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Managing seismic events through demarcation zones at a large block cave mine

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Abstract

In 2017, a very large seismic event generated a significant amount of damage and dust throughout a large-scale block cave operation in Indonesia. It was then thought that a visual alert and evacuation system may improve the safety of underground personnel, with the initial idea being inspired by airplane emergency exit strip lighting. With the demand for safer mining operations, the mine owners began to search for an existing off-the-shelf system that the mining sector could possibly utilise.

The initial scope for this emergency/evacuation system was that it needed to be able to provide real-time demarcation of where it was safe or unsafe to be inside the cave footprint, at any point in time. And then to be able to trigger real-time emergencies and evacuation events. This required multiple-light colours (red/blue/amber/green/white) combined with synchronised flashing and chasing modes. This system requires a centralised software control platform; and ultimately, to be able to be automatically triggered by the mine's microseismic monitoring system or people on site in case of major events. The system will also be combined with the existing radio communication infrastructure in the mine, to have a redundant verification system between the control room and underground shift.

Various LED strip lighting technologies were trialled and ultimately found not to be suitable. Total cost per meter versus features was big concern as the supporting devices required to reach the defined requirements.

IoT Automation was then approached to design and develop such a system that would be suitable for an underground block cave mining environment and with features to have a cost effective and operational based solution, with the FireFly smart lighting system being the result.

In 2018, the system was initially deployed into just one of the panels in a key production block of the mines extraction level, with encouraging results. Subsequent modifications to both the hardware and software of the system throughout 2019, including the use of the system as a network link for geotechnical instrumentation, RFID tag detection (pedestrians and mobile equipment) and software integration with microseismic and ventilation monitoring systems – resulted in approval to expand the system into all production block areas of the mine.

This paper details the planning, design, initial rollout, feature development, and expansion of the FireFly smart lighting system at this large-scale underground caving mine.

Keywords: *instrumentation, seismicity, safety, automation, iot*

1 Introduction

Mining-induced seismic events pose a significant risk to underground mines. Ensuring there are adequate warning systems on site to protect personnel is critical. The damage caused by artificial occurrences such as small sidewall rockbursts or mining-induced seismicity can affect underground mining operations and the associated surface infrastructure. Like most underground block cave mines, this operation faces a variety of operational hazards, including seismic, geotechnical, fire and gas exposure. Mining ranks among the country's largest industries, with coal, gold and iron ore mining as the leading sectors. According to Statista

(2022), approximately 188,000 people were employed in the Australian mining industry for the financial year 2021.

In 2020, the Australian mining sector had a 2.1 percent fatality rate (fatalities per 100,000 workers), ranking fifth in worker fatalities by industry. The mining industry also had a 10.9 percent incidence rate (serious claims per thousand employees), according to Safe Work Australia (2021).

Members of the International Council on Mining and Metals (ICMM) recorded a total of 287 occupational fatalities in 2019, a significant increase from the 50 fatalities recorded in 2018 and 51 in 2017. Of the 2019 fatalities, 250 occurred due to the Brumadinho tailings dam collapse.

In 2020, ICMM members recorded 44 fatalities, with the highest number of fatalities attributed to 'fall of ground' incidents. The next highest causes of deaths are mobile equipment and transportation, and fires and explosions (ICMM 2020).

In response to these key industry challenges, ICMM continues to facilitate sharing and learning amongst company members and support initiatives focused on enhancing health and safety in the mining sector to reach its goal of zero fatalities (ICMM 2021).

In 2017, a large seismic event generated significant damage and dust throughout an underground copper/gold block caving mine in Indonesia. It was believed that a visual alert and evacuation system might improve the evacuation or exclusion of underground personnel, with the initial idea being inspired by airplane emergency exit strip lighting. With the demand for safer mining operations, the client began to search for an off-the-shelf system that the operation could possibly utilise.

The initial scope for this emergency/evacuation system was that it needed to be able to provide real-time demarcation of where it was safe or unsafe to be inside the cave footprint at any point in time and then to be able to trigger evacuation in real-time emergencies changing the emergency communication methodology from a one channel communication system based on people's behaviour, to a massive centralized system. This required multiple colours light indicators (red/blue/amber/green/white) combined with synchronised flashing and chasing modes as seen in Figure 1. This system required a centralised software control platform with the ability to be automatically triggered by the mine's microseismic monitoring system and monitor the operational status of each part of the system in real-time. Various LED strip lighting technologies were trialled and ultimately found unsuitable due to power requirements, maintenance costs and control capabilities, among others.

