AREA REPORT

Technological change in the Canadian mining industry

By Suzanne Dansereau

In Canada the mining industry's downturn in the early 1980s resulted in greater research and implementation of technological change into all aspects of mining so as to downsize the workforce and reduce production costs. The industry is therefore reaching new levels of mechanization and in some cases moving into the early stages of automation. Suzanne Dansereau gives a background to this process and makes a preliminary assessment of direction and the impact on labour.

Suzanne Dansereau is an Associate Fellow at the Centre for Developing Area Studies, Montréal, Canada.

Address: 3715, Peel Street, Montréal, Québec H3A IXI, CANADA.

Introduction

Since the early 1980s, the Canadian mining industry has reorganized several aspects of production in response to low mineral prices and rising costs. A central objective has been the reduction of labour costs through technological innovation, moving the industry towards greater mechanization, with ongoing research into further mechanization and even automation. While mining's physical constraints result in a lag between research and application, there has, nonetheless, been a degree of modernization resulting in important changes to the labour process.

Canadian mines have been mechanized for a number of years. Early stages of mechanization had moved the industry from a traditional organisation of mining based on hand-held tools and a simple division of labour underground. The current move towards further levels of mechanization and the move into the early stages of automation has been undertaken to overcome the extensive division of labour accompanying mechanized mining, the result of its reliance on a large number of different pieces of heavy equipment.

This division of labour had resulted in a multiplication of rigid job classifications. Currently, technological change is moving towards the use of integrated mining process and machines, coupled with remote control and computerized applications, to overcome these job specializations, organizing work within flexible broad job categories filled by multiskilled miners, accomplishing a wide variety of tasks.

This search for flexibility in the labour process is one of the most common features accompanying current applications of new technology. The objective is to overcome excessive job specializations by grouping tasks and job classifications, re-organizing shifts to allow for changes in the sequence of work and provide greater training on a wider variety of tasks and equipment. Yet, at the same time, this flexibility is facilitating the downsizing of the workforce. By eliminating what were previously protected job specializations and grouping tasks, management is given greater flexibility in assigning tasks to those remaining workers, thereby making downsizing more viable as those remaining workers can undertake a wider variety of tasks.

This paper will examine these questions by looking at current research into further innovations as well as applications and changes to the labour process in three sub-sectors of the Canadian mining industry. The paper will examine technological change not only in terms of current changes, but by looking at ongoing research directions will situate them within long-term industry strategy. The paper will also note the constraints in the application of these technological innovations resulting from the existing organization of mining, especially in the principal extractive stages of mucking, drilling and blasting, the cost of putting into place and testing new machines and methods, the necessity of re-training workers and continued low mineral prices. This paper will demonstrate that while research and applications of new technology are attempting to develop a completely remote controlled underground operation by eliminating the miner and the reliance on miners' skills, what they are currently achieving is a downsizing of the workforce which continues to produce a larger output as a result of significant changes in equipment and the way work is organized.

While generalizations are difficult in any analysis of the organization of production in mining as each mine is designed to respond to a specific set of physical and economic problems, this paper will illustrate several trends in the major fields of the Canadian mining industry. These fields are grouped into three principal sub-sectors: soft-rock mining, hard-rock mining and small-vein mining. Research, application and the reorganization of production and labour process will thus be described in each of these sub-sectors. Illustrations, arising out of the author's visits and interviews between 1988 and 1990, will describe general innovations and problems affecting each. Cape Breton's (Nova Scotia) coal mines are used to illustrate problems found in soft-rock mining, Inco's base mineral mines in Northern Ontario illustrate large-scale hard rock mining, and Québec's small-vein gold mining demonstrate the problems of technological innovation in small-scale vein-type operations, again in hard rock.

The study is restricted to underground operations and especially to the mucking, drilling and blasting stages in spite of the widespread changes occurring in all aspects of mining and milling. These areas were chosen as they are the most central and complex of the stages of mining production and because the nature of the labour process in mining has continued to be made up of workers who, in the past, had managed to remain independent and highly skilled in spite of the high levels of mechanization. While an in-depth study is required to assess the current impact on these skills, this is beyond the scope of this present paper. Instead the objective is to provide indications of future technological change and industry strategy through an examination of current research directions and to make a preliminary assessment of the impact of technological change on the organization of work.

Technological change: objectives and research direction

Changes in the international market for mineral products had a profound impact on the Canadian industry, pushing it towards significant reorganization. The recession years of the early 1980s instilled a sense of caution in most companies as they searched for greater productivity and this was compounded by slow growth throughout the decade. This search led to the development of new mining methods and machinery. In 1986, Inco, for example, had over 200 people in Sudbury and Thompson entirely dedicated to making improvements in efficiency, mainly through technological change. Some of this paid off and by 1990, Inco was producing 9% more per year than in 1980, while the workforce was reduced from 34,000 to 19,300.

This search for greater productivity has had a degree of success. The Canadian Mining Association calculates that overall productivity has increased by 40% between 1981-1986, attributable to a variety of factors including the closure of less efficient mines with lower ore grades, and production decisions based on the extraction of only higher grades.

The emphasis on the extraction of higher grades is resulting in shorter expected mine lives for both new and existing mines, with a pressure towards increasing mine workers' mobility. The result has been an aggregate drop in mining employment, affecting all job categories, including engineers and middle management, from 100,500 nationwide in 1981 to 76,600 in 1988.

This search for greater productivity through new technology has focused on greater mechanization to extend the speed and strength of machines, and on automation to increase the capacity for greater control and information processing by machines and computer programs. An area of great interest has been the integration into a single process of the three main underground operations: mucking, drilling and blasting and a move away from traditional mining methods.

Mining methods vary from mine to mine, yet certain generalizations can be made. We can speak of a 'traditional' mining method and labour process that were widely used throughout the industry prior to large scale mechanization as the organization of labour underground varied little from one type of mine to another, i.e. between soft rock mining, base metal hard rock mining and even small vein mining. Traditional mining is characterized by a low level of worker specialization as most underground workers eventually accomplished all underground tasks, with little differentiation between job titles. Extraction was done by a team of 2 miners, usually one being the leader and the other the helper, who worked together in a small chamber or stope, dividing the tasks between themselves from mucking (removing the rock from the previous days' blast), installing roof support, preparing and drilling the face, and loading explosives. A significant amount of planning was involved in the organization of tasks, equipment and, after assessment of rock, in the preparation of drilling and blasting sequences. There was little supervision as the job was marked by significant worker autonomy in the organization of work. Instead of direct supervision, control was exerted indirectly by a payment method based either on a bonus system, as an incentive to production or on a sub-contracting system in which miners bid for particular tasks or places of work.

