A New Era of Blast Initiation Systems reducing Safety Risks, Costs and enabling Automation
(EFEE 2017 – Full Paper)

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ABSTRACT: This paper will discuss the history and development of wireless blasting, describe the verification, and validation performed and introduce the advantages of the next generation of blasting to the market; including safety, cost and automation.

1 HISTORICAL

The first known commercial interest in wireless initiation, found in the literature by the author, was in 1945 and authored by Imperial Chemical Industries, previously a parent company to Orica. The early patent describes a control system for detonating a charge, which upon reception of multiple wireless signals initiates said charge.

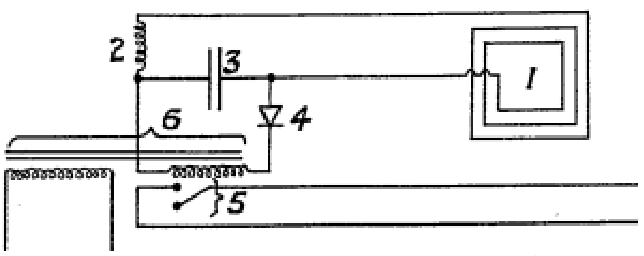

Figure 1. An image illustrating the wireless receiver from an early patent for a directly initiated detonator.

Further progression of wireless blasting and the development of a commercial wireless initiation system received only limited interest until recently, when remote blasting capability was developed and in 2003 commercialised. In such a remote blasting system, the blast is controlled from a remote location by 2-way radio communication with the in-hole primers connected by wire to radio transceivers on surface. This is the predominant wireless initiation system used in mining systems today.

Orica has been developing WebGen™100 for over a decade; a more advanced wireless system, capable of directly initiating in-hole primers via one-way communications that penetrates rock, water and air. This system is the first commercial initiation system to incorporate the initiation energy and ability to initiate completely within the device. To achieve this fundamental change significant investment and an evolution of the functional safety and design of initiation systems was required with substantial increase in verification and validation activities.


Figure 2. Evolution in the design of the directly initiated wireless booster.

The prototypes generated during the development of the wireless booster are shown in Figure 2. The initial prototype design was a comparatively larger cylindrical device focusing on larger surface boreholes and, as the development matured, the design was refined and reduced through a number of iterations. The final design was chosen as its size and performance affords the ability to target the majority of blasting applications.

2 INTRODUCTION TO SYSTEM

The wireless system consists of three different categories of components; the blast management computer; the wireless in-hole primers, encoder controller and accessories; and the transmission system; shown in Figure 3.

Prior to introducing wireless blasting to a mine site a wireless survey is conducted. The survey qualifies the suitability and performance of the wireless system at the site. The information from the survey is used to identify a suitable location for the transmitter, recommend a preferred antenna to be used; identify any anomalies, which may significantly attenuate the signal; and sources of noise, which may interfere with the signal.

As per current practice, the blast is initially designed with blast design software such as SHOTPlus™. The blast design is then exported to the blast dongle and loaded into the Code Management Computer (CMC); a dedicated tablet PC that hosts and manages blast codes for a blast site. Each set of codes consists of a blast group identifier, mine specific identifier and firing codes specific to each blast and is required to initiate the blast.

The wireless in-hole primer consists of a disposable receiver (DRX), a booster and detonator. Prior to encoding the detonator and DRX are mated energising the assembly. To encode the assembly, the Encoder Controller, a hand-held device connected to an encoder cradle is used. The assembly is placed into the cradle where communication of required blast parameters and interrogation of the unit are performed. The performance of the DRX and detonator are then evaluated and verified, encoded with the blast codes, and the timing and the detonator are recorded. Finally, the detonator, DRX, booster and components are assembled at the loading bench to create the primer, before being loaded into the required position.

Figure 3. WebGen™ 100 blasting system.

The transmission system creates the electromagnetic signals that enable firing of the wireless primer. During the blasting sequence, the user controls the transmitter via transmitter controller. The system supports a short-range and long-range antenna, either a quad-loop or cable-loop type. The user enters the fire command into the transmitter controller, enabling the firing signal to be sent via transmitter to all corresponding primers in range.

During the trials, the long-range cable-loop antenna was deployed. The radiation pattern for the antenna is shown in Figure 4. The specified range of this antenna, when operating in a standard environment confirmed by a survey, is 720 m in the vertical direction and 800 m in the horizontal plane.

