Tomorrow's underground mine

John Chadwick considers advances in communications, automation, continuous development and underground access, and even laser mining

The innovative Cat® Rock Flow System radically changes the way in which ore is moved in block caving mines from draw point to the primary crusher. The system comprises several components, all centrally controlled from the mine's main control room: the Rock Feeder RF300 to extract the ore from the drawpoint, the Rock Mover RM900 (a newly developed hard rock chain conveyor) to transport the ore and an automation unit to control and smooth the production process

Jan Kwak, Managing Director, Mining & Mineral Processing, at **Hatch** says: "Technology is reinventing processes, transforming mining in ways and at a rate we haven't seen in 100 years. We're just beginning to wade into the space that manufacturing has been living in for decades. The incentive is there, driving us to create the 'intelligent' mine of the future. And do it now.

"There's a wealth of information and tools out there that can be adapted to the kind of work we do. But they do need adapting. That's telling us that for automation to be most effective, the business of mining may have to be reconfigured. It may need to be based on business models that rely on this new, enabling technology.

"So, we're probably going to have to change the way mines work. To do that, we're going to have to change our culture.

"Automating a mining operation makes the entire process leaner, delivering more product with less cost, less waste, and less effort. The biggest gains are usually in underground mines, where processes are still largely stepwise in nature. By smoothing them into automated, sequence-organised tasks, most mining companies could improve efficiency anywhere from 10 to 40%.

"Outfitting a mining operation for automation is a detailed, orchestrated process. It starts with a complete assessment. We talk to people, asking them what works well, when, and how. Processes are observed, data logs reviewed and a road map developed. Communications and IT are evaluated.

"Things start getting really interesting when we retrieve information from sensors and apply data management analytics, using software and flowing in work practices that reduce process variation and increase speed.

"Having technology that can gather data underground and analyse it is a big improvement. In a fully sensor-equipped environment - all the variables that impact production are marked and managed accurately in real time. Then, the information is pulled into an integrated data highway that runs outside the mine itself. No paper, no transfers. The software can amass and condense large amounts of records and details, seeing patterns and pointing out opportunities.

"In mining, the devil is in the scheduling details. So that's the first place to begin an automation project. It's not uncommon to see different areas of a mine sharing the same equipment. Some even share people, causing processes to slow down or stop altogether as tasks hurry-up-and-wait for the right skills and tools to become available.

"Automation eliminates these kinds of bottlenecks, updating information and work status every 15 minutes. No more waiting for shift changes. Shorter, tighter handover; greater efficiency and safety.

"As automation begins to impact work schedules, predictions become more sophisticated and accurate. Digital paradigms begin to model the future, taking corrective action to maintain steady states and adjust controls as operations or their results vary. Feedback. Feedforward. Adjust. All in real time.

"Every mining operation that tries it—every company that's willing to let us show them what automation can do for them—is astounded by the results. The only question they have is why did I wait so long?"

"Hatch is working in collaboration with partners and clients to automate installations around the world. We're so confident in the business-morphing results that these upgrades can deliver that we offer clients performance-based contracts to minimise the risks of implementing the system. We see lots of stakeholders with different systems-integration strategies and project-execution processes. We're helping them all to scale down their capital cost estimates, because automation is being baked right into their existing processes, putting the focus on the operational budget instead.

"In mining, the future is automation, and it's rushing to meet us. Get ready to change your culture. You'll never want to look back."

Apps and more

Underground supervisors require considerable time usually at the beginning of his or her shift to locate personnel and equipment, and determine the status of everybody's daily work plans. Barrick notes that "because of this dearth of information, the supervisor is unable to respond quickly to unexpected developments on shift, such as an equipment breakdown." Meanwhile, a miner scheduled to work in multiple work areas, arrives at one of them and realises he or she has wasted the time getting there because that area isn't set up to complete the work. Not an uncommon occurrence.

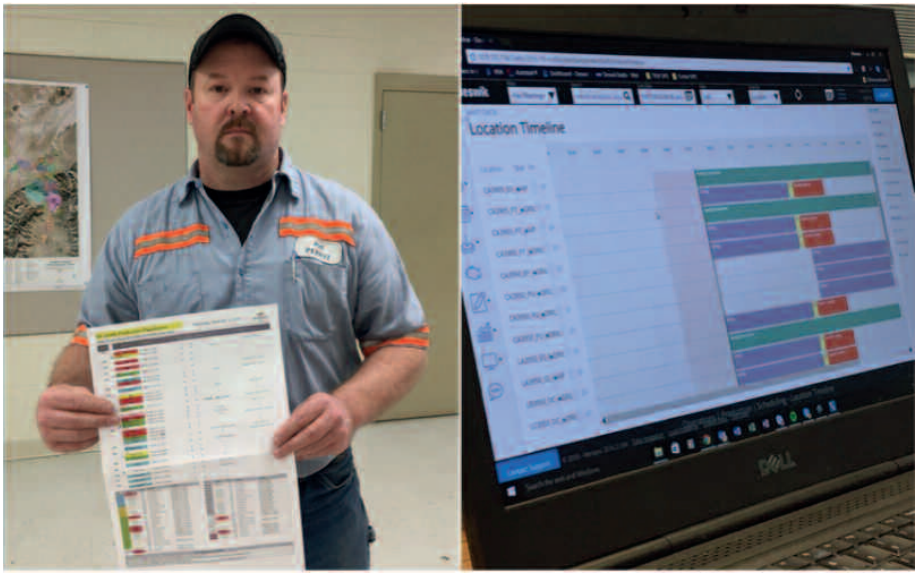
Barrick's Digital Transformation team has been working on a solution that combines several existing technologies, but uses them in a novel way. In particular, apps that provide real-time tracking of personnel and equipment, workflows, and the condition of equipment have all been rolled into one system. The team developed this system for underground mine operations at the CodeMine in Elko, Nevada—the company's digital transformation hub.

"We've spoken with our frontline people, and we know that we can not only alleviate their frustrations through digital solutions, but also improve their performance—which is really what digital is all about," says Ed Humphries, Barrick's Head of Digital Transformation. "The best part is our absolute focus on user-centred design. Our people are building our solutions and testing them at a speed that none of the traditional mining vendors can compete with."

The Underground Short Interval Control (USIC) project team, up until this point led by Barrick Project Owner Rob Neitzel, has been working with software development experts to test the new system, which is comprised of an app and an interface that can be accessed with a web browser, or as a computer program on a desktop. The project is now being led by Gordon Fellows, who led the development and implementation of a similar digital system at Dundee Precious Metals' Chelopech mine in Bulgaria.

Neitzel has since been tasked with heading another project after his efforts in developing the system this far. While not a final version, the app features a layout that changes depending on the piece of equipment that a mine operator is using. It enables mine operators to input data from tablets installed on equipment, such as when a task is started, what was accomplished as part of the task, and when the task was completed. Location data for personnel and equipment is available in real-time, meaning miners no longer have to spend precious time trying to pinpoint the whereabouts of their colleagues and equipment.

"While the design of this app today is nowhere near where we know it can be, this is a first step, and allows us to establish dialogue with our frontline operators whose lives we're trying to simplify," Neitzel says.



One of the components of the USIC system features a supervisor interface that turns several pieces of planning papers into one easy-to-use program

For example, the app enables a bolter, who is tasked with securing and stabilising new mine headings, to see tasks assigned to him for the shift. They can, for instance, see the status of the heading for their next task, and confirm it is ready for them to begin work. If an unscheduled change occurs, they receive alerts; and if they are assigned to another task, the app's interface changes to reflect this, as does their supervisor's interface.

The app also helps miners locate the equipment they require before their shift begins. If certain tasks were not completed, such as a heading not being fully cleaned, operators can flag this through comments for shift supervisors and colleagues to see. This increases accountability and transparency amongst operators, which drives continuous improvements.

