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AUTOMATION OF HARD ROCK MINING EQUIPMENT IN CANADA

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The development of innovative and creative technology in any industrial field is a sporadic occurrence. Often after its development, its introduction and acceptance in the industry awaits the occurrence of some major market force event. The downturn in the world economy in the early 80's and subsequent compression of world metal market was such an event for the Canadian hard rock mining industry. It necessitated a rethinking of the present level of technologies being used by the industry in terms of productivity, particularly in respect to mining equipment, information technology and the application of high technology from other fields.

This paper describes the recent advances in Canadian underground hardrock mining equipment which has brought it to the forefront of the world mining industry. The role that governments, mining operators, and equipment manufacturers have played in supporting the industry achievements is also described. The paper also provides a measure of Canada's achievements and success in the development and introduction of new technology relative to other countries with comparable mining industries.

Hard rock mining is usually more complicated than soft rock mining: greater occurrences of irregularly shaped ore bodies; multilevel mining with almost all the working levels having one or more active faces; non-linear road systems to accommodate ore body geometry; and hardrock formations with vastly different ground control requirements and conditions.

Many metal mining operations in the early 1980's faced the difficulty of developing survival strategies to survive the severe down turn in mineral markets and price. In part they had to rethink their attitude towards application of hi-tech and automation of mining equipment to achieve productive gains into the future. Reorganization and cost cutting measures in the frame of existing technology and methods have been the principal means to maintain, to date, the industry's competitive position. However, they can only be viewed, as short term solutions. In time, a strategy based on these considerations will be exhausted and the only avenue remaining to the industry to further enhance productivity will be the development and use of "new technology".

Unlike the manufacturing industry, the Canadian mining industry can not maintain its market share by producing a significantly better product than its competitors. Unit cost is the sole measure of success with respect to maintaining market share. Therefore, improvements in competivity have to come in the production process itself and be reflected in reduced unit production cost. It is also unfortunate that technology developed for automation in the manufacturing industry is not wholly and directly transferable to the mining industry. The technology required has to be specifically designed for the mining industry making it even more difficult and capital intensive with a much longer pay back period.

None-the-less, because of limited options remaining to improve competitiveness, industry is increasingly accepting greater utilization of automation and hi-tech applications.

In passing it is worth mentioning some of the events, that have fostered this change in the attitude in the mining industry during the 1980's:

- 1982 Versailles Summit Agreement; on international cooporation on automation;
- 1982 CANMET-sponsored study of robotics in mining;
- 1983 CANMET symposium on robotics and automation in the mineral industry;
- 1985 Workshops on mine robotics in London and Paris;
- 1985 Massachusetts Institute Technology (MIT)-sponsored symposium on innovative mining;
- 1985 Meeting of the Versailles Agreement countries to consider an international centre of excellence at MIT;
- 1986 MRL/CANMET/ORMC organized workshop in response to MIT initiative;
- 1986 Formation of National Advisory Committee on Mine Automation; -
- 1986 Canadian Symposium on Mine Automation;
- 1986 2nd MRL/CANMET workshop on mine automation in response to MIT initiative;
- 1986 2nd symposium on innovative mining (MIT/Penn State);
- 1987 2nd Canadian Symposium on mine automation - with increasing international participation;
- 1987 3rd Symposium on innovative mining (MIT/Penn State/Missouri);
- 1987 Formation of MITEC, MRD etc.;
- 1988 IFAC International Workshop on mine automation;
- 1988 3rd Canadian Symposium on mine automation with even larger international participation;
- 1988 Discontinuation of USA initiative on innovative mining symposia;
- 1988 Formation of Canadian Centre for Automation and Robotics in Mining (CCARM); and
- 1989 IT in mining workshop.

These events clearly indicate the numerous initiatives by CANMET in the 1980s to foster the application of hi-tech, automation and robotics in mining.

Where do we stand now?

Since the time of CANMET's first initiative in 1982, the Canadian mining industry has made tremendous progress in the use of high technology, particularly with respect to equipment automation in underground hardrock mining. The increased interest in the subject of high technology mining is evident from the number of Canadian symposia on mine automation and the changing mix of the attendees and papers presented. Table 1 provides a brief history of attendance at these symposia.

