

# Going underground, or not



Sandvik three-boom mining jumbo.

**John Chadwick** considers the trend to increased underground mining, looks at surface mine automation and offers the opinions of industry leaders on these trends and the equipment and techniques that the industry needs to employ to raise productivity and beat rising costs

**T**he amount mined by open pits still dwarfs that mined underground. For instance in the USA, surface metal mines produce around 700 Mt of ore and more than 1,400 Mt of waste, for a total of probably at least 2,100 Mt, while underground mines

produced 19 Mt of ore and less than 3 Mt of waste. In other countries, underground has larger shares of total production, about 20% in Australia and Russia, rising to 25% in China and Canada, and to over 30% in South Africa.

Nevertheless, the general trend is for

underground to take a larger share of global production. The primary reasons for this are, firstly that the known near-surface deposits are becoming exhausted and we certainly will not be finding very many more very large near-surface deposits. Secondly, underground mining is more acceptable from environmental and social standpoints. An underground mine will often have a smaller footprint than an open pit of comparable capacity.

However, as *IM* editorial board member Hans Fernberg (Atlas Copco Rock Drill's Senior Advisor) warns, "underground mining using block caving or sublevel caving can sometimes leave unpredictable footprints, such as Kiruna where the railway, church and major parts of the town have to be relocated much further away on the hanging wall side to secure continued mining at depth. An open pit can be designed using pre split and optimum slope angles to prevent unexpected cave-ins." He also notes that underground iron ore mines leave a much bigger footprint because tailings from the flotation plant is not available as fill material as is the case with mines extracting sulphide ores and gold.

Generally, as Lars Josefsson, President of Sandvik Mining and Construction, told *International Mining* at the end of November, "the mining boom is not driving productivity with our customers." Mining companies are not achieving the productivity gains they need to make. He demonstrated research that showed the costs of the top 11 mining companies had risen almost 80% between 2001 and 2006, but their total internal productivity rose on 7-8% over that time.

Joseffson says "capital expenditure drives operating expenditure – we can really influence customer productivity." Commenting primarily on the underground sector he points out that "mobile mining equipment capex accounts for less than 2.8% of total mining cost, but influences 40 % of total mining cost." Those mobile equipment operating expenses cover spare parts, labour, tyres and fuel. Along with other operating expenses and overheads and distribution they make up total mining cost.

Joseffson summarised the main business drivers and trends in markets and technology. In markets they are:

- Continued high demand
- Exploration activities increasing
- Increasing lack of skilled people
- Investments in infrastructure.

In technology, he suggests:

- Mechanisation and automation due to productivity and safety
- The surface to underground trend



**CRCMining/P&H Laboratory.  
P&H 2100BLE loading a truck during  
testing of the payload system. Truck  
scales appear in the foreground**

- From drill and blast to continuous processes
- Mobile and flexible units
- Focus on total cost optimisation.

In particular he noted the skills shortage and the "exceptional demand of new projects," with "everyone facing the same challenge. We are competing for the same resources." Our industry is not attractive enough," he stressed. "We need to show the positive side of our industry."

His company has been a leader here with the launch of the Sandvik International Mining School last year. This is a joint project of Sandvik with the universities of Leoben (Austria), New South Wales (Australia) and Witwatersrand (South Africa), the Technical University of Helsinki (Finland), Camborne School of Mines (England) and Colorado School of Mines, USA. While these courses are currently only for Sandvik personnel, they are contributing a great deal to overcoming the skills shortage and raising the profiles of these mining schools and helping them pass on more mining skills to a wider market.

And Josefsson is happy for others to take the

idea and develop it for their own use as applicable. It is a standard concept used globally and is currently providing training and education for mining people from Africa, Latin America, North and Central Europe and India.

## Rock factories

"The new underground mines," says Pete McCarthy<sup>1</sup> Managing Director, AMC Consultants, "will include large caving mines, small high-grade mines and all sizes and styles in between. New and more cost effective methods of haulage and hoisting will enable these mines to be developed on orebodies that are currently subeconomic."

