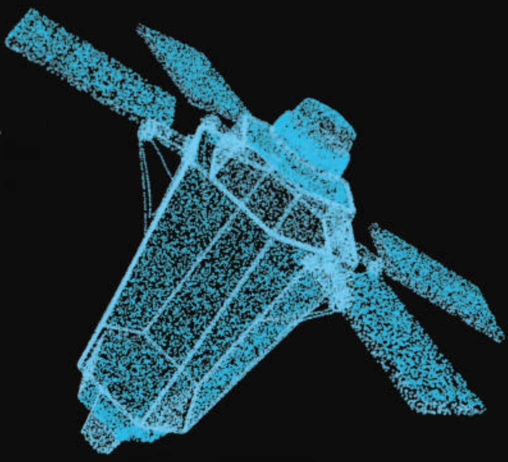

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We acknowledge the Traditional Owners of the lands and waters throughout Australia, and pay respect to the Elders past, present and emerging. We recognise the importance of connection to culture, land, kinship and community to the health and wellbeing of Aboriginal & Torres Strait Islander families. We acknowledge the cultural practices and traditions still carried out today and being passed down to future generations.

Designing a Safe and Reliable Wireless Blasting System

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ABSTRACT

Wireless blasting is transforming mining on the surface and underground. Users are developing new mining methods that recover more ore, faster and with less risk. The number of sites using a wireless initiating system is increasing quickly, and the first wireless system is now in its second generation. However, wireless systems introduce new risks that users must understand. When there are no physical connections to loaded blastholes, the blaster must use new methods to ensure that the right blast and only the right blast will fire. Without wires, strict communication protocols and pre-blast signal tests are necessary to give confidence that all primers will receive the firing signal and still be functional when asked to fire. If a wireless primer escapes from a blasthole, training, procedures and checks are essential to eliminate the risk of it initiating elsewhere. When neighbouring mines use the same wireless blasting system, the risk of interference and firing the wrong blast must be managed.

Orica's second-generation wireless initiating system is designed with these risks in mind. This paper describes the independently verified design, safety features and proof-tested systems of work that make it the world's safest and most reliable wireless initiating system.

KEYWORDS

Wireless initiating system, blasting

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1. THE WIRELESS BLASTING REVOLUTION

Conventional initiation systems use wire or signal tube to connect detonators in blastholes to a device that provides energy and signals. The term *wireless blasting* means initiating blastholes without a physical connection to the detonator. Some manufacturers make *wired to the collar* or *semi-wireless* systems that use a wired connection between the primer and the collar of the blasthole. The authors contend that a truly wireless system has no wires or signal tube in or between blastholes.

Orica introduced the first truly wireless blasting system to the mining industry in 2017, and since then it has been used in over 4000 blasts on 60 sites in 12 countries. The 100,000th unit was fired in June 2022. The second-generation system was released in late 2022. It includes additional safety and reliability features in four variants designed for specific surface and underground applications.

The underground production blasting segment adopted wireless blasting first. Underground miners mostly use wireless blasting to reduce risk and increase recovery. Wireless blasting significantly reduces risk to personnel by removing or eliminating the need for people to enter drawpoints to charge and connect blastholes. It increases recovery by providing a way to blast pillars and crowns that would otherwise be left behind. It improves productivity in more than one way. Wireless enables a whole stope to be charged in one campaign. Wireless methods create ways to fire ore towards a drawpoint, thus reducing the amount of tele-remote bogging (mucking) required. Wireless is enabling full mechanisation of development charge-up, removing people from another hazardous underground location. (Taylor and Spångberg, 2023).

Wireless blasting also reduces risk in surface mining. Misfires and unplanned initiation events caused by wire or signal tube interacting with machines are eliminated. There is no need for a person to handle the downlines during stemming, so risks associated with respirable dust exposure and machine/pedestrian interaction are eliminated. Orica's wireless primer is safe from unplanned initiation from lightning, fires, impact, pressure and electromagnetic radiation when in a stemmed blasthole, at least three metres below the surface. This creates new and unique opportunities to improve operational safety and increase productivity in surface mines. Examples include making a loaded blast into a temporary haul road and reducing or eliminating the requirement to shut down production around sleeping blasts during thunderstorms. (Stevenson, Hassanvand and Adam, 2023)

2. THE CHALLENGE OF BLASTING WIRELESSLY, SAFELY

Wireless blasting enables new mining methods and reduces or eliminates risks associated with conventional wired and non-electric initiation systems. However, it also introduces new challenges and risks. Some of the new risks are inherent to the technology, others depend on the application. People selecting and using wireless systems must understand these risks and associated controls.