Table 1 Attendance at Canadian Mine Automation Symposia

	Total	Foreign	Countries	% Foreigners
1986	165	7	4	4.2
1987	245	12	8	4.9
1988	182	30	10	16.5

The increase in both Canadian and foreign attendees indicates a national, as well as international interest in high technology and automation developments that are occurring in the Canadian industry. The majority of the participants at the 1986 and 1987 symposia, held in Sudbury, were from Sudbury with its large concentration of mines. The third symposium held at Montreal, in tandem with the IFAC Workshop, attracted significantly more foreign participants. Almost all the papers were significant in terms of advanced automation in mines. Unfortunately a number of good papers could not be accommodated because of the limited time available. The presence of the large international contingent resulted in some very profitable interchanges for the Canadian mining industry.

Attendance at all the referenced high tech mining symposia has provided the authors with an excellent world overview of research pertinent to the automation of hardrock mining operations. With this background knowledge, it has been possible for the authors to make a subjective comparison of the status of research and application of high technology in Canadian hardrock mining with the status in other technologically advanced countries, notably: Sweden, Finland, USA and Australia. These countries and South Africa, are the only technologically advanced countries which have the capability and economic interest to undertake research and development in automation related to hardrock mining.

A comparison of status of research and development in 17 fields related to automation in mining is presented as a chart in Figure 1. A 0 to 10 scale has been used for comparison purposes, with the most advanced state indicated by a 10. Several independent mining industry specialists concerned with advanced mining technology were asked to provide their views of individual nation status in the subject areas using the 0 to 10 scale (e.g. Inco research mine, Noranda Technology Centre personnel etc.). Australia has a large underground hardrock mining industry and competes with Canada in the market for several mineral commodities. Distances and the resulting lack of frequent communication with this country has limited North American knowledge about the technology thrusts and changes that might be underway in this country. A more thorough review of Australian advanced mine technology initiatives is merited, if funds and time become available. It is worth noting that in 1982 Canada would not have been as significant a contributor to such a barchart.

The backbone of any mine-wide automation system is a suitable integrated mine-wide communication system. Fully automated mines will not be possible unless there is a significant improvement in both the speed and capacity of transferring data from sources to a computer and back to machine actuators. This situation restricts present advances to the automation of individual units of equipment. Present telephone and radio communication systems are grossly inadequate to meet future needs. Information has to be transferred between sensors, processors and controllers with the precision and speed required for adequate operational control and decision making. Two-way transmission of data for some monitoring functions is not required, e.g. ore-pass levels. Table 2 provides the present status of radio communications systems in use in underground hardrock mines in Canada. The barchart, Figure 1, indicates that in this important field the Canadian industry is more advanced than other countries. Hardwired systems are suitable for fixed installations. Radio systems are suitable for mobile equipment where short distance transmission is required. Most mines will need hybrid systems. If one compares the number of installations to number of Canadian underground hardrock mines, it is apparent, the percentage of radio communications installations systems is low. None of the present communications system have been installed for equipment monitoring and control but for voice communication, and therefore unsuitable for use in mine-wide automation. However, the successful introduction and use of voice communications in underground mines should not be underrated in terms of its utility per se and as a step towards the introduction of mine-wide information communication systems.

Table 2

Wires Communications Systems
in underground Mines in Canada

	Type of System			
Province	Mine-wide	Shaft	Haulage	Other
Newfoundland	0	0	0	0
Nova Scotia	0	0	0	0
New Brunswick	2	1	0	0
Quebec	4	1	3	0
Ontario	13	11	9	4
Manitoba	6	8	3	1
Saskatchewan	4	0	1	1
Alberta	0	0	0	0
B.C.	2	0	0	0
Yukon / N.W.T.	2	1	0	0
Total	33	22	16	6

(data updated April 1990)

Some Canadian achievements in the field of mine automation

It is appropriate here to mention specific in automated equipment developments where, in the opinion of the authors, Canada has excelled:

1. DTH drill automation:

In 1981/82 Atlas Copco of Sweden developed a sophisticated (PROMEC-188 DTH) drill. It has two novel features: 1. automatic drill rod change with rod removal or return to a storage drum; accurate collaring of holes by the operator with a laser positioning system.

In the opinion of the authors, the system had a serious drawback which significantly reduced operational benefits resulting from its utilization. Location of hole collars to within 6 inches of their specific location was difficult to achieve with the laser system. For the system to provide precise location the drill assembly would have to be mounted on an adjustable table. This is not operationally possible.