"This looks like it can help us avoid having truck bottlenecks underground," says Clay Cutler, an underground miner at Barrick's Cortez operations in Nevada, where the technology is being tested. "We have a quota to make every day, and it gets frustrating when we don't."

The other component of the USIC system is an interface that supervisors can access on a tablet or on a desktop, allowing them to see the work completed in the previous shift. It also includes notes by the previous shift supervisor that let the incoming supervisor know if there was an equipment malfunction, or which pieces of equipment will require maintenance soon. This will help supervisors reallocate resources more efficiently, and quickly adjust plans for their shift.

The interface also indicates where blasts are scheduled, allowing supervisors to quickly assign personnel and equipment to active work areas. They can also see comments in real-time from mine operators that are logged during the shift, and see what the plan is for the following shift. This information helps supervisors create notes on the app for the next shift supervisor.

"Having access to this wealth of real-time data helps supervisors avoid sending personnel and equipment to headings that are not ready to be worked. It is also crucial in helping mine operators adapt rapidly to any unplanned events that occur during a shift," Neitzel says.

"Basically, what this does for supervisors is it takes three or four pieces of paper, and puts it in front of you allowing you to better set personnel and equipment," says Joe Pepiot, Shift Supervisor at the Cortez underground operations. "It'll really make my life simple."

The technology is being trialled at Cortez as part of a small pilot project. Temporary tablet mounts have been customised for five types of equipment. The tablets and mounts have only been installed in order to get feedback from the operators on the apps and their ease of use. Wi-Fi tags have been installed on 24 pieces of equipment, and over 40 tags have been provided to the four crews, in total, so that locations can be provided in real-time.

The pilot, which is nearly complete, will come in under budget, and, given the substantial efficiency improvements rendered by the app, the company has decided to proceed with an implementation that encompasses the entire Cortez underground mine. The implementation will begin in April, and run through June. This will allow the project team to collect data from multiple pieces of underground equipment, including LHDs, drill jumbos, and the trucks and bolters that operate underground.

3D-P, a global leader in providing wireless connectivity and IOT solutions for mining notes:

"Wireless communication in mines presents unique and significant challenges, and underground mines are particularly demanding. Traditional underground communications solutions offer limited speed and bandwidth and tend to be costly." It has just announced the availability of high performance, cost effective wireless networks for underground mines.

3D-P's underground wireless solution leverages readily available ruggedised network components that are well proven in the mining environment. The solution can provide continuous network access throughout the mine and provides full 802.11n network speeds at cost effective pricing. The 3D-P solution does not require continuous cables routed through the mine as do traditional leaky feeder systems and the radios only require access to power to operate. Being wireless, the solution offers much greater flexibility for being easily reconfigured as the mine expands.

"Constantly increasing levels of automation in our mines, and the requirement for real time tracking of the location of the mine's assets and people have increased the criticality of an underground mines' network. We believe that the 3D-P wireless network solution will extend the high level of performance and reliability that 3D-P networks have provided to surface mines to underground mines as well" says Ron White, 3D-P's Chief Technology Officer. "We believe that the greater flexibility, performance and cost effectiveness of our wireless solution will provide great value to our underground clients".

3D-P wireless connectivity makes the Internet of Things (IoT) a reality for mining. Through a complete range of wireless connectivity solutions, 3D-P ensures high performance of wireless networks and real-time access to critical production and asset health data, while 3D-P's Intelligent Endpoint (IEP) product line provides powerful edge computing, for optimal management of operations.

An underground mine in Brazil presented significant challenges to the successful deployment of a wireless network. Establishing a network was particularly important to the active stopes, where connectivity and throughput demands are high, and no wired infrastructure existed. A lack of infrastructure throughout the mine levels, very little power supply, and a lack of Ethernet on all levels further limited wireless connectivity.

The solution was a **Rajant** Kinetic Mesh™ Private Wireless Network. 3D-P was the Test & Kinetic Mesh Solutions Partner (KMSP).

Levels are connected by a tight spiral ramp that limits the distance wireless communications can travel. 3D-P's White tested five solutions, with mesh technology from Rajant and three other vendors. In order to test the impact of the spiral design, White created two test environments. He conducted the first onsite at the mine. In this test, he set up an infrastructure radio at one end and tested it against different radios and antennas, monitoring signal strength and throughput, and then continued around the spiral to measure how far he could get without the signal faltering. In this test, as expected, the signal dropped quickly when line of site was lost.

***Boart Longyear's** MDR700 brings much greater mobility to underground core drilling. It's a time-saver when moving from hole to hole using a diesel powered four-wheel drive carrier. During field trials, the average time to move the MDR700 rig from hole to hole proved to be up to 80% faster than a regular underground exploration rig. The carrier features three available steering modes – four-wheel, two-wheel, and crab-like movement. This unique design feature makes manoeuvring the rig underground easier and faster. The rig is easy to navigate and can move at up to 10 km/h. For improved visibility and safety, multiple cameras are located on the rig and viewed/monitored from the cabin of the carrier*

White used a non-working mine of the same design in the USA for the second test. Using a radiating cable, a Rajant 2.4 GHz radio and two 5 GHz antennas on the spiral, he was able to maintain connectivity all around the spiral, up to a distance of 500 m. White did not lose bandwidth with the Rajant dual radio because the InstaMesh® protocol allows the traffic to traverse a multihop network by switching radios at each hop, preventing throughput loss. Multiple Ethernet systems provided additional, and necessary, redundancy. Based on these results, White recommended Rajant's technology.

Specifically, he devised a highly effective plan that involved placing multiple Rajant nodes at each level, connecting them to the Ethernet switch, and meshing them with the rest of the infrastructure on that level. At each spiralling ramp, radiating cable connects the mesh networks on each level, ensuring redundancy as the core network can now be accessed on either level, preventing a single point of failure. A second level of redundancy was achieved by placing the individual radios at distances throughout the mine so that should a failure of a single node occur, a connection to the next radio in the tunnel could be established, although at reduced data rates.

In order to address the stope issue, White advised workers to place nodes on the vehicles, a mobile application for which Rajant's technology is perfectly suited. A battery-powered BreadCrumb® was also recommended, that could be placed in strategic locations to provide connectivity to the core network. As the operators work in the stope area, these mobile nodes would maintain communications with the rest of the network.

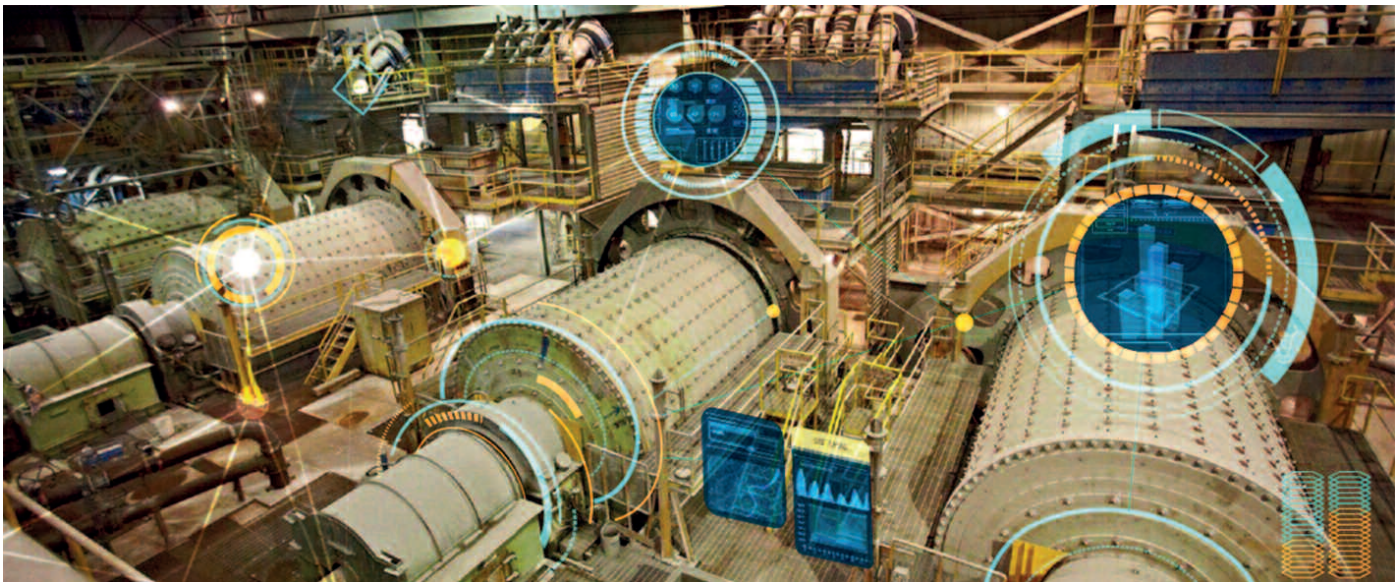
"I prefer Rajant's technology in this case. It enables communications to travel a minimum of 10 hops and maintain a robust network with the necessary high throughput these mining applications demand," White said.

