COAL INTERNATIONAL

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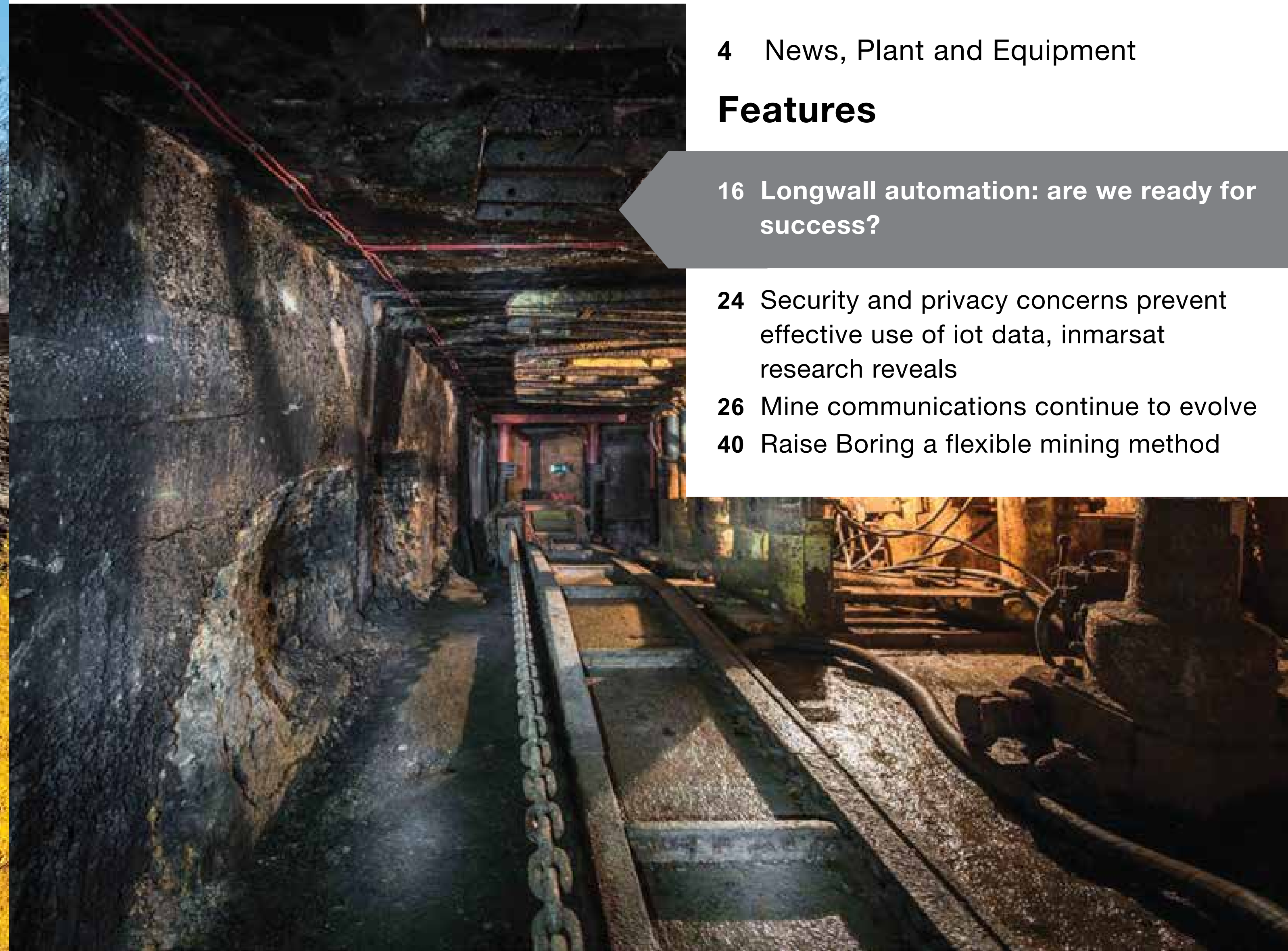

Famur

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NEWS, PLANT AND EQUIPMENT

Philippines plans bigger subsidies

The Philippines plans to spend more on fuel subsidies and increase coal supply, while considering additional food imports amid an oil price shock as the Russia-Ukraine war draws out.

"The Philippine economy will likely be collateral damage," Finance Secretary Carlos Dominguez said in a televised briefing. "It's as if we are hit by a ricocheting bullet."

The Southeast Asian nation, which imports almost all of its petroleum requirements, is cushioning higher oil's impact on food costs and the broader economy. The fallout from the war has pushed gasoline prices higher, leaving the consumer-driven economy vulnerable to shocks just as it has begun seeing a more solid recovery.

Economic Planning Secretary Karl Chua said the government can double the fuel subsidy to the public transport sector to 5 billion pesos ($96 million). It can also boost coal supply and reduce prices by cutting the so-called most favoured nation tariff rate to zero from 7% until December, he said.

Other proposals include:

- Boosting rice imports if local production falters, while extending lower tariff on inbound shipments of the grain and pork that was placed to curb previous price spikes
- Possible fish imports given a supply gap of 200,000 metric tons
- Increasing buffer stock of petroleum to 45 days from 30 days and of liquefied petroleum gas to 15 days from seven days
- Allowing foreign ownership in micro-grid, solar, wind and tidal energy

Some of these proposals will require certain changes in existing laws, and a special session in Congress may be recommended if the situation escalates, Chua said.

Philippines' Diokno Says Oil Is Key Risk from Russia-Ukraine War

With these measures, "we will be able to keep the inflation within our target range of 2%-4% and maintain our growth path of 7%-9% this year," Dominguez said.

House gives producers a tax break that will cost Wyoming $10 million a year

The Wyoming House of Representatives has approved a tax break that will save the coal industry money, but cost Wyoming around $10 million dollars a year. Gillette Rep. Tim Hallinan said it gives coal the same tax rate as oil and gas.

But Rep. Jim Roscoe of Wilson said the money will prop up out of state coal companies.

"I could support a bill like this if the $10 million stayed in Wyoming. If it went directly somehow to our coal miners or it helped Wyoming's effort for Carbon Capture and sequestration. Or even helped our legal efforts to keep ports open but sending it out of state doesn't really make a lot of sense to me," said Roscoe.

But supporters say the bill may help coal companies rehire displaced Wyoming workers. The bill now goes to the Senate for further debate.

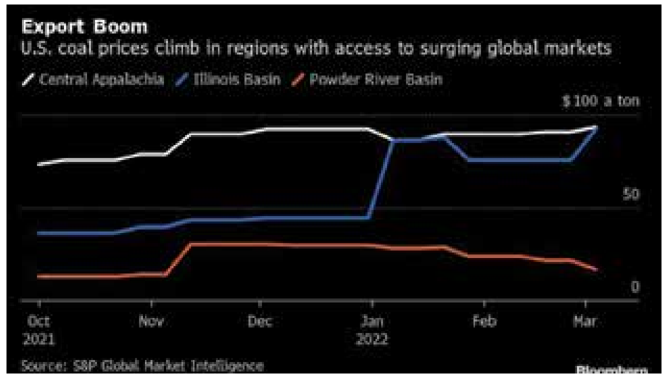
US prices soar as war drives global commodities rally

Concerns of a looming global shortage of coal are driving up prices in every US region that has access to export markets.

Potential sanctions on Russia, a key supplier, have buyers around the world scrambling to line up supplies of the dirtiest fossil fuel. The war in Ukraine has roiled global markets, sending prices soaring for key commodities from oil to wheat and natural gas to nickel, exacerbating an inflationary surge for energy-consuming nations and worsening a cost-of-living crisis for millions.

Coal from the Illinois Basin soared $17 a short ton to $92.50 recently, the highest in records going back to 2005, according to data from S&P Global Market Intelligence released Monday. Central Appalachia prices, the most expensive region, gained $2.85 to $93.40.

Only the Powder River Basin in Wyoming and Montana saw a decline in early March, with prices slipping $4.90 to $16.75. The biggest US coal-supplying region has no easy access to export terminals and its low-quality coal is used almost exclusively in US power plants.



QRC urges New Acland approval as prices soar

The Queensland Resources Council (QRC) has called on the Queensland government to finalise approvals for the New Acland Stage 3 project, as coal prices spike amid the Russia-Ukraine crisis.

"The world, especially Europe, needs Queensland's high-quality commodities now more than ever," QRC CEO Ian Macfarlane said.

"Queensland's high-quality coal has a role to play in ensuring energy security and stability for export nations.

"Delays in finalising approvals for the New Acland mine have not only cost jobs and hurt the Darling Downs economy, but they are also undercutting Australia's capacity to supply global markets at a time when they need our commodities the most."

Coal miner New Hope has been battling to gain approval for the Stage 3 development of its New Acland mine, in Queensland, and was last month backed by the Queensland Land Court which recommended that the mining leases and environmental authority applications for the project be granted.

New Hope subsidiary New Acland Coal currently operates the existing New Acland mine as a 4.8-million-tonne-a-year opencut coal mine; however, the mine's reserves are depleted. The Stage 3 expansion project will increase the mine's yearly output to 7.5-million tonnes and will extend the operation's life by 12 years beyond the current end-date of mid-2020.

Once approved the New Acland Stage 3 project will create 187 new jobs within the first six months, 487 jobs within 18 months and inject A$7-billion into the economy.

"In December the Land Court of Queensland recommended the New Acland Mine Stage 3 mining leases and environmental authority amendment application be granted, subject to conditions," said Macfarlane.

"Queensland's energy exports, including coal and liquefied natural gas (LNG), have a role to play as nations work towards net zero emissions goals, especially as export nations take the time needed to implement new technologies, including renewables, carbon capture and storage, and to further develop hydrogen potential.

"Queensland has the resources to be at the centre of each of these markets, but lengthy project delays are holding the state back and could compromise future opportunities.

"Australia has built its reputation as a trusted global supplier of commodities. The Queensland government cannot drag out a decision on New Acland any longer."

The QRC's call comes amid reports from advisory firm Wood Makenzie (Woodmac) that the Russia-Ukraine crisis had shocked the coal and broader energy markets, with price spikes observed over the past few days.

"European thermal coal prices have surged to record highs with futures prices above $400/t until Q4 2022. Some buyers in Japan and Europe have already indicated they are looking to replace Russian supply, and non-Russian thermal coal in Europe is attracting a significant premium over Russian material," said Woodmac principal analyst Rory Simington.

"Prices in the Asian market have also responded with Newcastle physical prices reaching $400/t. Metallurgical coal, used in coke production and injected into blast furnaces, spiked with PCI prices – a key Russian export – leaping to an unprecedented level and nearing towards $400/t."

However, Simington noted that relatively normal import activities remain the most likely outcome.

"Heavy reliance on Russian coal imports in the current tight market means a prolonged cut-off would bring damage to both Russia and importing countries and is unlikely in Wood Mackenzie's view.

Russian coal accounts for roughly 30% of European metallurgical coal imports and almost 70% of European thermal coal imports.

"North Asian buyers South Korea and Japan also have significant exposure to Russian coal with Russian thermal coal representing 20% of South Korea's imports and over 10% of Japan's, while Russian metallurgical coal represents over 15% and 5% of the North Asian markets' imports, respectively.

"Together, Europe, Japan and South Korea imported around 90-million tonnes of Russian thermal coal and 25-million tonnes of Russian metallurgical coal in 2021. These coals are predominantly high energy thermal coal and PCI and cannot conceivably be replaced in the currently tight global supply market."

Simington noted that power plants currently using this type of coal are specifically designed to run on high-energy coal and are unable to switch coal types. Furthermore, steel mill operators would also be challenged to replace Russian PCI and metallurgical coals given the current global spot supply shortages especially out of Australia.

NEWS, PLANT AND EQUIPMENT

Nokia trials next-gen 5G with Sandvik mining equipment

Nokia and mobile operator Telia are running a live trial in Finland with high-tech global engineering group, Sandvik, to demonstrate how next generation 5G Edge Slicing functions can operate with different mining equipment and digital applications.

This is the world's first deployment of 5G Edge Slicing on a live commercial network allowing operators to offer their enterprise customers next-generation, secure, reliable, and high-performing Virtual Private Network (VPN) services over commercial 4G and 5G networks.

"We are delighted to be the first to deploy the first-ever 5G Edge Slicing solution together with Nokia and our important customer Sandvik, who is investing heavily in digital mining technologies and the technology environment in its test mine in Tampere," Telia Finland chief technology officer Jari Collin said.

"Our advanced 5G network supports our customers' business by enabling new kinds of services and making the network more efficient.

"We will continue to develop innovations and the latest applications, as our mission is to bring the opportunities of 5G to our customers."

Nokia will also run a trial with Cellcom using sliced RAN-Transport-Core in Netanya, Israel, which will be focussed on business applications and the customer experience as well as enterprise interconnectivity over a high-speed metro network.

Once launched, both companies will be able to offer new services to their customers – driving new revenue opportunities – as well as partner with cloud application and infrastructure service providers.

Nokia's 5G Edge Slicing solution is an evolution of Nokia's previously announced 4G/5G slicing capability.

It enables operators to keep critical business data traffic local while running slice management, control, and assurance on existing central mobile data centres ensuring cost and operational efficiency.

It is also scalable, and the same virtualised network infrastructure can be used by several customers in the same area, for example in a business campus containing multiple companies.

"Network Slicing is the most exciting aspect of 5G, as it raises the possibility of new dimensions of 'higher performance', and enhanced ARPU from both consumers and enterprise customers," Mobile Experts principal analyst Joe Madden said.

"While many providers are focussing on deploying 5G private networks for enterprises, network slicing also opens up new market opportunities for operators with 5G Virtual Private Networks by keeping enterprise traffic local with Edge Slicing using the existing 4G/5G network."

These live trials follow a Memorandum of Understanding between Nokia and TPG Telecom last month to develop mobile private network innovations for the mining and energy sectors.

Sincere support to coal-mining front

South Phyongan Province powerfully support the coal miners who have turned out to implement the decisions made at the 4th Plenary Meeting of the 8th Central Committee of the Workers' Party of Korea.

Cities and counties, factories and enterprises and other units of the province have sent various kinds of tools, materials and supplies to coal mines thus contributing to the increased coal output.

Provincial officials make active efforts to solve knotty problems arising in coal production on the spot including the work of securing reserve cutting faces by prioritizing tunnelling.

Officials of different cities and counties such as Tokchon City and Chongnam County brought with them various tools and materials to coal mines and encouraged coal miners.

Officials of the provincial organs including the Provincial People's Committee and the Provincial Trade Administration Bureau supported coal mines in a substantial manner.

The province reviewed the state of supporting coal mines meaningfully and saw to it that officials and working people of every unit supported the coal front materially and morally with correct viewpoint on and attitude towards it.

In addition, it gives wide publicity of the model units and makes the others follow them.

The enthusiasm for supporting coal front is getting high in the province.

India to use its unutilized reserves to ensure energy security by gasification

India has a coal reserve of 307 billion Metric Tons and 80 % of the coal produced goes to produce thermal electricity. However, there is still enough coal which is unfit for thermal power plants and uneconomical for its transportation.

With crude oil price touching its eight years high at USD 108 a barrel, India is planning to use its unutilized coal reserves to ensure energy security by coal gasification and its conversion into precious chemicals mainly ethanol, blue hydrogen, and synthetic diesel.

"This year alone four projects of coal gasification and conversion of coal into chemicals are going to be set up by the Coal India Ltd (CIL) on BOO (Build Own and Operate) basis," said a senior officer of the Coal Ministry.

The Ministry has invited experts from the Industry, Academia, Research Organizations, and Engineering consultations along with policy makers are to discuss effective implementation of the Coal Gasification Mission, he said.

Govt plans new tech, digital infrastructure to support domestic mine operations

The government plans to implement new technologies and build digital infrastructure to support current and future coal mines operations, a move that would reduce the country's dependency on imports. Technological advancements in coal mining are also making operations more productive.

"The objective is to implement new technologies and build digital infrastructure to support current and future ramp-up for the mines," according to the government's draft technology road map for the coal sector. This involves a strong, multi-speed backbone information technology and infrastructure system that allows rapid deployment of new technologies.

"Creation of such system would require access to new-age ecosystems (e.g., start-ups, established vendors, research institutes, etc). The technological transformation will also entail the creation of a new culture in the organisation," it said. To reduce the dependency on imports, it is critical for Coal India Ltd (CIL) to reach the one billion tonnes (BT) target, thereby embarking on a technological transformation journey, it said.

New technologies can have a number of impacts on mining operations, including safety and productivity, environmental protection, and opportunities for women. Safer working conditions through improved underground communication, automation, more sophisticated mineral and metal transportation, and emergency response measures are achieved by integrating technology into mining projects, it said.

A new way of thinking will be inculcated in the entire organisation. A technology transformation team will be set in place to drive impact and sustain the programme with an established centre of excellence. A robust tracking and change management mechanism will be deployed to ensure timely resolution and delivery.

"The scope of this road map (is)…technology enablement in coal mines for transformation across business value chain, leveraging 'digital technology' as an accelerator for demonstrating performance enhancement from in the coal mines and increasing productivity, safety, and sustainability while…reducing environmental impact by upgrading conventional technologies to new technologies," according to the draft road map.

India had a total coal reserve of 344.02 billion tonnes. Commercial primary energy consumption in India has seen a rise of 700% in the past four decades. Major factors for the increase in demand for energy are expanding economy, rising population and the improvement of quality of life. The limited potentiality of other energy sources will lead to the continuation of coal as the primary resource in India's energy scenario for the next few decades

However, due to the high demand and poor average quality, the country has to import coal of higher quality mainly to meet the requirements of its steel plants, cement plants and sponge iron plants, among others.

Martin Engineering safety standards recognised for “zero deficiencies”

Martin Engineering has solidified its reputation as a pioneer in modern industrial safety with a RAVS Plus award from ISNetworld (ISN) – one of the world’s largest safety compliance groups.

The bulk material handling technology company has developed solutions to common industry problems for more than 75 years.

Now, the RAVS Plus recognition has demonstrated to Martin Engineering customers that the company’s products and services undergo a higher level of scrutiny.

ISN helps thousands of contractors and suppliers manage risk and support sustainability, evaluating company safety cultures by collecting and reviewing risk management documentation.

Martin Engineering global director of people and culture Janice Verbeke said such recognition takes commitment from the whole company.

“The entire RAVS Plus process was definitely a team effort,” Verbeke said.

“Everyone involved rallied to make this accomplishment happen. But the foundation of safety had already been established here long before I arrived.”

Over several months, an ISN audit found zero deficiencies in safety and only a short list of opportunities for improvement.

While COVID-19 restrictions stopped in-person audits to take place, five Martin Engineering technicians were surveyed to grasp their knowledge of policies, procedures, and training.

“Sue and I complemented each other well, with our different knowledge bases,” Verbeke said of the audit. “The questions ranged from overall safety knowledge on OSHA regulations to specific topics of what we do in the field.

“She provided information on our practices, protocols and equipment used in the field. I provided the safety and regulatory knowledge, training protocols and corporate administrative processes.”

Overall, the recognition allows Martin Engineering to continue believing in itself and understanding it’s on a strong path to success.

“The most positive outcome of the ISN recognition is the sense of gratification that we, as an organisation, we’re willing to put ourselves up to scrutiny and demonstrated that safety is our culture, it’s not just talk,” Verbeke concluded. “It’s a deep belief system that we practice every day.”

Anglo American resumes mining at Queensland’s Grosvenor mine

The group’s metallurgical coal production guidance for 2022 is now expected to fall between 20mln and 22mln metric tonnes, with unit cost guidance of $85 a tonne

Anglo American has resumed operations at its Grosvenor metallurgical coal mine in Queensland, Australia, more than 20 months after a methane explosion injured personnel and prompted a suspension of longwall mining.

The FTSE 100 miner said it received confirmation on 16 February from Resources Safety and Health Queensland that longwall mining operations could now resume.

Following the release of the Board of Inquiry’s report into the Grosvenor gas incident, the company had last year committed another A$5mln ($3.8mln) to improving safety at its underground coal mines.

Anglo American said its metallurgical coal production guidance for 2022 is now expected to fall between 20mln and 22mln metric tonnes. The unit cost guidance for 2022 has been raised from $80 to $85 a tonne. Unit cost in 2021 was $105 per tonne, the company said.

“Over the past 18 months, we have worked with leading industry experts and invested significantly in automation technology, remote operations, gas management and data analytics, introducing a number of advancements in the way underground coal mines can operate,” said Tyler Mitchelson, CEO of Anglo American’s metallurgical coal business.

Vietnam targets net zero amid struggles

At the COP26 climate conference last year, Vietnam's Prime Minister Pham Minh Chính unexpectedly announced a target of reaching net zero by 2050. The country also signed the Global Coal to Clean Power Transition statement, in which it committed to rapidly scale up renewables and build no more new unabated coal power plants.

This is a major and unexpected pivot for Vietnam. The country has invested heavily in coal power over the past decade and has the most installed coal capacity among Mekong countries, after China.

Just two months before COP26, the government released Vietnam's eighth power development plan (PDP8) which covered 2021-30 and relied heavily on foreign investment in non-renewable energy. The PDP8 would have doubled coal power capacity by 2030, with more to come in the five years after that.

After its COP26 announcements, the government asked the Ministry of Industry and Trade (MoIT) to revise the PDP8, though an updated draft is yet to be released.

By 2020, Vietnam's coal power fleet was generating as much energy as all other power sources combined. In that year, the sector emitted about 126 million tonnes of CO2, or around half of Vietnam's emissions. The country's emissions have increased in recent years, as those of its neighbours have mostly remained flat or fallen.

Brian Eyler, Southeast Asia director of the Stimson Center, a US thinktank, explains that as Vietnam exports more manufactured goods than its neighbours, sources of electricity generation needed to be developed more quickly, and coal and hydropower were "the easy solutions".

Around 2010, Vietnam stopped building big dams, instead favouring coal power, when it released its seventh power development plan (PDP7) for 2011-20.

"The Ministry of Industry and Trade judged that the hydro potential had been all but tapped, so they switched the focus to coal," says Tran Dinh Sinh, a technical consultant for GreenID, a Vietnamese environmental NGO.

"The latest draft [September 2021] of the PDP8 also showed 51 gigawatts (GW) of coal in 2030, so PDP8 is the continuation of PDP7. But [the ministry] are not explaining why they are doing this."

Research commissioned in 2017 by the Friedrich Ebert Foundation, a German non-profit organisation, found that institutionalised conflicts of interest were a barrier to Vietnam's transition from coal to low-carbon sources, an observation echoed by Eyler.

"It is hard to convince companies who build coal plants not to do it. They have a lot of power and special interest groups," he explains, adding that the balancing of interests in the PDP revision process has felt like a boxing match.

"One day the coal people are back on the ropes, and the next day they are fighting hard. It's just back and forth, back, and forth."

Coal investment drying up

Data from Global Energy Monitor shows that since 2010 Vietnam's coal sector has received at least USD 29 billion in foreign investment.

The Stimson Center's Mekong Infrastructure Tracker tells a similar story of reliance on foreign money to build coal plants: for every 100 MW of coal capacity in operation right now, 93 MW was built with some foreign investment.

"Coal was the cheapest and fastest way to meet Vietnam's electricity needs. And there was easy funding available," says James Browning, the communications director of Global Energy Monitor.

China, Japan and South Korea used to be the main investors in Vietnam's coal sector but have now backed away. Even before Vietnam's announcement at COP26, questions were being raised about how the PDP8 would be funded.

