Caterpillar’s Michael Murphy, Marketing Division Manager of Global Mining Technology Marketing, says “the value of autonomy has been the road to it, without necessarily taking it to the full autonomous mine.” Cat is a company that has not been afraid to delay or even change technology development if it believes that the original path was not going to achieve the right destination. The editor saw Cat demonstrate autonomous trucks at its Tucson proving grounds back in 1996. The company then put that system on hold as the world’s mines were not ready for it and the system itself needed more work. Today it is back with autonomous trucks.

Over the years, the company has developed a mining technology roadmap – a series of building blocks, building towards the autonomous mine. As the roadmap diagram shows, most of the R&D between the 1980s and today has been on technologies to improve the ‘manned mining system’. The next developments will build towards the ‘autonomous mining system.’

Asking the question why autonomy now? Murphy answers that mining companies are today looking, as ever before, for productivity and utilisation. However, today safety has come to the forefront. As he says, today’s mining company CEO is judged on the mines’ safety performance like never before.

Other good reasons to look to autonomy are to reduce infrastructure costs, to achieve process consistency and to counter labour shortages (which IM expects to become critical again in the not too distant future).

Another article in this issue considers remote control for dozer operation – which is one of Cat’s building blocks to autonomy. Aquila™ is another important building block. Murphy reports “strong customer interest in Cat’s autonomous drill system,” which, he says, will have “significant impact on mining operations.” It will integrate with OEM drill systems and builds upon proven Aquila drill system and mining autonomy experience. This will go out under test this year.

Another of the building blocks – the Caterpillar Integrated Object Detection System – was covered in detail in the November issue (p6). An adaptation of this for unmanned operation will ensure that no truck can run over people or smaller vehicles in its proximity.

The autonomous haulage system is in operation – the 2010 version, not the 1996 I have seen already. This, Murphy says, is a “significant value proposition” offering mines what they want: safety and sustainability, process consistency, utilisation and reduced infrastructure costs. He says it works for both brownfield and greenfield operations, and will involve interaction with other machines on the mine. It has been designed for a wide range of mining conditions. It “strongly leverages Caterpillar autonomy and technology knowledge.”

The system depends on today’s very precise GPS control and is already out in the field. A 793 system will go out on test this year.

The iron in iron ore
In May this year the autonomous mine at Rio Tinto’s West Angelas, East Pilbara operation, in Western Australia, went into production. The mine includes a Terex SKSS15 blasthole drill specially equipped by Rio Tinto for autonomous drilling. As of late May 2009 it had drilled 25,000 m on remote control (distances of more than 800 m) and had drilled tens of thousand of metres automatically. It has been deployed at West Angelas mine since May 2008.

It both drills and moves autonomously, undertaking complex manoeuvres between rows as well as tramming in straight lines. Rio believes this is a world-first for automated production drilling. It is achieving location accuracy within 250 mm and normally better than 150 mm and depth accuracy within 10 mm. Penetration rates
range between 2 and 300 m/h - either rotary or down-the-hole hammer percussion drilling.

The machine employs GPS and track encoders for navigation. The automated levelling uses digital tilt meters to achieve 0.2° accuracy. It requires just a flick of a switch to move between manual, remote control and full automation. There is also an independent emergency shutdown system.

Rio’s partners in this include Remote Control Technologies, the Australian Centre for Field Robotics and the Co-operative Research Centre Mining.

Also in May, Komatsu’s Autonomous Haulage System (AHS), Frontrunner went into full-time operation. This is only the second deployment of the proprietary system following delivery of the first fleet to Codelco’s copper mines in Chile. The West Angelas system consists of five Komatsu 930E autonomous dump trucks, along with several other non-autonomous Komatsu machines, these include a PC5500 hydraulic excavator, D475A bulldozer, WD900 wheel dozer and GD825 motor grader. Komatsu’s unique technology allows the 930E trucks to navigate safely in the complex mining environment, hauling payloads up to 290 t of overburden without the requirement for an operator.

At West Angelas the Frontrunner fleet is operated and controlled entirely using a computerised supervisory system at an operations centre. Future plans are for the trucks to be controlled from a remote operations centre located in Perth, more than 1,000 km away from the mine site.