The move away from traditional mining with the advent of mechanized mining has resulted in the division of these tasks into several separate jobs with specialized muckers, drillers and those who installed the blasting devices. Within these broad categories, several other specializations emerged ranging from separate titles for each of the drill handlers (i.e. longhole driller, jumbo operator), to the type of mucking machine operated (i.e. load-haul-dumper or slusher) and even to the underground area (i.e. driftman, stopeman). The timing of mechanization varied according to several factors including the development of the appropriate technology, the type of ore and rock, the nature of the market, the level and concentration of capitalization and control in each of the industry's sub-sectors.

Current research and technological innovation aimed at the automation of mining is attempting to overcome this problem by developing a continuous mining process, through the construction of a 'continuous miner', integrating all these functions into one machine. This includes eliminating the blasting stage by breaking the mineralised ore away from the rock face with the use of shearers in a continuous mining machine. The ore then falls onto a conveyor belt integrated to the shearer. There are several advantages to the use of such a continuous machine. By eliminating the blasting stage, the risk to underground personnel is reduced as rock control is generally made easier, allowing for smaller and cheaper support pillars to be left underground. It also eliminates certain side effects like fumes and problems associated with the handling of explosives. Most importantly, the high cost of organizing the various stages of drilling and blasting is eliminated as production is no longer interrupted and reorganized between each step. Other advantages also accrue: rock cuttings are more uniform in size making it easier to use continuous loading equipment; this also reduces the cost of muck transportation and ore processing. Finally ventilation requirements are reduced by the creation of smooth opening walls.

The development of the continuous miner will greatly facilitate automation as it will be easier to attach sensors and the 'intelligent' computer programmes currently being developed. The development of sensors on underground equipment, including on the continuous miner, is one of the main areas of current research as it would allow the operation of under- ground equipment by remote control from the surface, contributing to the development of a manless underground operation, especially when done in conjunction with advances in computer programming. These advances aim to substitute the operator's decision-making capabilities by the use of "fuzzy logic", allowing the increasingly sophisticated machines to adapt to changes in underground conditions. Thus not only would an operator be superfluous but his capacity to make decisions and evaluate the varying underground conditions would also be eliminated.

Both the research and application of new technology vary from sub-sector to sub-sector according to a series of factors including the nature of the rock and ore deposits, costs of developing and running a new piece of equipment and ultimately its impact on profitability. As research and innovation are taking great leaps forward, we are seeing a growing differentiation among sectors of the industry and even between individual mines as some are more able to make use of this new machinery than others.

For example, continuous mining machines have been successfully applied in soft rock mining, especially in coal, but the hardness of the rock in hard rock mining has led to disappointing results. The narrowness of the tunnels and veins in small-vein mines has made the installation of continuous miners and other large-scale equipment uneconomical. Thus soft rock mines tend to be more technologically advanced than hard rock mines, and the hard-rock mines tend in turn to be more capital intensive than the small vein mines, allowing bulk extraction while small veins require smaller scale equipment. In many cases, small vein mines are older, relying on traditional mining methods and older machinery. Some however, because of the nature of their geology have been able to benefit from some of the advances in other areas, putting into place some aspects of bulk mining methods.

The following will therefore look at the two principal categories of mines - the soft rock and the hard rock mines, examining in both cases the technological advances that are specific to each, the reorganization of production and changes in the labour process. In the case of hard rock mining, reference will be made to vein-type mining and the special circumstances which require the same high quality equipment required in hard rock, but adapted to the smaller-scale mines.

Soft rock mining - technological change

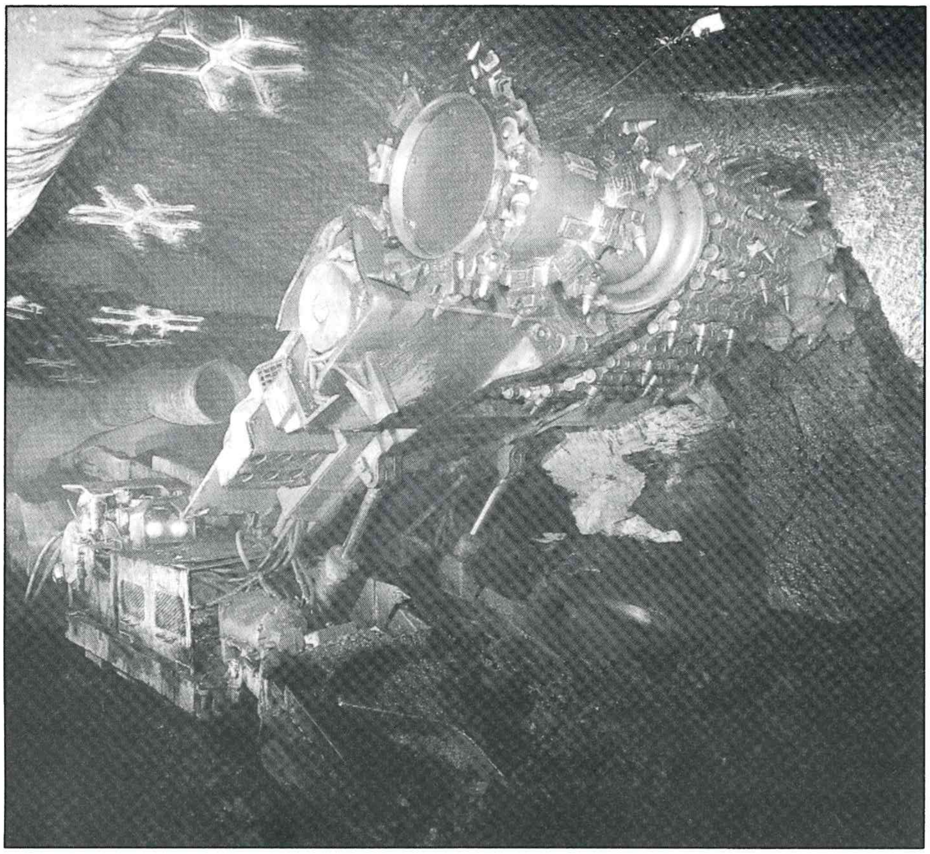
Changes in technology and the organization of production in coal mining, the most prevalent example of soft rock mining, can be grouped into four broad stages, each accompanied by a specific organization of production.