Another location based-decision support system that provides real-time positioning of vehicles, equipment and personnel in underground mines to maximise safety and productivity is **ABB's** Mine Location Intelligence™. It opens a new dimension to personal safety, reducing time for evacuation by showing the closest mining rescue chamber and the best emergency escape routes. It can also prevent people from accessing dangerous areas by providing automated surveillance.

Another dimension is related to production efficiency by using real-time location information for production control and mine automation. It can increase collaboration between personnel by integrating voice, message and CCTV services, available directly from the 3D view for better production efficiency.

GE's digital mine

GE notes that according to the Industrial Internet *Insights Report for 2015* (©2014 General Electric, © 2014 Accenture) 97% of miners put Big Data as a top 5 priority. Terabytes of data are being



Scott Phillips, CEO GE Mining, says Digital Mine "is a total mine solution above and below ground from rock to dock."

collected today, but data alone does not increase efficiency, process optimisation and deliver low cost production. Operational productivity requires domain data, algorithms and real-time analysis, physical, analytical and digital engineering models, industrial analytics and the ability to modify machines to achieve different outcomes.

What if you could predict when your equipment needed maintenance? What if every plant performed like your best plant? That is the Digital Mine, powered by Predix™. Predix, says GE, "is the first and only cloud-based operating system uniquely built for operating conditions," and scaled for industrial data and applications. Used with GE and non-GE built applications, Predix "provides real-time situational awareness to monitor, and continually improve, equipment and process performance."

"Digital Mine can optimise ore recovery, process throughput and increase energy efficiency," states Scott Phillips, CEO GE Mining. "It is a total mine solution above and below ground from rock to dock."

How does it work? "GE creates a software model of a physical asset or process called the Digital Twin, housed on the Predix Cloud," explains Doug Hanson, Digital Mine General Manager. "Real-time equipment data is compared to the Digital Twin's predicted behaviour, uncovering potential issues and preventing potential failures." Operators receive a real-time stream of developing problems along with diagnoses and prioritisations on their mobile devices. That's real insight to help optimise availability, increase reliability and automate entire processes.

Solutions developed so far bring estimated performance gains of 20% across all GE industries, which in turn could translate into approximately $8.6 trillion in value on an annual basis. Applying learnings from other industries allows Digital Mine to drive more efficient results.

Today, Digital Mine solutions help miners to promote safer mining practices, while increasing asset performance and optimising operations. How much could be saved with connected machines? A 1% improvement in operational costs across the entire mine value chain adds up to nearly $5.4 billion in savings, just amongst the top 40 miners (*Mine 2015, The Gloves are Off* © 2014 Accenture).

"What if you could increase asset reliability and availability while reducing cost and risk in operations?" GE asks. Asset Performance Management provides a unified, accurate view of assets within a plant. GE's advanced modelling, protected by over 40 patents, puts into context the normal operating relationships among all relevant parameters, such as vibration load, temperatures, pressures, and ambient conditions. Technicians receive real-time, data-based early incident alerts that highlight anomalies with maintenance recommendations. Average asset utilisation improvements can provide 3-10% savings. Overall, users have experienced 15% increase in fleet availability as well as reduced maintenance costs and unplanned downtime.

GE further asks, "What if you could increase revenue and margin by optimising the performance and throughput of your plants, sites, and portfolio?" Operations Optimization Management sensors, software and analytics help provide clarity to issues, identify potential solutions, analyse outcomes, monitor progress and measure results.

Every operation suffers from bottlenecks. For Lonmin, downtime in the drying area of the platinum smelter sometimes stopped the whole production line. Operations manager Percy French explained that this cost roughly R1.71 million/hr. Improvements made as a result of Digital Mine helped Lonmin achieve a 10% increase in smelter throughput and 1.5% more platinum from the mine.

To promote safer mining practices within operations, GE Mining's Collision Alert Systems (CAS), have been available for more than 12 years and have more than 270 million hours of operation. This proven solution is in use at 35 mine sites across more than 5,000 vehicle installs.

The underground CAS system uses a VLF magnetic system, enabling detection around corners and through strata to alert on potential collisions between people and heavy equipment.

Operation centres

As the industry strives to improve efficiency, reduce costs and increase safety, major mining companies like Rio Tinto and BHP Billiton are establishing operations centres for automation and analytical support of automated mining. So too are major suppliers, like **Joy Global**, helping bring mining performance to the next level.

Through JoySmart Solutions, Joy Global helps solve its customer's toughest challenges using data-driven intelligence, collaboration through partnership, and experienced-based service execution. It is a solutions-based offering designed to help reduce costs and increase productivity for customers, while helping them achieve or exceed their operating and financial goals. The program integrates:

- Data and analytics as well as operator training
- Direct engagement with the customer, focused on helping the customer achieve value through direct service
- Engagement with the equipment designers; the customer is just one call away from the person who designed the machine.

Smart, connected products deliver data to Joy experts, who partner with customers through the direct service network. The analytics produced

Among the services offered by Joy Global's facility in Australia's Hunter Valley are JoySmart solutions, prognostics and health monitoring, and life cycle management

allow Joy personnel to "provide direction, anticipating service needs and optimising machine productivity to drive results and move the needle in mine performance. In fact, some coal producers have increased equipment utilisation from below 50% to as high as 70%."

For example, Joy Global's smart, connected longwall systems include complex networks linked to highly sensitive gyroscopes, and thousands of sensors that are constantly monitoring the performance and health of the system.

During operation, as the longwall system moves forward, the roof is collapsing behind it. Sensors placed in the roof supports transmit data to the surface. Complex algorithms translate the data points into visual information that can predict significant changes in operating conditions in the mine.

"In a recent case study, the roof support data analysed by Joy Global's algorithms, detected a roof cavity forming. Through advanced analytics, we were able to predict roof instability, impossible to see with the naked eye, and define the root cause for those changes. This allowed for immediate actions that impacted the overall mine productivity," explains Mike Rikkola, Program Manager – Remote Health Monitoring.

Sandvik Mining and Rock Technology has just announced an agreement with IBM to jointly develop market leading offerings in Data Driven Productivity and Predictive Maintenance services. Under the agreement, Sandvik and IBM will develop advanced analytics solutions to improve safety, maintenance, productivity and operational services of mining and rock excavation equipment.

