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Development in deep, hard rock mines – beyond 10 m/day

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Abstract

Over the last 30 years, the hard rock mining industry in Canada has seen a continual decline in advance rates for access development in bulk, base-metal mines. The decline has been accompanied by the introduction of large and powerful equipment units that operate in sequence and require significant maintenance support. As Canadian mines progress in excess of 2.5 km below surface, the ventilation demand of this type of equipment becomes onerous and the combination of travel times to and from the face, and exclusively sequential activities, will continue to slow advance rates and help kill deep projects. Prior to 1975, the high advance rates achieved depended on work practices that can no longer be tolerated, but the way these operations were managed has a great deal to offer. We must re-examine these projects and re-learn the lessons these operations provide – in particular the focus on face utilisation – while ensuring the safety of the workforce at all times. We present a new approach to drift development for large face (5 m) drifts plus the simulation results that show how advance rates in excess of 10 m/day can be achieved.

1 Introduction

Over the last 30 years, the Canadian mining industry has invested many millions of dollars in research and development, engaging mostly with university-based research groups and academics. Since the successful transition to bulk mining methods in the mines of the Canadian Shield was completed, very few of the research projects have been adopted by mining companies. However, implementing new techniques or equipment into routine operations is the only real measure of innovation.

The costs of mining operations can only be affected by a change in routine mining practice, and for any innovation to take hold it has to be supported by businesses that supply the technique or process into the marketplace. The Centre for Excellence in Mining Innovation (CEMI) was established to accomplish the commercialisation of new techniques in underground mining, and is developing relationships with the small to medium sized enterprises (SMEs) in the service and supply sector to help implement innovations that have been developed.

Figure 1 shows how the innovation process is iterative and that the SMEs are essential for honing initial research products into a viable alternative that can be implemented into operations that will rely on the service sector to support it in the long term. Without this third part of the cycle the best that can be achieved are a series of one-off trials that ultimately have no impact on routine operations and so do not affect any change in mine productivity or cost profile.

In all of CEMI's productivity-related projects the overall objective is an improvement of performance by two or three times – or by reducing time or cost by one half or one third. This is not always possible, but this is the initial target. Although continuous improvement projects are typically focused on gains of a few percentage points, often less than 10% but perhaps as high as 50%, CEMI believes that much greater gains are necessary in the current climate. With current commodity prices, modest improvements in mine performance will still leave many mines very close to the break-even point so that relatively minor fluctuations in commodity prices can drive major tactical changes to the operations.

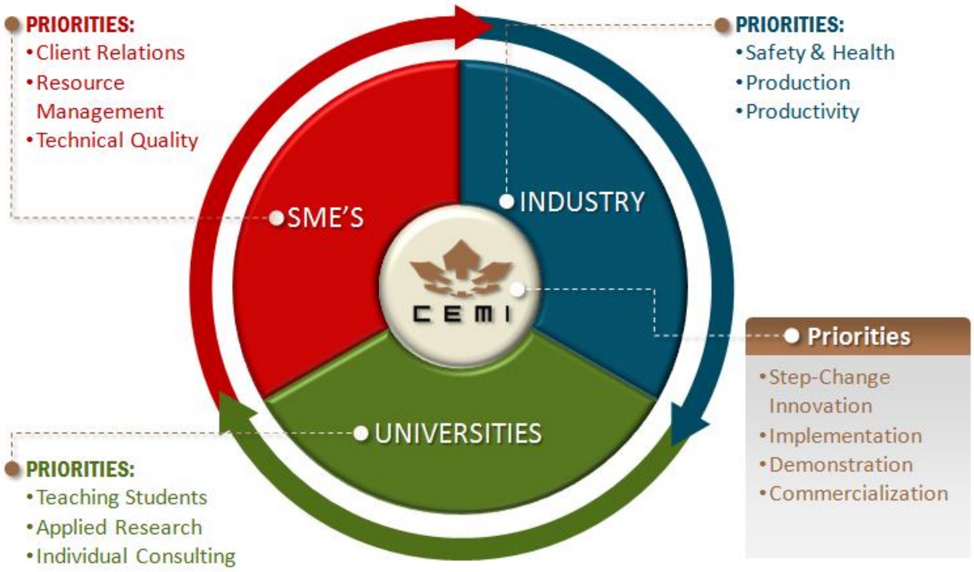

Figure 1 Showing the iterative relationship between the mining industry, university researchers and the SMEs in the service and supply sector, with CEMI managing priorities and the commercialisation process