The first, the handgot method is an entirely manual extraction method using picks and shovels with an organization of production corresponding to traditional mining. The second was a simple form of mechanization which saw the introduction of the 'longwalling' method, replacing the small rooms by long faces following the ore body, measuring hundreds of feet and extracting by drilling laterally into the mineralised body. Picks were replaced by an undercutting machine and pneumatic drills. Mucking was done by hand-loaded conveyor belts. Roof support became more complex given the size of the face and the larger equipment. Wooden supports had to be supplemented by steel arches, and sometimes cement filled. The greater complexity of this organization meant that different shifts did different stages of the work, repeating the pattern every 24 hours.

A third method came about with complex mechanization as the undercutter was eliminated in favour of the shearer and with the addition of the power loading machine. This mechanized the loading of ore onto the conveyor belts, marking the beginnings of a continuous mining machine. All tasks were re-integrated into each shift, eliminating shift specialization.

The popularity of the continuous mining machine in coal mining is now uncontested. As early as 1976, it was being used in 65% of underground coal mines in the US, in part because it was adaptable to a variety of mining methods such as the room and pillar method which then made up 90% of coal mining organization in the United States as well as to the shortwall and the highwall methods. The

The cutter drum of a continous miner preparing to sump into the coal wall.



continuous miner did not however integrate all underground tasks. Other tasks continued alongside: changing the place of the machine, roof bolting prior to the development of hydraulic roof support machines, and tasks associated with the ventilation of methane gas.

This problem was somewhat overcome with the development of yet another method: retreat longwalling, developed in conjunction with the continuous longwaller and the moveable hydraulic roof supports. The wall no longer advances away from the mine opening, instead the two service tunnels are developed to their full length, the continuous machine is installed and production then backs-up or retreats towards the mine opening. The advantage is that the roof and tunnels are allowed to collapse once the continuous miner has finished the cut. The cost of labour, material and especially the amount of space and other ventilation problems are reduced as the total area kept open and ventilated is much smaller.

Other problems persist nonetheless, leading researchers to claim that they can no longer be solved by further mechanization, but through automation. Many of the current attempts are aimed at automating one function at a time, the most important of which has been the application of robotics to the continuous mining machine and to the roof support systems by including guidance and monitoring systems to existing machines.

A more systematic approach is sought as well by efforts to develop a fully operational automatic longwall mining system which would not only allow for control from outside the face but would eliminate the need for a miners to guide the machine through the fluctuations in ground and ore conditions. Successful experiments have allowed a more fully automated machine to record the main operational parameters of the continuous miner: position along the face; direction and speed of travel; position of each arm with relation to the machine body; longitudinal and transverse gradients; oil and water pressure; power uptake by the motors; various temperatures, i.e. motors, oil, etc.; and the status of various monitoring and safety circuits. This system is coordinated with the roof support system to advance along with the shearer while monitoring the mine environment. Further advances include the installation of sensors and monitors on these robotic tunnelling machines, thereby increasing the machines' accuracy as continuous data is fed back to operators relating to specified tunnel line and grade through the use of laser centre-line reference systems.

These advances are limited by the continued necessity of obtaining a complete reference cut manually, after visual assessment by a miner who then records it in the computer. The automated machine can then repeat the pattern. Research in computer programming is trying to overcome this reliance on the miner's skills by developing "fuzzy logic" which imitates the human thought process and expert systems which guide machines from a knowledge base and broader rules of operation rather than a data base alone. The knowledge base and rules of operation are derived from a human "expert", which attempts to integrate the human's capacity to use 'rules of thumb' rather than absolute 'yes' or 'no', allowing greater flexibility of functioning, capable of being amended at any time, so that new or modified knowledge may be incorporated. In this way, they can become increasingly more effective as experience can be accumulated by the machine and its programme.

These new programmes are being adapted to the continuous mining machines so that they are not only "programmed" (i.e. automated) but "intelligent", thus eliminating not only the need for the miner to plan the initial cut but allowing the machine to adapt to changing rock conditions. With programmed control, a machine is controlled by a fixed script or command list which is executed in a fixed order; the target values for the machine and its appendage positions are placed in a list and executed in order without alternation. Intelligent control, on the other hand, alters or rewrites the script based upon the analysis of the current circumstances derived from sensor data and a programmed knowledge base. It is the use of current circumstances to alter the next and subsequent machine actions that makes the machine intelligent and thus able to operate autonomously.

This last development considerably advances the machine's capacity to replicate the miner's skills in the evaluation of ground conditions and consequently to modify production, and thus considerably assists the movement towards greater automation. Current, "The operator must guide a cutting machine tool within a coal seam following a plan that can be altered by local conditions and events." The future task of autonomous or expert systems is to develop programs that will tie all of these data gathering and information processing functions together in a complex computer system, "representing the human operator's capabilities".

Soft-rock mining: organization and labour process

Changes in soft rock mining have gone the furthest in all the mining sectors and reorganization has taken place in response to mechanization over a number of years. Yet changes are still ongoing and while there is a lag with the research presented above, we are seeing the beginnings of automation in this sector of the industry.

Soft rock mining, and especially coal mining has long ago left the stage of traditional mining, replacing it with a labour process made up of a highly stratified division of labour with a large number of job classifications. Current changes are attempting to move away from this stratification towards a grouping of jobs, greater flexibility in the allotment of tasks and modifications in training.

The study of changes in this sector comes from the Cape Breton coal mines in Glace Bay, the principal mining area of Cape Breton which the author had a chance to visit in 1988. These mines have the advantage of using not only relatively sophisticated technology, but Cape Breton coal mining has a long history, allowing us to gain information on the changes that accompanied the introduction of new technology.

There are currently three operating coal mines in the Glace Bay area, owned, since 1967, by the *Cape Breton Development Corporation* (DEVCO), a Canadian government crown corporation. These are the Prince, the Phalen and the Lingan mines, all of which have been using the longwall method since the mid-1970s, but only the Prince uses the retreat longwall method. Retreat longwalling was first instituted in Cape Breton in 1959 but was unsuccessful because of the steep qradient of the seam and the resulting overly slanted floors, making the use of retreat longwall mining and the current models of high capacity continuous miners too difficult to use. They are however using a tunnel borer for the development work of a new mine. In response to the problems of the slanting floors, Devco is developing an in-seam machine which would produce significant savings as it is smaller and can better follow the gradient of the coal seam because it can go uphill. It has only one shearer and makes smaller rectangular tunnels rather than the higher arching ones.

Prior to the longwaller, the Cape Breton coal mines were primarily using the room and pillar method, a traditional mining method. Each team did all the tasks, from preparing the wall, evaluating the initial cut, drilling, loading coal into the cars, squaring the timber and installing the roof supports, as well as managing the equipment. The teams were made up of two men who decided on their division of labour. They worked on a contract system based on a payment per box of coal from which was deducted on a regular basis, a wide-range of expenses including the doctor, the relief society, the hospital and the church. Out of this they also paid the check-weigh-man (the checker) who weighed their output. They worked without supervision, seeing a checker only once a month. All of the teams worked the same way with only a few other categories of workers such as the shot loader, the roadmaker and the trammers who pushed the coal cars on tracks to the ore passes. There were two shifts a day, each doing the same work.