The growth in onboard instrumentation and data gathering capabilities in heavy equipment are presenting natural resource industries with opportunities to employ advanced analytics and models to identify and resolve productivity issues and improve process optimisation and performance. Deployment of digital technologies is expected to create as much as $100 billion value to resource producing companies by 2035 (*Source: McKinsey Global Institute Report: How technology is reshaping supply and demand for natural resources*).

As two global leaders – Sandvik and IBM will be working together to make a clear difference in productivity improvements globally. A Memorandum of Understanding has been signed with the intent to create market leading offerings in data driven productivity and predictive maintenance solutions. The two companies are already working jointly with selected customers to pilot the concept and commercialise specific solutions. The first wave of work will be done on loaders and trucks, connecting up to 15 units and integrating live data from multiple on- and off board systems to run the analytic algorithms.

The IBM-Sandvik collaboration will involve the use of advanced analytics, remote monitoring and cognitive technologies to allow natural resource companies to combine equipment and application data from disparate resources and

automatically analyse patterns in the data to improve performance and productivity.

This combination of information services, remote data collection and data analysis will enable increased effectiveness by increasing productivity, saving cost and reducing time wastage. It helps mining and rock excavation companies make well-informed decisions regarding production plans and maintenance schedules and provides the opportunity to monitor and improve upon the general utilisation levels of their equipment. This will lead to higher yield at lower cost of ore per tonne. Sandvik has already seen cost per tonne decreases of 20-50% with some of the latest digital technologies and with this new analytical capability aims to push that even further.

"Sandvik has been working with mining customers on mine automation and remote monitoring of machines for more than 20 years. Our OptiMine® and AutoMine® solutions are also important systems for data collection and consolidation that provide us with a great platform to get a flying start with IBM analytics solutions. So it is a natural step for us to collaborate with a company like IBM – experts in advanced analytics cognitive computing and modelling – to create even more value for our customers," said Lars Engström, President, Sandvik Mining and Rock Technology. "This collaboration fits well with our service portfolio, which is based on traditional life-cycle, enhanced technical, and business services, all of which are aligned to improve safety, secure competences for mine operations and increase our customers' productivity."

"We look forward to taking our expertise in internet of things, advanced analytics and asset management and combining that with Sandvik's years of experience in developing mining processes and machine technology to build a collaboration around innovation and delivery of smarter digital services offerings for natural resource companies around the globe," said Anders Fredholm, VP Industrial Products Industry, IBM Europe.

The **Becker** MineView System is a modern software suite for process visualisation, continuous monitoring, communication and self-diagnostics. It provides the features you would expect from a state of the art SCADA system, i.e. a client-server structure, process data logging, data archiving, flowcharts, scripting and a user/group based access system. On top of these basic features, the MineView adds an easy-to-use fully integrated 3D visualisation component which allows the implementation of geolocation based features. All Becker products are fully integrated in MineView.

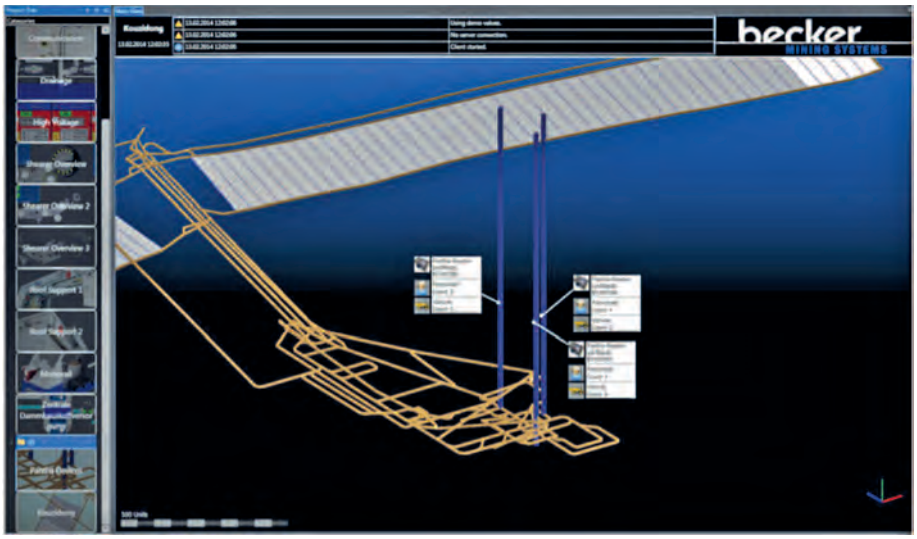
The MineView System can be used in a large variety of different fields. To name a few possible applications:

- General purpose monitoring of:
  - Mine face
  - Belt conveyor
  - Mine ventilation
  - Energy supply
  - Handling systems (conveyors)
  - Communication systems
  - Mine hoists
- Geolocation based applications (using the 3D visualisation):
  - Tunnelling
  - Tracking and tracing of vehicles, material and persons (collision avoidance, access breaches etc.)
  - Transport/escape route planning

Other potential uses might be visualisation and/or administration of access points and other IT components; and waste water management and freshwater supply.

The system is structured into three primary components: MineView Server, MineView Client and MineView Editor. The communication of these components is based on a client-server model. This means that the MineView Server is the central data point of the MineView System and all other components interact with it.

MineView Client is a highly customisable desktop application. Its key parts are the 3D mine visualisation, chart visualisation and log message view. The application can be used in different modes: a normal single window, multi



Becker MineView 3D visualisation of mine model

window, multi monitor, full screen or a combination of these modes. The MineView Client App (available for Android and iOS) provides access from mobile devices as well.

The MineView Editor desktop application is used for configuring MineView projects. It provides all the necessary tools to create new projects and maintain them. The tools include most notably the different editors for creating charts, server side scripts and 3D mine models. In addition, the MineView Editor features a simulator to test charts.

The MineView Server is the most important component of the system. Its main duty is to collect, store and archive all of the desired process data and provide interfaces which allow access to the stored information. Additionally, user written scripts will automatically be executed on the MineView Server. The execution can be controlled by a multitude of different triggers. For example, a script could be used to generate warnings if process values exceed certain limits or daily reports of important process data.

To be able to have maximum availability, the server component was designed as a redundant self-organising system. The MineView Server can be physically divided onto multiple computers. Through this, all the data can be stored redundant, so that a single point of failure – for instance a malfunctioning server computer - can't interrupt the whole service which could lead to a data loss. By self-organising these redundant features, it's also possible, with minimal configuration needs, to add additional server computers into the system without the need for a lengthy maintenance shutdown of the whole system. Another self-organising feature is the load balancing. Through this, the MineView System can automatically distribute all necessary tasks to the different server computer based on their current system load. This leads to an optimal performance of the overall system.

To improve the productivity and safety of a mine, wireless detection and position tracking of moving objects has become a very important factor. Due to the rapid evolution of technology, tracking and tracing offers a wide range of gainful applications: Position monitoring of mobile machinery, observation of material transport, localisation of personnel or area access control, to name only a few. This is made possible by simply equipping the personnel and machinery with special transponders and the on-site installation of appropriate tag readers, alternatively or in addition to any existing wireless networks.

MineView also integrates a centralised asset tracking system and provides TCP/IP communication to the Becker Wireless Router Access Points (WRAP) as well as Becker UHF tags and Wi-Fi clients to cover personnel, vehicles and assets. Important modules are the blast/shaft clearance as well as the generation of tip production reports. MineView's capability of combining position-dependent data with the 3D model of a mine, allows for an intuitive presentation and exploration of tracking data. The MineView system provides a full integration of tagging and tracking functions and data access via 3D visualisation:

- Management of various (security) zones and assignment of access permissions for the different zones (group-based or individually for single mobile units or individuals)
- Storage and representation of the time when entering or leaving an area
- Alerts for breaches of access authorisations
- Knowledge of the last known location of missing persons in an emergency (for example in case of fire and/or explosion)

MineView has its own symbol library that contains templates for all relevant Becker hardware, including but not limited to, predefined flowsheets for WRAPs and UATR tag readers, as well as a semi-automatic process data configuration to simplify the handling of the system.