The long-term stability of the mining industry in Canada will require adherence to strategic plans of more than a few months duration and it will mean abandoning cost-cutting as a way to build the future. CEMI believes that the focus on reducing direct operating cost has gone as far as it can go and what is now required is to focus on the cost-benefit of changes in mining practice, to improve the overall mine performance significantly (Graham 2003). This could mean increasing the direct cost of drilling and blasting, if it delivers much lower costs of materials handling, or increasing the cost of producing a much higher quality backfill if it allows for a much higher production rate at lower overall cost. And it means increasing the cost of creating capital development if it means significantly improving the net present value (NPV) of a project by reducing time to first production.

2 Historical trends in drift development

Figure 2 illustrates the records that have been achieved in Canada from the 1960s through to 2001 when the last survey was conducted. The case that most closely represents mine drift development is the second from the left – the Granduc Tunnel driven from 1965-68 with a face about 4.6 m square. The tunnel was approximately 17 km long connecting the Granduc copper mine to the port at Steward BC, and was achieved with an average rate, over the entire duration of the project, of 2.8 m advance per day, peaking at over 30 m advance per day. The optimisation of the face activities was accomplished by several separate innovations and was focused on maximising face time, i.e. the time during which activity is occurring at the face. The equipment used was pneumatic drills and mucking machines and rail-cars, so the advance rate included laying down rail track.

During the late 1960s and early 1970s pneumatic drills were being mechanised, but by the early 1980s electric hydraulic drill jumbos and diesel LHDs and trucks had replaced pneumatic equipment in all but narrow-vein gold mines.

During this period many base-metal mines were beginning to experience progressively more severe stability problems, including mining induced seismicity. This required a significant increase in the amount of ground support installed in order to maintain the safety and stability of the excavations. As a result, drift advance rates necessarily decreased as the necessary ground support requirements increased. At roughly the same time there was a major change in equipment away from pneumatic equipment, so the advance rates before and after this transition cannot fairly be compared and it is not correct to attribute the introduction of electric-hydraulic and diesel equipment to the drop in advance rates. In fact, the introduction of this large scale equipment made it possible for deep bulk mining operations to dramatically improve productivity, and so respond to the changes in global commodity prices as well as improve the safety of the workforce at ever-increasing depths.