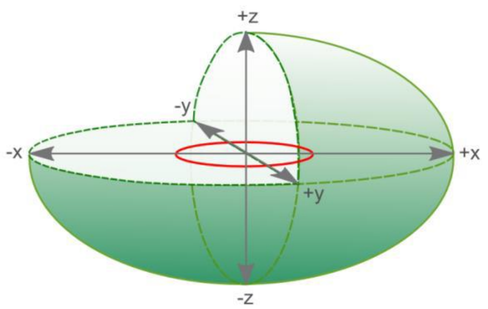

Figure 4. Transmission range of system.

3 INCREASED SAFETY THROUGH REDUCED OR ELIMINATED RISKS

There are so many mining methods to recover ore from underground and they all rely on the basic premise to break the ore into a manageable fragmentation size for extraction and then to stabilise the resultant void with fill material. The breakage of the ore spans from “drill and blast” to using the stresses of the void to break ore to enlarge the void, as in block caving. Practically all hard rock mining requires the drill and blast process for a large part of the setup or production stages.

Blasting is, by its nature a cyclic process that requires digging, drilling and blasting processes. The digging and drilling processes have been principally controlled with large-scale equipment that allows automation or the operator to be protected in a cabin where the conditions can be controlled. The blasting process, while options to automate the charging exists, has always required a very manual approach to the connection of the blast to a firing system and in most methods this occurs in the area of highest potential risk of injury due to rockfall and or unstable workplace due to movement of the floor.

3.1 SubLevel Cave

Underground production blasting requires a level of exposure to situations of increased risk. This is especially apparent during connection of the wire network of the initiation system. Sub Level Caving (SLC) operations in particular require this hook up within close proximity to the edge of the excavation and commonly above a bank of rock prone to movement. A number of SLC mines have had rushes that have resulted in fatalities in recent years.


Figure 4. Charge vehicle at SLC mine after an inflow

Orica’s Wireless Electronic Blasting System eliminates these high-risk hook-up processes and facilitates the development of automated charging. The system enables blasting techniques whereby in-hole primers initiate directly by communication though rock without the requirements of physical connections. Elimination of the wire network and connectors removes the need to have access to the collar of the hole after charging. This enables increased pre-charging of underground blast patterns, whereby a larger number of holes are initially charged, and the flexibility to initiate a group in each blast event.

SLC mines have situations where the edge of the excavation has retreated, or broken back, past the next ring to be blasted. If this occurs, either the next ring is fired, wasting primary draw and causing potential bridges/oversize, or redrilling is required in these locations. Having an operator re-enter these areas and redrill is both a costly exercise, and an activity with higher safety risk and slowing productivity.

Figure 5 Hook-up for a single SLC ring with risks partially controlled with backfill, shotcrete and bunding

Figure 6 2 Multiple wireless charged rings are ready to fire as soon as needed, note strapping indicators.

The loading procedure for wireless initiation uses packing tape that hangs out of the bottom of the hole to indicate that the ring has been charged, and as an indicator for the loader operator to determine if the charges have been moved by ground pressure of earlier fired rings. Further details of production blasts are found in Liu et al.

There are many papers and case studies, including S.Steffen et al., that show that having the primers in the correct place and reliable initiation; will improve primary recovery and minimise dilution. Wireless will enable every blast to be reliably initiated; with electronic timing, the blasting sequence for the near-optimal fragmentation can be achieved.

3.2 Sublevel Open Stoping

Sublevel Open Stoping (SLOS) has exposures due to the open stope. Ground within the open stope is normally not supported and uncontrolled falls of rock can be expected, which is why they have barriers to protect personnel entry. Mines use bunding and other means to protect potential falling rock into the work area, but the edge of the next blast packet requires charging and hooking up for the start of the next blast. Furthermore, where stress and ground conditions create unstable or squeezing conditions, the next blast can be delayed due to blast hole closure or dislocation. This is a major delay, cost and a heightened safety risk to control in recovering, re-drilling and correcting before charging can be undertaken.