Underground access

Cementation Canada, using a combination of existing and proven crushing, pumping and slurry technologies, has developed a proof of concept model for process injection hoisting that would eliminate the need for mine shaft production hoisting or trucking, transporting ore to the surface using a pump driven pipeline loop. The technology is adaptable to all mining methods and would substantially reduce energy consumption and ventilation requirements.

The team at Cementation builds mines from design through to construction and this invention has the potential to revolutionise underground mine development to the benefit of the entire industry. This technique was one of five finalists in the #DisruptMining competition sponsored by Goldcorp and Integra Gold Corp during the PDAC.

Cementation was the big winner of the evening as a co-winner of the C$1 million dollar grand prize and also the winner of the People's Choice Award as the audience favourite. Winnings for Cementation totalled C$650,000.

Roy Slack, President of Cementation Canada said: "It was a great event showcasing just how innovative the mining industry can be and all of us at Cementation are thrilled to have been involved and to have Injection Hoisting so well received."

During the presentation Cementation asked for a mine to install and develop a full scale prototype. By the end of the evening at least three mining companies expressed interest in working with Cementation to help develop the Injection Hoisting technology.

Last May, subsidiary Cementation USA completed sinking the deepest shaft in the USA at the Lucky Friday mine in Mullan, Idaho. With a finished diameter of 5.5 m, the Lucky Friday #4 Shaft was sunk to a final depth of 2,922 m below surface.

The Cementation group, which is currently sinking 15 shafts worldwide, has sunk the deepest single lift shaft in the world at South Deep mine in South Africa, the deepest shaft in Canada at Kidd Mine D No.4 Shaft, the deepest single lift shaft in the USA at the Resolution copper project, and now the deepest shaft in the United States.

Hecla selected Cementation USA to sink the shaft, excavate accesses, stations and pockets, and install the related infrastructure, which include a state-of-the-art fully automated ~200 t/h material handling system, a 500 gallon/min water pumping system, a centralised refrigeration system with 977 t of cooling capacity, a batch plant, and other systems.

The Lucky Friday #4 Shaft is a vertical shaft that begins underground, which makes it a winze, to use the correct mining terminology. A winze is an internal shaft which requires the equivalent of a shaft headframe and hoisting system to be installed underground before the excavation activities can occur

Herrenknecht's Haulage Boring Machine is a compact, mobile boring machine which achieves small diameters for access or production. Its compact layout is designed to enter the market and give an alternative to conventional methods which were the only option when TBMs cannot achieve the small diameter requirements.

Herrenknecht has also improved roller cutters for shaft excavation. Multi-row tungsten carbide insert (TCI) roller cutters are common on a variety of mechanical underground excavation machines. Herrenknecht has recently implemented several improvements in the design of multi-row TCI cutters to increase load capacity, reduce body washout and improve high pressure sealing applications.

Horizontal raise boring technology is expected to double mining productivity in kimberlite. **Master Drilling's** Horizontal Raise Boring (HRB) technology is ready for international roll-out after the successful pilot test at the Cullinan diamond mine in South Africa. HRB can replace conventional drill-and-blast mining and increase mining productivity thanks to its continuous process of rock boring. In addition it offers significant safety benefits. The company says "projects with less safe access, such as deeper mining operations and higher stress zones, are more likely to pass feasibility tests thanks to the safety improvements that HRB brings."

"HRB is a locally developed, world-first technology that promises to change the very fundamentals of the global mining industry," said Danie Pretorius, CEO of Master Drilling. "The feedback from our multinational business partners from Southern Africa and Latin America on visits to the actual technology has been highly encouraging."

HRB will provide the mining industry with an excavation and construction tunnelling tool for the mechanical excavation of a tunnel between two existing access points, very similar to the standard form of raise boring. The steady progress of the reamer is able to excavate an average 6 m/d, compared to 2 m in conventional drill-and-blast cycles, Master Drilling reports.

The technology offers the much-needed mechanisation to reduce the number of workers which are exposed to dangerous underground conditions. The benefits extend across the project-chain and include amongst others:

- No need to use explosives
- No blast effected damage inflicted to the tunnel sidewalls
- The structure of the tunnel is stronger due to the circular profile of the tunnel
- Reduced rock support costs
- Improved tunnel construction accuracy
- Lower excavation costs
- Continuous operations not effected by blast re-entry
- Greater remote operated possibilities
- In certain locations it is impossible to assemble a tunnel boring machine (TBM) due to its length and size. In these locations the plant for raise boring is smaller and easier to transport.

The pilot project at the Cullinan mine of Petra Diamonds involved boring and excavating a 180 m horizontal tunnel with 4.5 m diameter through the kimberlite ore. The method entails first drilling a smaller pilot hole through the

The latest version of the Master Drilling HRB was officially unveiled at the Investing in Africa Mining Indaba 2017, held in Cape Town; model shown here

kimberlite, which was challenging as no water can be used for flushing. The pilot hole also needed to be near perfectly straight. For these reasons Master Drilling pioneered using vacuum air suction and laser assisted directional steering in collaboration with **Vermeer**, which is typically used in civil construction.

"Tunnel Cutting Technology seems to be the next logical step in underground mine development," said Ben Swarts, Group Manager, Mining Projects of Petra Diamonds. "This technology brings with it additional benefits such as improved excavation integrity and safety, better advance rates and possible downstream financial benefits. The HRB is one of the very few options currently in operation. We are optimistic about the technology and are in progress to finalise a commercial agreement to continue the use of the HRB within Petra Diamonds."

Drilling advances

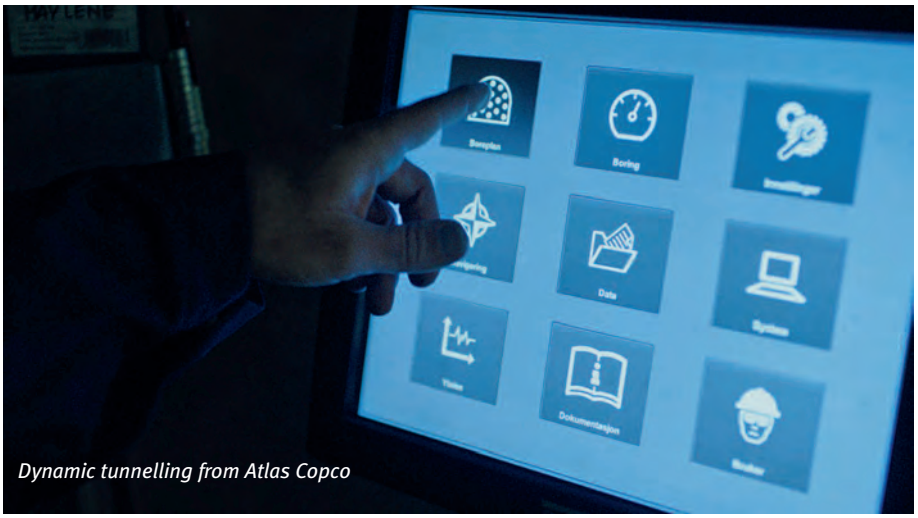
At the SME Annual Meeting, A. Chapman of **Peck Tech Consulting** presented *A Paradigm Shift: Developing, Refining and Delivering a Mobile Localization and 3D Scanning Technology for the Underground Mining Industry* noted that: "while the surface mining industry was greatly advanced with the introduction of global positioning systems (GPS) in the 1990s, no comparable technology yet exists underground. Similarly, 3D scanning underground is an emerging field but so far has been constrained to conventional, stationary surveying set-ups."