Figure 1 FireFly lighting colour options

IoT Automation was engaged by this block caving mine in Indonesia to design and develop a new smart lighting system that would ensure all underground personnel are provided with real-time warning and evacuation information if a seismic or emergency event occurs in an underground block cave mining environment. The FireFly smart lighting system was the result.

2 Methodology

In 2018, the system was initially deployed into just one of the panels in a key production block of the mines extraction level, with encouraging results. In collaboration with system users, subsequent modifications to both the hardware and software were done to the system throughout 2019, including improvements to the system's functionality. Expansion and improvements to the system includes use of the system as a network link for geotechnical instrumentation, RFID tag detection (pedestrians and mobile equipment) and software integration with microseismic and ventilation monitoring systems. This resulted in approval to expand the system into all production block areas of the mine.

2.1 Seismic monitoring in underground mines

Routine seismic monitoring in underground mines enables the measurement of seismicity exposure and provides critical information that can help steer efforts towards the prevention and management of probable rock mass instabilities that could lead to rockbursts (Mendecki et al. 2010).

As such, real-time seismic monitoring of block cave underground mines is now an industry best practice. Source data is used to guide the prevention, control, and alerting to any potential rock mass volatilities that could result in damage to mine infrastructure or the potential endangerment to mine workers as mine developments go deeper. Monitoring of regional and localised seismic activity is now widely adopted across block cave mines around the world, aiding the implementation of protocols for personnel rescue and improving mine monitoring processes.

2.2 Legacy emergency communications in underground mines

With the complex nature of underground mines, constructing and establishing reliable communication systems is crucial for personnel safety and productivity. Communication systems in underground mines can be classified as through-the-air (TTA), through-the-earth (TTE), through-the-wire (TTW) and their combinations.

Common technologies used for communications include fixed-wire telephones, leaky feeders, cellular radio, personal emergency devices (PED), optical fibre, and a combination of these systems (Jang & Topal 2020).

Current mine communication processes to raise an underground emergency rely on verbal instructions. Traditionally, a series of alerts are sent to the workforce to trigger evacuation procedures in a seismically active area, including emails and radio instructions. The limitations of these mechanisms are their reliance on timely delivery. Most systems also utilise wired communication channels, which make it challenging to deploy in various parts of the mine, especially throughout hazardous areas (Bandyopadhyay et al. 2010).

Additionally, many international mining companies now employ both national and foreign workers. It is common for critical radio announcements to be in a language that many of the workforce do not understand. In a study conducted by Yarkan et al. (2009), no single communication system is being used in establishing communications in underground mine environments despite the prevalence of underground mining disasters. Further to this, emails are subject to delays or being overlooked; as a result, they are, at best, a backup passage of information.

Another conventional method utilised by mines to raise awareness of an underground emergency is a stench gas system. This notification system uses the release of a strong-smelling gas into the mine's ventilation system to trigger emergency response actions. However, a mine's primary and secondary ventilation systems are regularly subjected to operational changes. These dynamic changes can reduce the effectiveness of the ventilation system in directing the stench gas smell to all areas of a mine, resulting in workers not receiving critical emergency information.

All these communication mechanisms are vital for any underground operation. Each system is an added layer of protection built on top of the next method. The purpose of multiple systems is to ensure the safety of all personnel underground. However, even with these current systems, there is the potential for gaps in providing precise and real-time information to underground teams. Thus, having a combination of these systems in place is beneficial in bridging communication gaps in the underground mining environment and enhancing emergency protocols and safety management.

2.3 Deployment of the FireFly lighting and installing the FireFly smart lighting as a visual warning system

The smart lighting specialist worked alongside the geoscience and electrical teams at this block caving mine to implement the new technology into their current processes. In 2018, the new technology was initially deployed into Panel 20 of Production Block 1 on the mine's extraction level, with encouraging results. Figure 2 shows how the 1,200 'smart' lights were installed across 21 km of the mine's undercut and extraction level tunnels.