According to the September draft, Vietnam would need roughly USD 44 billion to grow its coal fleet over the next 10 years, or roughly 50% more than all the foreign funds that have flowed into the sector in the past decade – an increase that seems unlikely in the new landscape of coal finance.

Doubt has therefore been cast on the feasibility of the PDP's projections. After President Xi Jinping announced last September that China would stop building new overseas coal projects, the Institute for Energy Economics and Financial Analysis published a brief.

It concluded that, given the turn away from financing coal by Asian and North American governments and banks, of the additional 30 GW of coal power planned in PDP8, only a third is still feasible. This covers projects already in construction or with funding secured.

Human costs and backlash

Research published in 2017 on the burden of disease arising from coal power in Southeast Asia estimated that if all the coal plants in PDP7 were built by 2030, then Vietnam would face almost 20,000 extra deaths that year due to the resulting air pollution.

Burning coal releases fly ash, which is abundant in tiny particulates. When inhaled, these can lead to heart disease, lung and throat cancers and respiratory diseases. There is, as yet limited data concerning how damaging Vietnam's coal plants are to surrounding communities.

In an effort to fill this gap, Nguyen Trong An, a paediatrician at the Center for Health Environment Research and Development (CHERAD) in Hanoi, travelled with a team to Vinh Tan commune on the country's southeast coast in March 2021. The area is home to three operational coal plants, with another under construction.

The team wanted to gather information from medical logbooks at local health stations in Vinh Tan and nearby commune Phuoc The. In Vinh Tan, the authorities did not supply original documents, claiming that the bookkeeper was away. An says the team plan to return this year to investigate further.

At Phuoc The, he claims to have found that from 2010 to 2020 the rate of death from cancer and stroke was higher than expected. Before the coal plants were built in 2010, for every 100 deaths, 33 were attributable to noncommunicable diseases such as cancer and heart attack. By 2020, this had risen to 70 in 100.

A correlation can be seen, but An says they may not be the only cause of the higher mortality rates and the findings will need to be corroborated with further studies this year.

Despite a lack of localised data on the fuel's harmful health impacts in Vietnam, some citizens have already turned against coal plants. Of the 54 coal power projects that Global Energy Monitor tracks in the country, eight have recorded protest or opposition.

Local residents in the vicinity of the Duyen Hai power station have complained that the removal of sand dunes to build a coal port has increased the incidence of flooding, landslides and soil erosion.

Meanwhile, the discharge of heated water from the Quang Ninh power plant has caused mass die-offs of fish and shrimp, destroying the livelihoods of hundreds of families.

Adapting to global shifts

At the end of November, MoIT said that by 2045, cleaner energy including gas, solar and wind will account for about 75% of Vietnam's total installed generating capacity.

However, many experts do not consider gas a 'clean energy'. Browning points out that, in the short term, the abundant methane released during gas extraction and combustion is 80 times worse than CO2 in terms of its warming effect.

Global Energy Monitor released a report in October 2021 saying that if all planned gas infrastructure in Asia is built then the goal of limiting global warming to 1.5C is unlikely to be met.

Vietnam's renewable energy sector's potential is booming. The draft PDP8 predicts that in 2030 the country will need 92 GW of electricity. To meet that demand, Vietnam must grow its energy structure by 18 GW in nine years, or 2 GW per year. In 2020, wind power alone grew by 4 GW, and in 2019, solar capacity increased by 16 GW.

"Vietnam can make a transition away from these previously forecast coal plants," said Eyler. "The biggest opportunity lies in offshore wind. We could see a very similar boom in wind as we saw in solar in the last two years."

He added: "I think the China commitment [to stop overseas coal projects] will produce results, and that could work to change the way that those [coal] groups think about the future. Because we've seen, like in the US, the big oil and gas companies, they are building solar now. They can make the transition."

Whitehaven rides through rough patch

Whitehaven Coal has made the best of a bad situation, achieving record first-half earnings despite lower production following the scheduled Narrabri mine longwall move.

The company produced 6.7 million tonnes of coal for the first half of the 2022 financial year, 13% less than the prior corresponding period (pcp).

This translated to 18% fewer coal sales over the same period and 6% less coal stocks to end 2021.

Whitehaven managing director and chief executive officer Paul Flynn said the company had performed well in difficult circumstances.

"The first half operationally was not without its challenges, with COVID impacts in recent months leading to elevated absenteeism which we had been able to avoid prior to Omicron," Flynn said.

"As previously reported, significant rainfall in Q2 disrupted operational rhythm initially, but also resulted in flooding that temporarily restricted access to the mines for two weeks.

"However, even with these recent disruptions at our operations and across the coal supply chain, we have posted record half-year earnings for the first half to December."

According to Global Coal, the Newcastle Coal Index saw a record monthly high of $US222 per tonne (/t) of coal in October, while the average price of coal for the half was $176/t.

This allowed Whitehaven to achieve record first-half earnings (before interest, tax, depreciation, and amortisation) of $632.6 million.

Reflecting some tough circumstances during the previous financial year, this represented an increase of 1601% compared to the pcp. At the same time, company revenue increased 106%.

The Narrabri longwall move from panel 109 to 110 was completed in December, following extended delays due to labour shortages.

"The step around from panel 110A to panel 110B is scheduled to commence in May 2022 and be completed in late June 2022," the company stated in January.

Disused mines provide zero-carbon heating

Abandoned collieries are coming back to life as geothermal heat sources for homes and businesses

As coal mines closed around the UK, they filled with water. Due to the depth of the mine shafts, the water is naturally heated by the Earth. In general, the temperatures of the underground water ranges from 10 to 20 degrees Celsius, although in larger mines, the temperature can rise to nearly 45 degrees Celsius. With nearly 25% of buildings in the UK located above disused coal mines, zero-carbon heating could become a reality for a significant portion of the country.

Bore holes provide access to the water, and a pump pulls the water to the surface and into a system where the water is heated through compression. Once the water reaches the required temperatures of 45 to 70 degrees Celsius for home and industrial use, it is circulated for heating. After the water cools, it is returned to the mine shaft for reheating.

Led by the UK Geoenergy Observatories (UKGEOS), and with investment from the European Regional Development Fund, a number of councils across the country are studying, developing, and building regional mine water heat networks. South Tyneside and Gateshead Councils are two local leaders in this area with plans to commission and build systems beginning in late 2022.

The sustainability of geothermal power is beginning to garner more attention, with Springwise spotting it contributing to urban developments that include a new harbour design for Aberdeen, Scotland, and as part of El Salvador's new cryptocurrency-based city.

Germany to transfer hydrogen technology to Africa

The German government is planning to transfer hydrogen production technology to African countries amid its efforts to quit coal and nuclear energy, a German government official said.

Germany will have to import 40% to 60% of the hydrogen it needs for its energy transformation plans, the official said ahead of a meeting between the African Union and the European Union scheduled to take place in Brussels.

Germany may extend coal use to replace Russian gas

Germany could extend its use of coal as the country rethinks its energy plans in the aftermath of Russia's invasion of Ukraine, according to Economy Minister Robert Habeck.

The former co-leader of the Green party said coal plants could run for longer and even said he wasn't "ideologically opposed" to extending the use of nuclear energy. Chancellor Olaf Scholz announced on Sunday plans to build two new liquefied natural gas terminals to expand Germany's energy choices and reduce its reliance on Russia.

The government wants to reach a point where it can "pick and choose which countries we want to build energy partnerships with," Habeck said in an interview on ARD television. "Being able to choose also means, in case of doubt, that you can become independent from Russian gas, coal or oil."

While Germany can manage without Russian gas for the coming months, the country would have to expand its purchasing strategy significantly for next winter, he said.

Micromine Nexus forms another piece of the puzzle

The company developed Nexus in response to customer feedback and built it to be scalable, customisable, user-friendly, and able to satisfy data security and regulation requirements.

Micromine chief strategy and product officer Kiril Alampieski said Nexus epitomised the company as it enables those in the resources sector to get the most from their mining.

"By bringing users, data and technology together, we can help mining organisations build end-to-end digital processes and enable completely new transformative business models," Alampieski said.

"We want to enable clients to use their data to accelerate smart decision making, maximise business opportunities and meet the challenges of delivering a sustainable future."

The last 12 months have seen Micromine expand to become an end-to-end solution from greenfield exploration to mine scheduling and management.

"The solution helps clients overcome the challenges of manual management that often lead to unstructured, redundant and discrepant master data," the company stated on the usefulness of Nexus.

"Users can also stay on top of key activities with integrated task management tools and automated notifications, ensuring clear, structured and repeatable workflows."

Alampieski said Nexus was just another piece of the puzzle as Micromine solidifies its capability across the mining timeline.

"The launch of Micromine Nexus delivers substantial and immediate benefits to the way clients manage project data and collaboration, while also progressing our longer-term vision for building a fully-connected ecosystem," he said

In 2021, Micromine acquired Precision Mining and its mine scheduling software, Spry.

Less than three months later, Micromine added another scheduling software, Alastri, to its ranks which chief executive officer Andrew Birch said was a massive achievement for the company.

"Rather than starting from scratch, and building products in competition, we are looking for best in class companies that have proven products and want to grow," Birch said.

"MICROMINE's international footprint, with more than 2,000 sites in 90 countries, represents 35 years of growth and investment that is very difficult for new companies to emulate.

"This way, we bring new products to our clients faster, and give great Australian technology the opportunity to flourish, with the backing of our global distribution, implementation and support teams."

Mastermyne takes control at Cook Colliery

Mastermyne will earn $280 million over four years as the mining operator at Constellation Mining's Cook Colliery coal mine in Queensland.

In July 2021, the contractor was selected to restart the mine, after it was purchased and put under care and maintenance by Constellation parent company QCoal one year earlier.

This included the recommissioning of existing underground infrastructure, overhauling of mining equipment, establishment of production panels and associated procurement works.

Now, the four-year term will see Mastermyne ramp the operation back up to about four million tonnes of run-of-mine coal per annum.

Mastermyne parent company Metarock chief executive officer Tony Caruso said it was a great time to be restarting another Queensland coal mine.

"We are pleased to have executed this contract with QCoal and to be bringing Cook Colliery back intro production at a time when we are experiencing record coal prices" Caruso said.

Data from the Australian Bureau of Statistics (ABS) found that coal and non-ferrous metals were among those to underpin Australia's export price index for the December quarter.

In the past six months, never-before-seen coal prices of more than $US200 per tonne have underpinned significant export values and the resurgence of companies like Whitehaven Coal.

The Mastermyne contract includes an option to extend by two years and will employ about 190 people full-time. 60 of these roles are already working on site following the mine's restart last year.

As coal mine operator, Mastermyne will be responsible for delivering ROM coal to the surface stockpile, while Constellation will manage all processing, rail, shipping, and marketing of the product.

The digital tire management of the future: ContiConnect 2.0 – data-driven decisions for fleets

- Comprehensive upgrade of the ContiConnect intelligent tire management solution: new web portal, new multifunctional app
- Coordination of vehicle and tire services generates cost efficiency, lowers CO2 emissions and strengthens sustainability
- Big data and artificial intelligence: broad pool of data and continuous analysis of data from tire sensors fuel drive towards predictive maintenance

Hanover, Germany, February 24, 2022. Continental is presenting a new generation of the ContiConnect tire management system. Version 2.0 puts in place the necessary infrastructure for the all-encompassing, digital tire management of the future. To this end, the technology company has refined its system environment to keep it perfectly in line with the specific requirements of fleet customers around the world. “ContiConnect 2.0 is focused on the digitalization of tires. It paves the way for intelligent tire management combined with a tailored selection of digital, service-based tire solutions,” explains Tansu Isik, Head of Business Development and Global Marketing at Continental Tires. Continuous analysis of the extensive data collected from the tires creates a broad data pool.

ContiConnect 2.0 will allow maintenance of tires – on passenger cars, trucks, buses and off-road vehicles – to be carried out exactly when it is needed. In the context of off-road vehicles, ContiConnect is already frequently used by fleet customers in the construction industry, intralogistics or in ports. “Our fleet customers benefit from the modularity, flexibility and compatibility of ContiConnect 2.0. It enables exceptionally secure digital tire management, increases vehicle uptime and maximizes cost transparency,” says Isik. Vehicles are out of use less of the time, and trucking companies and fleet managers on construction sites, in intralogistics and in ports will also gain from lower maintenance costs and higher tire mileage. ContiConnect 2.0 therefore represents a great solution in terms of sustainable mobility. The digitally optimized tire management system is a big plus for operators overall, allowing them to focus their attention on their core business.

Continuing the drive towards predictive maintenance

ContiConnect 2.0 is a new version of Continental’s proven digital tire management system developed from scratch. “With ContiConnect 2.0, we are building on existing functions such as continuous tire pressure monitoring to also enable our fleet customers to digitally track the remaining mileage, tread depth, and condition of all the tires in their fleets,” says Sven Wilhelmsen, Head of Product Management Digital Solutions at Continental Tires. Added to which, the user experience has been significantly improved – thanks to the release of a new app, which covers all the work taking place on the vehicle and presents

the fleet manager with the information relevant to them in an even more precisely targeted form.

Big data for precise tire forecasts

All of the available data on the tire and vehicle is continuously analyzed in the cloud. Big data therefore makes it possible to issue precise tire condition forecasts. Vehicle and tire services can be coordinated and aligned with one another to optimum effect, which creates synergies and seamless links to workshops and dealers. The result is increased fleet efficiency, lower overall costs and reassurance for fleet managers that their vehicles will be ready to use more of the time. “With ContiConnect 2.0, we are continuing to expand our offering of smart, digital tire solutions as we move towards predictive maintenance,” adds Wilhelmsen. ContiConnect 2.0 has been trialed successfully by a selected group of customers since late 2021, and the new platform will be rolled out worldwide over the course of 2022.

Designed for sustainable mobility

The technology company is using these smart, intelligent tire services to optimize tire management across its fleet customers in various fields of application around the world. ContiConnect 2.0 is a solution for truck, bus and passenger car fleets, as well as off-road vehicles. The fleet manager is presented with a fast and user-friendly overview of their entire fleet – regardless of where the vehicles happen to be. “The modular design of ContiConnect 2.0, the flexibility of its components and its level of compatibility allow us to integrate additional solutions, as requested by the customer,” explains Sven Wilhelmsen. “Plus, we are working on the integration of external systems for recording tread depth.”

The premium tire manufacturer enters development partnerships with customers and technology companies with the clear aim of continuously expanding its tire-related offering with service-based, digital solutions. Its goal is to offer the all-encompassing, digital tire management of the future: technology that can utilize the full potential of tires – as an important element in sustainable mobility – safely and as comprehensively as possible. “Our aim is to offer the best solution for tire monitoring and management,” concludes Tansu Isik. “A solution which can be integrated seamlessly into the processes and systems of our fleet customers.”

Longwall automation: are we ready for success?

The ACARP Landmark initiative has created the opportunity to advance the level of automation in the coal industry by first focusing on the core production area of longwall mining. A proposal for the project has been developed and is currently being considered by the ACR Board. The major outcome of automation using on-face observation has been divided into ten outcome areas that have been fully scoped for the three-year initial project life. A major facilitating technology has been the implementation of inertial navigation system (INS) that can map the shearer position in 3D. A focus of the project is to deliver a system that is at least as productive as the current most productive manually controlled longwall face.

BACKGROUND

In 2000 the ACR Board elected to set aside 1c of the 5c levy per tonne specifically for Landmark projects to enable the ACARP program to target a limited number of key problems and commit greater funding to their resolution. The first landmark project has been committed to the CRC for Coal in a sustainable Development. This paper describes the proposed scope of the second project on Longwall Automation.

The ACARP Research Committee has recognised the importance of increasing the levels of automation in the coal industry. As a first step, last July they invited two key science providers, the CSIRO and the CMTE, in conjunction with the ACARP Longwall Automation Steering Committee, to jointly develop a research proposal to advance longwall automation. Since that time the providers have developed a full proposal for consideration of the ACR Board. This process has included a reviews of past automation attempts, the current level of installed and utilised automation in Australian and overseas mines, the available technology for future automation and extended discussions with OEM groups both in Australia and overseas.

The final proposal has been developed under the guidance of a longwall automation steering committee and an industry expert as well as in consultation with the OEM's.

PROJECT AIM AND OUTCOMES

The aim of the project is to develop longwall automation to the level of on face observation by the end of three years.

The review of previous attempts at longwall automation and the use of current automation technology showed a lack of focus on exception issues from automation attempts and the imperative from operators not to lose productivity from the use of automation. In other words, automation attempts have only worked in ideal conditions. As soon as problems or "exceptions" occur on the face, operators revert to manual operation and the automation technology is disregarded. Even if the automation technology does work in good conditions, unless it produces as much coal as manual operation it will not be used. Operators consistently expressed the view that the longwall was the prime profit centre and that a high level of production consistency rather than manning reduct ion should be the focus of automation. A second focus expressed should be the removal of persons from exposure to respirable dust. Even with advanced dust control techniques, most high production faces were finding statutory standards difficult to achieve.

The achievement of full automation in all conditions requires an advanced development of sensors to replace the input from human sensors. This is in addition to the technical development required for automation under ideal conditions. The initial scope for the landmark project was developed to include both the sensor and technical development for full automation. However the costing for this full scope was larger than the funds available, and a reduced option of on-face observation was the basis of the final proposal for the three year project. Within this scope the face is fully automated, but may need operator input in exception conditions. Typical exceptions would include geotechnical issues on the face such as face guttering and mechanical issues such as broken rams etc. This outcome is significant and in many cases be all that operators require. It is also on the direct path to full automation.

The scope also includes several key sensor developments that will replace or supplement human observations. This includes condition monitoring, collision avoidance for flippers, convergence monitoring in the gateroads and preliminary AFC block-up surveillance.

There are ten key outcome areas that will be delivered by the three-year project. These are:

1. Face alignment
2. Horizon control
3. Open communications
4. OEM involvement/commitment
5. Information System
6. Components to enhance production consistency and reliability to minimise production risks in an automated environment
7. Redefined functions of face operators
8. Implementation at selected sites
9. Acceptable commercialisation plan
10. Implementation plan for progressive automation

These are described in the following section.

	Year 1				Year 2				Year 3			
	3	6	9	12	3	6	9	12	3	6	9	12
Face Alignment												
Real-time shearer position display			♦									
Chock movement controlled by shearer position				♦								
Automated creep control								♦				
Automated face alignment and creep control											♦	
Horizon Control												
Demo enhanced memory cut				♦								
Horizon control with integrated CID											♦	
Communications and Operator Interface												
Develop reliable shearer-gate end data comms				♦								
Construct driver level OEM software interface				♦								
Develop wide-band comms for non-critical data											♦	
Construct and test operator station								♦				
Collision Avoidance												
Implement void monitoring system								♦				
Site testing for collision avoidance system											♦	
Condition Monitoring and Reliability												
Reliability Analysis				♦								
FDI demo on off-line data											♦	
Trend analysis software demo on off-line data											♦	

Figure 1: Project tasks and Milestones

PROGRAM AND MILESTONES

A work program to deliver results in the ten outcome areas listed above has been produced by the project team and adopted by LASC. The breakdown of the work and the resources through each year of the proposed three-year time frame is included in the budget spreadsheets. The project is summarised in the Gantt chart of **Figure 1**.

Referring to **Figure 1**, the proposed work plan under each subheading and milestone descriptions are given in the following paragraphs.

1. FACE ALIGNMENT

This area of work concentrates on the geometry of the face within the gateroads. The goal is to automatically maintain face straightness by measuring the three dimensional position of the shearer in space and using that information to control the movement of the powered supports. This ability has eluded previous researchers. Shearer position measureme nt is performed using inertial navigation techniques, already developed to a high level by the project team. This technology has been applied extensively to highwall mining guidance and also in a successful trial implementation on a longwall face at South Bulga.

This is a relatively low-risk outcome. The various technology components, particularly those already present on OEM equipment are in advanced states of development.

This outcome area will supply the first deliverables of the project:

Outcome	Description	Year 1	Year 2	Year 3
1.1. Realtime shearer position display (3D*shearer)	Allows accurate measurement of actual shearer position in space in real time for dis play on the surface. Also provides for logging for later analysis. This is a stand-alone outcome on which the remainder of the automation system will be built.	• Complete real-time shearer position measurement system (based on ACARP Project). • Develop real-time position display software. Install and test chock motion system (in-kind contrib. from mine).		
1.2. Shearer position-controlled chock movement	Second pre-automation deliverable. Enhanced shearer initiation of chock advance to move chocks to exact geometry determined by INS navigation system. Assumes availability of OEM read-rod sensors. Face system manually controlled.		• Develop longwall-gateroad distance sensor. • Construct creep-control / auto hualgae software. • Field test longwall creep control / auto-haulage system.	
1.3. Automated creep control operational	Longwall equipment automatically steers along desired track between gateroads. First trials of automatic haulage control of shearer from remote operator station.			
1.4. Sustained automatic face alignment and creep control	Automation of extraction methods e.g. bi-di, uni -di, half web etc			Field test various cutting modes developed in 5.2

Outcome	Description	Year 1	Year 2	Year 3
2.1. Demonstrate enhanced memory cut	Enhanced memory cut utilises absolute position of the shearer as feedback to the existing open-loop OEM memory cut methods.	• Develop horizon control software based on shearer. • Evaluate coal interface detection sensing methods. • Survey mines for CID applicability. • Commence development of CID sensor. • Optical marker band detection. Pick force/vibration		
2.2. Site dependent interface detection	Extra information (3D seismic) added to input to horizon controller.			
2.3. Horizon control with integrated CID	Coal interface detection allows fine-tuning of the cutting horizon to closer tolerances than achievable with other methods.		• Site dependant data integrated to process controller. • Continue CID sensor development, • Commence CID software development. Purchase NGR sensor	• Manufacture and install CID sensor. • Test CID horizon control

2. HORIZON CONTROL

This outcome involves maintenance of the cutting operation between desired roof and floor horizons. The goal is to provide automatic horizon control responding to actual changes in seam profile. Two approaches will be used. One is to use the vertical position information available from the inertial navigation system employed in the face alignment system to greatly improve vertical control achieved in current memory cut systems. The second is to pursue sensor development for real-time coal interface detection (CID) systems.

Outcome 2.2 is low risk being built on components which themselves represent low technical risk.

Outcome 2.3 is higher-risk. Considerable work has been done on CID system development in the past without producing a general solution because horizon characteristics are highly site- specific. However this project will address two of the most promising areas, natural gamma and pick vibration and will examine a third principle which has not received much research attention in the past, optical following of marker bands.

3. COMMUNICATIONS AND OPERATOR INTERFACE

This outcome area is a vital part of the overall project, providing the physical linkage between all the equipment and system-oriented outcomes. Face alignment, horizon control, information systems and production consistency and reliability all require communication links between each other and information display to operators situated remote from the face.

This outcome has low technical risk. The highest component of risk is in securing the cooperation of the OEMs to contribute to an industry-wide common communications protocol. This aspect is addressed specifically in the next outcome area.

4. OEM INVOLVEMENT

This is a key outcome for the success of the project. OEM's need to be committed to the landmark project process to enable technical outcomes to be incorporated into future machine specifications. In addition, their direct involvement in the project will assist commencing and continuing the Project at best practice.

Outcome	Description	Year 1	Year 2	Year 3
3. Open Communications		• Develop reliable shearer / gate end communications for monitoring data transfer. • Develop mineral robust data comms system for critical real-time OEM control. • Negotiate data protocols with OEM's. • Construct driver-level OEM software interface. (In-kind OEN contribution assumed).	Develop wide-band comms. system for non-critical data transfer.	Continue wide-band comms system development.