Some of the great pits of the world, like Chuquicamata in Chile, or Bingham Canyon in the USA are getting old, and deep. Those are just two examples, (and planning to go underground has begun at both), there are scores of open pits coming close to economic limits. Current oil price rises bring others closer to their limit.

Talking of fuel costs, why is the idea of trolley assist trucks still so under employed?

Southern Africa led a minor charge into this technology with Iscor (Sishen) and Palabora at the forefront with two systems in South Africa at the start of the 1980s. Zambia Consolidated Copper Mines followed with Nchanga in 1983, and then it was Rossing Uranium in Namibia in 1986. However, interest remained firmly within that region until 1994 when Barrick's Goldstrike installed the first large system in North America.

Was Goldstrike to be the spur that encouraged others to see the advantages? No, nothing further developed for more than a decade. Today we are back to Southern Africa with a system going into Equinox's new large Lumwana copper mine in Zambia.

Over the last decade or so, Caterpillar mechanical drive trucks have outsold all electric drive trucks. Now that Caterpillar is planning to introduce its first electric drive models might the availability of some 'big yellow' trucks that can run on these systems bring about more interest in trolley assist?

Certainly big haul trucks are becoming an inefficient transport method in many mines. As CRCMining's Professor Mike Hood points out, in some of the world's biggest open pits, a truck driver may "only make two round trips a shift because it just takes so long to drive down to the bottom of the pit and drive back out again. That's just an insane way of moving dirt."

What answers does he see? Firstly, he is looking to automated trucks, and then secondly moving away from trucks altogether and using mineral sizers and some sort of

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*With all major manufacturers to be producing electric drive trucks by the end of this year, might we see more interest in trolley assist? Here, Caterpillar's AC electric drive simulator enables engineers to test full-scale powertrain components just as they work in a real truck. The controlled environment allows thorough and fast testing.*



A special Fullfacer machine made by Atlas Copco in the 1970s. The cutter heads swung sideways as well as undercutting to create the drift seen below right. This machine was developed for the White Pine mine. It worked well but took a year to debug it of initial technical problems, and when this was achieved, metal prices fell so much so the project was stopped.



The company has now logged many hours with five of its autonomous haul trucks working at a copper mine in Chile. Komatsu reports that the Autonomous Haulage System (AHS) "is a high-tech management system that controls an autonomous running of super-large dump trucks and manages

continuous transport system. Autonomous surface mining trucks have been around for years. Caterpillar demonstrated fully autonomous trucks back in 1996, but then backed away from this development as it feared it was too expensive to make the trucks sufficiently safe such that 'rogue' units roaming off their safe route was an impossibility. As long as there was still the slightest chance of an autonomous truck injuring or, worse, killing someone, there was little appetite for such systems.

Nevertheless, the great advantages of autonomous trucks remain very attractive, and are becoming more so. Removing the operator cab and all the weight that entails would reduce the deadweight of haul trucks hugely. Add to that the labour savings and the attractions are obvious.

Komatsu may be less than two years away from a worldwide launch of its unmanned electric mining trucks. "The autonomous vehicle is still in the development phase, but we're getting very close. I'd say within the next 12 to 24 months we'll have additional trucks in the market," Rod Schrader, Vice President and General Manager at Komatsu Mining division, told Reuters at the CRU World Copper Conference in late March last year.

the fleet as a whole in large-scale mines. It can serve to bring up the working ratio, save man-hours and heighten the safety level at mines."

The Mining Technology Group (MTG) of Freeport-McMoRan Copper and Gold (FMCG) has been researching automation technologies, first in communications and positioning infrastructure, and also an appropriate automatable mining process. MTG is focusing on four enabling technologies – mesh networks, GPS augmentation positioning, safety systems and fleet management systems (FMS). Motorola, Nortel Networks and CISCO have all announced products designed to work in a mesh environment. "As this technology evolves, it is hoped that the current limitations are eliminated, such as the inability to increase bandwidth and the lack of message broadcast capabilities?."