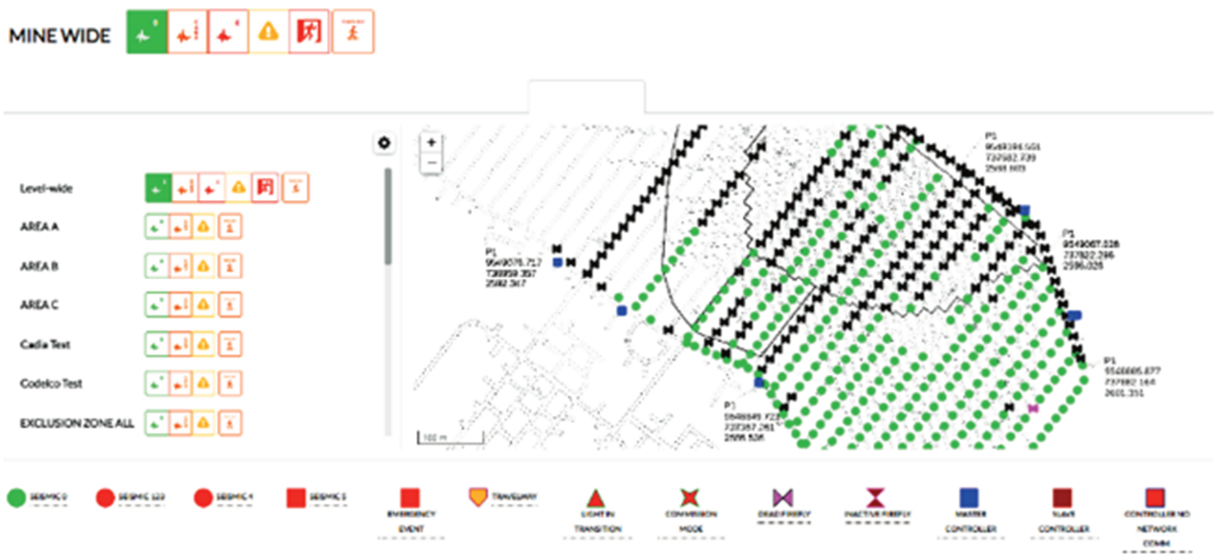

Figure 2 FireFly lights deployed throughout areas A, B and C of the mine

On the extraction level of this block cave mine, the drawpoints are spaced at 20 m intervals along the panel drives. The smart lighting modules are installed adjacent to each drawpoint at the same 20 m intervals. As seen in Figure 3, the smart lights are daisy-chained together by an armoured four core instrument cable that connects each string of smart lights back to the smart lighting control panel, which in turn is networked back via the mine's existing network infrastructure to the light's central server. As an added functionality of the smart lighting modules, the Bluetooth radio of each light is utilised to provide a wireless connection to the mine's geotechnical extensometers (MPBX), which are correspondingly also installed at 20 m intervals into the pillars of each drawpoint along the panel drives.

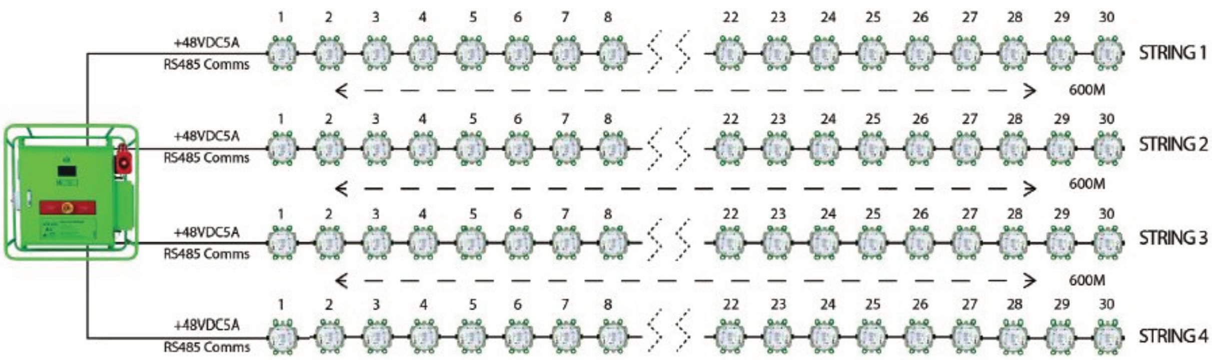

Figure 3 Daisy-chained FireFly lights

From there, the MPBX data is then transferred back along the light's wired network to the light's central server, then pushed out to the mine's geotechnical monitoring database. This transfer provides a robust and reliable data backhaul network for the mine's critical geotechnical data information. The mine now utilises the map-based smart lighting control application combined with the light network to accurately control and apply their seismic response plans to the underground mine workings. The software-controlled lighting uses various colours and lighting modes (e.g. flashing/chasing/solid) to indicate safe, unsafe and seismic work zones in the underground mine, depending on the category of seismic event recorded. Figure 4 shows the different seismic categories, event descriptions and the protocols implemented for these events.