Outcome	Description	Year 1	Year 2	Year 3
4. OEM involvement/ commitment	This is a key outcome for the success of the project. OEM's need to be committed to the landmark project process to enable technical outcomes to be incorporated into future machine specifications. In addition, their direct involvement in the project will assist commencing and continuing the Project at best practice.	• Establish key contacts. • Establish IP Agreements. • Establish mutual R&D linkages.	• Maintain R&D linkages.	• Maintain R&D linkages.

Outcome	Description	Year 1	Year 2	Year 3
5.1. Information Systems		5.1.1. Operator station hardware implementation. 5.1.2. Stage 1 – Communications with LM and OEM hardware. **(Part of Outcomes 1&2)** • Construct operator station cabin. • Install hardware. • Develop Landmark process control software. Part of 5.1 & 5.2.		
5.2. Automation sequence development/ process design		Develop process maps for each cutting system.	Design scripts and sequences for 1.3, 1.4, etc.	
5.2.1. Seam Horizon Modelling				
Seam horizon modelling system designed	*Design a system that autonomously models a seam horizon based on sensory data from the face and equipment, and known geological and geophysical data sets. The system will be capable of intelligently comparing these data and outputting control information to guide the longwall.*		*Design an autonomous seam horizon modelling and control system.*	
System development resources procured and installed			*Purchase and install all software/hard-ware required to develop the system.*	
System software developed	*Build and unit test each system module as it is developed.* *Unit testing will be conducted according to the testing strategy.*		*Build and Test system.*	
System tested offsite	*Testing will be performed with simulated inputs.*		*Perform offsite testing.*	
5.3. Exception Reporting			Provide information interface to basic display.	
				Maintain / enhance interface to basic display.

5. INFORMATION SYSTEMS

There are three separate work areas under this heading. The first is the development of the operator station. Given the concept of automation applying to this project, an operator station is required close to the face to facilitate both on-face monitoring and the development, testing and commissioning of automation systems. As the automation process matures, the operator station can be further withdrawn outbye. The second is the development and implementation of the automatic longwall process comprising the design of the automatic operation sequences to be input to the control systems and the modelling of simple geotechnical inputs required for horizon control and face alignment. The third is the development of display systems to efficiently report system operation and conditions existing on the longwall.

6. PRO DUCTION CONSISTENCY

Initial project planning revealed that to achieve full longwall face automation, a major effort requiring of the order of half the total project budget would be required to automate the functions carried out by on-face personnel which are not concerned with actual on-line control of mining equipment operation. These functions involve sensing and observation activities that are challenging to automate completely. Consequently, in view of the priorities of LASC the concept of on-face monitoring by personnel either on or close to the face was adopted for the duration of the current project. In this mode of operation, video systems are used to relay face and gateroad geotechnical conditions to the operator station. It was decided to conduct survey projects in the area of convergence and void monitoring and automated

Outcome	Description	Year 1	Year 2	Year 3
6.1. Coal Flow Optimisation.				• Visual lump/ void/blockup/ environment sensor. (cameras attached to comms system). • Radar lump/ void/ blockup/ environment sensor study.
6.2. Geotechnical Characterisation				
6.2.1. Improved Convergence Monitoring	Development and trialling of a new generationconvergence monitoring instrument			Survey convergence monitoring methods.
6.2.2. Software Development for Chock Pressure Analysis	Developing software for an already proven "non live" analysis method and site trialling as a live system. Will give the ability to view chock pressure information over any time scale. Also determine actual periodic weightings and assist in the prediction of these weightings and their effect with reference to other geophysical data.			Software development for chock pressure analysis.
6.2.3. Void monitoring and development of response to detected voids	Determining the most effective system to detect roof voids across the L/Wall face. Once system is determined, analyse/ interpret system output with the intention of developing a suitable response system and field trialling unit.			Survey voice monitoring systems.
6.2.4. Collision Avoidance	Develop a GUI system for "bolting on" to the OEM based collision avoidance system and field trial (part of outcome 1). Develop a GUI system based on sensing, analyse/interpret output with intention of developing a suitable response and field trialling.	OEM collision avoidance (part of outcome 1).		
			Develop collision avoidance sensing system.	
				Continue development and implement collision avoidance.
6.2.5. Gateroad monitoring	Determine most effective system to monitor gateroa d deformation. Develop GUI system to interpret/ analyse data and give suitable response and field trial system.		• Hardware design (laser and extensometer equipment). • Communication/ processing hardware. • Software development. • Hardware purchase (laser and extensometer). • Field tests.	
				Site installations and trials.

gate road monitoring and a full-scale project to develop systems to avoid collisions between shearer and supports.

6.3. Condition Monitoring and Reliability

A proper understanding of the reliability of the existing system is essential. We will start with the reliability block diagram of the longwall system including a hierarchical tree structure for the longwall system and its parts and appropriate representations for environmental characteristics and operator's actions.

Past failure data will be reviewed for nominated sites and

Outcome	Description	Year 1	Year 2	Year 3
6.3. Condition Monitoring and Reliability				
6.3.1. Reliability Analysis	Review of present machine reliability; Threats to automation regarding reliability; Proposals for engineering design changes and redundancy options to remove these threats.	• Review maintenance logs and monitoring data; carry out a FMCE analysis. • Produce reliability analysis report.		
6.3.2. Fault Detection & Trend Analysis	FDI (Fault Detection & Isolation) Software for timely detection and classification of machine failures and other external or internal discrete events that may be threatening production.	Analysis and pre-processing of on- line maintenance log data.	Statistical analysis of data; software to generate remote monitoring displays.	Develop FID software & demonstrate on off-line data.
6.3.3. Trend Analysis & Sensor Self-test	Software that primarily will use the machine data to detect events like slabbing off the face, piling, pick wear and coal seam conditions; Software modules for sensor self-test and on-line assessment of sensor data reliability.		Identify external trends that need to be monitored; collate training data for trend analysis.	Develop trend analysis software and demonstrate off-line.

a Pareto analysis will be performed to identify the critical failure modes. Root cause failure analysis may have to carried out for some of the failure types to identify the exact nature of the failure and its root cause. This is important because in a series system like longwall machinery, the failure of one item will lead a chain of failures and sometimes it is difficult to identify the original failure that sta rts the chain. The results of this work will lead to engineering design change recommendations to fix the problem or redundancy options to circumvent it. Present maintainability of critical items and maintainability under an automation regime will be evaluated. Another result of this work will lead to identification of limitations that will need to be placed on the automation system.

A Failure Modes, Effects and Criticality Analysis will be performed on the entire longwall machine system. This is standard practice to help identify reliability "sinks" in the system and to understand their cause-effect relationships. A review of the OEM-supplied or planned condition monitoring systems will be carried out and their implications for a successful implementation of automation will be assessed.

The deliverable at the end of the work-package will be a comprehensive Report that describes the results of the above work. This Report will also produce specifications for the ongoing tasks of fault detection and machine condition monitoring.

7. TRAINING: REDEFINED FUNCTIONS OF FACE OPERATORS

One of the keys to the successful implementation of longwall automation systems is recognition that the skills required in an operator of an automated system will be different to those at present required on the face. Attention must be paid to staff selection and training.

Outcome	Description	Year 1	Year 2	Year 3
7. Training				
Online training system designed.	The training system will include displays of documentation, operation check lists etc.		Design online training system using remote operators station	
Online training system developed.			• Build and test training system. • Develop content for on-line training/ simulator system (competency based).	• Seek industry feedback for training system (iterative approach). • Modify design of training system (iterative approach).

8. IMPLEMENTATION PLAN

This activity has no allocated budget. The implementation plan allows for the necessity to establish field sites at more than one location. Costs for duplication of equipment which cannot be provided for reliably in the initial project budget will be dependent on in-kind support form sites and OEM's.

9. COMMERCIALISATION

This activity will facilitate the technical transfer and presentation of project outcomes to the industry. Models for manufacture of automation system components and intellectual property arrangements will be developed and put in place as outcomes are delivered.

10. IMPLEMENTATION PLAN FOR PROGRESSIVE AUTOMATION

This activity will benchmark all longwall mines in Australia and will provide them with detailed information regarding their current automation status and a roadmap outlining steps necessary to achieve various levels of automation utilising Landmark project outcomes.

CONCLUSIONS

The ACARP landmark process has afforded the underground coal industry with a tremendous opportunity to develop and implement cutting edge technologies into a package that will provide an automation capability for our longwall operations. Key new technologies of INS and IT improvements from other industries will assist this process. The benefit for the industry will a potentially higher, more consistent production rate and the removal of face workers from more hazardous areas.

Although the task remains complex, the risks are relatively low as most of the technologies have been proven in other areas. The focus on productivity and designing the system for exception issues will also ensure a lower risk and provide an incentive for progressive operations to uptake the automation technology. The onus will be on the project team to communicate these outcomes progressively so that companies may include "landmark compliant" longwall specifications into future orders and upgrades.

The question remains, are we ready as an industry to take advantage of this technology?

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IOT DATA

Security and privacy concerns prevent effective use of iot data, inmarsat research reveals

Industrial IoT in the Time of Covid-19 – reveals majority of mining businesses do not share IoT data effectively across their business ecosystem but plan to in future

Research by Inmarsat, the world leader in global, mobile satellite communications, reveals relatively few businesses derive maximum benefit from the IoT data that they gather. Most of today's businesses only share IoT data within their own organisations, with security and privacy concerns preventing them from disseminating it to organisations in their wider supply chains. Infrequent data collection and lacking an IoT data strategy leaves many businesses surveyed struggling to extract full value from their IoT data. A more strategic, ambitious and open approach to gathering and sharing non-sensitive data could unlock substantial benefits for business struggling to make the most of IoT projects.

Collecting and sharing the right data at the right time enables companies and their partners to take better, more proactive decisions across the value chain to optimise operations as soon as a problem occurs, or even anticipate and mitigate it before it happens. Such data driven insight can help businesses reduce waste, increase productivity, improve customer service and run more sustainable operations.

The research was based on the interviews of 450 global respondents across the agriculture, electrical utilities, mining, oil and gas, and transport and logistics sectors. According to the research, of those who worked in mining, as many as 84% of respondents admit their organisation does not use the data collected from IoT projects as effectively as it could. This is despite high levels of IoT adoption overall. The most prevalent barriers are security and data privacy concerns, cited as a barrier by almost half (49%) of all respondents, followed closely by a lag between data collection and availability (48%) and the lack of an IoT data strategy (34%).

Accelerating IoT adoption over the course of the Covid-19 pandemic has highlighted the fact that many businesses' data sharing strategies are not yet as advanced as they need to be. Currently, only 23% of mining organisations make non-sensitive IoT data available to anyone in their organisation, and to their partners, to access and to use. Conversely, a third (33%) limit the use of IoT data to certain departments involved in their IoT projects. However, this is set to change, with a larger proportion of mining organisations (40%) shifting towards sharing data with their wider supply chain and far fewer (17%) planning on limiting IoT data to specific departments. This change is occurring as more businesses come to understand that the responsible and secure sharing of IoT data is a necessary step towards unlocking the maximum value of that data.

The research reveals that having a formal IoT data strategy is a vital step towards drawing the optimum benefits from the technology, ensuring data is produced, shared, and analysed between the right parties at the right time. Organisations with a formal IoT strategy are far more likely to gather data points in their IoT projects in real time (44% of respondents compared to only 22% amongst organisations without an IoT strategy).

There are also notable differences in how strategic mining businesses are in the usage of their IoT data based on the region they operate in and the size of their organisations. While only 27% of businesses in the Asia Pacific region struggle to use IoT data effectively due to the lack of an IoT data strategy, this increases to 42% of organisations in Latin America and 43% in Europe (excluding Russia). Likewise, while 14% of the largest organisations (over 5,000 employees) struggle with a lack of an IoT data strategy, 43% of smaller businesses (between 500 and 1,000 employees) cite this as a barrier to effective IoT data use.

Nicholas Prevost, Director of Mining at Inmarsat Enterprise said: "While we've seen the mining industry make great strides on IoT, it is evident that mining companies are lagging behind other businesses in their use of IoT data. It's no surprise to see mining ranked the second least likely to have a formal strategy on this, given that organisations are not using data as effectively as they could. This needs to change.

"Implementing a clear IoT data strategy will help ensure that mining companies' data is effectively communicated internally and across the supply chain. In such a critical industry, data and information is integral to the success of any mining operation, but to make the most of this wealth of data, a coherent strategy and approach is essential. Putting the right people and processes in place to make this a reality will be crucial."

Commenting on the findings, Mike Carter, President of Inmarsat Enterprise said: "While our latest research shows that the majority of today's organisations are now gathering IoT data, there is still plenty more that businesses need to do to derive the maximum benefit from it. The ultimate measure of an IoT project's success is how it improves the way a company and its partner eco-system operates. This is largely resultant on the type of data extracted and how it is shared and turned into practical and actionable business insights in a timely manner.

"It's clear from our findings that many businesses still need to employ an IoT data strategy as part of their overall IoT strategy, to ensure their data gets to where it needs to go within the organisation, let alone to other parts of the supply chain. Four out of five businesses currently share the data created from their IoT projects only within their organisation, due to concerns around security or privacy, limiting their ability to extract real business value from this data. However, it is encouraging businesses intend to change this situation, as organisations become increasingly open to sharing non-sensitive IoT data with their partners, increasing productive supply chains.

"Without a coherent IoT data strategy in place, businesses will struggle to develop the culture of open and responsible data sharing and collaboration required to ensure their IoT projects are successful. Inmarsat's Enterprise business is focused on providing IoT connectivity to business-critical applications and to remote locations, providing vital access to valuable data points across global supply chains. Our industry-leading ELERA narrowband network enables organisations that grow, mine, extract, move, save, and inform to access, use and share IoT data anywhere, helping them to improve efficiencies, safety and sustainability."

ABOUT INMARSAT

Inmarsat is the world leader in global, mobile satellite communications. It owns and operates the world's most diverse global portfolio of mobile telecommunications satellite networks, and holds a multi-layered, global spectrum portfolio, covering L-band, Ka-band and S-band, enabling unparalleled breadth and diversity in the solutions it provides. Inmarsat's long-established global distribution network includes not only the world's leading channel partners but also its own strong direct retail capabilities, enabling end to end customer service assurance.

Mine communications continue to evolve

New technologies in communications are now at the heart of mining safety and productivity and are becoming essential for running safe, productive, and efficient underground and surface mining operations.

Even today some mining sites are operating with outdated radio communications that has been at the forefront of a lot of accidents worldwide, this led to the USA lawmakers to implement new measures within the industry following, three major underground coal mine accidents in the United States that claimed the lives of 19 miners,this prompted the passing of the Mine Improvement and New Emergency Response Act (MINER Act) of 2006. One of the requirements of the MINER Act is to provide wireless *two-way communications* and location information between underground workers and surface personnel following an underground accident. At the time of the accidents in 2006, most coal mine communications systems consisted of either leaky feeder systems or pager phones. A few mines had electronic brass-in/brass-out systems or zone-based tracking, but location tracking throughout the entire mine was not a common practice. Since then, efforts to develop new radio communications and personnel tracking technology have resulted in many new systems on the market for underground mine applications, and new systems continue to be introduced. New communications technologies include radio node *network* systems, such as *mesh* and *Wi-Fi*; improved leaky feeder systems; low-frequency, *through-the-earth systems* ; *medium frequency radios*; and combinations of these technologies. New personnel electronic tracking technologies include radio frequency *identification (RFID)* and radio ranging techniques. Due to the increasing availability of new systems, the Mine Safety and Health Administration (MSHA) requires underground coal mines to have compliant communications and electronic tracking (CT) systems installed by 15 June 2011.

Coal International take a look at what mines should consider when installing a compliant system. For example, the mine's communications expert will need to understand how the underground environment influences the performance of CT systems, how different CT systems work, and their advantages and disadvantages. A tutorial produced by NIOSH (The National Institute for Occupational Safety and Health) sets out to explain the basic principles of the many options available and to assist mine management in making the right choices and better understanding of the systems available.

COMMUNICATIONS BASICS

All modern communications and electronic tracking (CT) systems depend on the transmission and reception of energy. Electromagnetic energy is energy associated with nearly all modern CT systems, and for all of the systems discussed in this tutorial. Electromagnetic energy is everywhere in the environment and examples include radio waves, visible light, and x-rays.

Many common devices depend upon sending or receiving electromagnetic energy for their operation. Some examples are televisions and radios, cell phones, automatic garage door openers, and remote keyless entry fobs for cars. Electromagnetic energy can be visualized as a traveling wave of electric and magnetic energy. All waves are characterized by

THEIR WAVELENGTH AND AMPLITUDE.

The wavelength is the distance between adjacent peaks of a wave. Notice that the wavelength of the dashed line wave in **Figure 1** is longer than that of the solid line wave. The unit of measure for wavelength is meters or feet. The amplitude is a measure of how tall the wave is. The dashed line wave in **Figure 1** has greater amplitude than the solid line wave.

In discussing their CT systems, manufacturers will typically mention the frequency at which the systems operate. The frequency relates directly to the wavelength. Frequency is a measure of the number of up and down oscillations or repetitions of the wave over a fixed length of time.

The fewer oscillations that a wave has within a fixed period, the lower the resulting frequency will be (and the longer the wavelength). The dashed wave in **Figure 1** has fewer oscillations than the solid wave, so it has a lower frequency.

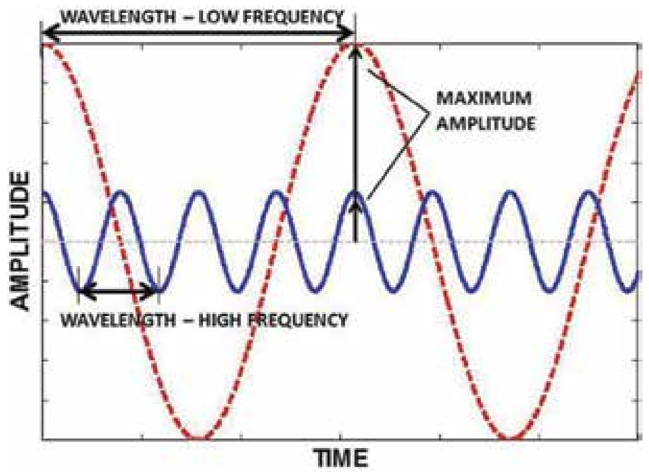


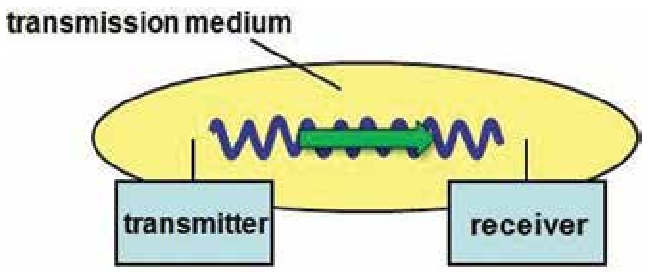
Figure 1: The Main Characteristics of Waves.

Cycles per second, or Hertz (Hz), is the measure of frequency. Low frequency waves have longer wavelengths while high frequency waves have shorter wavelengths. The maximum amplitude of a wave is the peak of the wave, labelled in **Figure 1**, whereas the amplitude of a wave is its value at any time, labelled on the y-axis.

The frequency (or wavelength) of a particular CT system is a very important factor in its design and operation because certain wavelengths lend themselves well to travelling through a given transmission media. For instance, very long wavelengths can travel a significant distance through the earth. Radio communications use short wavelengths, which travel well through the air or down tunnels, while extremely short wavelengths are required to travel within fiber optic cables.

This fundamental background in electromagnetic energy leads us to the principles of operation behind communications systems.

The requirements of most communications systems are more complex than that depicted in **Figure 2** because multiple physical communications links may be involved in establishing the connection between the sender and receiver. For example, a cell phone may transmit over the air to a cell tower, which transfers the signal to a telephone line, and then to a different cell tower, and finally over the air to another cell phone. The connection between the sender and the receiver involves multiple physical communication links from the user's phone to the cell tower, to the phone line, through the telephone system, back to another cell tower, and finally to the receiver's phone. These multiple link systems are called networks.



1.2 Networks

Two people using walkie-talkies to communicate will find that as they increase their separation distance, eventually the distance becomes large enough that they can no longer communicate. This limitation established by the separation distance, or range, occurs because energy is being lost within the transmission media. The transmission media dissipate energy until the energy is so low that the receiver can no longer "hear" the transmitter.

Another factor limiting the range between two transceivers is noise. Noise is unwanted electromagnetic energy that makes it difficult for the receiver to "hear" the transmitter. This is similar to attempting to communicate with someone across a crowded, noisy auditorium. To be heard a person may have to shout (increase power) or get the audience to be quiet (lower the noise level).

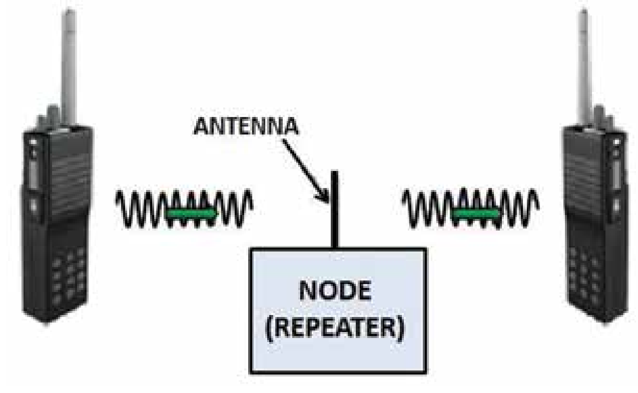


Figure 3: Example of a Very Simple Network.

Whether the cause is dissipation of energy in the transmission media, noise, or a combination of both, eventually the range of a single physical communication link becomes limited. Adding a node between the transceivers can increase the allowable distance between them. Among other functions, the node acts as a repeater, which relays the message from one transceiver to the next (in either direction) by automatically retransmitting the signals it receives. This retransmission may also involve converting the transmission frequency so that it can transmit across a different transmission medium, such as a wire. The retransmission may also involve sending the signal to multiple destinations or amplifying the signal. With the additional device of a node in the communications link, the result is a simple communications network. A communications network is a system of interconnected pieces of communications equipment used to transmit or receive information.

Figure 3 shows a simple network with two physical communications links: one from the radio to the node (repeater) on the left, and the other from the repeater to the radio on the right.

Generally, the same antenna on the node receives and retransmits the message, but there may be separate antennas dedicated to each function. In **Figure 3**, the node receives the radio frequency (RF) signal from the radio on the left. The signal travels into the node where internal electronics process the signal, amplify it, and then retransmit it. The radio on the right then receives the signal. In this case, the situation is more complicated than simply connecting two radios by an air medium.

It is easy to imagine extending the range of the communications shown in **Figure 3** even further by adding an additional repeater between the two radios. **Figure 4** shows two nodes, each with a defined communications range. The dotted line shows the range of the node on the left and the solid line shows the range of the node on the right. The antennas of the nodes are within the range of each other, because the left node's antenna is within the solid oval and the right node's antenna is within the dotted oval. Because the nodes are within each other's range, they can pass communications in either direction between the two nodes. With this network, two radios within range of either node will be able to communicate with each other.

The communications path between two radios can be referred to as direct point-to-point (involving only one physical communication link), or it can be achieved through a complex network that connects the source and destination (involving multiple physical communications links). The interconnection between the nodes in the network can be wireless or wired.