2.1 The challenge of wireless communication in blasting

Conventional initiating systems use a wire or signal tube as a signaling path from a blast controller or blast control device to initiation devices to trigger initiation of the initiation devices. In electronic systems the wire carries two-way digital coded instructions with high reliability, accuracy, and precision. In non-electric systems signal tube carries a reliable one-way analogue signal that is virtually immune to interference and lossless over long distances, but it can be degraded or stopped by oil, moisture, or low oxygen in the tube. Both systems transmit energy over a network, and the detonator in the blasthole has no external energy

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source until it is connected. This provides a degree of inherent safety to the system. The person firing the blast is assured they are firing the right blast and no other blast when they make the physical connection of wire or signal tube between the firing position and the blast.

To blast wirelessly, a signal must travel through hundreds of metres of rock, air, and water. Primers must carry their own power supply so they can sleep in a blasthole for weeks, and then wake and fire when commanded. Wireless primers must be always listening, then fire only when instructed, and always fire when instructed. They must ignore extraneous signals and external energy sources, but always respond when commanded.

Reliable communication to the wireless primer through air, water and rock over hundreds of meters is challenging. To achieve a useful range, the signal must have a low frequency, and it requires a lot of power. Low frequency signals have a low bitrate, so complex transmissions take time. A large antenna is required. Rock and groundwater are heterogenous media with highly variable transmission properties. Signal losses and errors occur. Minerals have different transmissivity for electromagnetic signals, so predicting or guaranteeing the range of a signal, or that a wireless primer will receive a complete instruction is difficult. Metal-rich ore can have particularly poor transmissivity, and this is usually the material miners are most interested in blasting. Magnetite, a magnetic iron ore, is a particularly poor conductor of electromagnetic signals.

Today's commercialised wireless technology is not capable of reliable two-way communication with a wireless primer in a blasthole at distances useful for mining applications, so verification and response to a transmission is not yet consistently possible over a wide range of blasting situations. Over long times data stored in digital memory (such as a primer's identity and delay time) can spontaneously change, and the probability of this increases over time. These factors complicate reliable, secure, accurate and precise communication to sleeping wireless primers in blastholes. The risks and reliability problems outlined in the next section must be managed within the constraints of low bitrate communication and under the assumption that data errors will occur in signals and in the primer's memory.

2.1 Unique hazards of wireless blasting

In a modern mine there is a broad-spectrum of electromagnetic energy sources. A wireless explosive device must be immune to all signals other than those intended for it. This problem also exists for wired electronic systems that use wires that can create a long dipole antenna when deployed down a blasthole. Fortunately, modern digital communication methods effectively filter noise and pass valid communications, so the problem has been solved for wired electronic systems. Wireless primers have much smaller antennas and carry an on-board power source. Designers must account for mechanical and electronic failures that could bypass controls, and ensure the system fails to a safe state under all conceivable conditions.

Most large mines do not fire all blastholes on the day they are loaded. Instead, they sleep blasts, sometimes over weeks. When there are many loaded blasts on a site, accidentally sending a signal that fires the wrong blast could be catastrophic. If the sleeping blasts are primed with conventional systems, it is a trivial task to ensure the correct blast is fired by observing the physical connection between the blaster and the blast. However, on sites with more than one sleeping wireless blast, the shotfirer (blaster) must identify and fire the correct blast without relying on a wired connection as visible proof.

When nearby mines use the same wireless system, there must be no way a firing signal from one mine can

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initiate primers at the other. Managing this risk is even more critical if multiple pits or a co-located open pit and underground share the same control and firing hardware.

If nearby mines use the same wireless system with their own control and firing hardware, there must be no way for system transmissions from one mine to interfere with system transmissions at the other. For example, if both mines attempt firing at the same time, the simultaneous transmission could conceivably result in partial or total misfires. While a total misfire may be an inconvenience, a partial misfire can be catastrophic.

There are credible pathways that a primer can escape from a loaded blasthole, or be accidentally left outside a blasthole after assembly – this is called a *liberated primer*. A liberated wired or non-electric liberated primer is a hazard because it can be initiated accidently by impact, but it is very unlikely to be initiated by a firing command while not connected. A liberated, functional wireless primer presents a new hazard because it can initiate anywhere if it receives a firing signal. If it is liberated within a muckpile it may detonate without being noticed. However, if it is found and returned to the underground explosive magazine and stored with other high explosives or near a person, the outcome will potentially be catastrophic.