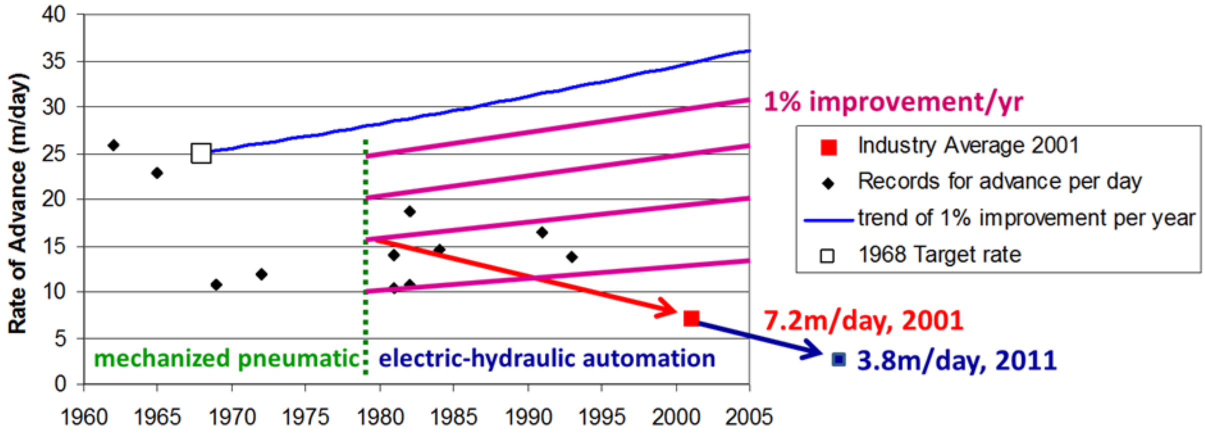

Figure 2 The graph shows historical trends in development rates in Canada, illustrating the decline in advance rates over the last 30 years

In any event, Figure 2 also shows the possible effect of a 1% per year improvement in performance, no matter the chosen target rate at the time, from around 1980 onwards. This contrasts sharply with the actual decline in performance the industry since that time. A survey conducted in 2001 (Graham 2003) gave a result of an average rate of 7.3 m/day and by 2011 this had dropped below 4 m/day.

Currently, the drift development cycle consists of four activities – removing the broken rock from the face (mucking), installing ground support, drilling the face (including the preparatory activities for drilling) and charging the holes with explosives and initiators. In the conventional approach to the development process, these four activities are executed sequentially using several different pieces of equipment, each of which must enter and exit the heading separately. In routine mining operations, the equipment units are often required to service several headings in different locations in the mine so that ensuring the availability of the right equipment at the right time can be very difficult. However, capital development is often on a preferred or high-priority schedule using equipment dedicated to the advance of the heading so as to maximise the active face time. Even in this case, the development activities have to be executed in sequence and the entry and re-entry of the equipment units constitute a loss of face time.

The first activity in the sequence is to remove the broken rock in the heading created by the previous blast; nothing can be accomplished until this is completed. Obviously, the size of the round – the area of the face and the depth of the round advance, determines the volume of broken material that has to be removed. For bulk mining operations the minimum drift size would be around 4.5-4.6 m square; a size of greater than 5.5 m square is currently common. The round advance can be varied depending on ground conditions, or shift limitations. Reducing the total amount of rock to be removed has a great effect on the total cycle time. The advance of a 3.5 m round per day equates to one cycle per 24 hours; if reducing the length of the advance to 3 m allows for two cycles per day, the daily rate increase to 6 m per day. In other words, to increase the average advance rate it is not necessary to reduce the time taken for every activity in the sequence – it is only necessary to reduce the overall cycle time so that it is possible to take two advance cycles (in this example) rather than one.

Because of the stability conditions that exist in the high-stress environments in hard rock mines below 2 km, the amount of ground support that has to be installed to ensure the stability of the excavation takes at least 8 hours to complete. One major effort to reduce the time to install adequate ground control measures was the development of thin spray-on lining (TSL), but to date, this has not achieved operational status. Currently, the ground support component is the longest single activity in the development cycle, and the activities of face drilling and face charging are of much shorter duration.

The sequential nature of the current process constitutes a very large component of the cycle time. The total time required to execute the essential activities is around 16 hours – leaving eight hours consumed in equipment relocation and other delays. If the cycle time can be reduced to less than 12 hours then the advance cycle can be executed twice in 24 hours rather than only once. This requires a new approach.

3 A new approach

The entire focus of the CEMI approach to drift development is maximising the utilisation of the face. If there is no activity at the face, no advance is being made. While the processes that are used in hard rock drift development are 'batch' or discontinuous processes, the primary objective is to ensure that there is always some productive activity taking place in the heading, excluding those periods where it is prohibited by mining regulations.

CEMI's intent is to introduce a protective canopy into the process, thereby facilitating parallel activities, rather than sequential. The canopy will allow the drilling and charging of the face to occur while the ground support is installed behind the face equipment. In practice the CEMI process involves two canopies; a front canopy to protect the face equipment and operators, and the support canopy to protect the ground support equipment and operators.