When the early longwallers such as the Dosco Miner were installed, the miner's job was significantly changed, becoming more differentiated, with a daily wage, supplemented by a production bonus, replacing the contract. The face was now 500' long and the new machines required three separate shifts to accomplish the various steps: one shift would move all the machinery, another would put in roof support, and the other would operate the longwaller. There were a series of new jobs with muckers, roofers, as well as new categories of supervisors as supervision increased, requiring that they visit job sites about once a shift.

Currently, production has become more streamlined with further mechanization and automation. The longwaller now has its double shearer integrated with hydraulic jacks for roof support and with the mechanized conveyor belt operating throughout the mine, transporting ore to the surface. Rock and coal is no longer shovelled onto the conveyor belt but manpower continues to be needed to monitor the movement of the coal at the intersections of the different belts (i.e. as they turn corners). The shearer moves along at about 5 or 6 meters a shift, with the face team repeating the cycle each shift. Greater efficiency has been reached as the Phalen Mine was opened to replace No. 26 Colliery and the new technology used at Phalen allows it to produce twice as much coal with half the workforce.

In spite of this greater integration of production, differentiation of tasks grew. Jobs are now far more diversified and, while many jobs have been eliminated such as the very early scraper operators and muckers, many more new ones have been added, especially those linked to the operation of the longwaller and with the application of computers underground.

The team on the face is now made up of 4 workers: 1 shearer operator, 1 roof support jack operator, 1 mechanic, 1 electrician. A panel operator is also part of the team, he remains in one of the tunnels (i.e. the bottom deep) to monitor a series of machines including the computer which moves the roof support jacks along by remote control. Supervisory personnel have now been added as there is also a team supervisor and a wall manager. (The wall manager travels between the two working walls of the mine and the third wall then in development.)

A greater number of support jobs continue to be needed, including pipe layers, equipment service personnel, ventilation technicians, development workers and construction crews. In addition, the new in-seam machine requires a more diversified team as well as requiring two alternating operators, and a team of 4 or 5 roofers to come along after and install roof supports. Devco is currently attempting to move away from this large job differentiation and increase the flexibility of its workforce by obtaining union concessions in the allocation of tasks, especially as it pertains to the face team, i.e. to the men working on the longwaller. The collective agreement dated March 26th, 1987 clearly demonstrates this move. It states:

> All men scheduled for the team, excepting the electricians and mechanics, on such a longwall face should be capable of brushing, extracting staples, driving advance headings, cutting machine operation, advancing conveyor and jacks, timbering and carrying out any other work required to achieve maximum machine utilization.

The greater duplication of skills and flexibility this allows the employer in allocating tasks is linked to the company's strategy of substantially downsizing its underground workforce at a time when the number of tasks is increasing as a result of this latest phase of mechanization. There is therefore an important incentive for employers to have lesser employees but ones who can fulfil more of the required tasks needed to assure the maximum use of the large and expensive equipment. It will also allow them to reassign personnel more easily as new developments in equipment become available, especially as the longwaller is automated further and sensors and computers applied to its functions.

At the same time, the company is making use of changes in the distribution of tasks to intensify the work itself by eliminating the system under which workers would be allotted a certain amount of tasks and, once these are complete, their workday would be ended. This has recently been eliminated however in favour of a system in which the shift must be fully worked, irrespective of the specific tasks allotted. This has reduced workers' incentive to accomplish tasks quickly and according to some this should mean an increase in safety, but to others will eventually lead to greater health problems as men are underground for longer periods at a time.

Accompanying this is a second management strategy involving a new training program aimed at making employees more interchangeable in their capacity to work on the longwaller. It is especially aimed at the growing necessity of overcoming the increasing specialisation between miners and equipment support staff resulting from the use of increasingly sophisticated equipment. This is aimed particularly at the men on the face team who will all be trained to obtain low-level certificates as mechanics and electricians. While this does not aim to eliminate the current mechanics and electricians, all members of the face team including the shearer operators will be expected to 'troubleshoot', spot problems more quickly and identify repair needs.

This new training program is described as a functional approach to training and employs a self-learn, self-paced method, providing the student with easily understood manuals as the primary learning tool. The manuals are developed and written by Devco employees who are trained as 'writers' to produce the material in the required format.

Seventeen Devco miners have thus been trained as writers to prepare 500 manuals on all aspects of their work. The courses are made up of detailed descriptions of work content written down in extensive detail in modular form so that the details on the work content can be transmitted easily to other workers. Each task is thus broken down into it's smallest component so that workers can easily absorb the details of all the tasks. While it is not expected that each underground worker will be able to adequately do all jobs, each will know a far broader range of tasks and become increasingly polyvalent and flexible.

A further objective of these courses and the modules is to improve quality control as the modules are written in such a way as to provide narrower specifications or parameters within which the task should be accomplished or the machine used. This will contribute to greater regulation of each of the tasks.

Thus the courses attempt not only to increase worker flexibility by enabling them to accomplish a more varied range of tasks, but more profoundly by having experienced workers write down their job contents in this form, it gives em-

Continous Mining Systems (CMS) in Sudbury, a subsidiary of Inco Ltd, designes and manufactures advanced equipment for hard-rock mining. Photo shows a CD360 S underground drill.

ployers partial access to that accumulated knowledge in an accessible form. We note therefore a replication at the level of training and manpower development of the advances being made in automation. While developments in computer programming are attempting to replace workers' detailed knowledge of underground conditions and decision-making processes, this form of training will facilitate such a process by transferring to detailed modules, a breakdown of work content into it's most detailed forms so that it could be transmitted not only to future trainees, but translated more easily into computer programmes, especially if "fuzzy logic" programmes reach the stage where they can successfully direct a machine using "rule of thumb" guidelines.

Hard-rock mining: technological change

As noted earlier, mining in hard rock, and especially in Québec and Canada's hard pre-Cambrian shield, poses distinct problems in the mechanization and automation of production. While many of the advances already described are applicable to hard rock mining, current efforts at mechanization are attempting to adapt some of these machines and techniques to make them economical in hard rock. Thus research directions in hard rock are aimed at developing mass extraction techniques using bulk mining methods and bigger and better drills, integrating the drilling and blasting stages into a continuous process by developing a continuous mining machine viable for the harder rock, and adapting sensors and computers to underground equipment to permit remote control and automated operation.