This presentation covered the authors' work in developing a mobile underground positioning and mapping technology for the mining industry. "This LIDAR-based approach has succeeded in its original goal of mine site-wide positioning with precision comparable to surface L1 GPS, and as a necessity has evolved an impressive capability for mobile 3D mapping." The process of commercialising this technology from the initial research stage to the finished product is reviewed, including technical challenges, input from industrial partners, and results from real world use cases. Also highlighted are capabilities of the finished product's technology platform, and a few applications of the technology with the potential to revolutionise underground planning and production operations.

The onboard control system of the Sandvik DU412i provides information on drilled holes such as angles, depth and penetration rate. Coupled with IREDES drill plan handling and drill diagnostics, consistent daily drill reports will improve and speed up the information that is available to engineering and operations departments. The radio remote functionalities also allow multiple units to be run from an operator command centre, from which one operator is able to run several units at the same time

Sandvik's new DU412i is the first in its next generation of in-the-hole (ITH) underground production drill rigs. Automation-ready, it is built on a modular standardised platform, delivering a truly flexible automated ITH longhole production and service hole drill.

Sandvik DU412i incorporates a completely new design, built on the proven Sandvik 400 range of



Dynamic tunnelling from Atlas Copco

centre articulated, carrier-mounted ITH drill rigs. The Sandvik 400 range is ideal for highly accurate production drilling, as well as drilling service holes and slot raises. It drills with ITH hammers that are powered by on-board high-pressure screw boosters. These can be used to drill holes with a diameter of 89 to 216 mm. The compressor control system controls the flow of air to remain constant, not just unloading when the pressure reaches maximum, which increases safety interlocks and full-time monitoring and data collection.

The updated drill module has fully modular feed, carousel and centralizers, facilitating maintenance and reducing service costs. At the same time it also has a rebuildable/reconfigurable system that allows for application changes at a later date and gives the customer the ability to change drill application by bolting on the new components that are needed.

Radio remote tramming gives the operator the possibility to tram and setup the unit without being in the operator area, increasing safety and allowing extremely precise setup, with excellent visibility of the work area. The tramming can be done on either diesel power or using the electric power pack. The power pack is a multi-voltage compliant system that gives customers freedom to move the drill from one country to another. The drill operates easily in different networks ranging from 380 V-1,000 V and both 50 and 60 Hz.

Atlas Copco's Dynamic Tunnelling package is new automation software for face drilling rigs, which offers improved accuracy of the advance thanks to the fact that drill plans will always be precise for the current section of a drift. With this software the drill rig can create its own drill plans directly at the face of the tunnel. Simply by downloading the contours of the mine drifts to the drill rig together with a drill rule file, the drill rig can create drill plans tailored for the section it is navigating within. This obviously means improved production at a lower cost

Customer Veidekke and its RV80 project in Bodø, Norway was one of the pilot projects for Dynamic Tunnelling. "Veidekke is working on the State highway 80 project in Bodø. There's a tunnel that's two times 2.5 km where we are going to excavate about 500 000 m³ of rock ", explained Jon-André Nilsen, Manager Surveying Technic Underground, Veidekke. Nilsen continued "The collaboration with Atlas Copco to develop the Dynamic Tunnelling package went well. Atlas Copco was responsive to our feedback and made adjustments to the program. Today, the drill rig operators make niches manually. They can turn out way too big or way too small. Dynamic tunnelling makes our drilling more precise. We can make changes to drill plans directly on the rig. We can move cuts or drill-holes. We are more flexible at the tunnel face compared to making all

changes at the office. We use the package to make niches (areas of the tunnel with larger cross section). This makes the work more precise ", he concluded.

"The Dynamic Tunnelling package is very easy to use. It is two keystrokes and you are started. The contour turns out very accurate. The end result is identical to the drawing. Dynamic Tunnelling has made my work a lot easier, says Kent Simensen, drill rig operator, Veidekke.

Today all tunnelling models exist in a 3D model. Previously you imported the model into Underground Manager (Atlas Copco software used for planning and reporting of drill rig data and information) and then made all the drill plans manually in Underground Manager. With Dynamic Tunnelling you still import the 3D model but you only need to set up a set of rules (a rules file) in Underground Manager. The set of rules and the 3D model is then transferred to the drill rig by USB or WiFi-connection. The drill rig will then make its own drill plans. The drill plans will always be precise for the section and size that should be excavated.

And loading and hauling

The first Sandvik AutoMine loading installations were delivered more than 10 years ago and the automation system continues its success story. At MINExpo last year Riku Pulli, VP Automation, Sandvik Mining and Rock Technology said: "This year seems to be a turning point, with many new SandvikAutoMine Loading Lite systems being ordered. Within this challenging business climate, mines are looking for reliable, easy-to-implement solutions that deliver higher productivity and efficiency in mining. We are proud that SandvikAutoMine has already delivered well on these requirements for many customers and there are more in the pipeline."

SandvikAutoMine Loading Lite is a simple, single-loader automation solution that helps ensure safer operation and high productivity. It is easy to set up, operate and maintain. The solution can also be easily expanded to applications that require more than one loader, operated by a single operator. SandvikAutoMine Loading Lite works in a wide range of mining methods including development, open stoping and sub-level caving.

It was recently updated with a unique new function, Automatic Bucket Loading Assistant that completes the fully automated loading cycle by bringing in technology that enables a loader to fill its bucket without any help from the remote operator in the control room. This new feature makes the full loading cycle much more consistent and allows operators to focus on the overall process supervision instead of a need to continuously load buckets over tele-remote connection.

Atlas Copco focused on automation at MINExpo, showcasing a wide range of solutions aimed at tackling many of today's toughest challenges in the mining industry. The booth had the slogan *The Future of Mining is Now*.

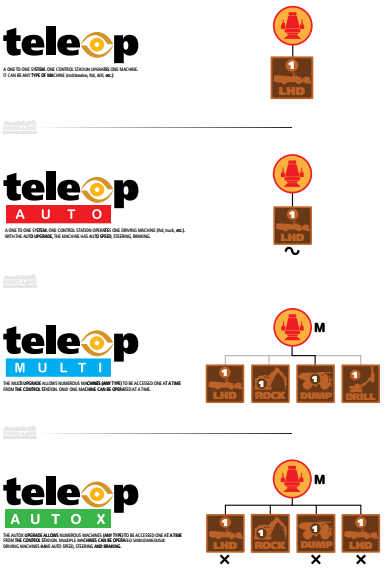
Johan Halling, Senior Executive Vice President of Atlas Copco and President of the Business Area Mining and Rock Excavation Technique said Atlas Copco's mission is not just to develop solutions that increase productivity and cut costs, but solutions that are environmentally sustainable as well. "We believe that this combination is the right formula for long-term success and makes us an ideal partner for future growth and prosperity."

The recently improved Scooptram Automation system with multi machine capabilities gives full control of the underground loading operation. Through the mine data network, up to 35 LHDs located in several production areas can be connected and controlled from one or several control rooms.

Hard-Line offers the Teleop system that can be built up in stages of complexity as users become familiar with it.

Hard-Line's Teleop teleremote control system allows tele-operation of heavy machinery (e.g., rock breakers, drills, excavators, LHDs, wheel loaders, dozers) from a remote control station, allowing the operator to be totally out of the proximity of danger.

The stand-alone WiFi based infrastructure has the ability to easily expand with a mine's progression, and the capability of interconnecting mine-wide for eventual surface control. The system saves time, heightens operator safety,



improves comfort, and allows a greater percentage of the workforce to operate equipment.

As the diagram shows, Teleop is a one to one system. One control station operates one driving machine (LHD, truck, etc.). Then with the Auto upgrade, the machine has automatic control of speed, steering and braking.

The Multi upgrade allows numerous machines (any type) to be accessed from the control station. Only one machine can be operated at a time.