This approach is focused on minimising the time for the development cycle. Other approaches are focused on individual components of the cycle – such as longer round advances or reduced or phased ground support. These have benefits to offer but with development cycle times at around 16 hours, CEMI believes that utilising the remaining 9 in the day should be the primary focus.

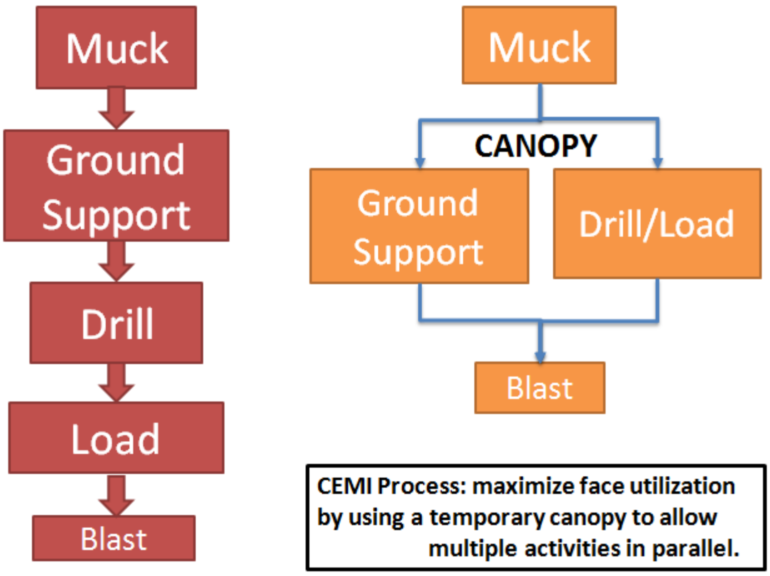

Figure 3 Shows the conventional approach to the drift cycle with sequential face activities, compared to the CEMI approach designed to maximise face utilisation by allowing for face activities in parallel

The front canopy has permanent screen attached to its top and sides, and unless damaged will remain in place on the canopy frame. The support canopy actually holds the mesh (standard support in deep hard rock mines) in place, so that the support crew is only required to install reinforcement elements such as rockbolts, rebar or split-sets, through the canopy in order to pin the mesh on the excavation surface.

Once the face mucking equipment leaves the heading the front canopy and the face equipment can move into position. The front canopy is designed so that it can contract, or partially collapse, and travel inside the support canopy to be positioned at the face and once it is located in front of the support canopy, it can expand to its operational size. At this point the face equipment – a modified drill jumbo - can also move through the support canopy and into place under the expanded front canopy. Finally, the ground support equipment can move in behind the face equipment, under the support canopy ready to install ground reinforcement. From this time onward the face equipment will be captive at the face until the ground support installation activity has been completed. If the face equipment is sitting idle at the face, waiting for the support process to be completed, then face utilisation is being reduced.

Hence, for this system to work and so maximise face utilisation, the drill jumbo has to be modified so that it also has the capability to charge the holes with explosives and detonators, and it must be equipped to carry a container and pump for the bulk explosive emulsion. The use of emulsion is a significant benefit to the face development cycle since the higher brisance explosive can provide better roof and wall control that will reduce damage to exposed drill booms. The emulsion also produces a muckpile with a smaller fragmentation profile. The higher cost of the emulsion explosive is easily compensated by the reduced time for ground support installation, for the ease of mucking smaller face material, and reduced damage to installed services – essentially, the higher explosive cost buys time during the rest of the face activities.

Figure 4 shows a conceptual layout of the canopy system and face equipment.