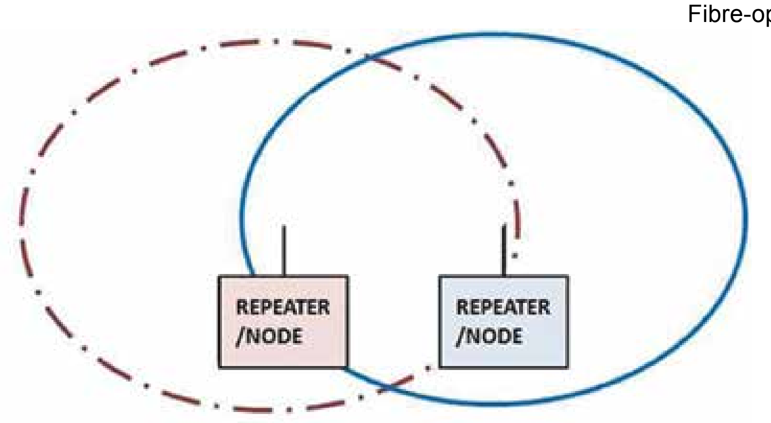


Figure 4: The Communications Range of Two Nodes.

Fibre-optic cable or other means can also be used to connect the nodes. **Figure 5** shows three examples of network configurations for interconnected nodes.

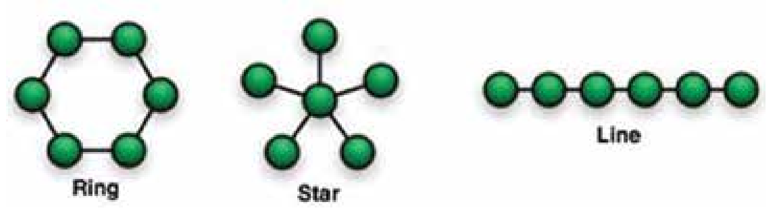


Figure 5: Examples of Network Configurations.

The solid lines in the above diagrams (**Figure 5**) represent physical communications links between the nodes. A well-designed network configuration increases the survivability of communications (the potential for the system to continue operating after an accident) should one or more of the nodes fail. For example, if one of the nodes in the ring configuration fails, the remaining communications can survive by reversing the direction of traffic in the region of the failed node. In the star configuration, the failure of an outlying node does not disrupt the rest of the network, but the failure of the centre node will shut down the entire network.

1.3 Wireless Versus Wired Systems

The definition of the term wireless as used in this document, and as it relates to underground mines, requires some discussion here. Most people consider a cell phone to be a wireless device, but many cell phone calls actually travel over conventional telephone lines before reaching the receiving party's cell phone. Neither person recognizes the use of conventional telephone lines during the communication. The main convenience for the user is that there are no wires or cables connected to the handheld device, even though they are integrally involved in the signal transmission. This example of "wireless" communications is consistent with the definition adopted for this tutorial: "a system that operates locally without wires" (see the Glossary for more details).

Two people using walkie-talkies that can communicate over significant distances exemplify another possible definition of wireless. In this case, there is only one type of physical communications link. It is common to call such communications devices radios, and to refer to the communication between these radios as wireless. In relation to mining applications, some suggest that the definition of wireless should be restricted to the simple concept of "one physical link" (no intervening cables, nodes, or devices of any kind). Another definition of wireless commonly used is that the system can contain multiple physical communications links but that each link has to be wireless.

There has been considerable debate over exactly what Congress intended in the MINER Act by requiring "wireless" communications via "a wireless two-way medium." To address this issue within the context of this tutorial, two assumptions were made: First, for practical purposes, the communications system miners use must be an untethered device (i.e., one without connecting wires or cables). An untethered device, such as a small radio, can be worn or carried by the miner. Second, the principal intent is to ensure a survivable connection between the miner and the surface throughout the area where the miner may need to work or travel. Within this tutorial, a wireless communications system is defined as one that does not require a physical connection to the miner's handheld radio. Therefore, in this context, wireless refers to any system in which the miner uses an untethered device for communications. Readers should review the latest guidance from the Mine Safety & Health Administration (MSHA), and state regulatory agencies, for their definition of wireless and detailed requirements for compliance with the MINER Act.

1.4 Primary Versus Secondary Communication Systems

The communications technologies can be classified into two main categories, primary communication systems or secondary communications systems, which are explained in more detail below.

Primary communications systems are characterized as those that have a transceiver small enough to be comfortably worn (carried) by a miner throughout an entire shift. Primary communications systems typically function at conventional radio communications frequencies, use small antennas, have a long battery life, and provide sufficient radio channels for general operations. Of the systems that will be discussed in this tutorial, the leaky feeder and node-based systems are considered primary systems.

SIGNALS AND COMMUNICATIONS

Secondary communications systems require a larger and heavier antenna, making these systems still portable, but less manageable for wearing throughout a shift. Secondary communications systems typically operate at lower, non-conventional radio frequencies and generally have only a single channel for communications, and do not have sufficient throughput capacity for general operations. Of the systems discussed in this tutorial, the medium frequency (MF) and through-the-earth (TTE) systems are considered secondary communications systems.

COMMUNICATIONS SYSTEMS PRINCIPLES OF OPERATION

2.1 Hardwired Systems

Many underground coal mines use some form of telephone as the primary means of communications between the surface and the underground miners. It is easy to imagine two phones (or transceivers, as introduced in Section 1.1) directly connected by wires to form the physical communications link. Relating to the previous discussion of **Figure 2** in Section 1.1, the energy from the transmitter directly couples into the transmission medium, which in this case is a wire or cable. For mine pager phones, which are the most common form of communications in underground mines, two wires are typically used. Connecting additional phones into the same wires forms a network of phones. With this network configuration, the phones operate in a page mode in which all the telephones broadcast simultaneously when a button is pressed on the transmitting pager phone. The system works well in the case of an emergency when all miners must be notified. However, there is no capability for private or simultaneous conversations.

Some mines use a dial telephone system similar to a commercial phone system, but the mine phones are completely separate from, and cannot communicate with, a commercial phone system. Private conversations between miners are possible. Key personnel are assigned ring codes to indicate when the phone is for them. Personnel must also remember the phone numbers of other workers with whom they wish to talk.

Another type of hardwired communications system is the trolley wire or carrier phone. Mines with extensive rail haulage use trolley phones. The electromagnetic (EM) signal couples to the trolley power line. The physical communications link is similar to the dial telephone described above, except the wire is the trolley power line. Phone locations include the trolley-powered vehicles and strategic areas that identifiable in the mine. Communications to cages and elevators in vertical and slope shafts use the same system.

Despite their capabilities, hardwired communications systems are generally not robust. The typical network configuration for a hardwired phone system is the bus structure shown in **Figure 6**. The connecting wires are easily broken or shorted by rock falls. Once a line is shorted, the communications may be severely affected or cease altogether. These systems lack redundancy, which is the ability of the network to maintain communications

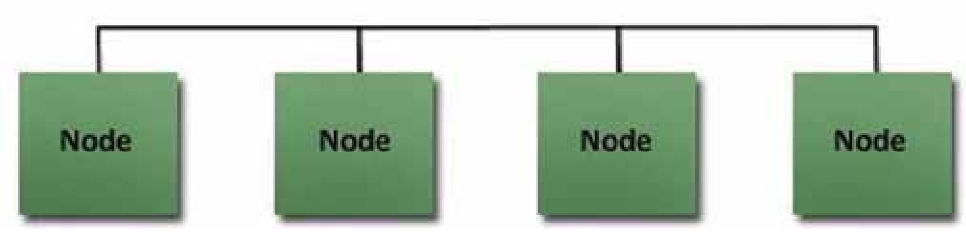


Figure 6: A Bus Network.

with the surface even when there is a disruption of a single pathway. In an underground coal mine the available network configurations are highly limited. The long, linear tunnels and the limited access pathways to the surface restrict the design choices.

2.2 Wireless Systems

The following sections present four different wireless communications technologies. The primary difference between them is their frequency bands of operation. Each of the frequency bands uses a different mechanism for the propagation of the EM waves. Each of these systems has the advantage of permitting the miner's radio to be untethered, as discussed in Section 1.3.

As shown in **Figure 7**, in a wireless communications link the antennas couple the EM energy from the transmitter to the transmission medium and capture the energy at the receiver location from the medium. The coverage range is the maximum distance between the transmitter and receiver while still maintaining good quality communications. The coverage area is the area within which radio communication is possible.

There are two broad categories of antenna systems – discrete antenna (single-point) systems and distributed antenna (multipoint) systems. Most people are familiar with discrete antenna systems, which are often made of simple pieces of wire. Examples of discrete antennas are TV antennas on a house or the radio antenna on a car. Sometimes the wire is contained in some sort of enclosure for protection, such as the rubber or plastic antenna protectors found on portable radios and cell phones.

There are two types of discrete antennas – directional and non-directional. A non-directional antenna (sometimes called an omnidirectional antenna) radiates energy more or less uniformly in all directions. This is analogous to how a lighted match or a light bulb radiates light in all directions. On the other hand, a directional antenna focuses the energy in one direction. Using the light analogy, a directional antenna is similar to a flashlight. A flashlight points most of the light energy in one direction. A flashlight uses a reflector (behind the bulb) that is shaped to focus the energy in the desired direction. Similarly, reflectors behind an EM energy source create highly directional antennas, such as in a satellite dish.

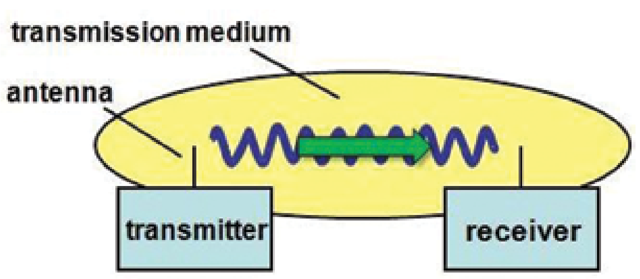


Figure 7: Basic Components of Wireless Communications Link.

In most discrete antenna systems, one antenna both transmits and receives from the transceiver. However, some systems use separate antennas for the transmitting and receiving functions. A discrete antenna has a limited and localized physical size, and the dimensions of the antenna are much smaller than the coverage area or coverage range.

The other broad category of antenna systems is the distributed antenna system (DAS). Unlike a discrete antenna system, where the energy transmits and receives at one location, a DAS distributes the energy over a broad area and the antenna system can be quite large. The use of DAS has been popular for years in providing radio coverage in confined spaces such as tunnels. More recently, DAS systems have been used to provide cellular radio coverage inside large buildings and other hard-to-reach areas, such as parking garages and casinos. Given this history, DAS systems are good candidates for applications in underground mining.

Most DAS applications create a continuous coverage area by providing many overlapping radiation points or continuous radiation along the length of the system. The leaky feeder system discussed in the next section is an example of a DAS that has continuous radiation along the length of the system.

An important limitation of a DAS is that parts of the system require power to boost or amplify the signal. As the signal travels along the length of the DAS, energy is lost due to the energy radiated along the length. To offset this loss, electrical power is required for the amplifiers within the DAS to boost the signal. The availability of power and the safe handling of this power is a significant limiting factor in using a DAS in an underground coal mine.

Another limitation to a DAS system is that it receives the signal along its entire length; therefore, it is also receiving noise over its entire length. As discussed earlier, in Section 1.2, noise can reduce the coverage range of a system; therefore, the cumulative noise can limit the size of a DAS.

SIGNALS AND COMMUNICATIONS

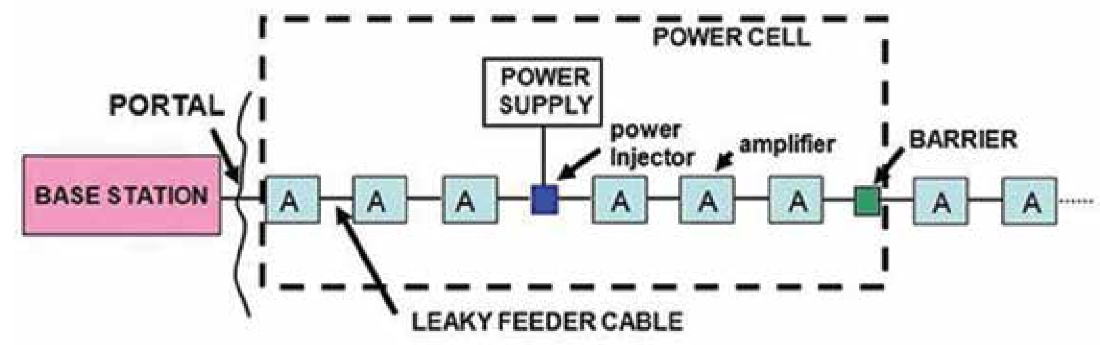


Figure 8: A Leaky Feeder Communications System.

2.2.1 Leaky Feeder Systems

A leaky feeder system used in an underground coal mine typically involves a single large transceiver on the surface that can communicate with all miners' radios along the length of the system. The transceiver on the surface, called a base station, connects to a DAS system. Leaky feeder systems operate at a frequency that is conventionally used by two-way voice radio communications, with the electromagnetic energy transmitted and received through radio frequencies (RF). **Figure 8** shows the main components of a leaky feeder communications system.

A DAS consists of a specially designed coaxial cable (commonly called leaky feeder cable) and amplifiers. This leaky feeder cable "leaks" the radio signal in or out along its length, thus creating a continuous coverage area along the tunnels in which the cable is strung. The coaxial cable has regular openings in the outer shield, as shown in **Figure 9**, which permit RF energy to enter or leave the cable. It can receive and transmit signals down its entire length. Wherever a mine desires communications, it installs leaky feeder cable down the entries to the mine. In addition to transporting the RF signal, the centre conductor of the cable also carries the DC power (typically 12 volts) for the amplifiers.

Leaky feeder systems for coal mines are commonly marketed as very high frequency (VHF), operating around 150 megahertz (MHz), or one million cycles per second, or ultra-high frequency (UHF), operating around 450 MHz At these operating frequencies, the handheld radios can establish a physical communications link through air, but the range is very limited underground. The leaky feeder system overcomes this range limitation by extending the receiver antenna (the leaky feeder cable) to the general area of the handheld radio, which greatly extends the range and permits surface personnel to talk with distant underground miners. The radio transmits the RF signal, which the leaky feeder cable receives if the radio is within range. The signal travels down the cable, radiating as it travels. If the receiving radio is within RF range of the cable, it receives the signal and makes the connection. **Figure 10** shows a cutaway view of an underground room-and-pillar coal mine with a leaky feeder cable installed down one entry. The orange dots (dots along the labeled leaky feeder) represent the path of the RF signal.

Leaky feeder cables cannot transport radio signals for indefinite distances. Attenuation (signal power loss) exists in the cable itself, and continual radiation of RF energy flows through the openings in the outer shield. Therefore, a mechanism that periodically boosts the strength of the RF signal is required. Amplifiers are electronic components periodically inserted in the cable to boost the signal by increasing its amplitude. The amplifiers receive their power from a power supply through the centre conductor of the

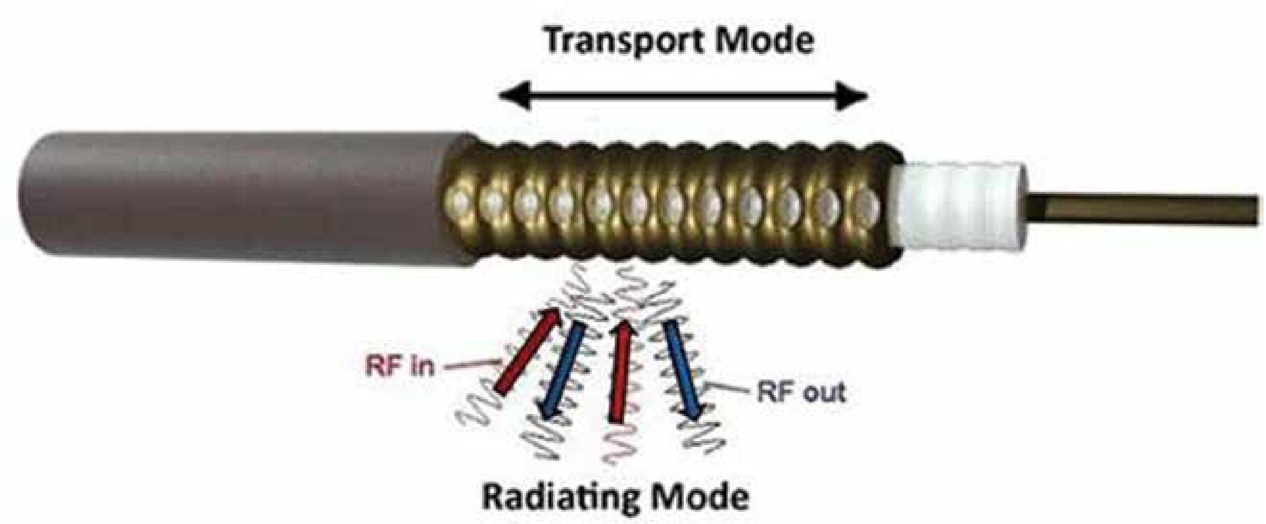


Figure 9: Example of a Leaky Feeder Coaxial Cable.

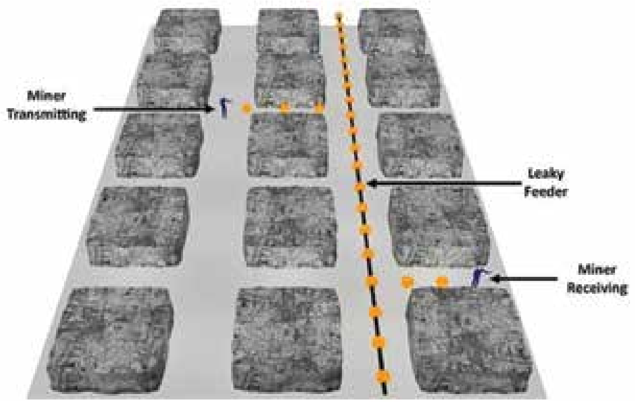


Figure 10: Example of a Leaky Feeder Communications System.

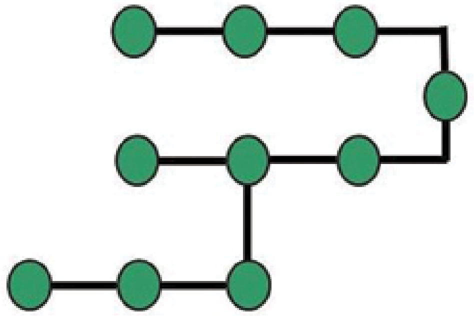


Figure 12: A Tree Configuration of Power Cells.

cable. For underground coal mine applications, one power supply can generally support six amplifiers. The power supply, amplifiers, and sections of leaky feeder cable form a building block, called a power cell, for the leaky feeder system. **Figure 11** shows the power cell components of a leaky feeder system. In an underground coal mine, a typical power cell might be 8,700 feet in length.

In a long entry, multiple cells are used to provide radio communications coverage everywhere along the entry. To establish interconnections between power cells, leaky feeder networks typically use a tree configuration as shown in **Figure 12**. The circles are the power cells of the leaky feeder system. The cell furthest to the right is either on the surface or just inside the portal and provides the communications connection to the mine operations centre. Should something happen to that power cell, communications with the surface are lost. Therefore, to increase the network's survivability, some leaky feeders use an alternate communications path to the surface, perhaps through another portal or a borehole to the surface. For the communications link at the surface, ordinary conductors, fibre optic cable, or through-the-air transmission can be used to complete the connection to the mine operations centre.

2.2.2 Node-Based System

Node-based systems refer to systems that use discrete antennas connected to small transceivers called "nodes." The nodes also contain small computers (microprocessors) that perform a variety of functions. In all node-based systems, the node can detect when a miner's radio is in range and provides an automatic connection to the network. Beyond that basic function, the capabilities of nodes vary greatly depending on the manufacturer and choice of technology.

In node-based systems, the access link is the first link, which is through the air from the miner's handheld radio to a node. The access node is the node providing the communications service or link to the miner's radio. The backhaul is the communications path from the access node to the surface. The backhaul links are the connections between nodes – through wires, the air, or both; thus, node-based systems come in many forms.

Node-based communications systems for coal mines can be assembled from a number of different technologies. Wireless Fidelity (Wi-Fi), also referred to as wireless local area network (WLAN), is the foundation of one node-based system used for underground coal mines.

Common uses for Wi-Fi systems are in the home, the local coffee shop, and airports to provide wireless access for a computer to the internet or any device or network that uses standards-based Internet Protocol (IP). The advantage of these systems is that many devices and networks support IP, offering a variety of potential applications such as video monitoring or remote control via the internet. In these systems, the access nodes need to communicate with a gateway node located at the mine operations centre, which provides the communications link to the surface facilities and supplies message routing information and other data to the access node. The backhaul link is from the access node to the gateway node through wires, fibre, or other radio links. Some proprietary variations of Wi-Fi systems use the wireless link between nodes as alternate backhaul links.

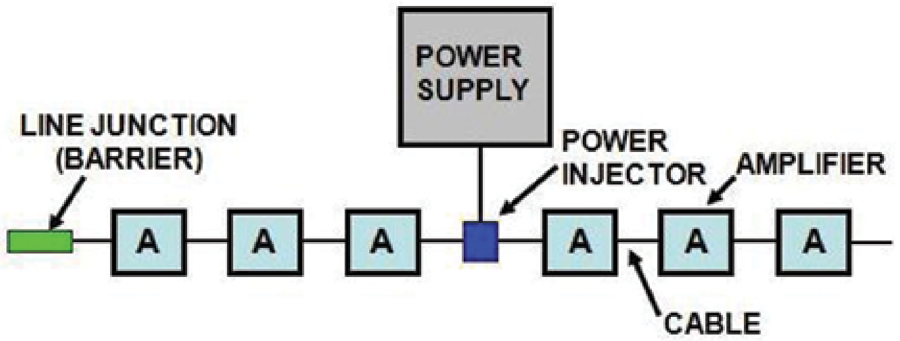


Figure 11: Leaky Feeder Power Cell Structure.

Using UHF radios is another approach to node-based communications. In the underground coal mine environment, UHF radios can communicate directly with each other over significant distances, perhaps 1,000 feet. To extend the communications range, it is necessary to use repeaters (also called nodes) as intermediate components in the communications route. Section 1.2 introduced the concept of a node as a device that relays an RF message from one device to the next by automatically retransmitting the signals it receives. **Figure 13** shows a wireless link between two radios that involves two nodes to complete the connection.

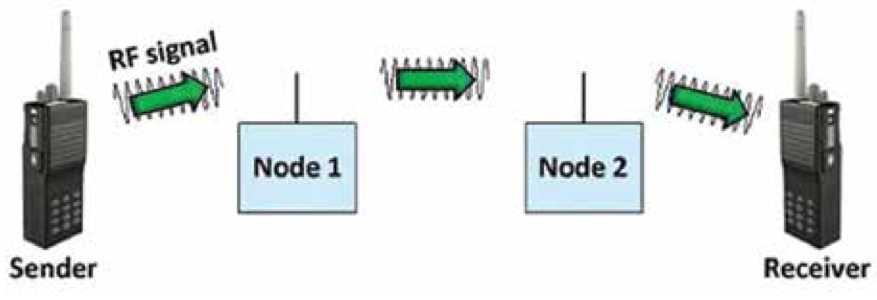


Figure 13: A Wireless Route Using Two Intermediate Nodes.