All data from the trucks in use at the mine – including information on the location of the vehicles and their running status – can be verified via the supervisory systems. This is expected to contribute to a significant increase in productivity at the mine, which is in a region that has traditionally struggled to attract skilled operators.

Komatsu’s Frontrunner autonomous haulage system is a comprehensive fleet management system. Trucks are equipped with vehicle controllers, a high-precision GPS system, obstacle detection systems and a wireless network system, jointly developed by Komatsu, Komatsu America and Modular Mining Systems (which is part of Komatsu). The trucks are operated and controlled by a supervisory computer system, enabling them to be unmanned.

When loading, the trucks are automatically guided to the loading spot, based on the position of the bucket of the GPS-fitted excavator or wheel loader. The supervisory system then directs the trucks along the route to the dump location.

The fleet control system prevents collisions with other dump trucks, service vehicles or other equipment at the mining sites. If the inbuilt obstacle detection system detects another vehicle or person inside the haulage area during autonomous operation, the trucks will reduce speed or stop immediately.

AHS enables continuous operation under difficult conditions such as at high altitudes or in sparsely populated, arid desert areas. At the same time, by optimising operational efficiency, the system contributes to reducing maintenance and consumables costs, conserving energy and limiting CO₂ emissions.

The top speed of the trucks is 50 km/h. Each one weighs 225 t empty and carries a payload of 290 t. They are fitted with radars, lasers, communication antennas and high-precision GPS and operate on a 3 km round trip from excavator to waste dump. The trucks navigate haul roads and intersections autonomously, move within the loading and dumping areas and enter the tie-down area for refuelling.
The trucks interact with manned equipment including the excavator, grader, wheel dozer, dozer and light vehicles. That equipment is fitted with GPS and communications software. The operator interacts with the autonomous trucks via a screen. Trucks send messages to ask for permission to approach or pass. There are emergency stop buttons in all trucks and manned equipment.

The shovel operator indicates where he wants to load the truck by raising his bucket, and the truck moves to that point autonomously. A control system divides a manually defined dumping area into dumping nodes and tells the truck exactly where to dump each load. Similar Komatsu trials in Chile have 11 autonomous trucks operating.

The first autonomous movement of overburden by truck was on December 18, 2008. By May 2009, the fleet had moved 3.6 Mt of overburden. Training was undertaken in January and February and full daytime operations began in March 2009, with fulltime production in April. This is a 15-month production trial.

Production drill assistance
Leica is well experienced at combining real-time monitoring software with the latest in HP-GPS technologies. DrillNav Plus, one of many products within Leica Geosystems’ Jigaw360 mine management suite, is its latest refinement, aimed at improving drill accuracy, efficiency and safety.

Offering sites added flexibility, Leica DrillNav Plus offers the option of designing drill patterns in the office, before downloading them directly to the drill, or the drill operator can layout standard patterns onboard the machine. Operators can navigate and position themselves across the pattern without the need of a surveyor.

By replacing the old levelling screen with the new ‘levelling bubble’ operators benefit from better drill control as well as panning and zooming features. The levelling screen shows the bubble to be green when inside a configured tolerance, and red when outside. An alarm message appears in the centre of the operator’s screen to warn if the mast angle does not match that planned. Thus, patterns are drilled accurately to design.

Leica DrillNav Plus records, and reports on, many key performance indicators (KPIs) including: activities versus delays; target depth; number of holes drilled; rate of penetration, and total shift meterage. Operators can view their KPIs onscreen, in real-time, with their progress displayed as a percentage.

You can now track consumables such as drill bits, shock subs, steels, hammer and deck bushes to determine their lifespan versus metres drilled. The advantage: better manage product inventory, and the costs associated with it.

Warning zone alerts should improve safety. Warning zones are represented on the operator’s navigation map when safety is compromised. A warning message appears in the centre of the operator’s screen alerting them to potential dangers.

DrillNav Plus can be used on existing Wi-Fi networks or across 900 MHz spread spectrum radio networks.