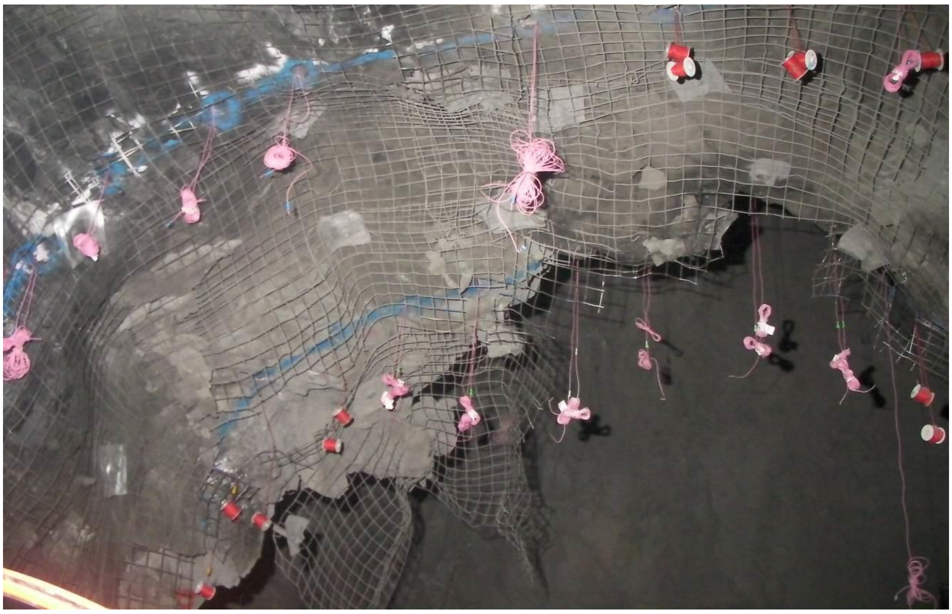

Figure 7. Charging complete for the Hook-up process to tie it into the detonating cord at the open stope brow

Wireless allows the next blast section to be loaded and pre-charged before the previous section if fired, thereby eliminating the influence of dislocated and squeezing holes and the high risk process close to an open stope on the charging process. Obviously, the priming frequency should, as it is now, be chosen to allow for primers to initiate the most of the explosive charge in the blast hole. The type of initiation does not change the frequency and position of primers in a blast hole. The frequency is decided from the level of discontinuities in the rock, the powder factor in the blast and the criticality of the blast hole.

An example of this use is in an opportunity to leave “isolated pillars” to improve the stability of Modified Avoca Stopes and the recovery of ore by leaving these pillars behind in the centre of a stope after it has been charged with the wireless initiated explosives. Modified Avoca can be a down hole benching or up hole rings that can have dry rock fill introduction during the mining of the stope.

The method can reduce the need for slots to be established (or permanent pillars) for the next stoping block as once one panel has been complete the fill can be introduced to the point where the waste rill comes to touching the brow of the next ore block. At this stage, the walls of the previous stope are being passively supported with the dry rock fill, introduced from above, such that the next block can be mined, thereby leaving no pillars. This increases the recovery of the ore body and reduces costs of slots. Unfortunately, sometimes the passive support is not good enough to limit dilution for the stope walls. Extra support from isolated pillars can assist the clean ore recovery before the isolated pillar is extracted. The use of isolated pillars that can be recovered is a method that would be applicable to other open stoping methods.

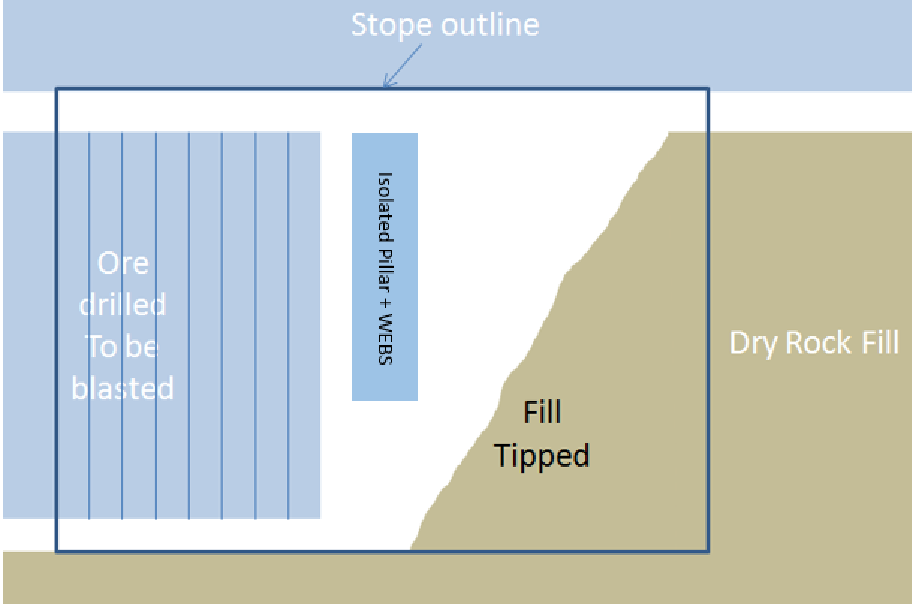

Figure 8. Long Section of Modified Avoca Stope with isolated pillar charged with wireless for later extraction