Wireless systems offer new mining methods on the surface and underground. Some of these methods rely on sleeping primers for weeks, and those primers must survive multiple adjacent blasts. Dynamic pressure, vibration, and the electromagnetic pulse of nearby detonating blastholes might sympathetically detonate or damage a sleeping wireless primer. Primers sleeping for weeks must also resist the high hydrostatic pressure at the bottom of an emulsion column, and elevated temperatures. Hence, although wireless primers are larger and more complex than conventional electronic and non-electric primers, they must also be more robust.

3. DESIGNING A SAFE WIRELESS BLASTING SYSTEM

Orica recognised the unique hazards and controls required for a safe wireless blasting during development of the first generation WebGen™ 100 system. Due to technical limitations in a first-generation product, many of the controls are procedural. In 2022 Orica launched the second-generation WebGen™ 200 system with higher reliability and more safety features.

A WebGen™ primer includes three main components – a Pentex™ cast booster, an i-kon™ electronic detonator and a DRX™ (disposable receiver). The DRX™ includes the electronics, far-field and near-field communication devices and power source. The WebGen™ primer is assembled and encoded with an identity and delay time just before it is loaded into the blasthole. Once loaded, it periodically wakes and listens for a command to arm and fire. Depending on the application, it may sleep for several weeks. Many adjacent blasts may be fired in the meantime. The user can also merge separate blasts to fire them as one blast if desired. This is done without two-way communication with the primers.

3.1 Designing for reliable communication

A wireless primer must recognise and respond to a signal bearing the unique blast identity or group to which it belongs, and no other signal. It is essential that a wireless primer only fires when instructed, and that it is immune to all other signals and extraneous energy sources.

SIL (Safety Integrity Level) is a measure of reliability and risk reduction used in many international standards. WebGen™ primers have a Safety Integrity Level 3 rating – the highest practical rating possible for a

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commercial blasting system. The SIL 3 rating provides the highest practical assurance that a WebGen™ primer will only fire when instructed and that failure or defects in the electronics will not lead to initiation.

The WebGen™ system uses signal surveys to measure signal strength at the intended firing location. An operator installs *magnetic induction recorders* (MIRs) at the intended firing location before the blast is charged. The MIRs record the strength of test transmissions, and the operator assesses these against set criteria before deciding if the antenna location and orientation is suitable for the intended blast.

Even if the signal is strong enough, the firing signal could be corrupted, and receipt by the primers cannot be verified by the sender. WebGen™ uses a unique protocol to ensure reliable communication. Each WebGen™ blast ID is tested to ensure there is a negligible probability of it being mis-identified, even if it is corrupted in transmission or storage. Orica uses a rigorous hazard-studied protocol to ensure there is a negligible probability of assigning two blasts the same blast ID at the same time, anywhere in the world. This is another layer of control to ensure a wireless blast will not respond to a wireless signal from another user.

By using SIL3 reliability, signal surveys and sufficiently unique identifiers, users can be confident a WebGen™ primer will receive and recognise instructions intended for it, and that it will not mis-identify instructions intended for another WebGen™ primer.

3.3 Protecting against deprogramming, detonation or failure while sleeping

While sleeping, each wireless primer must maintain energy sufficient to wake and listen for instructions and then arm and fire when instructed. The quality of the battery, resilience to fluid ingress, temperature stability of the components and protection against dynamic shock are therefore critical to reliability. As the wireless unit carries its own power supply, it is essential the battery remains healthy during transport, storage and sleeping. To confirm the health of the system before any operation, each micro-controller in a WebGen™ 200 DRX performs a pre-operational self-test of the hardware resources and battery voltage. The battery voltage reading is checked against an expected value and if it is out of range, the unit cannot be used. This level of on-board testing ensures that the DRX will have full functionality for the specified sleep-time in the borehole.

While sleeping in the blasthole, a wireless primer is exposed to long duration hydrostatic pressure. Adjacent blast events create electro-magnetic pulses and high dynamic pressures that have the potential to cause fluid ingress and damage, leading to de-programming or failure. To maintain functionality of the system in mining applications, it must be designed to withstand long-duration but relatively mild hydrostatic pressures, as well as short high amplitude dynamic pressures, and extreme acceleration.