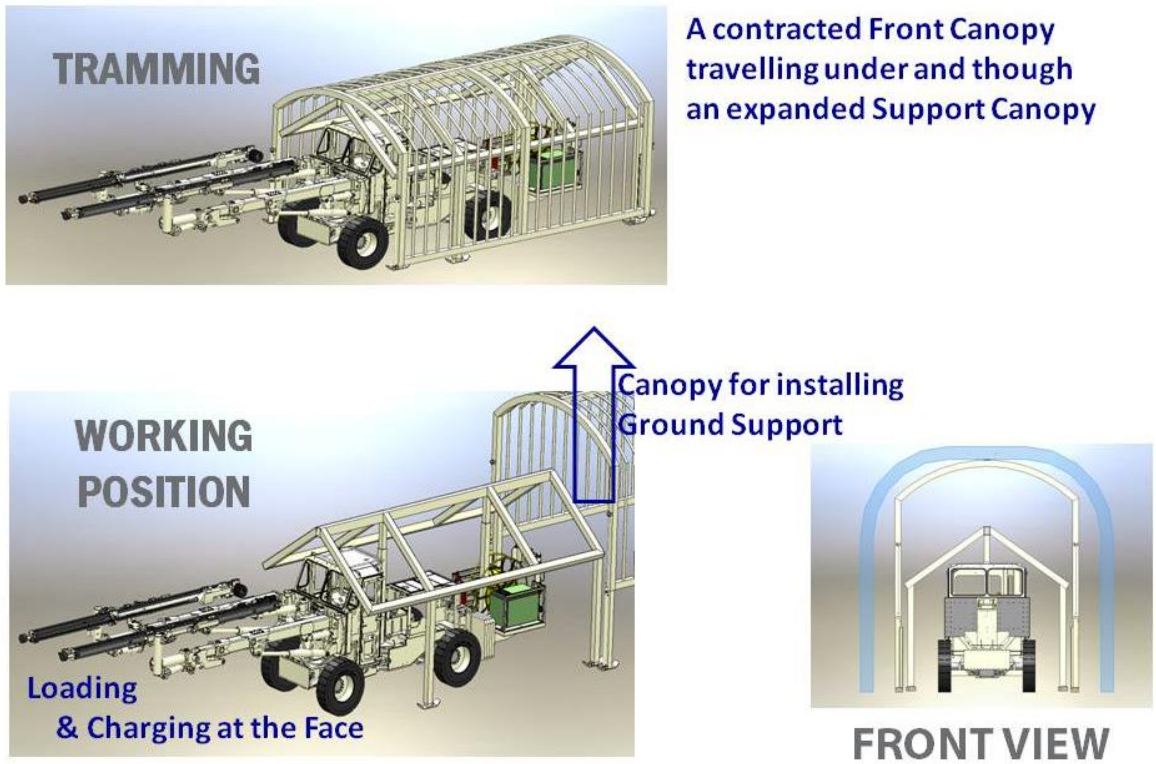

Figure 4 The conceptual deployment of the canopy system being developed by CEMI

4 Simulation results

The effect of the modifications to the development process were simulated by Labrecque Technologies (2013) using the Arena software, under the direction of H Parsons, A Akerman and S Haapamaki of CEMI. The simulations of a 5.5 m face showed that the base rate of advance was 3.14 m/day, but that using emulsion explosives would increase this to 3.51 m/day. The same simulations were run for a 4.5 m face to give 3.57 and 3.96 respectively, but by including hot-seat changes to the process the rates jumped to 5.01 and 5.56 m/day. The rest of the 4.5 m face simulations included these conditions, simulating the effect of jumbo-charging, the use of the canopy and the use of continuous mucking.

The simulation was used to experiment with several detailed variations on the use of the canopy and the results presented in Figure 5 are the best of these. There is a base case using the conventional activity sequence (with Anfo explosives), then four process modifications (a) using emulsion explosive, (b) using a canopy system to allow personnel access ahead of installed ground support, (c) using a modified jumbo to charge face holes with emulsion; and (d) the effect of continuous mucking in place of LHDs. These simulations were based on early version of the canopy systems and as the system continues to be improved we expect increases in the overall advance rates. Most importantly, after the functionality and destructive testing phases of canopy development have been completed, we expect the most beneficial modifications and improvement to the performance of the canopy system to be made during the initial field trials.