FMCG and Novariant developed the Terralite system for GPS augmentation. For safety, the "current on-board obstacle detection system is a series of SICK lasers ([www.sickusa.com/gus/enhtml](http://www.sickusa.com/gus/enhtml)). FMCG has chosen **Jigsaw Technologies** (now part of Leica Geosystems) as the FMS vendor/developer. "**Jigsaw's unique implementation of its truly distributed architecture provides significant advantages for the ultimate deployment of automated haulage**

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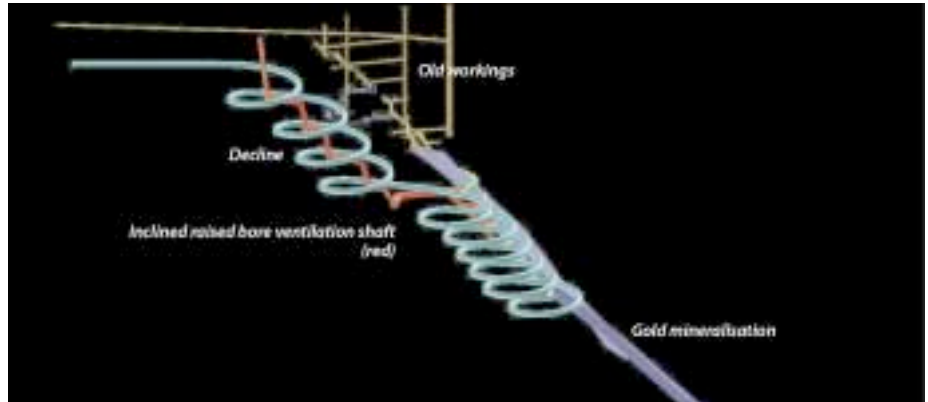
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Perspective view of how raises and underground ramps might be used on an expansion/deepening project.

control technology," MTG says.

Phase 1 of MTG's program includes "the identification and development of a test haul circuit at an abandoned mine site that will later be developed into the San Juan mine, where ongoing system enhancement and simulated production testing can be performed. The test circuit has haul routes, with simulated loading and dumping areas and a simulated fuelling area that will also be a staging area for manned-to-automation hand-off. San Juan, a development mine, can provide the opportunity to develop and possibly deploy the automation technology in an operating environment without the typical production pressures encountered in a working mine."

For more than four years CRCMining and P&H Mining Equipment<sup>3</sup> have been collaborating to develop "advanced technologies leading towards the automation of mining shovels." Two 'operator assists' that have been developed are "an accurate payload estimation system capable of achieving better than 2% accuracy and a [shovel] track protection system."



CRCMining continues to work on facilitating "the full automation of an electric mining shovel." Active research areas include:

- Investigation of methods for relative localisation between multiple equipment units
- Formulation of a general robust collision avoidance approach
- Develop methods for facilitating collision avoidance
- Dynamic terrain modelling with the aim to provide an environmental model of the work environment of a shovel.

On the subject of automation, Peter Knights, Program Leader – Smart Mining Systems, CRCMining (and a member of *IM's* editorial board), notes overload damages truck frames,

motors, drive trains and tyres, as well as increasing unscheduled downtime and reducing fleet availability. "Underload under utilises truck capacity." Knights believes 'smart trucks' are an answer and explains "haulage is the major operating cost for most open-cut mining operations. Haulage performance is governed by the way in which the truck and road interact:

- Rolling resistance: a 10% increase causes fuel consumption to rise by 30% and productivity to drop by 35%
- Tyre wear: tyres account for 20%-30% of operating costs
- Road quality: duty on frame and other components is a function of roughness.