The cost savings from Leica DrillNav Plus include better fragmentation and better blasting. Correct drill angle and orientation is aided by the DrillNav Plus mast angle alarm. Also it allows drilling to elevation rather than depth. A preset depth option removes the pull-down pressure once the desired depth has been reached. Real-time updates for drill-to-drill awareness on a pattern provide increased productivity and safety. Delay detection and analysis is possible. Onboard targets to keep operators and management on top of KPIs. Consumables can be tracked and no stakes are needed for drill pattern layout.

Better loading and hauling
Underground, Caterpillar has launched the next generation of its underground automation system, MINEGEM™, designed to enhance safety and boost operator efficiency. Such systems can also have a significant impact through increased machine availability, decreased operating costs and extended machine life. MINEGEM is Caterpillar’s first commercially available semi-autonomous system and the company says it “completes one important element of the company’s strategy to develop and deploy a comprehensive suite of autonomous mining systems that address mining companies’ business needs.”

The system allows the operator to work from a safe and ergonomic work station far from the LHD — either on the surface or underground without sacrificing machine productivity. Studies have shown the productivity of a MINEGEM equipped LHD operated remotely to be significantly more productive than teleremote or line-of-sight systems. Utilisation is increased and significant time savings achieved due to the operator not having to travel from the surface to the machine. Sandvik’s AutoMine is another system offering very similar benefits (IM, January 2008, pp14-25 and June 2008, pp18-20).

The MINEGEM system also boosts productivity by operating in second gear compared to first gear operation for teleremote and line-of-sight systems. During the load-haul-dump cycle the operator, based in a remotely located control station, loads and dumps the material under teleremote control. The system then enables the machine to autonomously steer during hauling, preventing the LHD from hitting sidewalls. This is achieved by using a combination of on-board
The latest version of MINEGEM enhances mine site safety with the inclusion of the Area Isolation System. Access restrictions are maintained by a barrier control panel located at each entry to the operations area. If the machine leaves the operations area or personnel enter the restricted area, the MINEGEM equipped machine will shut down. Additionally, zones can be configured within the operations area to automatically regulate machine speed and to establish ‘no go’ areas at required points.

MINEGEM or AutoMine automation extends machine life as the LHD will encounter less damage because the systems keep machines from hitting drift walls during the mining cycle. Additionally, the systems ensure that LHDs are operated with in their intended manufactured specifications to reduce wear and tear on components. With MINEGEM, real-time machine health status is displayed on the remote operator console, enabling monitoring of key machine parameters.

LADAR, a laser detection and ranging system, located on the front and rear of MINEGEM LHDs provides spatial information about the loader’s location to the remote operator. Similarly, the cameras provide real-time video to the remote operator. These components allow for good visualisation of the work environment, enabling the operator to be highly accurate and efficient.

Murphy notes that operator safety and fatigue drivers for automation are to be able to use machines in potentially unstable areas, for better operations in a challenging work environment and to overcome some of the lost time of blasting operations in a challenging work environment. With AutoMine-Lite is for applications where mobility is required. It is designed for fast installation and startup and allows quick relocation from one production area to another. Each time it is set up, the loader simply learns its automated tramming route by a single drive-through between the load and dump points.

The intent is for mines to be able to set up a new AutoMine-Lite operating area in a couple of shifts. The best system move achieved at Pyhälamoi took less than one shift.

AutoMine is for larger, long-term installations in mass mining. The Lite version brings the automation advantages to other mining methods. No mine redesign is required for this flexible system. Lite can also get mines used to automation and allow them to graduate with confidence to a full AutoMine system.

It offers complete working safety, ease of operation and high productivity, as the LHD cycle is semi-automated. The repeatable tasks of tramming and dumping are fully automated, and bucket loading is undertaken by teleoperation. It is available for use on Sandvik’s LH307, LH410, LH514, LH517 and LH621 LHDs.

An unmanned LHD is the ideal solution for hazardous environments, but in safety, AutoMine-Lite goes even further. The production area is isolated with a dedicated safety system. Should anyone attempt to enter that area, the system will automatically and immediately stop and shutdown the LHD.

Two infrared light access barriers guard each entrance to the production area. This keeps people and the LHD isolated from each other. A physical barrier can be installed by the mine but the system does not require this to keep the area safe. The system can guard up to five entrances.