Mechanization in hard rock small vein deposits must respond to specific needs of the industry. The need to limit the dilution of ore to waste material by following the vein requires equipment which is more flexible, smaller and more precise, yet still strong enough to tackle the hard rock. Research is aimed at the miniaturization of machines developed in other mining sectors. Since the primary problem is the hardness of the rock, thereby limiting the viability of shearer-type continuous mining machines, advances in this sector and changes in mining methods have paralleled improvements in drill technology. Traditionally, the most widely used drill was the hand-held jack leg drill, requiring the miner to start the hole and provide leverage as the drill is pressed forward. The organization of work accompanying this technology is simple. A small team of miners, made up of from 2 to 8 men, depending on the size of the ore body, accomplish all the tasks during each of the shifts, using essentially traditional mining methods. Advances were 8' per shift, the length of hole permitted with this technology.

The fan drill is one of the first in a series of larger and stronger mechanical drills. It rested on a platform of hydraulic lifts which raised and stationed it. Two hydraulically operated booms (or drills) were placed against the mine wall, drilling a fan-shaped ring of holes overhead about every five feet. In addition to its strength, it drilled longer holes, up to 100'.

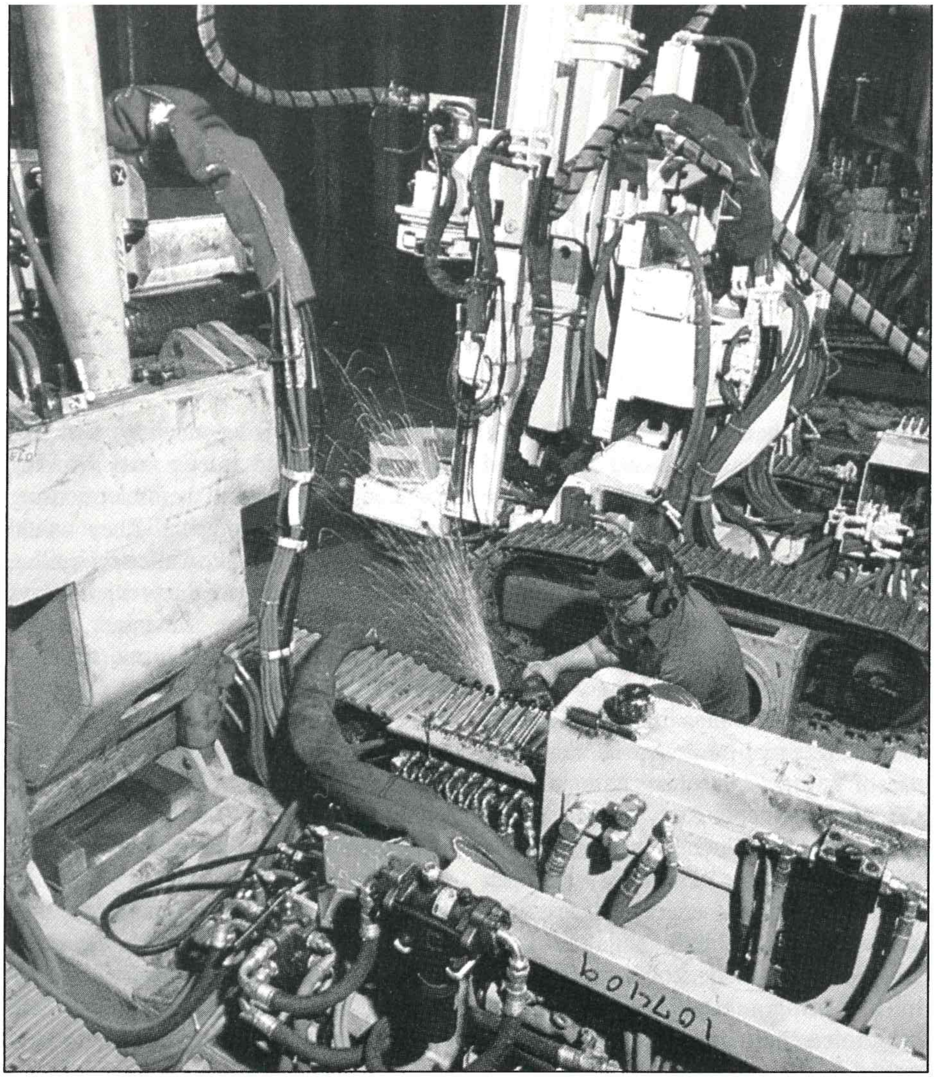
This led to significant changes in the organization of production. Since the holes would now take longer to drill and the areas to be drilled were larger, the miner's job was divided into different tasks, contributing significantly to job differentiation. When the required pattern of holes was complete, the driller would move into the next area, while different workers would accomplish the other tasks such as loading explosives, installing roof supports, and removing the muck. Shifts became differentiated with most production done on the day shift, while the night shift was reserved for supply and servicing.

Finally, the advent of the jumbo hydraulic drill, also a form of longhole drill, allowed the development of truly bulk mining methods using mechanized undercut and fill with stopes 40' wide and 100'-250' long. These drills are entirely mechanized, mounted on a trackless vehicle and operated by a single driller who drives the vehicle from one stope to another. Many can be operated by semi-remote control in which the operator retains visual control but can operate it from a distance of about 25'-50'.

The development of the more precise in-the-hole drill, also a longhole drill, which could drill to greater depth with greater accuracy, allowed the development of vertical retreat mining using the "largest panels anywhere" - 40'wide, 40' long and 400' deep. Levels are now opened only every 400' as 8.5" diameter in-the-hole drills drill down 400' at a time. Blasting occurs during the night or on Saturdays when only a skeleton crew is on hand. Mucking is done at the bottom of the panel, at the next level 400' below with scooptrams or continuous loaders.

Other areas of mechanization have included drastic changes in mucking equipment, contributing to significant savings as massive amounts of rock are moved by fewer workers. Mucking has progressed from the shovel to the slusher, and most recently to the scoop trams or load-haul-dumpers (LHDs). These are mechanized, trackless vehicles introduced in the 1960s that remain the main means for moving ore in most hard rock mines. Significant research is still going on to develop high-speed mucking machines, loading machines such as the osciloader and conveyor type machines which could then be integrated more easily into a continuous miner.

Research into other forms of mechanization are now attempting to develop the continuous miner and the continuous loader for hard rock. Problems associated with continuous miners in hard rock are linked essentially to the cost of operating shearer-type rock breaking techniques to the hard rock as the rock's hardness wears out the cutting or drilling mechanism too rapidly, making it uneconomi-



cal. Research is aimed therefore at developing harder drill bits, steel discs, and other impact devices. Other areas include improving machine design to obtain a better combination of strength, mobility, flexibility and size. Machines such as the tunnel boring machine, the mobile miner and roadheaders are all being adapted to underground hard rock mines, with varying degrees of success.