3.3 Seismically Active Mines

Further difficulties may arise within mine locations prone to seismic events. These active areas require further management controls including exclusion zones to limit the exposure of personnel to rock bursts and closures. Traditional blasting methods in these areas will require an operator to access the hazardous area and hook up the initiation system prior to blasting. An example would be a block cave mine which is newly establishing the cave or due to high stresses on the Undercut Level. Preloading several rings away from the high stress "active" areas can mean that these areas can be remotely dug and fired.

Investigations into remotely charge with vision systems to identify holes and remote operation have occured. The wireless system is uniquely suited to this use as the detonator complex can be made up and loaded into a cassette for use in an autonomous charging vehicle capable of making up the primers, inserting them into the blasthole (either up or down) and charging.

Figure 9. Early Remote Control Charging Equipment with Smart Vision Systems to identify blastholes

Wireless Electronic Blasting technology is being introduced into production environments following the successful product development and verification stages. During these stages, the system validation occurred, performed by leading internal experts and external authorities; in laboratory, underground and surface operating environments.

The five stages of testing performed on the system are described in this section; consisting of System Lab Tests performed during development; Internal Field Trials, Customer Trials, Live Trials and Production Trials performed during the final system tests in the first half of 2015.

4.1 System Lab Validation and Verification

Orica teams located in Troisdorf, Germany, and Brownsburg, Canada, and five independent external organisations located in Germany, Canada and the USA performed the design and lab testing. The external organisations included our design, functional safety and independent lab verification partners. A summary of the battery of validation and verification tests performing on the system in order of ascending system design level is included below.

Firmware, module, and unit testing, verified and validated the smallest individual testable blocks of the system, and was performed both internally and by the project design consultant, and included complete code coverage testing of the firmware, individual module and unit testing via both software and interfacing with hardware firmware.

Design, integration and system tests were performed to verify that the integration of the software and hardware tested modules performed as specified. As the lower level functionality has previously been tested a “black box” testing methodology against the system requirements was performed.

Figure 10. System testing of wireless units.

Fault-Insertion testing was performed by both our functional safety partners and by ourselves. Within this testing regime, faults were injected into the firmware and hardware of the device to increase the coverage area and investigate the robustness of the system. The injected faults were triggered by modified source code and via external electrical stimulus.

Finally, assembly and finished device testing were performed on the finished device aiming to provide the best possible test coverage by only exercising the functionality present in the device. Qualification testing was also performed on the finished device, including water ingress, dynamic shock, and electro-static discharge performed by external certified authorities to assess the product for introduction to market.

Figure 11. Lab testing of wireless units.

In total, more than 240,000 tests were performed during the verification and validation of the system. A summary of the overall documented number of tests performed at each stage of verification and validation is shown in Table 1.

Table 1. System Lab Validation and Verification of system.

Stage	Number of Unique Tests	Number of Times Performed	Total Tests Performed
Firmware, Module, Unit	104	>1,145	119,080
Design	47	>4	188
Integration	17	>3	51
System	169	>3	507
Fault-Insertion	28	1	28
Assembly	5	>1,000	5,000
Finished Device	22	5,303	116,666
External Lab	3	1	3
Qualification	22	1	22
Shock and Dynamic Shock	18	40	720
Pentex™ W Booster	12	135	1,620
Accessories	4	20	80
Totals	**>>450**	**-**	**>>240,000**

4.2 Internal Field Trials

Wireless internal field-testing trials occurred at Orica Kurri Kurri Technical Centre near Newcastle, Australia, throughout January 2015. The trials involved further functional verification of the entire system in a field environment and also included feedback for the refinement of the design. Measurements were taken across a large forested geographical area with only limited infrastructure. Within the 2,500-meter radius of the trial environment the infrastructure included an emulsion plant, explosive testing ground, magazines, workshops and a number of commercial office buildings. The system was initially validated with dummy explosives with the range of the devices starting at 300m and increasing gradually to 2,500m. It was verified that system performed as expected, successfully receiving the signal to a range of 1,650 meters. A number of further test were performed at longer ranges between 2,000 and 2,500 meters, but no signal was received at these distances.