High volume waste handling is necessary to maintain output from deeper open-pit mines. Another item on the industry's 'wish list' is mining methods that require less waste handling (such as in-situ mining). All this, Knights says will involve continuous versus batch extraction systems (analogous to manufacturing), shovel/crusher/conveyor systems and hydraulic mining solutions.

## Time to sink a shaft?

For underground, CRCMining is working on rapid underground development. The aim is develop a drilling optimisation system for multi-boom jumbos to reduce the time spent drilling at a face without the need to alter existing equipment. Key elements of the system include determination of feasible drill sites, based on current system conditions, and feasible path planning, and an optimisation algorithm.

Sandvik, focusing on speed, has recently released a multi-boom mining jumbo. The new Sandvik DD530 is a three-boom mining jumbo and the company claims "we offer performance, efficiency and quality never seen before. Time can be cut down noticeably with our purpose-built carriers that are not only fast, but easy to access to facilitate the maintenance of the machine." Sandvik DD530 relies on a 110 kW engine with a Clark 20 000 hydrodynamic transmission. A higher speed carrier is also available with a 170 kW diesel engine, available as an option. The three drilling booms cover up to 75 m<sup>2</sup> cross sections and feature a high frequency HFX5T rock drill. This machine's capabilities can accelerate any mine's schedule in development drilling. The challenges that safety issues present to operators can be easily tackled with any combination of on-board diagnostic systems, extra working lights and FOPS (ISO 3449) certified cabins.

CRCMining is developing a computer based system that can give guidance on drill hole selection to the operators of multi-boom jumbos. "The mathematical programming framework developed will take into account geometry and collision avoidance constraints,



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be able to adapt to changing conditions, and solve the problem over a receding drill hole horizon.<sup>4</sup>

Mechanised excavation is high on miners' 'wish list', and must conform to the need for drifts to follow orebody geometry. "Tunnels are often short, and often not straight," Knights points out. "Not conducive to TBMs.

"Rock is stronger, more confined, and often more abrasive at depth. But there is potential for very rapid tunnel advance (continuous 1 m/h), and the quality of the tunnel will be far superior:

- Far less rock support, maintenance
- Flat floor (tyre wear, maintenance, back strain)
- Lower ventilation costs."

He notes that to date boring machines have generally been very large units, because "disc and button cutters break rock by indentation, effectively loading rock in confined compression. Consequently cutter forces are very high, which requires large, inflexible machines to react to these forces." CRCMining is looking at the advantage of undercutting discs – breaking rock in tension.

Four synergistic techniques combine to lower forces:

- Undercutting – promotes tensile failure
- Oscillating – fails rock in fatigue
- Water jets – eliminate cushioning effect and cools tool
- Inertial mass.

Atlas Copco developed undercutting machines in the 1970s that worked well in sandstone and limestone.

Magnus Ericsson of Raw Materials Group, writing in Atlas Copco's latest edition of *Mining Methods in Underground Mining*, notes customers are demanding higher productivity, "and there is an increasing focus on machine availability and simpler service procedures in order to reduce downtime.

"The competition for land in some densely populated countries has further meant that underground mining is the only viable alternative. Such developments have halted the growth of open pit mining and it is projected that the present ratio of 1:6 underground to open pit mining will continue in the medium term."

## Trucks or hoisting?

Fernberg notes that "mining of dipping orebodies starting not too far away from the surface are naturally best suited for ramp haulage. There is no need to invest in defining the mineralisation at depth and mining can generate positive cashflow pretty quickly.