Yet their continued high operating cost and inflexibility is prompting research into improving the far more flexible and smaller in-the-hole drill by increasing its strength and accuracy. Accuracy is considered "the most significant drawback hindering quality assurance in modern underground mining", and attempts are being made to attach a laser detector and a micro-processor to the in-the-hole drill, to the jumbo drill and to roof bolting to calculate and correct drill deviation. In addition, this new technology is capable of continuing to operate the machine without the operator once it has been set up. The operator's job would not be eliminated but substantially changed, requiring that he design the drilling pattern and sequence. Optimum results would be achieved, according to one researcher, by a combination of operator and computer working together, allowing for human intervention in the case of the "unexpected" that always occurs under- ground.

Other computer applications attempt to go further and eliminate the operator completely by adapting expert systems to the drilling activities, to give it "drilling intelligence". These drilling machines would have the capacity of making decisions by controlling operating parameters to meet pre-set drilling objectives. This is one of the most difficult mining operations to automate, as the level of sensing and intelligence necessary to handle exceptions in the highly variable underground environment is sophisticated and underdeveloped at present, as it still requires, as in soft rock mining, the development of the appropriate sensing and 'intelligent' computer programs.

More successful has been the adaptation of computers to mucking operations which has allowed a degree of operator-control from a distance. The objective in robotising LHDs is eventually to allow for complete remote control, replacing current partial forms that are widely used but require the operator to retain visual control of the operation and the machine. Applications of computers and sensors would allow miners to operate more than one machine at a time, and to better monitor the machines' maintenance requirements. Such advances would process data to determine location, follow the drift and center lines, plan paths between dump points and ore passes, compare sensed position with planned position and initiate appropriate control commands, sense vehicle operating status and vehicle health, key on features or targets for special tasks like high speed turns, perform end of travel tasks (loading and dumping), and detect and avoid obstacles.

Specialised machines are also being developed for small vein mining in addition to usinq equipment and methods developed for the larger scale industry. One such attempt involves the "Machine Roger", developed by a Val d'Or (Québec) based company, currently operating as a vertical excavation machine, and adapting it for horizontal use. Vertical excavation is currently done by pneumatic hammer which it is estimated, once modified, will have the capacity not only to break the hard rock but have the flexibility to follow the uneven vein. It will also eliminate the blasting stage and integrate a continuous mucker. Other adaptations include computer modelling and expert systems and adaptation of sublevel stoping mining method for narrow veins.

Hard-rock mining: organization and labour process

The use of bulk mining methods and various forms of longhole drills and LHDs is currently widespread in the Canadian base metal industry, replacing traditional mining in most cases. Many small vein gold mines continue to use early forms of mechanization with the jack leg drill and somewhat traditional mining methods, but in some cases, their geology has permitted the application of new equipment and bulk extraction methods.

While the level of automation and mechanization is not as far advanced in hard rock mining as in soft rock, especially as regards the integration of the stages of production, many employers are using advanced mechanization and some early forms of automation with the application of computers to jumbos and other drills and partial remote control operations. There have been attempts to make use of the continuous miner in hard rock gold mines, but so far these have not been viable. Parallel to this, mine managers are reorganising work in order to achieve greater flexibility. They are changing the make-up of work teams and shifts, modifying classifications in order to achieve greater flexibility in the assignation of tasks to miners, as well as bringing about changes their training programmes.

The author had the chance to visit mines in both Northern Ontario and in Northern Quebec, an area made up of several base metal mines, large gold mines and many small vein gold mines. Unlike the Cape Breton mines, the experience of mechanization is more varied in this region given the more varied geology and pattern of ownership. Nonetheless, and in spite of the large geographical areas divided by language and provincial boundaries, the region is a sub-economy integrated as a result of its own rich mining history and the significant movement of both miners and mine management between the two provinces.

Ownership ranges from the largest of the Canadian multinationals such as Inco and Noranda, each owning several mines, to smaller companies owning a single mine such as Sigma. Organization of production varies as well. There are large base metal mines such as Inco's North Mine, in Sudbury Ontario, using vertical retreat mining with panels measuring as much as 40' wide by 40' long by 400' deep, using jumbo drills, osciloaders and down-the-hole drills. At the other end of the scale, several small scale gold mines using jack leg drills and equipment on track such as Pierre Beauchemin and Goldex can be found readily around Rouyn Noranda and Val d'Or and areas further north. Their lifespan is often much shorter, while mines often open or close according to the fluctuations in the price of gold.

Several gold mines in the area are far more substantial however and can make use of advanced mechanization such as the Doyon mine, in Rouyn-Noranda, operated by Lac Minerals in joint-venture with Cambior Inc. Previously an open pit, when it opened underground, it used a combination of bulk and traditional methods. One section of the mine uses bulk mining methods with jumbos, longholes, and partially remote-controlled LHDs. Another portion with narrower veins is organized traditionally using jack legs and stopers. Doyon recently introduced a computerized down-the-hole drill that would automatically drill the longholes once the machine was set up by the operator. The two zones operate semi-independently, linked by mucking operations and a common management and workforce.

Given the geology of gold mining, this combination is not unusual. Hemlo mine which uses bulk mining methods, also has to adjust its mining methods when it encounters the smaller veins. Another, Kiena, as discussed above, is attempting to use the most advanced technology by installing a tunnel borer, thereby replacing the jumbo drills, yet it is also looking for smaller more flexible machinery to deploy in areas where the ore body is narrower. There are also several mines, such as the Pierre Beauchemin mine, which continue to use only traditional methods.

Overall, the move has been away from traditional mining as described by a Québec miner based on his experiences from the Matagami Copper mines during the 1950s. Small chambers or stopes were mined by two miners, doing all the tasks, working independently, with the jack leg drill and stopers and mucking the area they worked themselves, using either shovels or scrapers. They would wash down the muck, walls and ceiling to dampen fumes from the previous' days explosions, equalize the muck, use a scraper to move some of it out, scale the walls and roof, install roof supports, mark the face, drill the series of 8' holes, load the dynamite, ending their shift when they had prepared the area to receive the backfill. They would organize their own work day so as to advance the required 8' sections daily by 'getting their round', with little supervison, then leave the mine once the work was done. In the case of the large ore bodies, usually base metals such as copper and nickel, the organization of production was essentially the same but with larger teams, up to 8 people in some cases.