To ensure reliable operation, Sandvik has developed a WLAN-based system that meets the demanding requirements of underground radio communications for autonomous operations. The communication system provides real-time video, audio and data communication between the LHD and the operator station. This can be in a container outside the production area or, as in Pyhäsalamoi’s case, in the back of a van.

The integrated onboard LHD automation package includes a navigation system, a mobile terminal for communications and video and audio systems. The navigation system enables high-speed automated trarming in challenging environments.

Controlling the LHD remotely, the operator’s exposure to operation area hazards such as falls of ground, dust, noise, vibrations and gases is reduced. Instead, the operator works in a comfortable environment and receives comprehensive information from the LHD through the supervisory system.

So, unlike with RRC, the AutoMine-Lite operator never has to climb on or work in close proximity to the machine, making operation safer and more productive. Similarly, compared with teleremote systems, the semi-automated operation is less intensive and tiring than the constant concentration required when tele-operating the whole cycle. Also, teleremote operation is typically restricted to second gear to reduce the risk of collision with the walls of the drift. With AutoMine-Lite, only the road conditions limit the tramming speed, generating another boost to productivity.
Damage forms a major component of LHD maintenance costs when using RRC and teleremote systems. “When operating with AutoMine-Lite, damage costs can be virtually eliminated,” Mikko Mononen, Sandvik’s Product Manager, Mine Automation, Underground Mining, explains.

The optional tele-operation assistant further supports the loader controls. Dynamic visualisations of the LHD’s position in the drift (2D top-view) with collision warning indications and display of the bucket position simplify the tasks of positioning the machine and bucket. This speeds up loading, increases tyre life, reduces fuel consumption and enables a better bucket fill factor.

In Canada recently, Rio Tinto’s Diavik mine took advantage of the diamond market slowdown to verify and commission automated loading technology from Atlas Copco. The mine lies some 200 km south of the Arctic circle in Canada’s remote and spectacular North West Territories, and is literally in ‘the middle of nowhere.’

As the mine moves from open-pit to underground mining, initial ore production from
blasthole open stoping is a difficult environment for conventional LHDs. Diavik has acquired three Scooptram ST14 LHDs, one of which is equipped with Scooptram Automation components for remote control. Over a period of months, this unit is being put through its paces in a section of the mine with a view to introducing autonomous mucking and hauling by February 2010.

Working closely with Atlas Copco, three main objectives have been set. The first priority is to increase operator safety. Next, the partners want to achieve the same or better productivity than is achieved at the present time. And thirdly, they are looking for quantifiable reductions in overall running costs for mucking operations.

**Hole management**

For the underground driller, Atlas Copco’s new unique High Precision Tunnelling (HPT) concept points the way to further process refinement and greater cost efficiency. It features five innovative options for drill rigs and machines, based on the latest technology and drift development knowhow.

Tunnel Manager is the intelligent PC-software that enables the worksite office to provide operational support to Atlas Copco Boomer rigs equipped with the Rig Control System (RCS). Tunnel Manager is used to plan, store and evaluate data for the drilling process. Transfer of data to the drill rig ensures more efficient and precise navigation, generating significant cost efficiencies. It comprises the latest advances in computer technology and is available in three versions, involving progressive gains in functionality. The most advanced version permits analysis of accumulated data, using Atlas Copco’s upgraded Measurement While Drilling (MWD) technique. This allows rapid translation of raw data into specific properties such as rock hardness, crack zones and more, which can be used to correct and fine-tune the tunnelling process.

Good communication with the underground drill rig is a key to efficient drifting. The Rig Remote Access (RRA) option ensures rapid and secure transfer of the latest data to and from the drill rig – as well as secure storage of all necessary information. With the drill rig online, the whole organisation has constant access to the latest information. The production planning department can initiate immediate analyses of incoming data, automatic updates eliminate the need to manually collect new drill plans for the operator, and service personnel can conduct online diagnoses and order appropriate replacement parts prior to actual service calls. This should result in minimum time loss and a lot more drilling hours. With the RRA server software, online file transfer is assured, even when the drill rigs are temporarily beyond WLAN range.

With Total Station Navigation (TSN), the rig can rapidly be navigated into precisely the right position – every time, and with limited need for surveyors. Navigation is not only extremely precise (accuracy better than 10 mm compared to the more normal 100 mm), it is fast: no more than five minutes, compared to the 10–30 minutes for manual methods. More precise navigation also cuts costs, due to reduced over- and underbreak.