"In the case of a flat orebody with defined


depth like the KGHM copper mines in the Lubin area, Poland, I think it's pretty obvious that shaft hoisting is the logical and most economic alternative. The case is often that ore is later found below shaft bottom horizon and internal ramps are used to truck the ore up to the main railbound haulage level for transport to crusher and skip station, such as Mt Isa mine's 3000/3500 orebodies and 1100 orebody south extension." (see longitudinal section)"

Another AMC Consultant, B.E. Hall<sup>5</sup> considers the question for near-surface underground miners – whether to convert from truck haulage to shaft hoisting? As he explains, "the desire to defer capital expenditure frequently delays investigation of the shaft option, or deferral of a decision to start shaft sinking, unless the shaft option is clearly significantly better than trucking. By the time increasing depth makes trucking uneconomic, there may then be insufficient resource remaining to justify a shaft, and the mine must close. However, had the shaft been built earlier, its lower operating costs would have permitted the mine to continue to greater depths."


He argues that "frequently, in order to minimise exploration expenditure, the resource is insufficiently identified at various stages of the mine's life to allow rigorous evaluation and justification of a shaft, but in retrospect, with improved knowledge of the resource from ongoing exploration, it becomes evident that a shaft could have been justified earlier, had the knowledge been available earlier. The mine closes earlier than it could have, returning less to its owners than it could have done."

Today, with more money available, and the industry perhaps having learned some lessons, more consideration seems to be being given to future underground operations at fairly early open-pit planning stages. While some of this no doubt is aimed at offering a 'better story' for long-term investors, some of it, one hopes, is backed by technical study.

Hall says: "Simplistically, a shaft should not be sunk earlier than when production is at the depth where truck haulage costs become more expensive than shaft operating costs, and there must then be sufficient reserves remaining for the lower operating costs to pay for the shaft development." His 2005 paper describes "a methodology for identifying how product prices may influence the economic limit of mining with and without a shaft, and, whether a shaft is viable or not, how the value of a shaft diminishes with deferral and when it becomes uneconomic. It also indicates how the resource required to justify a shaft ahead of the current mining front will vary, in particular increasing rapidly as the date of the shaft installation is



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deferred as long as possible.”

Truck haulage and shaft hoisting are viewed as complementary technologies in underground mining. However, SKM's Graeme Medhurst<sup>6</sup> challenges the commonly adopted methodology employed in assessing the costs for these two alternatives. “Rather than detailing the respective hoisting/haulage comparisons in isolation, it is proposed that broader battery limits be employed to pick up the extensive and significant cost impacts on mine operations and mine infrastructure.

“In particular, the impact of ventilation costs is critical in the assessment of truck haulage and shaft hoisting at depth, and should not be overlooked even in the broadest of scoping studies.

“Direct truck haulage to the surface is clearly preferred at relatively shallow depths, particularly at low tonnage rates when a small truck fleet is adequate. However, capital costs for the truck fleet and associated mine infrastructure escalate rapidly with depth, with costs for infrastructure required to support decline truck haulage being up to twice the cost of the truck fleet at a depth of 1,000 m.

“Truck haulage is highly effective at modest depths; however shaft hoisting is effective both in limiting the size of the truck fleet and in controlling operating costs at depth. Timing for the installation of shaft hoisting is clearly important, as mine operations may quickly become uneconomic at depth if burdened by both increasing haulage costs and associated infrastructure capital requirements. Continued reliance on truck haulage from greater depths must inevitably lead to ‘high grading’ of the resource, with operations ultimately becoming uneconomic and resulting in premature closure of the mine.

“Where the investment can be justified, shaft hoisting provides the means for lowering cutoff grades and for extending economic ore reserves at depth. The impact of shaft hoisting on reserve estimates, production rate and life of mine should clearly be reflected in any assessment of truck haulage and shaft hoisting.

“The challenge for all mine owners is to realise the maximum potential from each

resource. Long term planning is essential for the timely commissioning of a production shaft, as the process of evaluation, assessment, approval and construction of shaft hoisting systems may typically span a period of three to five years, depending on depth and mine development. This has clear implications for the mine development schedule and the exploration program necessary to justify the capital expenditure for a production shaft.

“There are many issues to resolve in planning the introduction of shaft hoisting, including the timing, the location, the depth, the size and the capacity of the system. Ideally, this planning process commences very early in the life of the mine with adoption of a conceptual plan. In this way, the value of the production shaft may be optimised not only in terms of total hoisting and haulage, but also on the development and integration of the mine ventilation system and other mine infrastructure.”