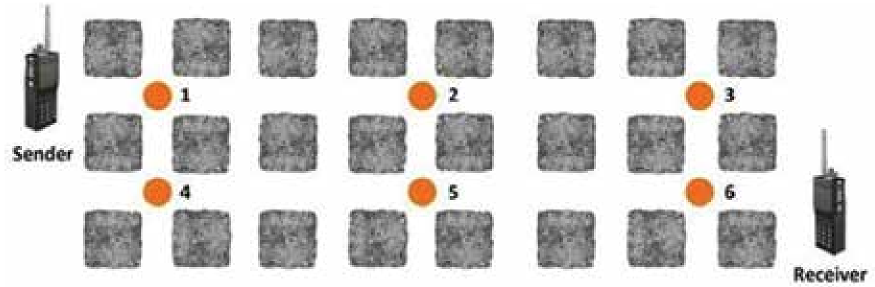


Figure 14: Node (Orange Dots) Based Communications System.

The communications connection between the sender and the receiver is generally from the transmitter to air, air to node, node to node (i.e. may possibly involve multiple nodes), and, finally, node to air to receiver. Note that the node-to-node link is also through the air. The manner in which a UHF radio wave travels through the air in a coal mine is different from through the air on the surface. In an underground mine, the tunnel opening guides the UHF waves, which bounce off the walls, floor, and roof. The tunnel acts as a guide, or pipe, for transporting the radio waves. This guiding effect is important because it contributes to a loss of signal power in the RF link through the air, which determines the effective range of the communications link.

The number of nodes participating in the connection between the sender and receiver will depend on the locations of the radios and the nodes and the path or route taken through the nodes to link the radios. **Figure 14** shows six nodes (numbered orange dots) in a portion of a mine. The route from the sender to the receiver could be through nodes 1-2-3-6, or 1-4-5-6, or one of several other possible combinations of nodes.

For a UHF network, fibre-optic cables or metallic conductors can connect the nodes in the entries to the mine. However, because the UHF nodes both receive and transmit UHF signals, a wireless connection is possible, with no cabling needed.

In addition, each node can contain a small computer programmed to detect when another node is within RF range and that node's identity. The computer can automatically establish a wireless connection between the nodes. When a sender and receiver wish to link, the computers work in concert to determine the optimum route between the participating nodes.

Figure 15 shows a cutaway view of a mine with a UHF node-based communications system. Orange dots indicate the RF signal route between the two miners. Should an incident occur that disables one of the nodes, it is possible for the node computers to recognize the loss and to determine a new route for re-establishing the communications link, as shown in **Figure 16**.

As demonstrated, a UHF node-based communications system can be made to be quite robust (i.e., able to re-establish or reconfigure itself following an accident). To provide an alternate communications path following an accident, two requirements must exist: (1) There must be enough nodes within RF range of each other to establish alternate routes when required. This requirement is partly a cost issue; additional nodes cost additional money. (2) The nodes must be capable of automatically reconfiguring the network. This means that the manufacturer must install the computer chips and appropriate programming into the nodes.

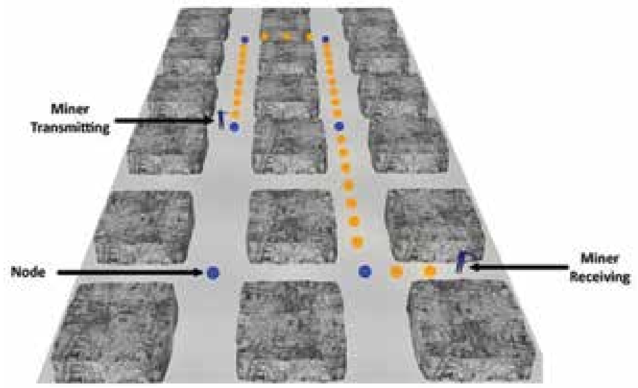


Figure 15: UHF Node-Based Communications System.

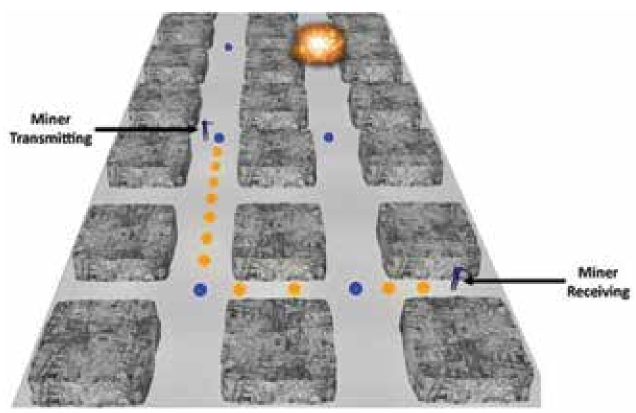


Figure 16: Node-Based Network Establishes Alternate Communications Path.

The type of node-based network described above, using UHF radios as an example, is a mesh network. There are a variety of mesh network types. A mesh network where all the nodes, including the miner's radio, can relay the network traffic and automatically reconfigure the network over any arbitrary route in real time is an ad hoc mesh network. A mesh network that can only reconfigure periodically is a constrained mesh, e.g., one where the reconfiguration is dependent on predefined alternate routes, or one in which the miner's device cannot relay traffic. A full mesh network is a network in which each node connects to every other node by a direct physical communication link. A partial mesh network is a network where each node connects to several other nodes, but not to all nodes. Because room-and-pillar mines can extend for miles, a full mesh may be impossible. The nodes in **Figures 15** and **16** are able to communicate with the adjacent outby and inby nodes, as well as the adjacent node in the crosscut. These nodes form a partial mesh network.

2.2.3 Medium Frequency System

Medium frequency (MF) communications systems typically operate at around 500 kilohertz (kHz – 1,000 cycles per second). In addition to their operating frequency, what distinguishes them from other communications systems is the way the RF signals travel in the mine. At these frequencies, the radio signals couple onto metallic conductors such as power lines, phone lines, wire lifelines, other electrical wiring, and metal pipes. The conductors play the same role as the coaxial cable does in the leaky feeder systems, as conduits for the radio signal. MF radio signals travel along the conductor. In addition, the conductor acts as a distributed antenna, able to transmit and receive signals continuously along its length, just like the leaky feeder cable.

Direct MF radio to MF radio communication distance is very limited unless metal conductors are present along the communications path. Since many mine entries already have conductors and because installing simple conductors is inexpensive, the MF communications distance easily extends to miles without the need for a repeater or amplifier. **Figure 17** shows a typical connection between two MF radios.

MF radios and antennas are considerably heavier and larger than UHF or VHF handheld radios. Therefore, it is not likely that the miner would continuously carry these devices while performing daily work. The MF radio might be used as a redundant communications system, or a system used mainly for emergencies.

An up/down frequency converter is able to interconnect MF and higher frequency systems like UHF or VHF. The device changes RF signals received in one frequency band to RF signals transmitted in a higher or lower frequency band. For example, the converter can down-convert signals received in UHF to signals transmitted at MF, or conversely, receive MF and transmit UHF. Thus, the converter is somewhat like a repeater, except that it retransmits the signal it receives at a different frequency. These up/down frequency converters are referred to as bridge repeaters or bridge nodes.

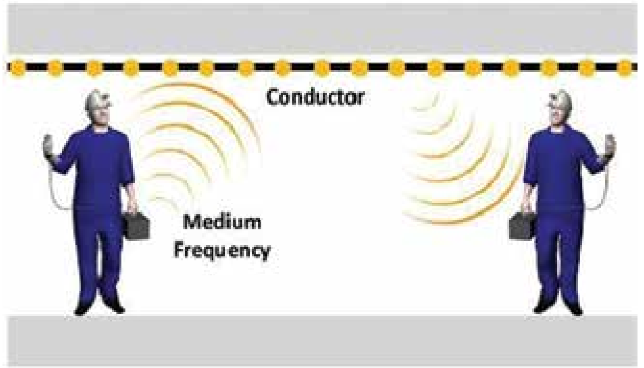


Figure 17: Typical Connection between Two MF Radios.

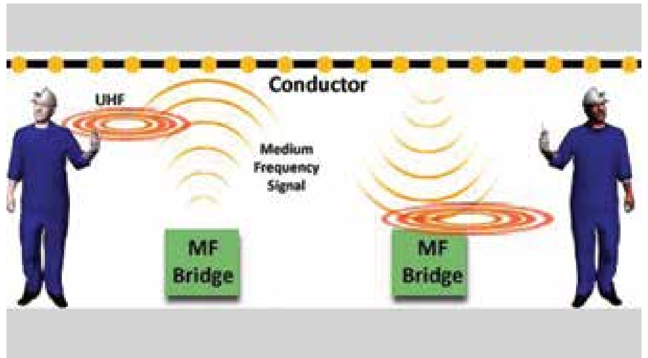


Figure 18: A Hybrid or Combination of MF/UHF Communications Systems.

The bridge repeaters provide flexibility in networking by permitting hybrid systems, i.e. systems that combine multiple frequency technologies. **Figure 18** shows a sample hybrid configuration. A miner, using a UHF handheld radio, can transmit to a bridge repeater that receives the UHF and retransmits MF, which, in turn, couples to a conductor. The conductor transmits and receives MF as the signal travels along. At some point, another bridge repeater picks up the MF signal which then transmits the message in UHF. Another miner with a UHF handheld radio can receive the message. The receiving miner can send a reply which will be transmitted through the reverse of the above process.

An extension of the hybrid system in **Figure 18** illustrates how one of the miners is replaced by a nearby UHF leaky feeder cable, which acts as an extended antenna that is able to receive or transmit RF signals. The leaky feeder system would likely be the main communications system in the mine. The MF portion acts as an extension of the UHF leaky feeder, and the bridge repeater provides the conversion between the UHF leaky feeder and the MF system. Such a combination is one way to extend communications to the working face of the mine without having to extend the leaky feeder cable as the face advances.

2.2.4. Through-the-Earth Systems

Through-the-earth (TTE) communications technology is the only technology that can transmit an electromagnetic signal between a sender and receiver with a worker underground and another on the surface without relying on a network or other additional infrastructure. Most electromagnetic waves normally reflect off the earth or rapidly weaken as they

SIGNALS AND COMMUNICATIONS

pass into the earth, such that they penetrate only a few feet below the surface. However, at frequencies less than about 10 kHz, it is possible for the waves to propagate more than 1,000 feet through the earth. There are several factors that limit potential applications for TTE in underground coal mines: antenna design, low frequencies necessary to transmit the signal, and other noise sources.

Antenna design has a large impact on TTE systems. An antenna is a metallic device that converts electromagnetic radiation into an electrical current; the variation in the electrical current carries the radio signal or signal information. When those currents flow on the antenna, they generate an electromagnetic wave. Similarly, if an electromagnetic wave impinges on an antenna, it generates currents on the antenna.

Antennas are most effective at transmitting and receiving RF wavelengths that are comparable to the largest dimensions of the antenna. This can be a problem for the very low frequency TTE waves. A 10-kHz electromagnetic wave has a wavelength in air of about 19 miles, which is not a practical size for an antenna. Thus, all practical TTE antennas are much smaller than a wavelength. The resulting inefficiency in the antenna means that only a very small fraction of the electromagnetic energy applied to the antenna radiates. Similarly, on reception, only a small portion of the electromagnetic energy contacting the antenna converts to an electrical signal on the wires connected to the antenna.

Loops or coils of wire are effective antennas for generating TTE electromagnetic waves because they increase the surface area available for contact with the electromagnetic waves without increasing the overall footprint and it is relatively easy to lay out a loop in a room-and-pillar mine. For example, wrapping wires around a coal pillar creates a loop antenna. **Figure 19** shows a representative TTE configuration - a loop on the surface transmitting a signal to a loop underground. To obtain a strong enough radio signal between the two loops, their coverage areas must partially overlap.

The low frequencies needed for TTE communications also limit the amount of information transmitted in the message and may delay the receipt of the message by several minutes. This limited information flow makes it very difficult to use TTE for voice communications and to include TTE communications links in a network.

Another limiting factor in the use of TTE communications is the variety of natural and man-made noise sources existing at these low frequencies, including electromagnetic energy from power lines and electromagnetic noise naturally occurring in the atmosphere. These noise sources further limit the range and information flow of a TTE communications link.

Given the constraints on antenna size, signal power, message size, and delivery delay, TTE systems are most likely to be used only in emergencies. An advantage of a TTE communications link is that it is highly survivable. As such, a TTE system could play a significant role as an emergency alternate communications path. Section4 discusses alternate communications paths further.

3. TRACKING SYSTEMS PRINCIPLES OF OPERATION

3.1. Manual Tracking Systems

The intent of a tracking system is to record who is underground and where they are located. The mine operations centre displays this information on the surface, so that in the event of an underground emergency, rescue workers can effectively plan their operations.

When using manual tracking, at the beginning of each shift, the mine foreman provides the dispatcher with a list of names of people and where they will be located in the mine. Once underground, if a miner needs to go to a different area to work, the miner notifies the dispatcher using the underground dial phone. The dispatcher then updates the list.

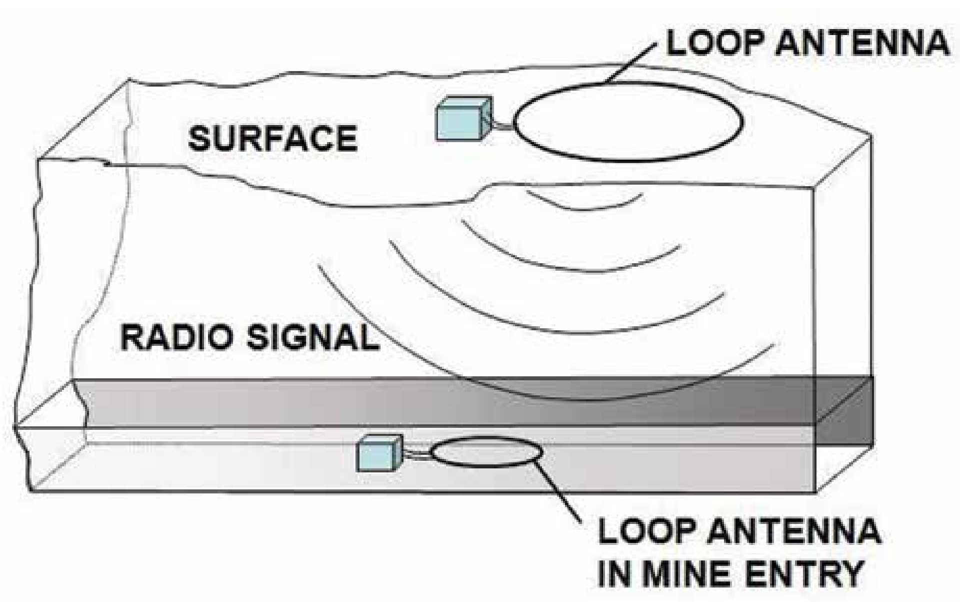


Figure 19: Example of a TTE Communications System.

Manual tracking has a number of limitations. A miner may report a location as being within a working section, but that can be quite a large area, perhaps covering two square miles.

Occasionally a miner will forget to notify the dispatcher when changing work locations. Also, the dispatcher has many duties and may not be available when a miner calls to notify the surface of a change in location. In an emergency, the phone system may not be operational.

Electronic tracking systems can address most, if not all, of these limitations. The following sections discuss several types of electronic systems.

3.2. Reader-based Tracking Systems

3.2.1. Radio Frequency Identification (Zone-Based)

Nearly all department stores have vertical sensor plates near their doors, which shoppers have to pass through on their way out of the store. If a customer has not paid for the merchandise, an alarm sounds. Radio Frequency Identification (RFID) is the basis for security systems such as this. Within the item being purchased is a small tag, typically about the size of a postage stamp, containing an electronic circuit. The vertical sensor plates at the exits are continuously emitting an RF signal. The sensor plates are RFID readers. If the reader signal reaches a tag (interrogates it), the tag sends back a response that is detected and read by the sensor plate and the alarm is sounded. On checkout, the tag is de-activated when the purchased item is rubbed on a particular region of the counter, producing a magnetic field that interacts with the circuit of the tag, making it inoperable.

The tags used in the department stores are passive tags, because the tag has no internal power source. Thus, the tag is passive and does not emit any RF energy until interrogated by the reader. Once interrogated, the tag absorbs a small amount of the RF energy from the interrogating signal and uses it to send a reply. Passive tags are very inexpensive because they are simple and have no internal battery. However, the range of the reader and tag system is quite short, typically a few feet; that is why the vertical readers at the store's exit are so close together.

A more advanced level of RFID tracking can be used to track the locations of underground miners. To extend the tag-to-reader range, an active tag is used. Active tags have an internal battery to power the signal transmission. The tag is a very small radio, able to transmit and receive messages. Each miner wears a tag that transmits a unique identifier. Whenever the miner passes within the RF range of a reader, it interrogates the tag. The reader relays the detection information to a central location (usually the mine operations centre) over wires, through fibre-optic cable, or even wirelessly. Each RFID reader has its own identification and a location associated with that identification. When a given reader interrogates a tag, then forwards the information to the operations centre, personnel at the centre know that the miner is within a certain distance of that reader's location.

Figure 20 shows an example of RFID readers (blue circles) installed in a mine. Each reader has a location associated with a survey marker (black circles, each with a unique number). The blue ovals illustrate the RF range of each reader. The red ovals show the RF range of the miner's tags. Miner A is within the RF range of the reader at survey marker 58301. Miner B is not within range of any reader, but if he had recently left the reader at marker 58289, his location would be his last recorded position. This is zone-based RFID because each reader only detects tags within its RF range or zone.

The tracking system as presented in **Figure 20** is independent of the communications system. Both the tracking and communications systems need to provide a link to the surface; therefore, it is logical to integrate the two systems. For example, the RFID readers could transmit their location information to a leaky feeder cable, which would then transfer the information to the operations centre. Not all RFID zone-based systems operate in the same way or use the same frequencies. Each manufacturer will develop features unique to their product. Given that flexibility, a representative RFID reader range is about 300 feet. In this case, the identified miner is within a circle with a radius of 300 feet (100 meters), centred at the RFID reader, as shown in **Figure 21**.

Interpreting this figure allows us to determine possible locations for the miner. Clearly, the miner is not located within the coal; he is either in the entry with the reader or in one of the crosscuts. It is unlikely he is in a parallel entry (even though the 300-foot circle would permit it), because the RFID reader requires a line-of-sight with the tag (i.e., an unobstructed straight-line path between the tag and reader). Therefore, the miner must be within the red-shaded zone shown in **Figure 21**.

The resolution of a tracking system is a measure of the smallest detectable change in position or location of

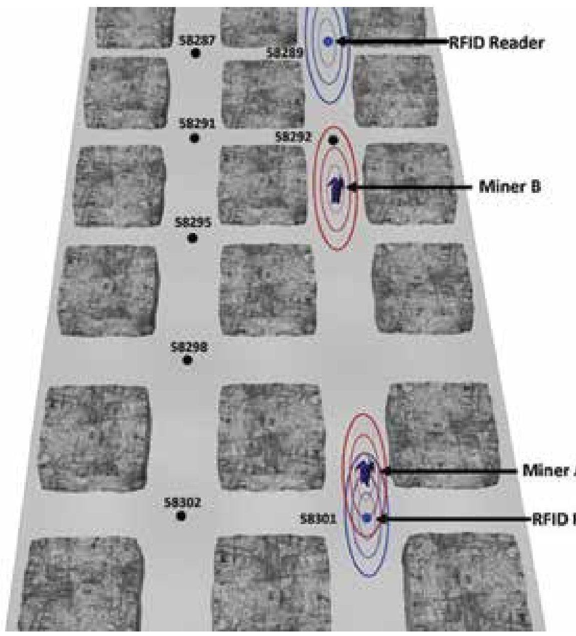


Figure 20: Zone-based RFID Tracking.

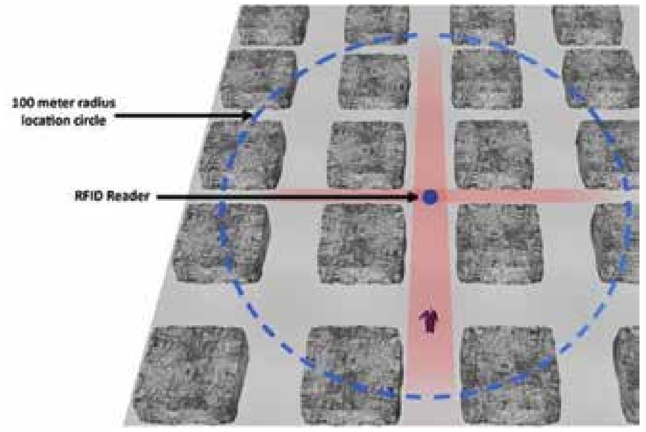


Figure 21: Miner Location with RFID Reader.

the miner. For RFID reader-based systems, a miner's position is associated with a particular reader's location and the resolution is determined by the reader spacing. Therefore, if a higher (i.e., better) resolution is required, more readers will be required, thus increasing the cost of the system.

3.2.2. Reverse RFID

Zone-based RFID systems are well established and are being used increasingly for industrial applications. However, for high-resolution applications over large areas these systems require a large number of readers, which in turn increases the cost and complexity. This section will discuss a relatively new approach, reverse RFID, which is currently being considered by some manufacturers.

In the reverse RFID system, each miner wears an RFID reader, and the tags are in fixed, known locations. The location information obtained by the RFID reader must still reach the mine operations centre. To accomplish this, the reader has a radio transmitter that periodically transmits the miner's location data to the mine's backhaul (the network's backbone or the main route to the operations centre communications system. **Figure 22** illustrates a reverse RFID system in which the backhaul is a UHF leaky feeder system.

The RFID tag periodically emits its identification information, shown in **Figure 22**. A separate antenna, possibly mounted

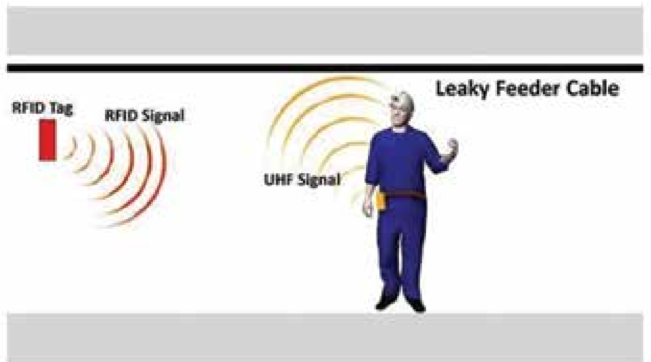


Figure 22: Example of Reverse RFID System with UHF Leaky Feeder Backhaul.

on the miner's cap, receives the RFID tag signal. The RFID information transfers to the transmitter on the miner's belt, relays to the leaky feeder cable, and ultimately to the mine operations centre. A UHF transmitter mounted on the miner's belt transmits the location information to the leaky feeder cable.

RFID tags are relatively inexpensive when compared to the RFID reader. Tags can be located close together so that the miner's location can be determined accurately. Each tag contains a battery, which makes maintenance a concern, but the batteries can last 10 years.

Using a more sophisticated approach than just recognizing when a miner is in a certain zone can further enhance the location accuracy. If a miner is within RF range of two RFID tags at the same time, comparing the received signal strengths from the two tags can determine the miner's location within 50 feet. As the miner approaches one tag, the strength of the signal from that tag increases. On the other hand, as the miner walks away from the other tag, the strength of the signal from that tag decreases. A comparison of the rates of change of signal strengths pinpoints the miner's location. Analysis of this comparison also determines the miner's speed and direction of travel. This technique is referred to as Received Signal Strength Indicator (RSSI).