Failure due to hydrostatic pressure and dynamic pressure were identified as a deficiency of the prototypes of WebGen™ 100 when compared to conventional initiating systems. The performance is mainly related to the DRX's electrical connection to the detonator made by the user just before loading, and the size of the mechanical enclosure housing the electronics. While conventional detonators include the timing module in the detonator, the WebGen™ system requires the external DRX™ coupled to the detonator to communicate wirelessly and detonate the i-kon™ detonator. The DRX™, by design, cannot benefit from the same construction robustness of a metal tube as used in detonator construction, as it would attenuate the magneto-inductive signal. Development of WebGen™ 200 has focused significant effort on improving resistance to hydrostatic pressure, dynamic pressure and acceleration.

In surface blasting, sleeping blastholes might be struck by lightning. A strike can cause initiation or premature detonation of loaded blastholes if the wire or signal tube transmits energy to the detonator and primer down the hole. Usually, the threat of lightning demands establishing an exclusion zone around loaded blastholes, and this causes production delays that total hundreds of hours a year on some sites. With no connection to the surface, wireless blasting offers the possibility of avoiding these delays if it can be demonstrated that the wireless primer is protected from premature initiation and deprogramming when lightning strikes. Orica has extensively modelled and tested WebGen™ 100's susceptibility to lightning induced currents. Provided a WebGen™ 100 primer is more than 3 metres below the surface, there is negligible risk of deprogramming and premature detonation. This removes a major risk for mines in thunderstorm prone regions, and with appropriate risk assessment and controls delays due to lightning can be greatly reduced or eliminated.

3.4 Firing only the right blast

Each WebGen™ primer is encoded with a delay time and a blast ID as it is loaded into the blasthole. The blast ID is a critical safety control. A sleeping WebGen™ primer may hear many arm and fire commands, but it must only respond to the arm and fire command intended for it. As described in Section 3.1, WebGen™ blast IDs are tested to be sufficiently unique that the chances of a primer mistaking a signal not intended for it are negligible, even if the signal is corrupt.

In WebGen™ a labelled *blast file key* (BFK) identifies a blast. At firing time, a person selects the BFK of the blast to be fired and inserts it into a computer. When there are multiple sleeping blasts on a site, there is a risk that a person mis-identifies the blast to be fired by selecting the wrong BFK and sends a valid signal to the wrong blast. In the WebGen™ 100 system procedural controls prevent this. Two people must verify the blast file key is correctly identified. WebGen™ 200 uses a piece of hardware called a blast pattern indicator (BPI) as an additional control. The BPI is a device that must be nearby when WebGen™ 200 primers are encoded on a blast. The BPI must also be nearby the blasting computer when firing the blast. Keeping BPIs in the correct location reduces the probability of transmitting a firing command for the wrong blast.

3.5 Managing liberated primers

Although all liberated primers are potentially hazardous, wireless liberated primers are uniquely hazardous. A wireless primer is designed to respond when it receives a firing signal, but if it detonates outside a blasthole the result could be catastrophic, especially if the primer is returned to a magazine.

With WebGen™ 100 controls for liberated primers are mainly procedural and rely on training people in the mine to correctly identify and react to liberated primers. Orica devised a *liberated primer test* to assess the effectiveness of this control. The test involves leaving an inert WebGen™ primer unattended in the mine under controlled conditions. If a mineworker finds the primer and fails to follow the correct procedure, extra awareness training is scheduled. If they follow the correct procedure, the training effort is maintained.

WebGen™ 200 includes engineering controls for liberated primers. Locksafe™ is an optional attachment that senses if the primer is no longer in a sleeping blasthole and deprograms it if it moves a preset distance from its original position. Deprogramming reduces the risk because the liberated wireless primer will not respond to a valid firing command. However, as with any misfired primer, it is still a hazard that must be controlled. While these additional engineering controls reduce the risk of liberated primers, procedural controls are still necessary and important.

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4. CONCLUSION

Like electronic detonators introduced in the early 2000s, wireless initiation is a once-in-a-generation revolution in blasting technology. Wireless initiation is already enhancing productivity and reducing risk in mining. Wireless initiation adoption is growing at an exponential rate, and those who buy and use wireless systems must be aware of the unique hazards and controls required to operate wireless systems safely. This paper has outlined those risks and the controls used in Orica's WebGen™ wireless initiating system.

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