Finally, the AutoX upgrade allows numerous machines (any type) to be accessed from the control station. Multiple machines can be operated simultaneously. Any driving machines have automatic control of speed, steering and braking. Hard-Line has just opened its new US Operations office in Utah.

Caterpillar of course, through its extensive MineStar offering has Command for Underground to improve safety and utilisation with line-of-site remote control loading, remote and guidance operation and semi-autonomous operation. It reports a 44% cycle time improvement and summarises the benefits as:

- Relocate operators to a safe, comfortable location underground or on the surface
- Enable control of multiple machines from a single Remote Operator Station
- Eliminate exposure to noise, dust and other hazards
- Prevent collision damage with tunnel wall
- Optimise shift changes
- Return to work quickly after a blast
- Improve operator comfort, retention
- Monitor operators through video
- Configure zones to regulate speed
- Continue operation through seismic events.

In surface mining, Fleet has resulted in such benefits as:

- Assignment +19% tonnes
- Shift Change +10-25% tonnes
- Fuelling -13% in time
- +9 hours per shift
- Tyre life +1,500 hours.

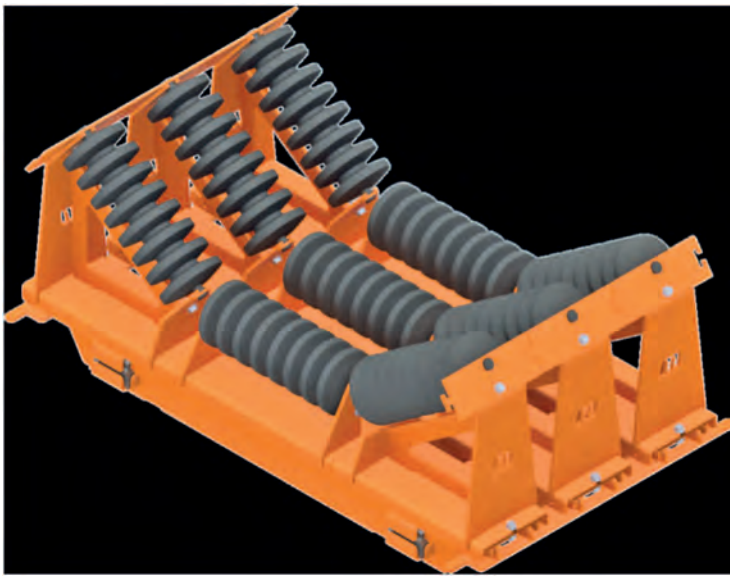
Great things are anticipated from the new MineStar Fleet Underground in equipment scheduling, material movement, fuel use, cycle times and more.

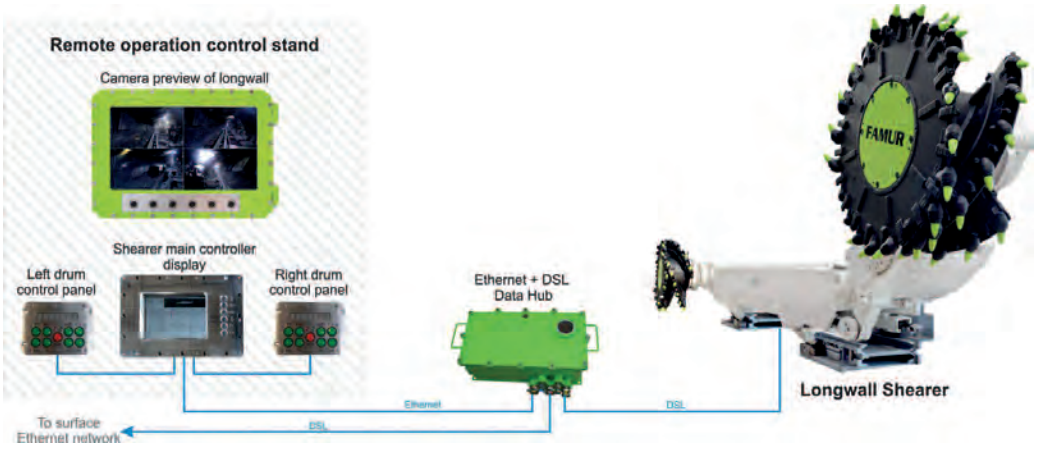
The Cat® Rock Straight System is a fully mechanised longwall system designed for continuous mining of flat and tabular deposits and reefs of hard rock minerals. The system combines the use of a hard rock shearer that uses Cat Activated Undercutting Technology, which is specifically designed for the extraction of bedded hard rock deposits. A low-profile hard rock chain conveyor and hard rock hydraulic roof supports complete the system, which delivers simultaneous cutting, loading and hauling—controlled by the proven Cat longwall automation system

Conveyor haulage

Conveyors underground are a great way to automate haulage but "this movement [can] suffer lots of problems, including carryback, spillage, dust, and belt wander. Many of these issues are created at the transfer points where the belts are loaded." Richard Shields, **Martin Engineering**, examined this in a presentation to this year's SME Annual Conference, *Improving Conveyor Transfer Point Performance In Hard Rock Mines*.

A copper mine application has demonstrated the advantages, and durability of Martin Engineering's high-speed roller impact cradles. One application was on copper ore, crushed to -19 mm; the daily load or throughput was 100,000 t that moved through the chute and landed onto the belt.





"The problem arose," Shields explains, "in the long material drop to the conveyor loading zone. There was a 3.67 m fall from a 1,829 mm belt onto the 1,524 mm receiving belt. This proved a challenging application for the belt support systems. The long drop led to damaging levels of impact below the loading zone of the receiving conveyor. The mine had regularly seen failures with conventional impact idlers; it would typically need to change four or five damaged rollers, and one or two broken idler frames in an 'average' month of operation.

"These challenging conditions made it seem that the high speed roller impact cradle would be the right equipment for this application.

"After installing a series of high-speed impact cradles, the mine put 2.9 Mt of copper ore through the transfer point during a two-week period. There were zero idler failures. While this can be seen as a brief trial, the severity of the application holds the promise of improved performance for those installations where high conveyor belt speeds limit the opportunities for improved belt support systems.

"In another application, the high speed impact cradles performed well in a coal mine application in South Africa, demonstrating reduced impact damage and material spillage."

Digital age coal mining

Karol Bartodziej, Operational Director of **FAMUR**, notes the "the efforts to connect all the machinery involved in the production process into one coherent network, so as to make it possible to create a centralised system of production supervision and control. The widely promoted development of IIoT technology (Industrial Internet of Things) or the concept of Industry 4.0 make it become clear that, despite the existence of several industrial data transmission standards, the standard to be a leading one in the near future is the transmission of process data over Ethernet."

In underground coal mining such systems have not been very popular so far. "This was mainly due to two factors: the presence of explosive atmospheres near the transmission devices and the presence of large quantities of impurities.The design of network devices that can operate in explosive atmospheres enforces the limitation of energy at their outputs, which significantly impedes the transfer of high speed digital signals over long distances. In turn, the use of the fibre-optic technique for the transmission of data poses challenges related to the need of keeping connectors clean. In the highly impure environment, maintaining the efficiency of fibre-optic lines is a huge challenge and requires great working discipline from operators. Assuming that the underground mining machinery is located several kilometres away from the nearest server room, this issue seems significant. In such operating conditions, the well-known DSL technologies turn out to be helpful – they allow the users to extend Ethernet networks using telephone lines and are ideal for mining conditions provided that their signal is properly adjusted to the intrinsic safety regime. Building vast underground Ethernet networks is the first step towards the implementation of IIoT or Industry 4.0 concepts.