Seismic Category	Criteria	Event Description	Protocol	Hydrofracking Activity (fracking)	Hydrofracking Activity DCIZ (fracking)	Assembly Point	FireFly Light State	FireFly Geotech User Interface Icon (OFF)	FireFly Geotech User Interface Icon (ON)
Normal (0)	Seismic Event Below Threshold	Mw <0.7; EvI < Level 2	Working Normally	Working Normally	Working Normally	-	Green Solid	0	0
1	Undercut Blasting	Undercut Ring Blasting	Clear red zone as per GeoEngineering recommendation in undercut & extraction	Working Normally	Working Normally	Outside red zone/ UFF	Red Solid	1 2 3	1 2 3
2	Seismic Event Index	Event Index = Level 2	Clear red zone until event index change to level 1	Stop activity No Evacuation	Stop activity No Evacuation	Outside red zone/ UFF	Red Solid	1 2 3	1 2 3
3		0.7; EvI ≤ Mw <2.0	Clear red zone 2.5 hours in undercut & extraction	Working Normally	Working Normally	Outside red zone/ UFF	Red Solid	1 2 3	1 2 3
4	Seismic Event Above Threshold	Mw ≥ 2.0 (Outside Footprint)	Clear Mine until further notification from GeoEngineering	Stop activity Evacuation	Working Normally	UFF/LFF	Red Solid	4	4
5		Mw ≥ 2.0 (Inside Footprint)	Clear Mine until further notification from GeoEngineering	Stop activity Evacuation	Working Normally (Follow Re-Entry Protocol Hydrofracking & notification)	Outside Mine (Portal)	Red Flashing	5	5

Figure 4 FireFly light protocol according to seismic event categories

Subsequent modifications to both the hardware and software of the smart light system throughout 2019, including the use of the system as a network link for geotechnical instrumentation, RFID tag detection (pedestrians and mobile equipment) and software integration with microseismic and ventilation monitoring systems – resulted in approval to expand the system into all areas of production blocks 1 and 2 throughout the mine.

3 Data

At the block cave mine, there are three production zones (A, B and C) which produce ore at different rates. Table 1 estimates the split of ore production by zone during CY2020 and the relative cost per hour for each zone.

Table 1 CY2020 actual production and profit per hour of the mine

CY2020 – actual	Copper	Gold	Totals
Tonnes per day (tpd)			25,000
Ore grade	0.87 g/t	0.75g/t	
Daily production	435,000 lb	661 oz	
Profit	USD 2.80 per lb	USD 1,400 per oz	
Profit per day	USD 1,218,000	USD 925,400	USD 2,143,400
Profit per hour	USD 50,750	USD 38,558	USD 89,308

The smart lighting control application is used to configure, monitor and manage the entire system. This web-based application is also the key user interface for triggering underground emergency or evacuation alerts.

The smart lighting system uses intelligent illumination to communicate critical information to underground mine workers. The software can be integrated into the mine's seismic monitoring software to provide automatically triggered real-time visual and audible communications to the underground workforce. The lighting modules can also wirelessly connect to a mine's geotechnical instruments.

This flexible system enables the mine to trigger immediate actions and systematically update zones on a daily or weekly basis. The mine can create exclusion zones around the cave front, close access to specific drives or shut down entire levels during undercut blasting. Additionally, in an emergency, the system will initiate mine-wide evacuations, while also providing guidance lighting to direct mine workers to the correct route they should take in order to arrive at a refuge chamber or to access the primary or secondary escape ways.

4 Results

With the implementation of smart lighting technology, the mine was able to substantially reduce lost productivity by enabling 'safe zones' unaffected by seismic activity during the Category 3 events to continue ore production. These safe zones were easily demarcated and controlled in real time, using the lighting control software.

One year following implementing the new technology, the mine had 30.5% less production downtime due to seismic shutdowns, equating to USD 16.9 million in additional productivity, as shown in Figure 5. This was made possible by the system's ability to demarcate safe zones to facilitate ongoing production and prevent mine-wide closures.

Based on the zone-closure data provided by the client for CY2020, the new technology was able to reduce production losses in safe zones by 510 hours ; nearly a 30% reduction in total lost hours, had the system not been in place.