3.3. Radio Node-Based Tracking Systems

Radio node-based tracking systems use the same physical components as the node-based communications systems. Radio node-based tracking uses the known locations of the fixed position nodes as reference points. Each handheld radio has a unique identifier assigned to it and the identifier is associated with a specific miner. A fixed node with a known location is linked to a radio with a unique ID and assigned to a specific miner, hence the location of the miner is known. Similar to RFID systems, the resolution is limited to the node spacing.

Applying the same concept of comparing radio signal strengths (RSSI), which is used in the reverse RFID technique, RSSI can be used for determining how far the miner's radio, and thereby the miner, is from the node. In a reverse RFID system that uses RSSI, the tags are in fixed, known locations, and the miner wears a receiver that detects and measures the signals radiated by the tags. Since a node-based UHF communications system has all the necessary components to implement the RSSI technique, it does not require RFID tags. In a node-based system, the access node and/or the miner's radio makes the signal strength measurements; hence the node-based system provides both communications and tracking in a single system.

Positioning the nodes close enough so that there is continuous communications coverage allows the handheld radio to receive signals from multiple nodes and to determine the signal strengths. Each signal also contains information identifying the node from which it came. In some systems, the information accumulates in the miner's radio and then transmits back to the mine operations centre for analysis.

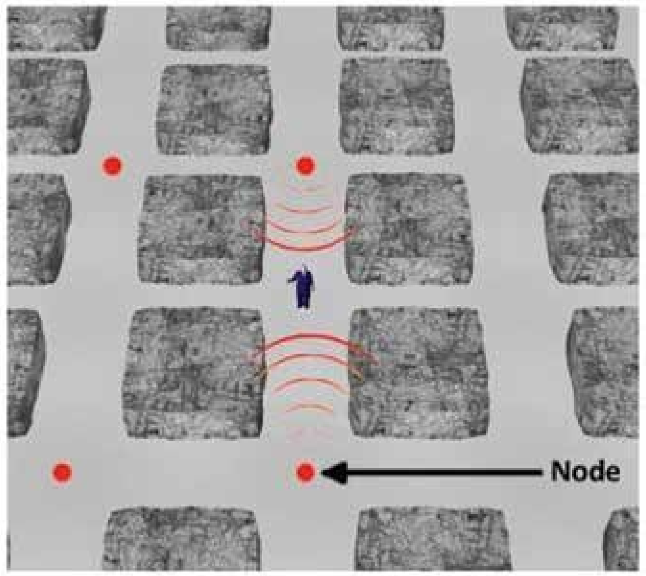


Figure 23: Radio Node-Based Tracking.

Other systems compare the signal strength received from two or more nodes in the miner's radio. The location is resolved using RSSI, which determines the distance of the miner from each of the nodes within the miner's RF range.

Figure 23 illustrates the main features of a radio node-based tracking system. The red arcs represent the RF signals transmitted from the nodes. The illustration appears almost identical to the depiction of node-based communications as shown in **Figures 14-16**, which is why electronic tracking is easy to implement in a node-based communications system.

Unfortunately, there are many factors in the underground mine environment that introduce uncertainties into the RSSI determination of location. These factors include any blockage that reduces or eliminates line-of-sight between the access node and the miner, including stoppings, equipment in the entries, turns in the entries, undulation in the coal seam, etc. With these uncertainties, the miner's location may not be determined to better than about half the spacing of the distance between the nodes.

4. NETWORK OPTIONS

Section 1.2 introduced the concept of networks. A communications network is an interconnection of communications components that allow a user to send a message to a specified destination. The network receives, interprets, transports, and delivers the message to the destination. For simplicity, this discussion focuses on communications networks, but it applies equally well to electronic tracking networks.

Figure 24 illustrates the main responsibilities of a network – access and transport. The concepts of access and transport are analogous to a city bus network. The buses travel predefined routes and pick up riders at specified locations; but to achieve transport, a rider must access the system (go to a bus stop). Similarly, in a communication or tracking network, the interconnected nodes provide the message transport, but the user must access the network in order to send the message.

Section 2.1 on leaky feeders introduced the idea of an alternate communications path. Alternate communications paths provide the key to ensuring the survivability of systems in a coal mine, and the support of these alternate communications paths is a critical consideration in evaluating a mine operator's network option.

Figure 25 shows a leaky feeder system, which establishes redundancy by providing an alternate communications path by means of an overland, fiber-optic link between the airshaft and the primary base station at the elevator shaft. The surface link maintains the communications even if there is damage to the underground connection between the two shafts. **Figure 25** introduces the issue that an alternate communications path typically emerges at some point on the surface separated, possibly by miles, from the primary path exit point. In this example, the primary base station would generally be located at the mine operations centre (MOC) and a mechanism is required to connect the secondary base station back to the MOC. As shown in **Figure 25**, the overland connection could be fibre-optic cable. Other options include hardwiring through leased lines from the telephone company, or a wireless link.

5. MINE OPERATIONS CENTRE

The MINER Act requires wireless communications between underground miners and surface personnel. The MINER ACT also requires the use of electronic tracking systems by personnel on the surface for obtaining information on the location of underground workers. Both of these requirements are administered through the mine operations center, the central location of a mine's operations on the surface above the mine.

5.1. Tracking Displays

The MINER Act specifies that surface personnel must have the current location or immediately pre-accident location of all underground miners. There are a number of ways that tracking systems display the location of miners. One method is a simple list of the names or identifying employee numbers of all miners underground along with the nearest survey spad station. An easier format to interpret is a computer display of a mine map with the names of the personnel working underground. Zoom and pan features would make it possible to view the entire underground mine, including the current location of all personnel. **Figure 26** shows a sample display.

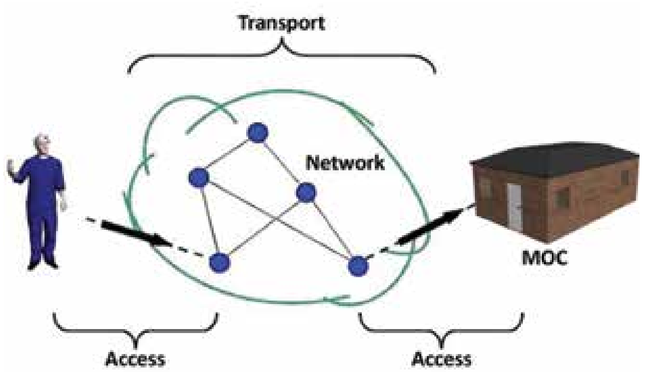


Figure 24: Main Responsibilities of a Network: Access and Transport.

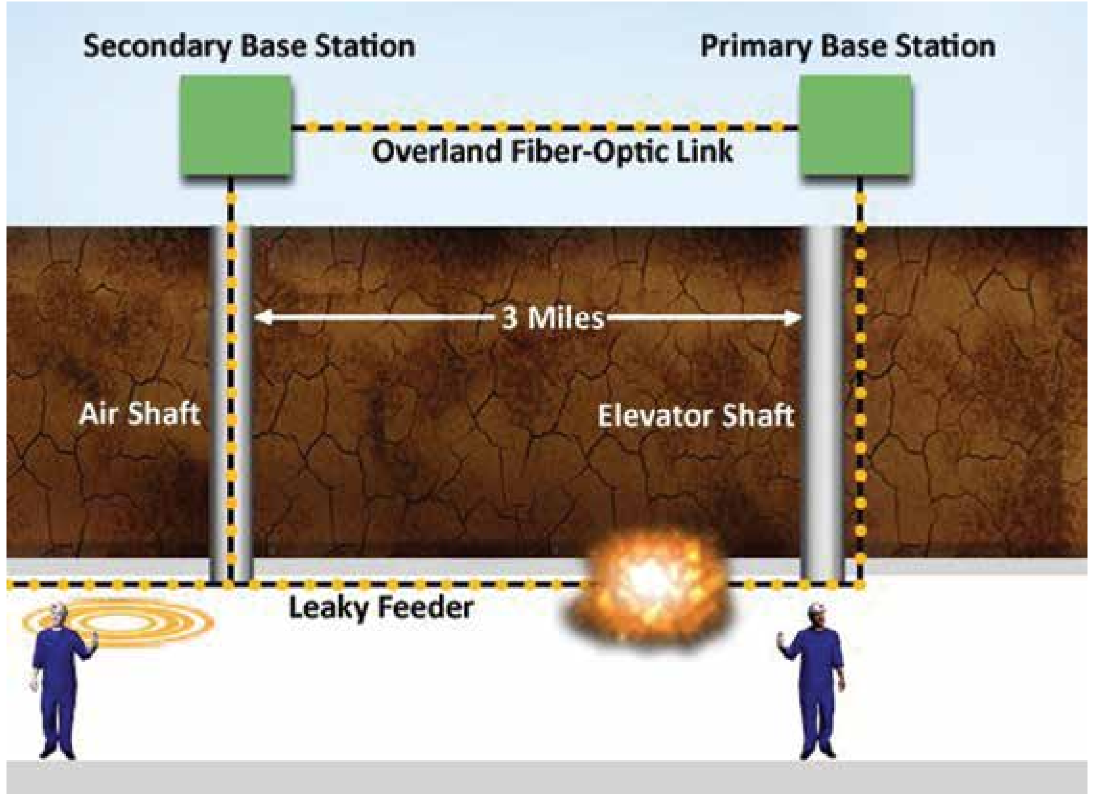


Figure 25: Example of an Alternate Communications Path.

5.2. Surface Communications

The communications network established underground must provide access to surface personnel. As discussed in Section 4, there may be multiple points where the alternate communications paths exit the mine to the surface. These locations are referred to as surface points of presence (POPs). Each of these surface POPs should be linked or be able to be linked in the case of an emergency, to the mine operations centre.

There are a variety of options available for linking these POPs

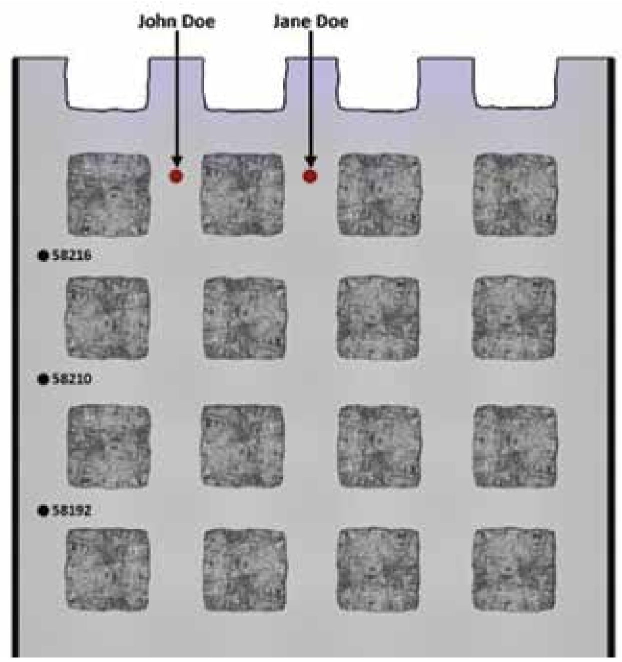


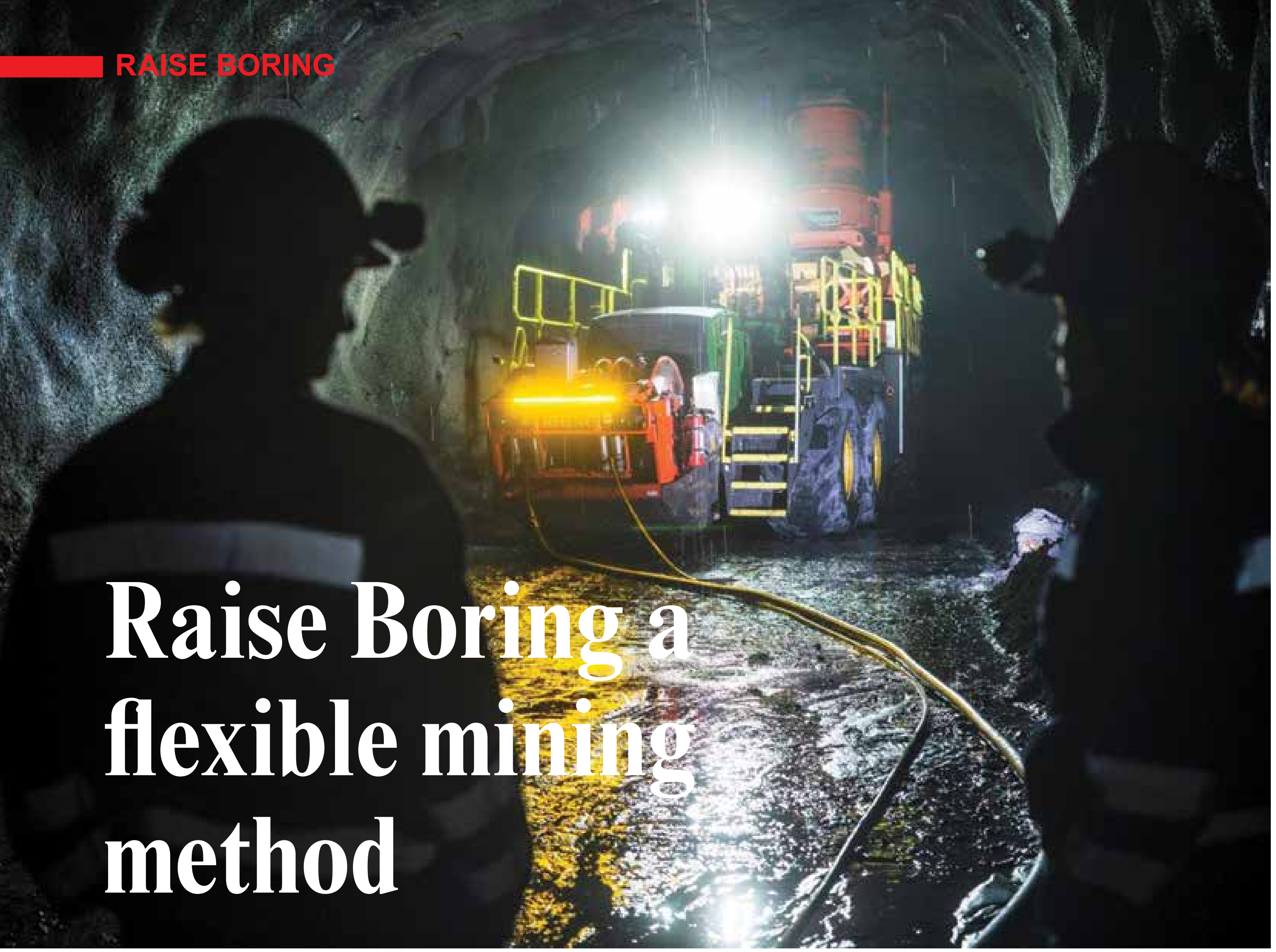
Figure 26: Sample Display of Miner Locations.

back to the operations centre. Where the mine operator has access to the required real estate and surface rights, the operator could install fibre-optic cable, wires, or a wireless link directly back to the mine operations centre. Another option is to lease copper lines from the telephone company. These lines appear to the mine operator as a directly connected line to the POPs and the operator can connect his communications right into the lines.

A third option, with widespread availability due to the proliferation of Internet Protocol (IP) capable devices and "broadband" networks, is to lease a connection that relies on the Internet. This option includes DSL modems through the telephone companies, cable modems through cable television companies, and satellite modems through satellite service providers. While not all mine communications inherently support IP protocols, the equipment vendors are beginning to offer such an option; currently, converters that enable mine communications through the Internet are available.

An advantage of using the Internet-based approach is that mines can remotely monitor their communications links and other systems within the mine. Some equipment vendors and third-party providers already offer services to monitor the systems, thus eliminating the burden of the mine operations personnel of monitoring and troubleshooting the networks.

Because mining communications systems are for day-to-day routine use as well as for emergencies, when an emergency occurs, it is essential that a protocol exists to ensure that the dispatcher in the mine operations centre immediately recognizes when the nature of the communication is an emergency. An emergency communication generally includes audio alarms for voice communications systems or visual alarms that display on the screen for text systems.



Raise Boring a flexible mining method

***Coal International* studies the concepts of shafts constructed by raise boring in underground mines.**

The conventional raise boring methods, such as the wood support method, the hanging cage method, the creeping cage method, and the deep-hole blasting method are all areas that have played a significant part in this crucial mining operation, however, in addition to this Raise Boring machinery and its associated technologies have progressed over the years, allowing greater depths, diameters and flexibility to be achieved.

It is without doubt that Raise Boring machinery and its uses have created a buoyant and extremely healthy marketplace for its services.

In addition, the raise boring machines are classified into different types and the characteristics of each type are described within the article. The components of a raise boring machine including the drill rig, the drill string and the auxiliary system. Based on the analysis of the raise boring method, the rock mechanics problems during the raise boring process are put forward, including rock fragmentation, removal of cuttings, shaft wall stability, and borehole deviation control. Finally, the development trends of raise boring technology are described as follows:

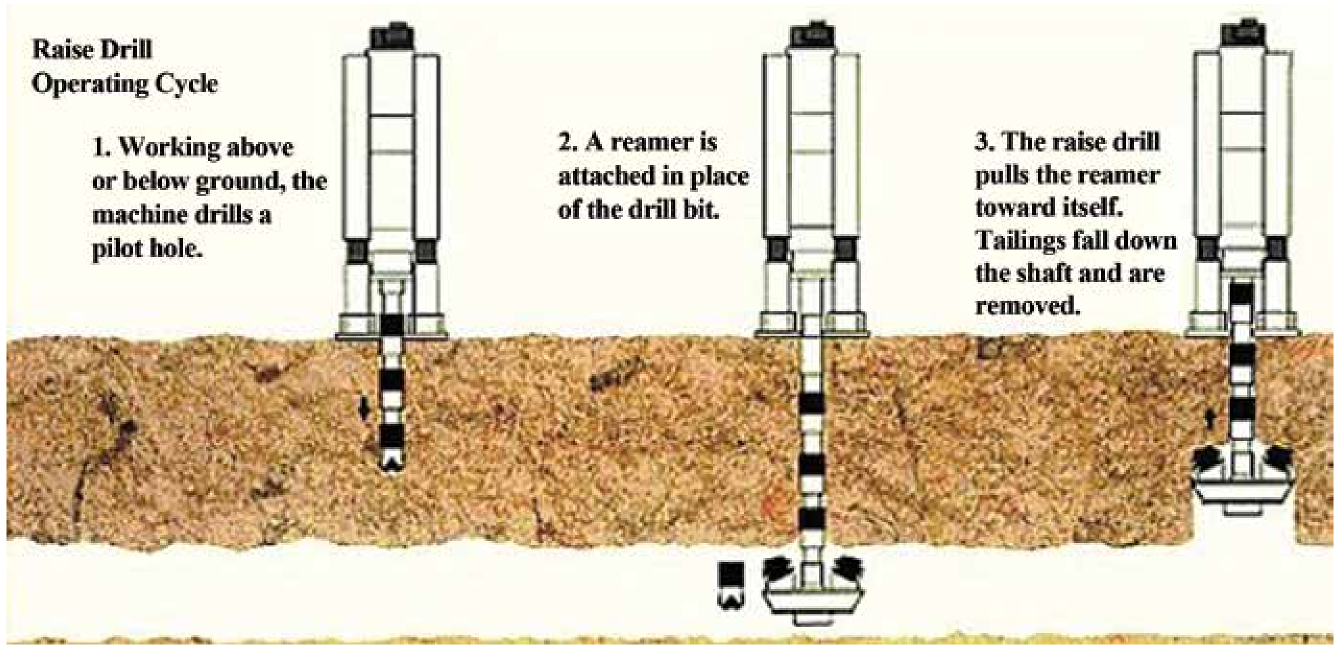
(i) improvement of rock-breaking modes to raise drilling efficiency.
(ii) development of an intelligent control technique.
(iii) development of technology and equipment for nonlinear raise boring.

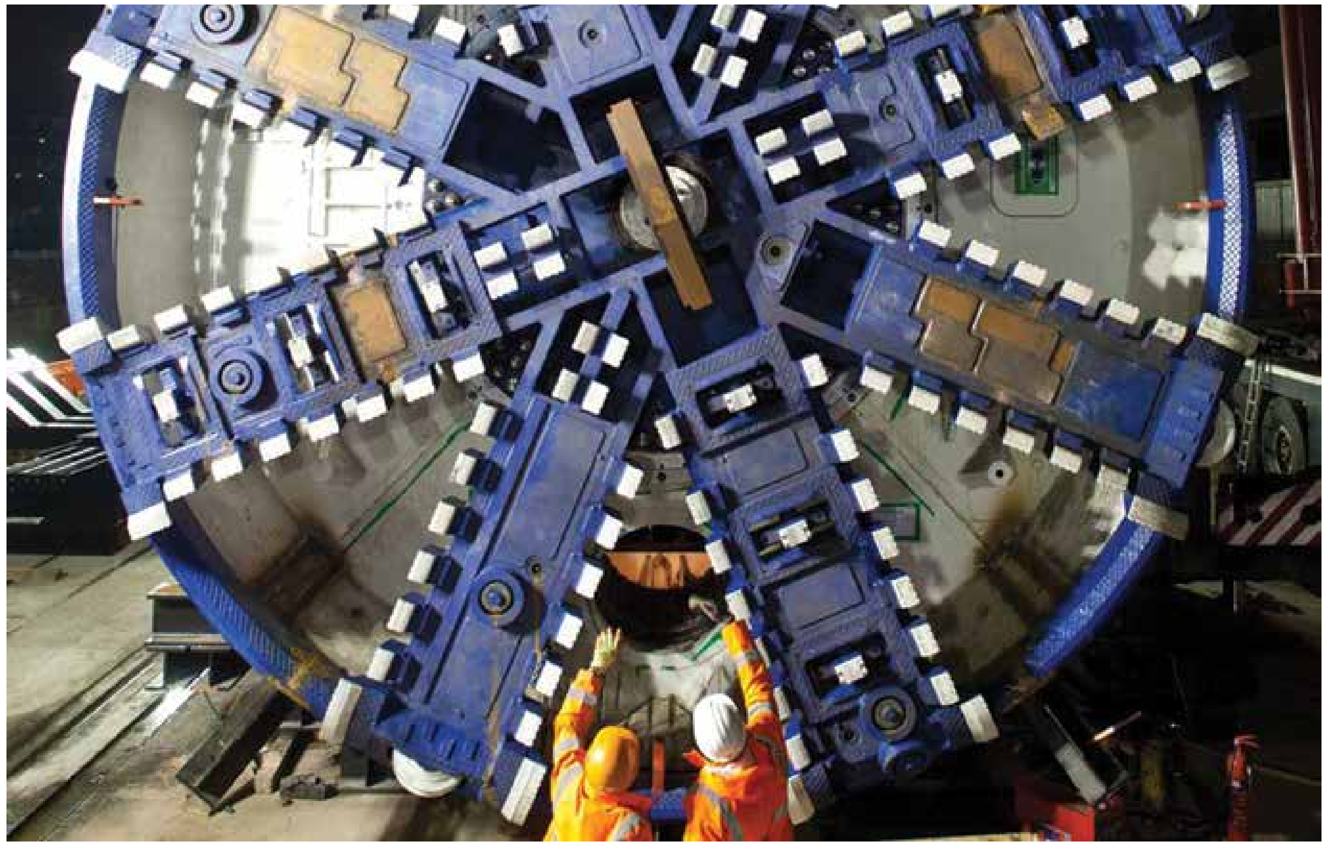
According to the site-specific conditions of most mines, most mineral resources need to be exploited by shaft access mines. As tunnels enter into the ore body, vertical and inclined shafts are constructed from the surface to the desired depth. When the shaft excavation reaches the designed mining level, some horizontal roadways for transportation, ventilation and pedestrian access to the ore body can then be driven. According to the distribution characteristics of the ore body, a variety of shafts should be constructed, such as blind vertical or inclined shafts connecting with ore body at different levels, ore bins storing minerals, ore passes for slipping minerals to the collection level, etc. There is no outlet on the ground for

these underground shafts, and due to the dimensions of the shafts, drilling equipment and support facilities are restricted or forbidden in a narrow space.