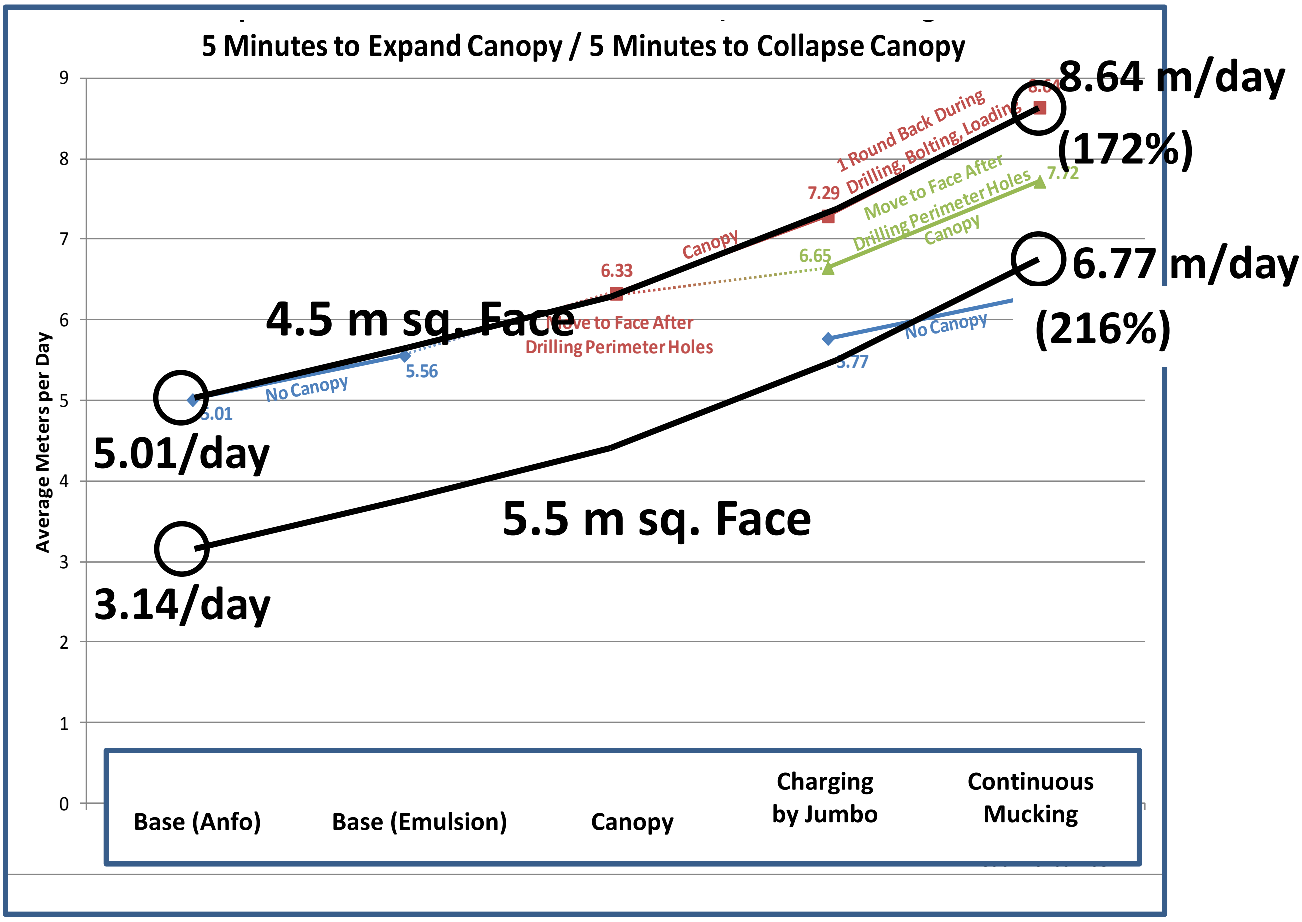

Figure 5 **Shows the result of the simulations for the use of four modifications to the development process, for a 4.5 m face, with an extrapolation for a 5.5 m face**