A summary of the testing and figures are shown below.

Table 2. Summary of internal field trials

Range (m)	Number of Trials	Number Units	Number Fired	Percentage	Notes
300 - 1650	15	386	386	100%	Dummies
2000 - 2500	2	30	0	0%	Dummies
500	1	2	2	100%	Detonators

Figure 12. Orica internal testing of wireless units.

4.3 Customer Trials

Initial trials on customer sites were conducted at a customer range in NSW, Australia, during January and February 2015. The aim of the trials were to gain further understanding and data of the field performance of the system, and to introduce the wireless boosters to boreholes loaded with bulk.

The customer site was a quarry adjacent to a cleared field with limited surrounding infrastructure, outside of the crusher and engineering workshop. The firing range used during the customer trials was limited to approximately 600 meters due to the geology and size of the site. The transmitter was deployed near the boundary fence and a pattern of boreholes was drilled at the opposite boundary of the site.

During the initial week of the trial, dummy units placed on the surface to confirm the system was deployed and functioning correctly. Once the system was validated the units were positioned in the base of the blastholes and again verified.

During the final week of the trial, live explosives were introduced to the site. The initiation chain was increased in steps; initially, the trials were simulated with dummy explosives, and after successfully simulating the trial, detonators, then boosters and finally bulk explosives were introduced.

Table 3. Summary of customer field trials

Range (m)	Number of Trials	Number Units	Number Fired	Percentage	Notes
500	21	204	204	100%	Surface Dummies
500	21	110	110	100%	In-Hole Dummies
570	5	40	40	100%	Dummy
500	4	9	9	100%	Boosters
555	1	8	8	100%	Bulk
500	1	2	2	100%	Bulk

Figure 13. Customer field-testing of wireless units.

4.4 Production Trials

Following the successful, lab, field and customer site testing the wireless system was introduced to a customer's production blasting. The introduction occurred at a different customer quarry site from the previous tests, though also in NSW, Australia, during February 2015.

A simulated blast was initially performed to ensure the functionality and correct setup of the system which was successful. For the production blasts, blast holes were double primed with wireless units at the top and bottom of the holes. A number of smaller limited production shots were initiated to gauge the performance differences between wireless and i-kon blasting.

As all previous blasts were successful, the final larger production blast, of 88 wireless units, was initiated. All units performed as expected and the blast initiated as designed. Images and details of the blast results are presented below.

Table 4. Summary of production trials

Distance (m)	Number of Trials	Number Units	Number Fired	Percentage	Notes
450	4	104	104	100%	Dummy
450	3	32	32	100%	Production
400	1	88	88	100%	Production

Figure 14. Production testing of wireless units.

5 SUMMARY AND CONCLUSIONS

This is an introductory paper and a precursor to a number of further production trials. Some of the actual and potential applications, details of the testing and preliminary results of introductory production trials in operational mines are presented.

6 REFERENCES

Orica. *WebGen™100 User Manual*. Orica.

AusIMM Underground Operators conference in Australia in October 2017.

Z. Liu, C. te Kloot, T. Purvis, S Thomson and M Lovitt. *Improving Safety through Technology: Orica Wireless Electronic Blasting System Trials at Ernest Henry Mine*. 13th AusIMM Underground Operators' Conference, Paper Number: 30.

S. Steffen and P. Kuiper, 2014. *Case Study: Improving SLC recovery by measuring ore flow*. Caving 2014.

7 ACKNOWLEDGEMENTS

The authors wish to acknowledge their gratitude to the following colleagues for their assistance and support throughout the wireless development and trials including;

Orica Brownsburg Technical Center, Canada, including Dawn Goosen, Daniel Mallette, Francois Guillemette, Yves Hamel, Pascal Durand, Marc F Green, Gabriel Gaudreau;

Orica Kurri Kurri Technical Centre, Australia, research team, including Richard Goodridge, Johann Zank, Matthew Craft, Maciej Ciez, Tuan Nguyen, Emma Cook, Geoff Stevenson, Laurie Simpson;

Orica Troisdorf Technical Center, Germany, including, Dirk Hummel, Thomas Boos, Christian Juenger, Jan Lindenau, Walter Piel, Margit Fischer-Michely, Ulrich Steiner;

Orica Gyttorp Technical Center, Sweden, including Johan Lind;

And our external consultants from Germany, Canada, and the United States.