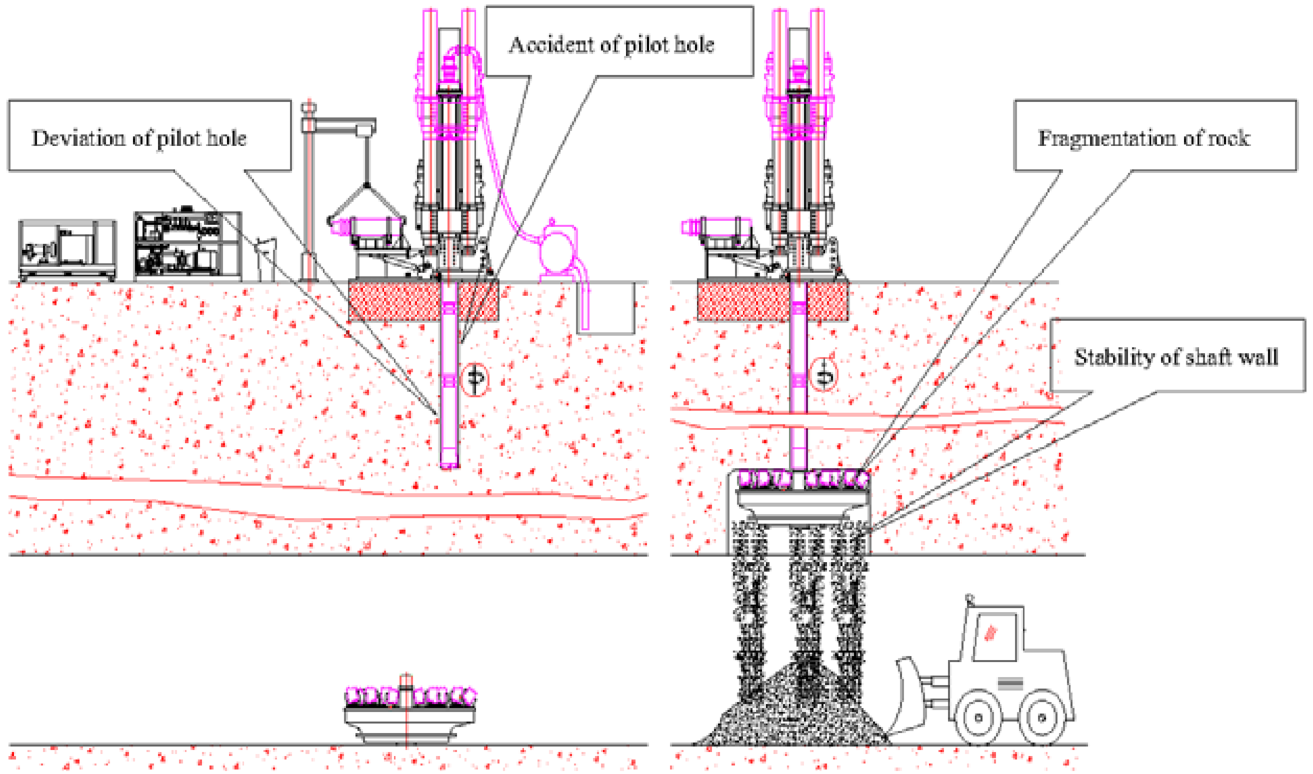
Therefore, the reverse sinking method, called the raise boring method, is generally used on site. The raise boring method is suitable for production of vertical or inclined shafts from bottom to top in underground mining operations. Generally, a small-diameter hole, called pilot hole, is first drilled, through which the cuttings fall to the lower level. The raise is a type of excavation that can be constructed by the raise boring method. Raise boring is very important in the mining industry, and is also applied to other underground engineering projects, such as water conduits, air shafts, elevator hoist-ways and cable shafts in hydro-power stations and pumped-storage power stations to name a few.

According to industry and construction practices, there are a variety of reverse sinking construction processes. In the past, due to factors like complex formations, weak self-supporting ability of rock, and harmful gases in coal mines, the wood-supported raise method, also called conventional raise mining, was generally used in the coal industry in China. With this method, workers first build cross-bracing, ladders and platforms from bottom to top, and then drilling, charging and blasting operations are carried out on the platform. After ventilation, loading and scaling, the next blasting cycle starts, and wood is used as support structures to maintain the stability of roadways. The creeping cage method was generally used in the hydropower industry, and was adopted as transportation equipment for workers and working platforms for excavation operations. The hanging cage method was generally used in metal and nonmetal mines. In these raise boring methods, workers need to enter the working face to apply operations of drilling, charging, blasting and supporting and as a result are liable to be affected by water gushing, harmful gases, rock caving and so on, leading to frequent accidents and low work efficiency. To solve the above safety problems of construction, the deep-hole blasting method was developed. A set of parallel





boreholes is drilled along the axis of the shaft at the top by the drill rig, charging is carried out from the upper level, and blasting is applied piecewise from bottom to top. The accuracy of drilling holes limits the construction depth of this method. Therefore, new methods and equipment were needed. In 1850, a percussion-type drilling machine was first used to drill a small diameter shaft. In the 1930s, the rotary rig was adopted for drilling vertical shafts, and the tunnel boring machine (TBM) was applied in tunnelling gradually. In the 1950s, miners applied the rock-breaking mechanism of shaft drilling machines and TBMs to raise boring, and gradually the modern raise boring machines were developed. However, raises constructed by raise boring machines have small diameters and often act as pilot



(a) Pilot drilling (b) Back reaming

Figure 1: Raise boring method and correlated rock mechanics problems.

Table 1: Main functions and components of raise boring machine.

Component	Function and purpose	Main structure
Drill rig		
Frame, rotation and auxiliary operating system of the raise boring machine	Provide thrust, tension and torque for rock breaking; sustain reactive tension and torque in the drilling process; transmit the reaction force to the rig base; achieve the purpose of dismantle or connect the drill string	*Propulsion and guiding parts* Propulsion: hydro-cylinder type, chain type, gear rack type Guiding: frame type, cylindrical structure type, rectangular structure type *Rotation and driving parts* Hydraulic motor (high-speed motor with planetary gear reducer, low-speed motor with multi-stage reducer), frequency conversion motor, DC motor, AC motor, etc.
Power (driving) system	Provide power for propulsion, rotation, auxiliary functions of the drill rig using high-pressure oil and controllable electricity	High-pressure oil: motor or diesel engine driven hydraulic pump Electricity: inverter, DC/AC controller
Control system	Control and regulate the power to achieve the function parameters and auxiliary operations of drill rig	Hydraulic valves control, switches control and computer-aided control
Drill string		
Drill pipe for pilot holes	Drill pilot holes and ensure the drilling accuracy	The drill pipe for pilot holes is made of round steel processed by cylindrical grinder
Common drill pipe	Transmit thrust, tension, torque, etc., for rock breaking	The drill pipe or its upset end is made of round steel
Special-shaped joint	Fit nonstandard thread of drill bit	The special-shaped joint is made of round steel
Pilot bit	Break rocks during the pilot drilling	Tricone drill bit, diamond drill bit
Reamer head	Crush rocks during back reaming	Spherical, conical, flat structure, integral structure, assembly structure
Cutter	Mount on the reamer head to directly crush rocks	Disc cutter, roller cutter (conical button, spherical button, composite button)
Stabilizer	Support the drill string	Spiral, straight, reamed hole and other types
Auxiliary system		
Circulation system	Remove cuttings, cool down drill string and stabilize the hole wall during pilot drilling	Centrifugal pumps, submersible pumps, mud pumps, high-pressure gas, mud, detection system
Cooling system	Cool down the hydraulic oil or electrical components, reamer head and cutter, and reduce dust during drilling	Fan, outer recycle cooling water, internal recycle cooling liquid, recycle cooling pump, water supply within drill pipe, water supply in annular space, nozzle spray of reamer head
Cutting removal system	Remove cuttings during back reaming	Scraper loader, rock loader, side loader, scraper, rake loading machines, belt conveyor, tramcar, etc.
Quality checking of boreholes	Detect and correct borehole deviation and situation during pilot drilling	Inclinometer, screw power drill string under the shaft, signal transmission, underground TV, rotary directional drilling system
Water supply	Provide water for pilot drilling, cooling, and mud mixing, etc. during raise boring	Pipes, pumps, etc.
Power supply	Provide power for electric-driven equipment	Control switches, etc.

holes. Thus, other methods are needed to ream the pilot holes by raise boring machines to the designed sections. This study presents the concept of shaft excavation by raise boring machines. To this end, the large raise boring machine, drilling process, rock breaking and shaft wall stability during raise boring should be studied.

DRILLING PROCESS AND CONSTITUTION OF RAISE BORING MACHINES

The raise boring method is a way to excavate shaft by back reaming the pilot hole using drill rigs. The drill rig plays a significant role in underground engineering, such as mineral exploration and blasting. For rotary type of drill rigs, the rotational torque and axial force are exerted to drill bit (called pilot hole drill bit for raise boring machines) along the drill pipe to create a circular hole. Generally, the cuttings are removed from the hole with the aid of flushing medium (as shown in **Figure 1a**). The construction process of the pilot hole by raise boring machines is the same as that by conventional drilling machines except the back reaming process introduced in the raise boring method. When the pilot hole breaks through into the lower level, the drill bit is removed and replaced with a large-diameter reaming head. The reamer is rotated and pulled back toward the drilling unit, and through this way a large-diameter shaft is formed (**Figure 1b**). A complete set of raise boring machine includes drill rig, drill string and auxiliary system, as shown in **Table 1**.

CLASSIFICATION OF RAISE BORING MACHINES

Different from the conventional drilling machines, the cuttings usually fall down to the lower level by gravity during raise boring, which is the common characteristic for all types of raise boring machines. The above-mentioned conventional raise borer is only one type of raise boring machine, and the drilling process involves two steps, i.e. pilot drilling and back reaming. In fact, there are many types of raise boring machines. For example, they can be classified into box type, frame type and column type according to the structure of the drilling frame; chain type and cylinder type according to the propulsion mode; motor-driven type and hydraulic motor-driven type according to the rotational power source. However, these classifications are not based on the essence of the raise boring machine. The raise boring machines can be classified into two types according to the back reaming process, i.e. upward reaming type and downward reaming type. **Table 2** briefly lists the characteristics of two types of raise boring machines. According to the reaming direction of the raise boring machine, the drilling process can be classified into two categories, i.e. the upward reaming method (**Figure 2a**) and the downward reaming method (**Figure 2b**). The following conclusions can be drawn by comparing the two reaming methods:

1. In the downward reaming method, the cuttings fall down through the annulus between the drill pipe and the hole wall to the lower level. The cuttings shattered by the cutter in different positions on the reamer head converge at the center of the head and are repeatedly broken by other cutters. In the upward reaming method, however, the cuttings usually fall down by gravity, and are rarely repeatedly broken, so its efficiency is higher than the downward reaming method.

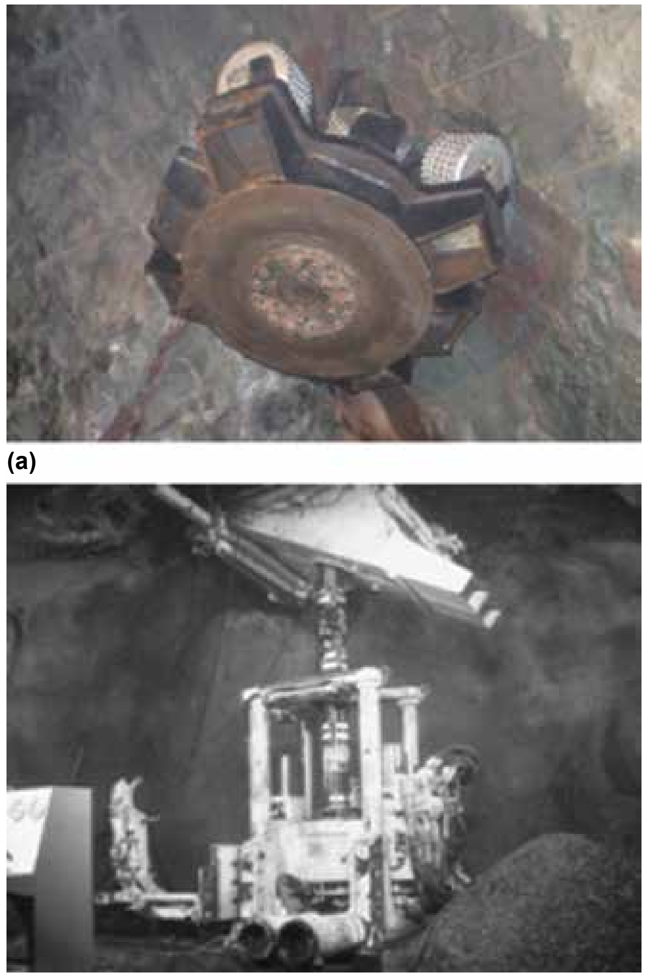
2. In the downward reaming method, the pilot hole is the passage of the drill string and cuttings, thus the falling down of the cuttings can damage the drill string. In the upward reaming method, however, the pilot hole only serves as the passage of the drill string which needs small-diameter hole, so the drilling speed of the pilot hole is fast.

3. It is easier to drill pilot hole and control hole deviation by upward reaming than by downward reaming. In the downward reaming method, since the drill string is under compression during pilot drilling and easily bent, the quality of the hole is difficult to control, and the drilling depth is limited.

4. In the upward reaming method, since the workers operate the drilling machine in the upper level, the working condition is safer than that of the downward reaming method. In the downward reaming method, since the cuttings removal and drilling operations are carried out in the lower level, the working condition is poor.

Table 2: Comparison between two types of raise boring machines.

Raise boring machine	Position of drilling machine	Drilling direction of pilot hole	Position of replacing reamer head	Reaming direction	Reaming mode	Drilling depth (m)	Borehole diameter (m)	Cuttings removal	Applicable condition	Advantage	Disadvantage
Downward reaming type	Lower level	From bottom to top	Upper level	From top to bottom	Multi-step reaming	<200	1.2	Cuttings during reaming process fall down to the lower level and are mucked out by loaders	There are roadways both in upper and lower levels	Weight of the drill string is helpful in rock breaking, thus the energy is saved. This kind of machine has low power, relative small size and weight	Cuttings removal and drilling operation can affect each other. Hole diameter of each reaming is small, and rocks are repeatedly broken. Drilling efficiency is low. Reaming should be conducted for many times, and speed is low. Accuracy of borehole is hard to ensure
Upward reaming type	Upper level	From top to bottom	Lower level	From bottom to top	One-step reaming	1000 (maxi-mum 1260)	7		There are roadways both in upper and lower levels	Drilling operation and cutting removal are separately carried out on two different levels. Working condition is good. Influence of geological conditions is little. Perpendicularity error of borehole is easy to control	It is difficult to drill pilot hole, and many auxiliary equipment is needed
	Lower level	From bottom to top	Lower level		One-step reaming	<100	1		There is a roadway only in lower level	It can be used when there is no roadway or production system in the upper level	The power of drill machine is high. Cuttings removal and drilling operation can affect each other
	Upper level	No pilot hole	Lower level		One-step reaming	<100	1				



(a)

(b)

Figure 2: Photos of two types of reaming method: (a) Upward reaming; and (b) Downward reaming.

MAIN TECHNICAL PROBLEMS DURING RAISE BORING

The raise boring machine has completely changed the working conditions in raise construction, and workers operate machines far away from the dangerous working face. All drilling processes are achieved by the raise boring machine, which lays a good foundation for automatic and unmanned drilling technology. In the past decade, great achievements in raise boring technology and equipment research have been made in China. The diameter and depth of drilling holes reach 5 m and 600 m, respectively, and the application of the raise boring machine is extending to other fields gradually. The progress in raise boring technology needs to address many important issues about basic theory and key equipment of raise boring machine. According to the drilling process of the conventional raise boring machine, a series of rock mechanics problems should be concerned, including stability of hole wall, interaction of drill string and rocks, drilling trajectory control of pilot hole, etc.

Pilot drilling

Pilot drilling is a process of drilling a pilot hole in a small diameter along the axis of shaft (**Figure 4**). When the pilot hole breaks through into the lower level, the roller bit is removed and replaced with a reaming head. The reamer is rotated and pulled back toward the drilling unit, and

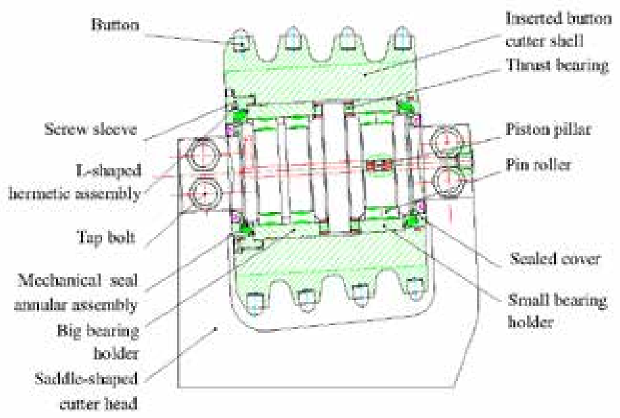


Figure 3: Sketch of rock-breaking cutter.

eventually the shaft is formed. The following requirements should be satisfied for pilot hole in raise boring:

1. The axis of pilot hole should be linear as much as possible and its curvature cannot change too large.

2. The maximum distance from axis of pilot hole to shaft axis must be kept within the engineering allowance, i.e. the deviation rate of the pilot hole should be minimized.

3. In the drilling process, accidents must be avoided, and the finished pilot hole should be smooth and stable.

Rock breaking in pilot drilling

During pilot drilling, rocks are separated from the rock body by tricone roller bit. The mechanism of rock breaking by the drill bit has been researched extensively in petroleum engineering and thus can be used in the raise boring. Different from petroleum drilling, raise boring aims to detect rock properties and geological structures in advance, and to provide a reference for selection of reamer and supporting method. On the basis of regression equation of drilling speed, weight on bit, rotational speed and torque during pilot drilling through different strata, rock drillability classification and relationship between back reaming parameters and pilot drilling parameters should be studied.

Cyclic cuttings removal in pilot drilling

The flushing media used for cuttings removal include mud, water, compressed air, etc. Introduced through the center of the drill pipe, the flushing media are sprayed out through the tricone bit nozzle with the aid of the pump. The rock broken by the cutter is separated from the hole bottom, and removed out of the borehole along the annulus between the drill pipe and hole wall. The basic condition for effective cuttings removal is that the speed of flushing media is higher than the sedimentation speed of cuttings in the flushing media. As a typical flushing media, the mud has good suspension properties, and it also can help to prevent the collapse of hole wall. However, the sudden loss of mud pressure when the hole breaks through into the lower level can result in hole collapse and drill devices buried in unstable strata. Therefore, water is often used instead of mud to remove cuttings from pilot hole. With the aid of water flushing, the unstable strata can be easily explored and addressed to prevent the accident after hole drilling.

Compressed air can achieve efficient cuttings removal in the condition that the strata are relatively stable and hard, with abundant cracks and small caves, but the leakage of flushing fluid is serious. Thus the flushing medium and flow in different strata and reasonable parameters such as pressure need to be studied. According to different flushing media and cuttings flow, the risk of strata should be determined to prevent drilling accidents.

Deviation control of pilot hole

Deviation of pilot hole is that the center line of pilot hole does not coincide with the planned shaft axis. Deviation rate of pilot hole is a ratio of raise length to the maximum deviation. Deviation of pilot hole is generally caused by anisotropy of strata, machining accuracy of drilling devices, artificial control, etc. In pilot drilling, rock is broken by drill bit. The drill bit is connected with stable drill pipe and ordinary drill pipe to form a drilling string to stabilize the drilling process and to reduce its impact on the borehole deviation. However, the machining cannot ensure that the axes of all drill pipes are connected in a line. Drilling tends to deviate from the designed direction, affected by the drilling pressure. Underground stratum is a typical anisotropic body which can produce uneven hole bottom and additional moment, making drilling deviate from the designed drilling direction. The interaction between the drill string and hole wall can also bring in stress changes of drill string and influence its normal operation. The adaptability of designed drilling schemes to the mechanics parameters of different strata, including drilling pressure, rotational speed, and torque, will also cause deviation of pilot hole. Therefore, the influences of physico-mechanical properties and anisotropy of strata, interaction of drill string and hole wall, and drilling parameters on deviation of pilot hole need to be studied, and automatic-correction drill string by terrestrial magnetism should also be developed.

Pilot hole stability and accident control

When the deviation of pilot hole is beyond the engineering allowance, the pilot hole cannot be used anymore and has to be abandoned. In addition to this serious engineering accident, there are many other drilling accidents, such as drill string loss and pilot hole abandonment due to leakage of flushing fluid, hole shrinkage and collapse, and drill string burying induced by unfavorable geological conditions. The drill string is generally more expensive than the drill rig, thus the damage of drill string will cause greater economic losses. For this reason, cyclic cuttings removal, drilling parameters changes, vibration of drill rig and other factors should be studied to determine strata conditions and early-warn accidents, and reinforcement and modification technology of strata in advance should be researched to prevent wall collapse of shaft with large section and no support in back reaming.

Back reaming

Efficient rock breaking

In back reaming, the raise boring machine drives the drill pipe rotation, and energy is transferred to the reamer head along the drill pipe. Then the cutter is driven to crush down the rocks, and the cuttings fall down by gravity to the lower level, where they are mucked out using loaders. As shown in **Figure 3**, the cutter is composed of drill button, cutter shell, sealed bearing, saddle, etc. Two cutters are in a group and laid symmetrically to finish rock breaking. As shown in **Figure 4**, the main technical parameters of the cutter include generatrix length, cone angle, diameter of large end, button spacing and row spacing, etc. The button parameters include button shape, diameters, and so on. During back reaming process of raise boring machine, the reamer exerts certain force on the cutter in the drilling direction until the cutter presses into the rock, and the rock fails when the deformation is beyond its elastic limit. Meanwhile, the cutter rotates under the combined action of rocks and rotating reamer head, and the cutter buttons extrude and scrape the rock, bringing in button marks on it. These marks in similar size and depth cause gradually separating of rock fragment from rock body and formation of rock breaking with circular section, which can meet the project requirements. Therefore, mechanism of rock breaking by cutter, rock drillability, structure and shape of cutter, material and structure of cutter button, wear resistance, arrangement of cutters on the head, spatial arrangement of the head to satisfy efficient cuttings removal need to be studied.