To date, the benefit in advance rate calculated by the simulation is shown in upper line for a 4.5 m face drift, increasing from about 5 m/day up to about 8.6 m/day – 172% the base case rate. Detailed simulations of the 5.5 m face drift have not been completed and although some aspects of drift development are made easier by the larger face, some are made more time consuming. Consequently, we have made an initial estimate for the performance of a 5.5 m face employing the combination of techniques described above, and the lower line shows a performance of about 216%, comparing the base case rate of 3.14 m/day increasing to almost 6.8 m/day.

The use of the larger, 5.5 m face drift is required for production systems relying on truck haulage to the main crusher (or other disposal site), first to provide sufficient flow of ore and secondly to allow sufficient ventilation for the trucks. CEMI has other projects that are examining ore haulage systems that will not require the use of trucks and can be accommodated in the 4.5 m face drift. The potential gain from such an ore transport system is that it would allow the transition to a smaller, faster capital development access.

Using the graphs in Figure 5, the performance of 8.6 m/day represents a performance which is 276% of the base case rate of 3.15 m/day – close to triple the current base case advance rate.

To use the example of a 5 km haulage drive to a new orebody, the impact of these changes is a reduction from the base case (about 1,600 days or 4.4 years to completion) to about 740 days to completion for a 5.5 m face and about 580 days to completion for a 4.5 m face. The amount of time saved is more than half of the base case, saving 2.4 and 2.8 years respectively, from the base case of 4.4 years.

5 Conclusion

Historically, the Canadian mining industry has seen much higher advance rates than those we see today, but the comparison is unfair. The stress conditions and mining-induced seismicity experienced by today's bulk mining operations were largely unknown until 30 years ago and the standards demanded by society for a safe workplace, including safer work practices, are justifiably much higher than before.

But the difference between advance rates of more than 20 m/day and those of today (just over 3 m/day) has a serious impact on the viability of new underground mining projects. Quite apart from the difficult ground conditions and antiquated work practices, CEMI believes that by making comparisons with the past we can see that something more has been lost. Current logistical systems have focused too much on the efficiency of individual activities, relied too heavily on economies of scale, and have paid too little attention to the effectiveness of the process as a whole. The total length of current development cycles are about 16 hours and the remaining 8 hours are lost to management logistics – the availability of people and equipment.

It is relatively easy to take issue with the actual techniques currently being adopted by CEMI, such as the canopy, or the details of any component of the development process presented above. This approach is in its early stages and many issues, such as intersections have yet to be resolved. If ground conditions are particularly difficult it may be that operators may have to return to conventional development processes. The system that is being developed with this approach will require several iterations to complete and a variety of field trials, including destructive testing, will be conducted in the second half of 2014.

But regardless of all of the alternatives that can be devised, the crucial step in making improvements to advance rates is not technological but philosophical – it is to recognise that no significant improvement in drift advance can be made unless face utilisation is increased significantly. The same is true for improving any other aspect of the mine production system. The current approach of trying to reduce the direct cost of individual components of the process has been taken as far as it can go, and is just as likely to increase the final unit product cost as reduce it. CEMI's approach is to shift the focus away from cost-cutting and towards cost-benefit analyses and process simulations that can objectively examine the effect of changes on the production process as a whole and will lead to a lean production process.

References

Graham, CB 2003, 'Is technology working for you?', in CH Graham & DM Morrison, *Proceedings of The 16th CIM Mine Operators' Conference*, Canadian Institute of Mining, Metallurgy and Petroleum, Westmount.

Labrecque Technologies Inc. 2013, *Advance Rate Simulations*, report to the Centre for Excellence in Mining Innovation by P Labrecque, Labrecque Technologies Inc., Sudbury.