Mining the right profile from start saves a considerable amount of time and money. Atlas Copco’s Tunnel Profiler is an intelligent 3D-scanning system for rapid and high-precision profiling. A section can be scanned immediately prior to drilling the next round, requiring very little extra time. Data is processed by the Tunnel Profiler software and the rig operator is informed about any over or underbreak in a matter of minutes. This means drill plans can be corrected very quickly. Rapid adjustment of drill plans can save up to 50 mm in overbreak. In a tunnel with a 40 m² profile, this can yield savings in overbreak-costs of about €125,000/km, in terms of concrete and man-hours.

The MWD technique has enjoyed rapid development, through computerisation of the drill rigs. Atlas Copco’s upgraded MWD is a rig option offering rapid acquisition of vital drilling data, such as penetration rate, feed force, rotation speed and more. With Tunnel Manager MWD, the data can also be used to analyse rock hardness, crack zones and other relevant rock mass characteristics. Thorough knowledge of the rock’s properties allows for...
adjustment during drilling, for improved safety, efficiency and economy.

Bolt Angle Indication is support software that gives guidance of the rock bolting operation. The system focuses on guiding the operator to install bolts with the correct distance between them. By using this guidance system, there is no longer any need to mark the walls to achieve the correct bolt pattern, and if different operators install bolts, the job will always be done with the same spacing and with minimum human error. Furthermore, Bolt Plan Navigation enables planning, guidance and logging of rock bolting. Today, different methods of installing the correct bolt pattern are used, but the one thing they all have in common is that they rely on the operator’s ability to manoeuvre the bolting equipment. With the Total Station Navigation function, which is included, the rig can rapidly be navigated into precisely the right position - every time, and with limited need of surveyors. With Bolt Plan Navigation it is easy to see where bolts are to be installed without guide marks painted on walls and roofs. It provides reports about bolt types, amount of cement used and other data that can be saved for future analysis. The logging function shows how many bolts have been installed and their exact position.

At the coal face

Bucyrus is a world leader in automation in the underground coal sector. Its PMC®-P offers a standalone XP optical-fibre Ethernet solution for state-of-the-art communication between controllers, the computer network and third-party systems. This allows real-time data exchange between subsystems and monitoring and control from underground or surface control centres. The system allows data rates of up to 100 Mbit/s and transmission over a range of up to 9 km without repeaters. The PMC-P comes in a flameproof (FLP) housing and is powered by a single 12V 1.4 A power supply.

Figure 1 shows the position of the PMC-P in the automated longwall – it can be used with or without an underground control centre (ExPC). Whereas conventional data lines only allow transmission rates of 9600 Baud, the PMC-P allows transmission rates of 100 Mbit/s via Ethernet fiber optics and/or 115 kBaud serial communications via copper cables. Bucyrus says “this high-speed data communication allows real-time monitoring and data exchange between the subsystems and between underground and surface control centres for the first time. Also, the increasing number of automated systems and the growing flood of data from ever more sensors make high transmission speeds essential.”

Fibre optics allowing distances of 9 km to be covered without repeaters is of particular interest for transmission to the surface, particularly when the mine does not have a computer network that extends to the face. The optical barrier for all signals simplifies worldwide approval. The PMC-P has four inputs for subsystems and two outputs with one mine-duty hose patch cable for easy optical fibre connection.

PMC stands for Programmable Mining Control and is the generic term for all Bucyrus underground mining controllers. They are freely programmable controllers that can be adapted to each specific application – both with regard to hardware and software. All PMC controls are based on the same CPU family and vary in appearance and in the number and type of input and output interfaces depending on the application. Control tasks are distributed to the various control units which are optimised for their particular role. There are four variants of the control unit:

- **PMC-R**: Dedicated for roof support control and several smaller control tasks
- **PMC-D**: Used for direct measurement and high-speed closed-loop drive control tasks
- **PMC-V**: Mainly used for data visualisation and commands

**Figure 1**: The PMC-P in the automated shearer longwall.

It allows data transfer between the various automated subsystems of the longwall (shearer, AFC and roof supports). Data from third-party equipment can also be integrated, with appropriate translation of data and commands.
parameter setting in PMC-D systems

■ PMC-P: Network provider for communication within the PMC family and with other systems.