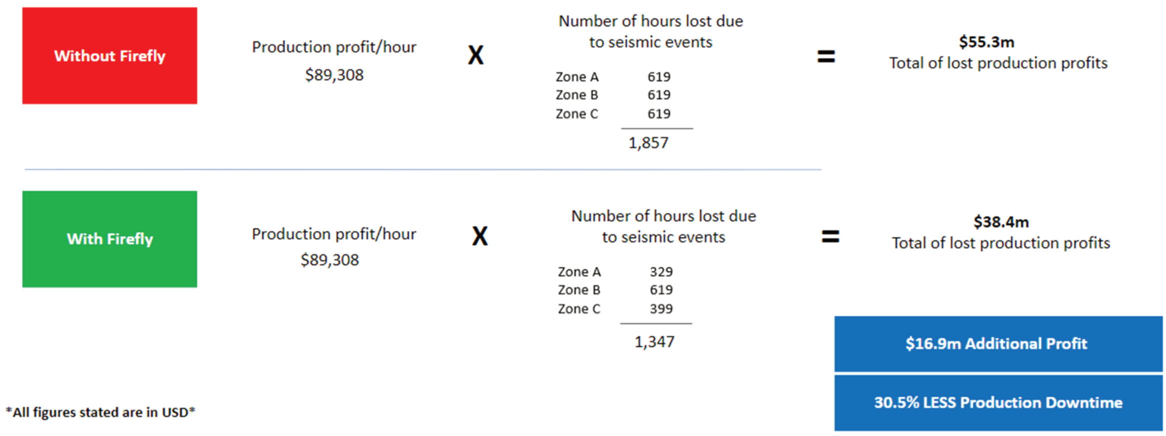

Figure 5 Comparison of production profit per hour before and after the deployment of FireFly lights

4.1 Reduction in workforce exposure to seismic risk and hazardous events

The smart lighting's alert system ensured effective removal of personnel from areas of increased seismic activity or regions affected by a seismic event with minimal delay. The system is also used to prevent personnel from entering an unsafe area isolated due to the advancing cave front, hydrofracturing, or other high-risk mining activities.

4.2 Rapid and automatic response

Utilising the smart lighting network throughout the underground mine, the geoscience team can now provide real-time and immediate seismic threshold trigger response outcomes. This direct and controlled visual and siren communication mechanism enables the mine to reduce the exposure of their underground workers to seismic risks. By providing precise and immediate information as to whether the areas they are working in are safe, unsafe, or required for evacuation.

4.3 Improved productivity and reduction in total lost hours

The underground mine has three production zones, namely Zone A, Zone B, and Zone C—all of which produce ore at different rates. In CY2020, the mine reported seismic events that would have caused all three mine zones to shut down.

Data was sourced detailing actual seismic event reports from 1st January 2020 to 2nd December 2020, in conjunction with actual CY2020 production, sales, and cost analysis. During this period, the mine reported a total of 196 Category 3 seismic events and 4 Category 4 events, as shown in Table 2.

Table 2 Closure hours of zones A, B and C and breakdown of lost profits using the FireFly lighting system

Seismicity events and zones affected				Cost of closures			
Event rating	**No. of events**	**Zones that closed**	**Hours closed**	**Zone A (USD)**	**Zone B (USD)**	**Zone C (USD)**	**Totals (USD)**
Cat. 3	16	B only	38	0	1.02 m	0	1.02 m
Cat. 3	74	A and B	182	8.12 m	4.88 m	0	13.00 m
Cat. 3	102	B and C	252	0	6.75 m	4.50 m	11.25 m
Cat. 4	4	A, B and C	147	6.56 m	3.94 m	2.63 m	13.13 m
Totals	196		619	14.68 m	16.59 m	7.13 m	38.40 m

Each of these events would have resulted in mine-wide closures where all productivity stops. The mine has a production profit per hour of USD 89,308. In total, the closures would have resulted in 1,857 hours in lost operations across the three zones (A, B, and C), with a total of USD 55.3 million in lost production profits due to these seismic events. Therefore, site-wide stoppages such as these have a significant impact on the operating profit of the mine.

However, FireFly was able to mitigate lost productivity by enabling safe zones to continue to produce ore during Category 3 events. Based on the zone-closure data provided by the mine for CY2020, FireFly was able to reduce production losses by more than 30%.

5 Conclusion

The lighting's real-time situational awareness capabilities helped underground mine workers navigate the mining environment and make safe and informed decisions on whether a particular part or area of the mine is safe or unsafe to work in.

The system also provided the mine with the ability to indicate safe, unsafe, and hazardous zones and efficiently communicated critical information to the underground workforce during emergencies and evacuations. It improved day-to-day operations by minimising traffic issues and reducing accidents, especially in low-illuminated levels, one-way passages, and steep inclines.

The mine had seen encouraging results on their productivity and operations as well. With the new technology, the mine had nearly 30% less production downtime due to seismic shutdowns, equating to

$16.9 million in additional productivity. This was made possible by systems' ability to enable safe zones to facilitate ongoing production and prevent mine-wide closures.

Acknowledgement

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