Bulk mining methods are now widely used throughout the region, prompting a growing division of labour and differentiation of work into multiple teams with greater shift specialization in many mines. The example of the Doyon Mine is used here as it is representative of the organization of mines using bulk methods and modern equipment in hard rock. Firstly, in it's zone using bulk methods, the drilling is done either by a jumbo operator whose work consists of operating a single machine all day, either the jumbo or another of the longhole drills such as the down-the-hole drill, drilling the series of holes required. In the case of the jumbo drill operator, he would then drive the machine to another drill face. The long hole operator, a more stationary function, proceeds only from one hole to the other, continually drilling a series of long holes in a row, within the same area. The drillers are followed by the "scissor team" working on a platform truck (i.e. a scissor lift), using jack legs and stopers to install roof supports and load the dynamite. They also do several other tasks as well, including pipe laying. They travel from one area to another throughout the work day. Down-in-the-hole drillers, working in a level where roof support had been laid during its development, are followed by a longhole blaster who prepares the area for blasting and loads the holes. Blasting goes on at the end of each shift. Mucking is done by a different team of workers, working in different areas of the mine, operating LHDs, some of which are partially remote control, especially in the more dangerous areas. Much of this equipment has been modernized as well with the application of diesel, hydraulic and pneumatic technology which increases their speed and capacity.

The shifts vary according to the type of work being done. For the face teams - i.e. drillers, rock bolters, and blasters, shifts schedules are determined by the need to accomplish certain tasks before blasting at the end of the shift, at which time everyone must leave the mine for a number of hours to allow explosion fumes to dissipate before the next shift comes in. Shift hours are usually 8:00-16:00, 20:00-4:00, leaving 4 hours between shifts. The mucking teams are not cyclically regulated by the demands of the blasting cycles, and instead have twelve hour shifts - 9:00-20:00 and 20:00-8:00. Each group also has a different sequence of work and holidays. Both groups are now expected to move from site to site within the mine until their shift is finished, unlike traditional mining where workers could leave the mine once the tasks completed. This new system requires an increase in supervision, as supervisors must now direct workers to the different sites and coordinate the sequence of work teams and equipment needed. Supervisors check all work teams and production sites about once or twice a day.

With this large distinction in jobs and work schedules, job allocation had became rigid, regulated by a series of job classifications with a very narrow task content. In some cases, there were as many as 32 separate classifications in the underground production department alone and these were protected by the collective agreement. For example, at the Agnico-Eagle mine in Joutel, there are 24 underground classifications with separate classifications for driftman, raiseman, longhole driller, shaftman, and stopeman. These are all drillers of one form or another, yet operating more than one type of equipment with a very different organization of their work day. Job stratification was increased with the introduction of each new machine and mining method as they would each require new classifications.

In the 1980s, management strategy to achieve greater efficiency used a combined push for further mechanization while downsizing the workforce. Like the Cape Breton mines, mine managers in several of the hard rock mines visited looked for a way to distribute the wider variety of tasks to a shrinking workforce. Thus we see in several mines a move away from rigidly defined job categories to a wider, more generalized grouping of categories.

The most common movement is towards a looser system with only two broad categories: the miner and the support worker. In effect, this becomes one large category as it groups all underground production workers, except the support workers, otherwise called utility men whose main function is to provide support to the miners by moving material around and bringing supplies underground. Within this large category of miners, there is often found a ranking, called classes, based on skills.

In 1983, Inco's Sudbury mines instituted this type of classification. Underground workers were now classified as Production Miners, ranging from Class I to IV, with Production Miner IVth class reserved for support staff. Inco termed this "job enrichment" as job classifications were grouped and miners now did a wide range of jobs which had previously been spread over several job categories. When Doyon opened its underground operations, it grouped underground production workers into two categories: miners (without grades or classes) and utility men. Both groups receive the same hourly wage and were included in a same seniority list.

Bousquet Mine, also in Northern Québec, modified its system of classification as it moved from Bousquet I to Bousquet II (i.e. opening a second more modern production area in the same vicinity). Classifications were reduced from 23 categories to one category of miner with a 1-2-3 class system.

In Inco's case, this classification has been found to fit best in its more modern mines, and with younger workers who are more receptive to change. In general, the mines which continue to be organized with older methods and equipment, retain the system of multiple classifications, yet there are exceptions. Agnico-Eagle's Joutel mine has retained it's 24 underground classifications yet it uses relatively large scale methods such as sub-level retreat and modern equipment including jumbos and longhole drills. By contrast the Pierre Beauchemin mine, a vein-type mine, using traditional methods of jack leg drills and narrow tunnels, has moved to a classification based on fewer categories. The only classifications that remain in its mining department are the hoist operators, miners - class 1,2,3, general underground labourers, dryman and utility men.

This system was nominally put into place to enrich miners' jobs by making their work more varied and with more responsibilities, yet it is also intended to increase workers' skills through a greater accumulation of experience and training. Yet this has met with criticism by several trade union representatives. According to certain Cooperative Wage Study Committee members, Inco has broadened job categories while the job rotation needed to gain the required experience remains insufficient as does access to training. The result is therefore a nominal increase in flexibility but without the workers' gaining the required training or experience to benefit from it, leaving the company capable of shifting employees throughout the mine according to their requirements, while employees would not necessarily have greater freedom in obtaining a job for which they might earn higher wages or bonus'. In Quebec, the Metallos have claimed that workers are being assigned to tasks and machine operations for which they have been insufficiently trained, adding to the continued high rate of accidents.

One of the key elements in this new structure is the way these broader classification schemes allow management greater ease with which to get around seniority clauses in the collective agreement, a clause which has been hard fought and protected by trade unionists for generations as a way of eliminating employer manipulation and favouritism at the workplace and especially the substitution of younger workers for older more experienced ones. In all collective agreements, the protection of seniority in the assignments of tasks, promotions, transfers, demotions due to a change or reduction in operations, lay-offs, and rehiring after lay-offs, is limited by the companies' right to choose those workers who either have the skills, as in the Doyon agreement or who will best fulfil the requirements and efficiency of operations and ability, knowledge, training and skill of the individual to fill the normal requirements of the job, as worded in the Inco agreement. Since only management has the information on workers' skills and training, while the union has no control over this area, the largely undefined job classifications provide management with a significant amount of lee-way in assigning workers to specific tasks. Seniority clauses now remain the only measure to protect access to jobs and bonus' at a time when the number of jobs were becoming increasingly diversified and modified with the advent of the new technology and changes in mining methods. For management, flexibility increased, allowing it to reach its objective, which was to maintain and even increase output but with far less employees. Thus increased mechanization allowed for a reduction of the workforce but only if that workforce could be more flexible, assuming a wider variety of tasks.