Bucyrus recently delivered the 50th ExPC, its ruggedised PC for use in explosion-hazard areas. It opens up a completely new dimension of data processing, recording and visualisation underground and in explosion-hazard areas. The first ExPC was delivered to Xi Shan in China in January 2003. The 50th was recently delivered to OKD’s CSM II mine. The ExPC collects data from drives, roof supports and the shearer or plow and visualises these at the coal face. It also transmits this data via fibre-optic cable or DSL to the mine network for visualisation, control and troubleshooting. The explosion-protected housing, the armoured glass screen and the waterproof keyboard with built-in mouse ensure that the ExPC can work safely and efficiently even in dusty and explosion-hazard areas. Intrinsically safe ports and network connection guarantee smooth data exchange with other control systems. No mechanical damage has been reported on any of the 50 ExPCs in use in mines around the world.

The ExPC operates as a Visualisation Control Unit (VCU). There are visualisation programs for the various control tasks – VShield, VPlow, VShearer, VDrive and VLongwall. They allow parameters to be read and set, as well as visualisation of operational data. Each component also allows logging of operational data and has a Replay function for visualisation, analysis and process optimisation.

Secure communications

Cattron Group International has released its high performance SIAMnet Diagnostic System (SDS) for underground mine communication. Installed with virtually no interruptions in service, the SIAMnet system offers a stable, reliable and flexible solution for data transmission.

Interfaces:
- four x serial communication up to 115 kbit/s
- two x Ethernet fibre optics 100 Mbit/s
- External I.S. power supply 12 V, 1.4 A

Protocols:
- Ethernet, TCP, UDP, IP, DHCP, Telnet, HTTP
- PMC-Network Protocol, PMC Packet ACD
- Rockwell PCCC, Ethernet/IP style connection to external PLCs
- Rockwell DF1 serial connection to external PLCs
- Modbus / TCP connection to external PLCs

Interfaces:
- Ethernet output for underground PC

Figure 2: The PMC-P offers a standalone XP optical-fibre Ethernet solution for state-of-the-art communication between controllers, the computer network and third-party systems

Technical data at a glance

Interfaces:

- four x serial communication up to 115 kbit/s
- two x Ethernet fibre optics 100 Mbit/s
- External I.S. power supply 12 V, 1.4 A

Protocols:
- Ethernet, TCP, UDP, IP, DHCP, Telnet, HTTP
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features applications that are operation critical in an underground mine, allowing a problem to be rapidly diagnosed and minimising downtime.

This diagnostic system monitors every SIAMnet amplifier and reports status information on a periodic basis. In the event that an amplifier is faulty or operates outside of the set parameters, the mine technician can see exactly which amplifier is causing the problem without traveling into the mine. By interrogating the system through the SIAMnet Diagnostic Manager, issues such as a power outage, damaged coaxial cable, low supply voltage or weak signal can be identified. If an amplifier reports abnormal conditions, an alarm is generated locally and an email is sent to the contact list.

While monitoring information is available to all users, the configuration screens are password protected and reserved for the mine technician. A web page, with current system status, may be made accessible from any location worldwide by the mine network administrator. The mine technician can get online with the SDM, via a secure Internet connection, and troubleshoot the SIAMnet. When required, a service technician can be dispatched directly to the area; however many issues may be resolved remotely.

The SDS is useful in calibrating a new SIAMnet network. Once installed, the amplifiers can be adjusted remotely to match the exact mine configuration. A perfectly configured SIAMnet optimises the data rates while the voice communication audio quality remains exceptional, Cattron reports. Amplifier configuration and alarm files may be kept for reference and further analysis. The SDS includes a basic Spectrum Analysis feature and can display the signal strength over the entire 800 MHz band as well as the cable modem band. Although it does not replace an expensive spectrum analyser instrument, the SDM can identify RF noise issues and display signal strength in a graphical way. Should a thorough analysis of the SIAMnet be required, every amplifier has the possibility to generate signals over either band, which can be used for troubleshooting. These features will help maintain a system without investing in expensive tools and expertise. IM