"Another key element in the mining process is the use of machines with control systems that enable transmission over such networks. A perfect example of a machine that is ready for integration in Ethernet network with the entire technological process is the KGE-710FM shearer, supplied to one of the customers of FAMUR. This machine is quite unusual, because mining industry safety regulations usually require that an operator is present in sight of the extracting machines." This restriction results in typical shearers only sending their diagnostic data to SCADA systems, without the possibility of remote control of the machine.

However, the aforementioned KGE-710FM shearer has been supplied to a customer operating in very difficult mining and geological conditions that cause frequent rock bumps and roof collapses. In view of the fact that local rock falls can be life-threatening for the miners who operate the machine, the customer obtained the consent of the mining safety supervision authority for the remote control of the shearer in locations of locally occurring risks to workers. The remote control station is designed in such a way as to ensure that the actions performed by an operator are identical to those performed during his regular work directly on the machine. Therefore, the station is fitted with a monitor displaying the screens that are identical to those the shearer operator sees on the machine in his everyday work and control panels that are the same as those on the shearer, and additionally all other control-related functionalities are mirrored so that the operator would not have to learn a different way of operation. The station is additionally equipped with a set of cameras which permit observation of the machine in operation. The procedure of starting the shearer in remote control mode is based on guidelines on the equipment operational safety, issued by an appropriate state authority.

"It has therefore some specific activating procedures to prevent starting the machine without complete knowledge on whether its operation could endanger the safety of any person," Bartodziej explains. The station can be located at any Ethernet node, so it might as well be installed in the mining galleries near the operating machine or on the surface, or even anywhere in the world thanks to the possibility being connected through the Internet. Thanks to such network architecture, the location of the operator's workstation is solely up to the user."

The KGE-710FM shearer is only one of the examples. Most FAMUR longwall shearers for many years have been fitted with control systems that enable the transmission of data using Ethernet. So there are no technical impediments to equipping these machines with similar functions to those mentioned above. However, Bartodziej notes, "an aspect preventing the development of remote controlled shearers, or even automatic ones, is the fact that many decisions of the longwall shearer operator are based on their subjective opinion and experience. Therefore, very often the decisive factors are the ones that are difficult to measure, such as the way of crushing the mined rock, or the sound of the shearer's cutting drum coming into contact with the mining spoil. As a result, in combination with varying geological conditions, the remote control of the machine or the replacement of an operator with the standalone operation algorithms is a relatively difficult subject."

Electric power

A February article (*IM, pp68-77*) focussed on underground electric power (*see also MacLean's news in the Canadian article*). Since then **Artisan**

Artisan Vehicle Systems' core technology is its proprietary battery packs, electric motors, power electronics, software and control systems. Artisan's underground mining machines are designed from the ground up around its high powered, highly reliable, field proven battery electric powertrains

Vehicle Systems has made further progress, delivering two battery-powered zero emission 1^{5}3 loaders to Hecla's Lucky Friday mine. "I've never operated a machine that's this powerful in the muck pile," said David Konsbruck, Head of Equipment Maintenance at Lucky Friday. "The ergonomics and visibility are much better than our other loaders."

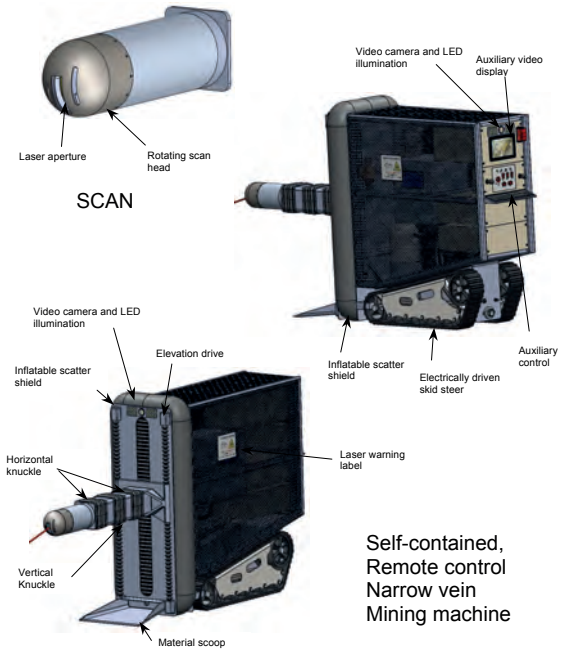
Hecla is addressing ventilation and cooling issues related to the depth of its Lucky Friday operation. Diesel equipment exacerbates the problem with its exhaust and extremely hot powertrain. "Battery equipment lets us continue operations without costly upgrades to our ventilation and cooling infrastructure," said Clayr Alexander, Lucky Friday's Mine Manager. "We are excited about the promise of battery technology to deliver increased performance while reducing emissions and increasing worker safety, and are confident in our choice of Artisan and its new loader."

Artisan has designed the 1^{5}3 around its cutting edge electric powertrain, battery, and advanced operator control system. The 1^{5}3 is smaller in all dimensions than a comparable diesel LHD, "but," says Artisan, "has 300% of the power. It loads quicker, hauls up steep grades faster, and is more precise and responsive to operator commands. Operators prefer our battery powered units over diesel because of their higher productivity, more tonnes moved per shift, zero diesel emissions, extremely low heat, and quiet operation. Moreover, the total cost of ownership is comparable, and in many cases lower, than diesel."

"We are very excited about working with Hecla. Our mission is to increase their production and decrease their costs," said Mike Kasaba, CEO of Artisan. "Of course, battery power saves on ventilation and cooling expenses, but we expect much more from our machines. We are determined to beat diesel equipment on every key performance indicator. Power, productivity, drivability, reliability, and total cost of ownership. Diesel's days are numbered in underground mines and we are doing everything we can to finish it off."

Laser mining

Merger Mines Corp says it "is the global leader in the development and use of lasers for mining. This innovative use of lasers and robotics has the potential to change the way mining is done worldwide. Merger's innovative mining methods will lower mining costs significantly, and reduce miners' exposure to dangerous situations they typically encounter when using explosives and traditional mining equipment."



The Merger Miner

The Merger Miner makes use of a commercial kilowatt power fibre laser in a patented device for mining in narrow veins of precious metals. *See also August 2016 issue of International Mining, pp66-77.*

Merger has world class technical experts overseeing the design and manufacture of its robotic laser vein miner arrays, and Merger says it "has one of the finest mining engineers in the US to assist the Laser Vein Miner design team with his mine design and operational expertise." They will be working closely at any mining location where Merger is testing and fine tuning the laser arrays, and they will be available to assist mining companies that purchase or lease the mining arrays from the company.

Merger's design and manufacture of high tech, state-of-the-art laser vein miner arrays which incorporate the use of robotics and highly sophisticated computer programs are specifically designed to achieve maximum production.

Merger anticipates having its first scan head ready for laboratory testing within the next 12 months. Computer modelling of the narrow (762 mm wide) vein miner is well underway and will see detailed engineering drawings completed within the next 15months, with fabrication, system integration and performance evaluation to follow soon after.

Merger has signed an agreement with Groundhog Mining and Milling of Dillion, Montana to form a working partnership wherein Groundhog will be the prime field operator of the Merger Laser Miner in its mine rock density characterisation function.

After characterisation parameters are set, Groundhog will act as installer and trainer for purchasers and lessors of the Merger Miner at their respective mine sites. Groundhog will continue its operations as a contract mine operator and will install and operate the Merger Miner for those who purchase or contract for its services.

"Signing this agreement with Groundhog Mining marks an important milestone for Merger," stated Merger President Lex Smith. "We have known Del and Nathan Hunt (key Groundhog executives) for years and their mining expertise will be invaluable to any party that purchases or leases one of our Merger Miner laser mining units. Further, our working partnership with Groundhog gives Merger the ability to actively mine properties we acquire with our Merger Miners and by conventional means as well."***IM***