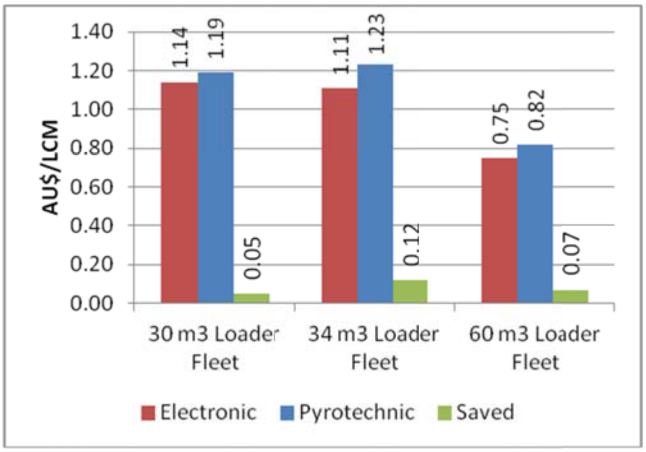

Figure 5: AU$/LCM saving opportunities for each loader fleet

Table 6: Net savings when using an electronic blast initiation system

	30 m^3 fleet	34 m^3 fleet	60 m^3 fleet
Total AU$ saved	85,757	205,817	120,059
Electronic AU$ difference	27,524	27,524	27,524
Net AU$ saved	58,233	178,293	92,535

CONCLUSIONS

This study was completed in order to identify if savings opportunities existed due to an increase in fragmentation through the use of an electronic blast initiation system at an open cut coal mine in Queensland.

Through completing statistical analysis, it was found that there was an increase in both the number of loads per operating hour, and material in each load by 1.0-9.1 % and 0.9-7.5 % respectively. These increases translated to an overall increase in material moved per operating hour by 4.7-14.7 %. These findings are consistent with those suggested by Cardu (2013) and Sullivan (2003).

Through this production increase, it was found that the case study site was saving AU$0.05, AU$0.12 and AU$0.07 on each LCM moved for each of the 30 m^3, 34 m^3 and 60 m^3 respectively. These savings translate directly into savings opportunities of AU$58,233, AU$178,293 and AU$92,535 for the conceptual blast. This finding is consistent with that found by Martin and Miller (2007).

Through the completion of this study, it has been found that the use of an electronic blast initiation system over a pyrotechnic blast initiation system increases both fragmentation and downstream productivity (overburden loading and hauling) significantly enough that substantial savings opportunities exist.

ACKNOWLEDGEMENTS

The author would like to thank the case study site for the use of their data, and Saiied Aminossadati from the University of Queensland for his support of this study.

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