## Underground processing

Being able to process ore underground and thereby greatly reduce the amount of waste hoisted to surface has been a goal for decades, with serious development beginning in the 1970s. Gekko, the processing equipment vendor, recently presented its latest innovation – the Python Underground Processing Plant (Python UPP). This high-tech, fully automated modular plant is the outcome of five years of intensive research, designed to operate in a 5 m x 5 m underground drift and produce a high-grade concentrate that can be pumped to the surface.

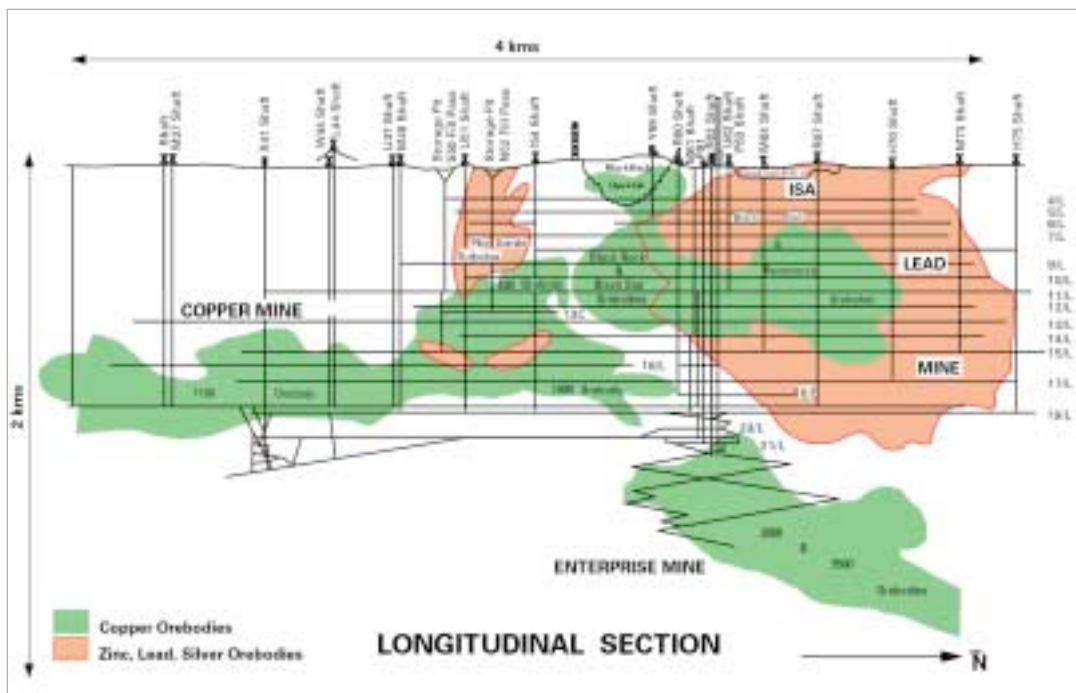
“We believe that mining companies will save up to 15-25% of their total costs. Experience

curve benefits will result in even higher returns”, noted Gekko's Technical Director, Sandy Gray. “Step change savings can be expected in haulage, ventilation, backfill, grinding, staffing, tailings disposal and environmental costs. Installation of the unit may also de-bottleneck production and it has the potential to lower cutoff grade.” Underground processing may well also decide mines to go underground at an earlier stage in the life of an open pit.

The process design concept is to operate the crushing, grinding and pre-concentration plant underground and to pump the concentrate to the surface. Depending on available space underground, and metallurgical test work, it can be expected that a volume concentrate of between 5-30% mass will be pumped to the surface – eliminating the need for trucking. **IM**

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How a mature mine can look with shafts and internal ramp systems – Mount Isa mine, courtesy of Atlas Copco.