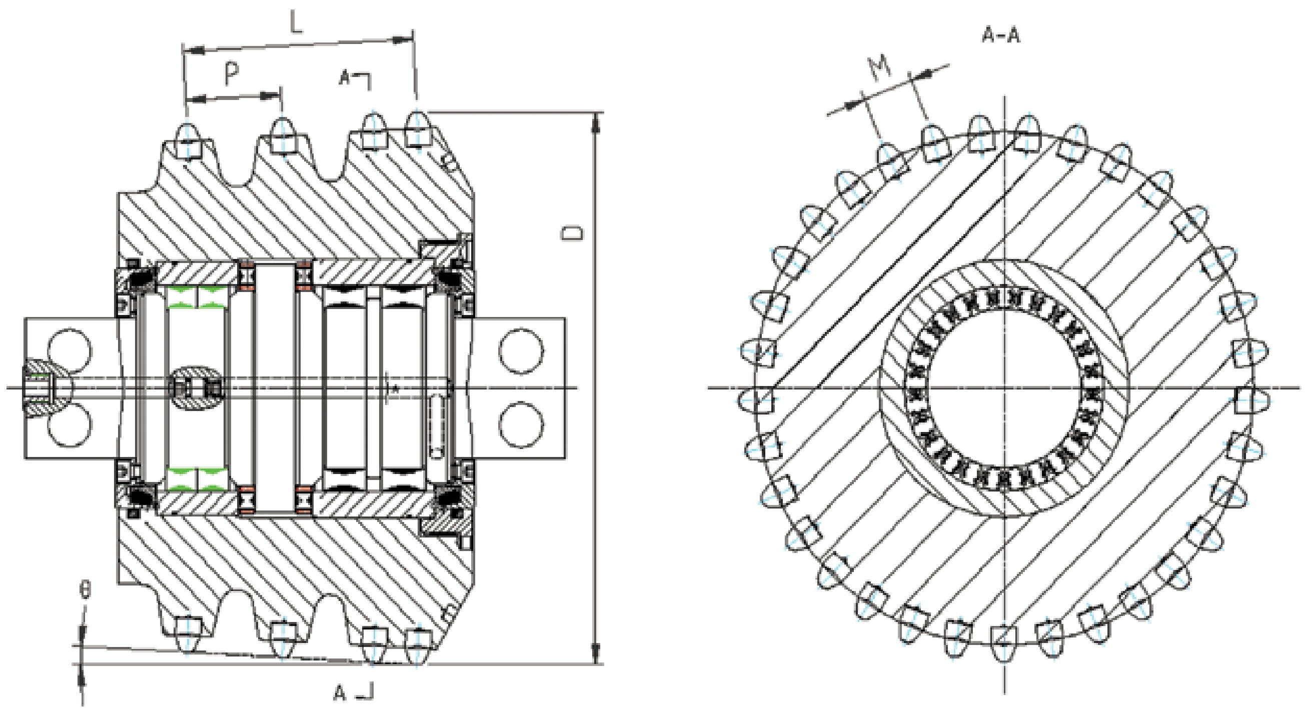


Figure 4: Basic parameters of cutter. *L* – generatrix length; *P* – row spacing; *D* – diameter of large end of cutter; *M* – button spacing; *θ* – cone angle.

Stability of shaft wall

Although the back reaming of raise boring machine has minor disturbance to shaft wall, a variety of factors that affect stability of shaft wall still exist.

1. Stratigraphic conditions. When the shaft is constructed in an unstable formation, the formed shaft wall after back reaming cannot support its stability, and phenomena like rock expansion and crushing by contacting with water often occur and will cause partial collapse, rib spalling, caving of the shaft.

2. Gushing water and cooling water in strata. When the pilot hole breaks through into the lower level, the flushing water leaks out, and the mud pressure on hole wall disappears, making the water contained in strata flush into pilot hole. As the exposed area of rock increases during back reaming, the water inflow grows. In the back reaming process, heat produced by breaking rock results in a sharp rise in the temperature of the cutter. Thus a nozzle is set in the reamer head to spray water to cool the cutter down. Meanwhile, the water mist can clean dust produced in rock breaking to reduce the influence of dust on the lower production system. The gushing water and cooling water have adverse effects on strata stability, for example, they will flush cement of shaft wall rock, reduce cohesion and internal friction coefficient of rock, and increase rock instability risk.

3. Concentration and redistribution of stress. In the process of raise boring, the shaft gradually forms, and the original rock stress distribution gradually changes. Generally, stress concentration occurs on the pilot hole wall, shaft wall and interface between cutter and rock. In fractured strata, once the broken condition is satisfied, partial collapse will occur.

4. Prolonged exposure of shaft wall. The exposure time varies in different parts of shaft wall using raise boring method. The exposure time of the lower shaft wall is the longest, and it includes the time of back reaming, the time from the dismantling of the raise boring machine to the installation of support and lifting equipment, and the time of temporary support from top to bottom. As to the raise boring shaft with 400 m in depth and 5 m in diameter, back reaming generally lasts for 2-3 months, dismounting and mounting of lifting equipment and hanging scaffold for a week, and temporary support of anchoring and shotcreting generally for 1.5-2 months. Thus the exposure time reaches 110-160 d. The exposure time of shaft wall reduces gradually from bottom to top, and the influence of exposure time on stability of shaft wall needs to be studied.

TECHNOLOGY AND EQUIPMENT OF RAISE BORING

Application conditions and main technical parameters of raise boring machines

Application conditions

The study of raise boring technology was initiated from the construction of air shafts in coal mines, and then it was conducted in hydropower projects and other underground engineering. In these projects, the boring machines drill through rocks characterized with different properties. In coal mines, coal is one of the major types of sedimentary rocks with low uniaxial compression strength (UCS) (<120 MPa). The drilling depth in coal mines can reach 600 m, and the maximum diameter of back reaming reaches 5 m. The boring inclination ranges from 50° to 90°, and the maximum rate of back reaming is 0.8 m/h. In hydropower projects and other underground engineering, the rock masses are mainly composed of igneous rocks with high UCS of 120-200 MPa. The drilling depth can reach 600 m, and the maximum diameter of back reaming reaches 3.5 m. The boring inclination ranges from 40° to 90°, and the maximum rate of back reaming is 0.5 m/h.

Main technical parameters

1. Drilling pressure, P_f

The reamer head of 5 m in diameter (Dr) contains 30 cutters on it, and the 3.5 m diameter head contains 18 cutters (**Figure 5**). When drilling is performed in the rocks with UCS less than 120 MPa, the pressure on cutters for breaking rocks should be approximately 35 kN, thus the drilling pressure for reamer head of 5 m in diameter is 1050 kN. When the UCS of rocks reaches 200 MPa, the pressure exerted on cutters should reach 80 kN to meet the target drilling rate, thus drilling pressure for reamer head of 3.5 m in diameter needs to be 1440 kN.

2. Rotational speed, n_r

In order to achieve high efficiency of rock breaking and low wear of cutter buttons, the time of cutter buttons in contact with rocks should be 0.02-0.03 s, and correspondingly the linear velocity (V_c) of side cutters should be controlled at 0.7-1.0 m/s. Through calculation, $n_r = 60V_c/\pi D_r$ = 2.67-3.8 r/min, thus the designed maximum rotational speed of raise boring machine is 5 r/min.

3. Torque, M_s

Based on the drilling rate and rotational speed, the drilling depth (h_r) in each round is 1.6-2.7 mm. In addition to the drilling depth in each round (or the drilling rate), the maximum torque of rock breaking is also related with the diameter of the reamer head and the friction coefficient of the cutter bearing. In rock breaking, the cutters require energy to separate rock from rock bodies, and the cutter

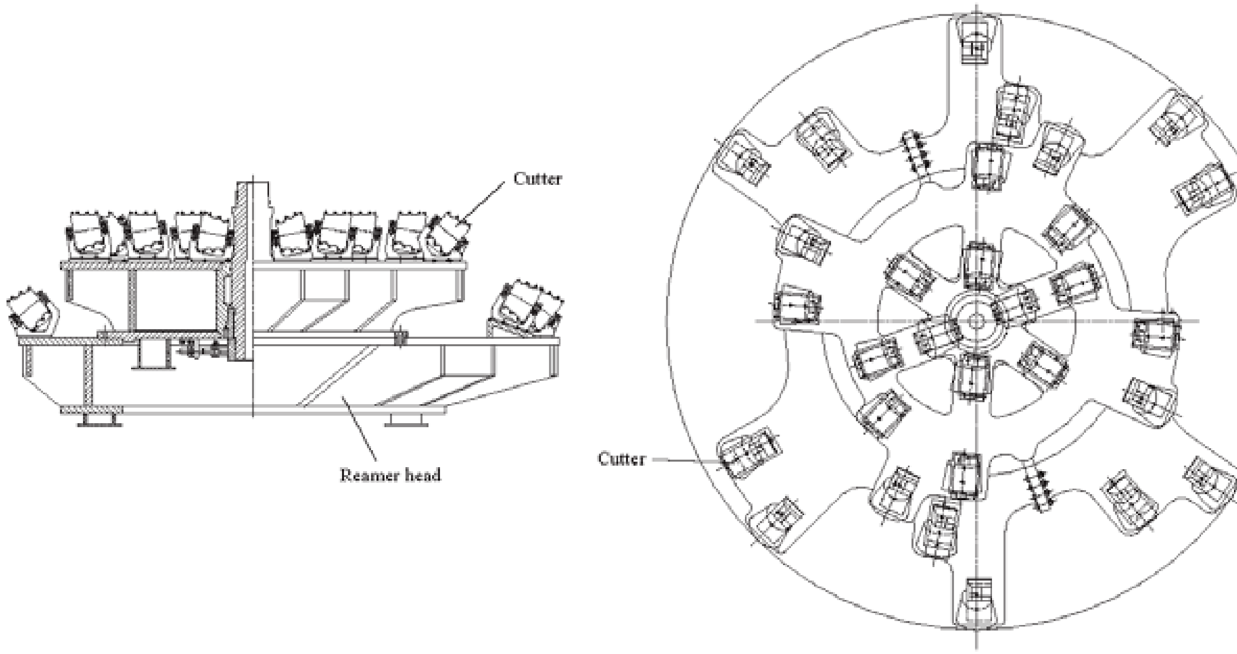


Figure 5: Structure of reamer head of the raise boring machine for shafts of 5 m in diameter.

bearing and friction between reamer head and rock can also consume some energy. Without considering some other minor factors, the torque can be calculated as

$$M_s = \frac{K_r \pi \left(D_r^2 - D_p^2\right) h_r}{4}$$

where K_r is the required energy to break unit volume of rock by cutters, and it contains energy loss. The consumed energy in the laboratory experiment of UCS is low, and the common consumption value is 5 × 10^7–9 × 10^7 J/m^3. D_p is the diameter of the pilot hole.

The required torque for different drilling rates ranges from 156 kN m to 264 kN m. Considering other accident treatments, the torque of the raise boring machine is 300 kN m.

Other parameters

Based on the rotational speed, torque, and drilling pressure, the tension of the raise boring machine is calculated. Considering the total weight (3160 kN) of drill pipe 600 m long (2700 kN), drill bit 5 m in diameter (400 kN), and driving unit (60 kN), the lifting force of the raise boring machine is 4610-4750 kN. Considering the machine's capacity, the tension of raise boring machine is designed to be 6000 kN.

The main technical parameters of the self-developed raise boring machine ZFY5.0/600 for shafts 5 m in diameter are shown in **Table 3**.

Development of raise boring machine for large-diameter shafts

Figure 1 shows the schematic diagram of site application of the self-developed raise boring machine ZFY5.0/600. Considering the capacity improvement of the raise boring machine, there are 4 cylinders, 2 guide posts (**Figure 6**) and 4 motors (**Figure 7**) in the drill rig. The main force-bearing components are bolted rigidly. The adjustable angle of the machine body is not less than 30°. The electrohydraulic control system is adopted in power and control system to ensure the flexibility, intelligence and safety of the drilling machine. The drill pipe is 1.5 m in length with 1:8 cone thread. The reamer head is composed of removable segments (as shown in **Figure 6**), facilitating underground transportation and installation.

Case illustration

The auxiliary ventilation shaft in Baoxin coal mine of Lanhua Coal Industry Group in Guxian, Shanxi, China is 4.7 m in net diameter and 482.2 m in depth. The shaft passes through the rock strata of upper Shihezi group, lower Shihezi group, Shanxi group, and Taiyuan group, with UCS less than 100 MPa. The self-developed raise boring machine ZFY5.0/600 is adopted in this project. In order to ensure the stability of the shaft wall and safe construction, risk assessment should be first performed using detailed geological exploration data, including rock composition, physico-mechanical properties of rocks, geologic structure, development of fissures and bedding, and underground water situation in strata. Secondly, pilot drilling should be considered. Based on the investigation of the exposed rock, leakage of drilling mud and drilling parameters, the stability of the shaft wall after back reaming can be determined. Through analyzing geologic exploration data, the upper unstable strata may lead to the collapse of the borehole by water flushing during drilling process, thus partial excavation and shotcreting are conducted (**Figure 8**). The unstable strata are removed from top to bottom and supported temporarily, and the stable strata are reinforced using low-grade concrete. As the concrete reaches certain strength, the raise boring machine is installed and the drilling starts. The drilling site of the raise boring machine is shown in **Figure 9**. The pilot drilling of the Baoxin coal mine took 25 d from March 15 to April 10, 2012, within which 215 h is consumed for drilling. The finished pilot hole is 350 mm in diameter and 482.2 m in depth, with deviation rate less than 0.2%. The back reaming started on April 25, 2012, and ended on June 10, 2012.

After successful application to coal mines, the raise boring machine ZFY5.0/600 has constructed a dozen deep shafts in hard basalt layers with UCS larger than 150 MPa in Baihetan hydropower station, which further tests the capacity of the raise boring machine.

Table 3: Main technical parameters of the self-developed raise boring machine ZFY5.0/600.

Basic parameters					Parameters of pilot drilling			Parameters of back reaming				Other parameters	
Diameter of pilot hole (mm)	Diameter of finished shaft (m)	Drilling depth (m)	Drilling angle (°)	UCS of rock (MPa)	Rotational speed (rpm)	Thrust (kN)	Rated torque (kN m)	Rotational speed (rpm)	Rated tension (kN)	Rated torque (kN m)	Maximum torque (kN m)	Mass of drill rig (kg)	Power of drill rig (kW)
350	5	600	60-90	120	0-18	1300	92	2-5	6000	300	450	25,200	284.7

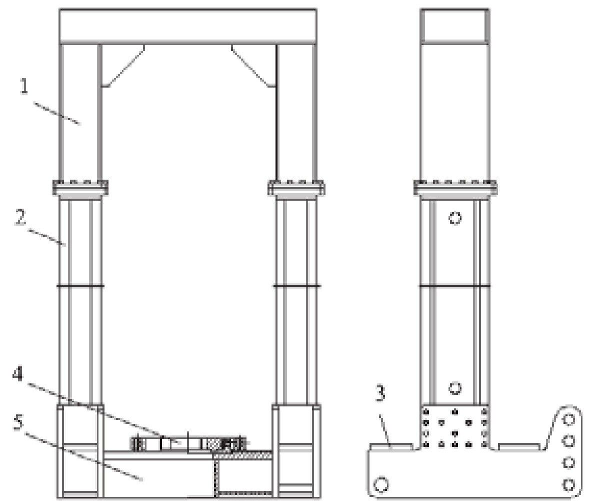


Figure 6: Structure of drilling frame of the raise boring machine ZFY5.0/600. 1 – beam; 2 – guiding square columns; 3 – connecting flange of the propulsion cylinder; 4 – flashboard assembly; 5 – base.

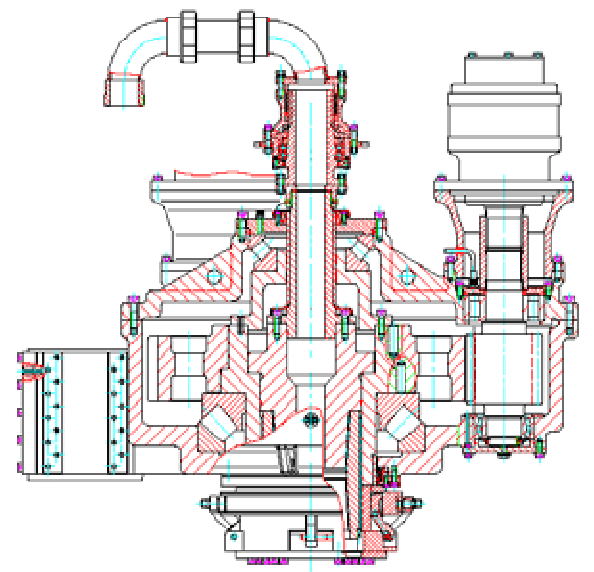


Figure 7: Structure of the multi-motor driving unit.

DEVELOPMENT TREND OF RAISE BORING TECHNOLOGY

Improving rock-breaking method to increase drilling efficiency

The cutter is the key component of raise boring machine to break rocks, and it is also the main consumable material. The energy consumption of cutting is much higher than that of conventional method like blasting. Therefore, efficient and low energy consumption cutter needs to be developed through the improvement of cutter body structure, cutter button structure and the use of new materials. Based on the physico-mechanical properties of rocks, auxiliary rock breaking technologies, such as high-pressure water jet, microwave vibration and chemical modification, need to be studied to further improve the efficiency of rock breaking and drilling by raise boring machine. With the development of new technologies, such as laser, high-energy particle,

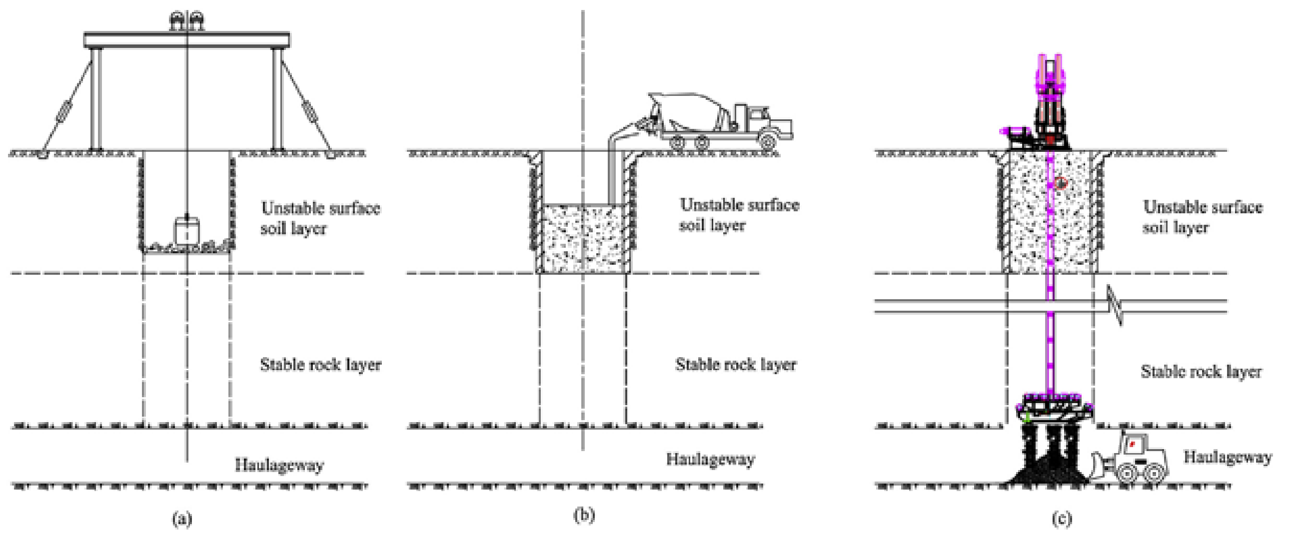


Figure 8: Support process of upper unstable strata. (a) Excavation; (b) Pouring concrete; (c) Back reaming.

and directionally controlled micro-blasting, current full-face rock breaking methods with which all the rocks are broken can be changed. By forming controllable and regularly shaped artificial fissures, rocks can be separated from rock body. In the process of rock breaking, the shaft wall that needs to be stable can be melted and recrystallized, and the rock properties are fully used to solve the problems of breaking rock and preventing rock crushing.

Intelligent control technology

With the development of raise boring machinery, it is increasingly used in various fields of underground construction, and it is suitable for all kinds of excavations from horizontal to vertical. Therefore, improving drilling accuracy and ensuring the drilling along the designed borehole axis become the most important issues for the raise boring machine. Development of pilot hole drill bit and drill string which can intelligently control the drilling direction is the key to solving the problems. There are some issues to be addressed, such as accurate positioning measurement and signal transmission of drill bit in three-dimensional space, servo-control of drilling direction, structure of small drill bit with these functions, energy supply method of drill bit, etc.

Some projects with nuclear radiation and overflow of harmful gases are not suitable for field operations of workers, and these unfavorable conditions have an adverse impact on equipment performances, or interfere with data communication. Thus the intelligent remote control technology can be applied to efficiently transmit the signals and achieve the unmanned operation of the raise boring machine. In various working conditions, supply, grab and positioning of drill pipes should be intelligently controlled. The raise boring machine has functions of judgment and pre-treatment, and errors can be automatically diagnosed. The drilling work can be carried out by pre-programmed procedures and remote control.

To ensure the stability of the shaft wall, the remote shotcreting technology in conjunction with the raise boring needs to be studied. By timely reinforcement of the surrounding rocks, stability of shaft wall is improved, and accidents during back reaming are reduced. Firstly, intelligent recognition technology of surrounding rocks in the drilling process should be researched. Secondly, remote-controlled shotcreting devices and robot control technology should be studied to achieve intelligent detection of shotcrete layer, intelligent control of shotcreting, and shape control in formed shafts, and thus the following work can be well carried out.

Nonlinear drilling

To meet requirements of safe mineral exploitation under different geologic conditions, it is necessary to develop different types of raise boring machines. The raise boring machine with a drill pipe plays an important role in promoting the development of raise boring technology. However, due to the limit of drill pipe stiffness, the present raise boring machines can only drill in a straight direction which is difficult to control. Therefore, raise boring machinery without drill pipe at early stage of development should be considered when the wire rope was acted as traction and guidance component. With the development of control technology, it is necessary to develop raise boring machines without guidance by the wire rope or so-called “hamster” type of raise boring equipment to exploit nuclear material, gold and other rare minerals along the mineral vein. Thus through tracing the minerals, the raise boring machine can reduce the ore dilution, decrease mining costs and impact on the environment, finally achieving green mining.

CONCLUSIONS

The raise boring machine has made great progress in the last several decades. As a type of equipment used in site-specific conditions, the raise boring machine can now be applied to many fields, including coal mines, hydropower stations, transportation, underground building, military engineering and other underground projects, with the maximum excavation diameter gradually increasing. Particularly, the successful development of the raise boring machine ZFY5.0/600 achieves large-diameter shaft construction, whilst former raise boring machines can only drill small-diameter raises. The raise boring machine ZFY5.0/600 constructed a ventilation shaft 5 m in diameter in a coal mine and drilled a dozen deep shafts 3.5 m in diameter in hard basalt at the Baihetan hydropower station. However, many theoretical, mechanical and other technical issues about raise boring machines and the drilling process need to be further studied to solve problems on aspects of drilling efficiency, energy savings, safety, unmanned operation and so forth. Optimization of the rock-breaking method, intelligent control technology, and nonlinear drilling of the raise boring machine need to be further researched and developed. As a reliable mechanized construction method, the raise boring technique is an ideal supplement to traditional shaft construction, and provides an efficient, mechanized construction method. Compared with the conventional drill-and-blast method, mechanized construction methods can greatly reduce the number of operating workers, improve safety in the construction of shafts, reduce injuries of workers and improve working efficiency. Therefore, the development and application of raise boring technology are prospective.

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