According to one union spokesman, the contract language to protect members in the new combined jobs, or against the possible negative impact of new technology, did not exist. While many of the collective agreements now have specific language relating to new technology. this is limited to the already recognized principles of job security and protection of seniority in training, but in specific relationship to new technology. In addition, unions are welcoming the new recombined jobs as a way for their members to achieve the top grades at the workplace and while several have noted that in order for this to happen, training must be ongoing. Yet the unions themselves are not monitoring this training, leaving it instead in management's hands, preferring as an alternative to rely on their seniority clauses to assure that access to training be undertaken with equity.

For their part, mining companies see training as a way for miners to learn the miner's job that had previously been gained through years of experience and to obtain the appropriate broader technical skills now needed in the more complex underground operation.

In the past, miners would learn through hands on experience, taking several years to move from assistant to full fledged miner, i.e. to move from helper to leader in charge of his own stope. A typical example is related by one miner who took 15 years before being given responsibility for a production site (i.e. a stope), the equipment and to supervise the work of other miners.

Instead, mines such as Doyon have put together broad ranging schemes to allow miners to gain a wider variety of skills quickly. This program was based on the common core program given in Northern Ontario and Inco. Like Cape Breton, it takes a modular approach but it's aims differ by seeking to provide a broad base of mining skills to miners who are now called upon to do a wider variety of jobs. Training is narrowly focused and practical, as trainees work for a specified number of hours on specific tasks with a trainer who is himself an experienced miner. The Common Core programme provides the basic miner's skills including the skills acquired with traditional mining methods: operation of the jack leg, the stoper, LHDs as well as how to drill, scale, prepare timber and install roof bolts, loading and setting charges as well as several other techniques. Once these basic skills had been acquired, other courses are then given on specific equipment. A common practice, as in the Doyon case, is that beyond the common core, access to training is regulated by seniority and the needs of the mine. In addition, specialized training for new equipment is being offered by machine manufacturers.

Yet they, and mining companies, find that in order to acquire these specialized skills, it is necessary for the miner to have the basic skills acquired by miners using traditional methods, but in addition, they are increasingly requiring the capacity to operate complex machinery, and in some cases, requiring some computer skills. While this emphasis on training is not present throughout hard rock mining, it is certainly gaining momentum. Inco for example, now requires all new miners not only to do the common core programme, but will now only hire people who have completed secondary education.

Thus several mines such as Kiena, Casa Berardi, Joutel and others are instituting, or taking part in programmes, to compensate for the disappearance of skilled miners during the 1980s but they are also doing it so that their miners will have the necessary skills to accommodate current and future changes in technology and mining methods.

Sources and references to the material used in this article can be obtained from the Editors or the author.

Conclusion

This article has demonstrated that the search for greater productivity spurred on by the industry's downturn in the early 1980s resulted in greater research and implementation of technological change into all aspects of mining so as to downsize the workforce and reduce production costs. The industry is therefore reaching new levels of mechanization and in some cases moving into the early stages of automation.

Ongoing research and innovation into remote controlled and computer applications have as their long term objective to reduce the number of workers even further and some industry spokespeople are going so far as to speak of a completely manless mine. This may seem fanciful given the significant advances it will require in the development of expert systems and intelligent computer programmes. Yet this research is currently being undertaken.

Current applications are much further behind however. Remote controlled operations are only partial, as they continue to require visual control by the operator, especially the commonly used remote controlled LHDs. Simple computer programmes are being applied to jumbos and down-the-hole drills and these are vastly different to advanced intelligent programmes and expert systems that researchers are speaking of.

Further advances have been made however in the area of integrated machines and processes with the continuous miners. These apply best to soft rock mining however while their unprofitability in hard rock is slowing down their implementation.

Research is therefore directed towards adapting them to hard rock mining whether in base minerals or in narrow vein-type mining. As an alternative, a significant amount of research has taken place and these have been successfully applied to the improvements in drill performances and in computer applications to drills, especially the long-hole.

The article has demonstrated that these changes to machinery and mining methods had, in the past, resulted in important modifications to the labour process, moving it from traditional mining with its undifferentiated workforce to mechanized mining with a highly stratified work force and multiple job classifications. The labour process accompanying the early stages of automation is now beginning to emerge. The increased flexibility in the assignment of tasks and the broader range of skills sought by industry in the labour process is seen as a way of overcoming the parcelisation of tasks that accompanied earlier stages of mechanization and to adapt to future changes in equipment, especially the new integrated machines and process'.

The multiplication of equipment with new drills, along with the addition of diesel, hydraulic and pneumatic power sources, as well as computer applications, at a time when the industry is downsizing is resulting in the need to broaden the skills and the flexibility each miner must have. Thus it is unclear if the current push towards training and flexibility is linked directly to the emergence of automated process or to the fact that downsizing is going on at the same time. What is obvious however is that the new technology being put into place allows for the reduction of the workforce through the use of labour saving mining methods and equipment. It is also clear that these changes to the labour process also provide management with a workforce and a labour process which is much better adapted to the demands of the automated underground mine.

Among the strategies selected by management to face the industry crisis since the early 1980s, has been the emphasis on the acquisition of a wide variety of skills by its fewer remaining miners. Workers' response, through their union, has been to protect access to this training and against the possible side effects of new technology through clauses in their collective agreements relating essentially to job security and protection of seniority. In several cases, these have been supplemented by clauses relating specifically to new technology but again protection is assured through the respect of job security and seniority.

In spite of these measures, it is not clear that workers will be acquiring the skills needed to respond to these ongoing changes. It has been noted that management emphasizes not only skills training but its right to assign workers to specific tasks in relation to their skill levels in clauses that override the seniority clauses. This has been facilitated by the creation of the broader job categories and the disappearance of the multiple job classifications. It has been noted by some union representatives that, in fact, their members had not received the training needed to reach the desired objective.

In addition, the multiple more specific job classifications had the advantage of more clearly indicating the relationship between worker's skills and job content, as for example an experienced long hole driller did in fact accomplish those specific tasks. With their disappearance, a vacuum is created in terms of the unions' control over job contents.

It is important therefore that the issue of skills' acquisition and especially workers' control over this issue be treated more thoroughly by the unions so as to seek measures to gain access to information regarding their members' skill levels and the training they should be receiving. This would provide protection over job content and allow workers and their unions to have a say in the assignment of workers to appropriate jobs beyond simply the protection afforded them through a well protected seniority list. It would also provide a useful union strategy to protect their members and allow them to adapt more easily to ongoing technological changes and the important changes it will bring about in the way they will do their work. ■