In 1985, MRL/CANMET sponsored an alternative solution to the Swedish DTH drill machine consisting of a bit placement system retrofitting on a DTH drill. The unit could perform the following functions:

- guide the operator in accurate placement of the drill on the collar using laser inclinometer, mine survey points and collar co-ordinates;

- give accurate azimuth and inclination information for drill steel orientation;

- track and record the azimuth and deviation of the drill bit trajectory for the entire depth of the hole;

- stop automated drilling when unacceptable hole deviation is detected; and,

- control drill hydraulic functions and optimize drill penetration.

The drill automation accessories prototype which was completed 3 years ago and reported on in two journals, is being fitted presently with new, more reliable sensors to measure rotational speed and penetration rate. Also, software has been improved and is being tested. The results indicate that an accuracy equivalent to the accuracy of a manual survey is being achieved.

The system has been licensed by CANMET and is under commercial development.

2. Automated haulage truck:

Inco's research mine in collaboration with UTDC-Lavalin Ltd. has developed a driverless truck for use on main haulage systems. It is capable of hauling 70 tons of ore/waste at a rate of 8 miles per hour and can negotiate a ramp gradient of 20%. The power is supplied by 600 VAC trolley wire and the drive mechanism is hydro-static. It is designed for chute loading and side door dumping with shuttle-car type operation (bi-directional drive). The truck is fully computer controlled and allows for line switching. After preliminary trials, some modifications are being made to increase the reliability of on board electronic assemblies.

3. LHD monitoring and maintenance system:

The INCO Ltd system monitors 73 LHD parameters which are stored on board the LHD until the machine enters an information transfer bay. Radio communication in the bay is used to transfer the data to an industrial IBM PC/AT for analysis. The analysed data provides management/maintenance personnel with a visual display of the functional status of various LHD parameters.

The maintenance assistant system, an extension of the monitoring package, is a diesel machine status diagnostic expert system. Once the system is in place, it can also be used to train new personnel.

Presently, a second prototype is being built with less sensors and to give more useful data.

4. Automated surveying

Surveying instruments have become very sophisticated in design, and are accurate and simple to use. With some, stored measurement data can be transferred to a computer for analysis, computation and the preparation of final surveyor reports. Never-the-less, such instruments have to be manned. In a mine where surveying is done regularly to determine mining progress, an inexpensive surveying instrument could be placed in strategic locations and the survey data automatically transmitted to the central processor.

A cavity surveying instrument has been developed by Noranda Technology Centre. It can be placed in a cavity such as a stope using a borehole. Although the instrument is not yet commercialized, it is a first step in the development of a man-less surveying instrumentation.

Besides the above four examples, there are many others that could have been selected. They are representative of an area where Canada is leading and a number of products are close to commercialization.

In some areas, such as jumbo and fan drills, cable and roof bolters, optical guidance system for vehicles, Sweden and Finland are far ahead.

It should be mentioned that PCS with Martin Marietta (Canada/USA) has developed an on-board navigational system for their 'orebiter' potash miner. It has the potential to increase in-seam potash mine recovery to nearly 100 % with little dilution. Similarly, USBM has extensive programs to develop autonomous coal mining equipment,which will not depend on an operator to guide and control it.

<u>Where do we go from here?</u>

Until the recent past, technical management of mines was entirely in the hands of generalists. The Mining engineering profession is lagging other professions, such as medicine, where general practitioners are increasingly complemented by specialists in the provision of health care. Every industrial sector is faced with the need to develop teams and the team approach to solving problems because of their complexity. It is the authors' opinion that the mining industry has the structure and the specialists to adapt to this approach which has served other industry sectors so effectively; electronics, aviation, etc. In this regard, since 1982 interdisciplinary seminars, and workshops have been held to promote and discuss developing technologies in terms of mining industry needs and potential applications. Approximately 20 % of the attendees at the 3rd Canadian symposium were non-mining professionals while 50 % of the attendees at the March 1989 IT in Mining Workshop were non-mining professionals.

Existing mine organizational structures will have to change if mines and mining companies are to successfully integrate the new technologies into their operations they require to remain competitive. Technology changes which are already taking place will be increasingly felt in terms of personnel requirement and qualifications, and financial expenditures.

Some consensus positions arrived at by participants at the IT in Mining Workshop with respect to the Canadian mining industry are summarized below:

- the mining industry is largely run by generalists and that this will hamper the introduction and use of the innovative changes the industry will require;
- the universities are not doing an adequate job of promoting the mining industry as a career area to IT and to computer science graduates;
- the universities should do more to sensitize university faculties and staff of the multi-disciplinary nature and requirements of the mining industry;
- the need to retrain mining engineers without removal from the industry;
- the mining industry should make a greater effort to hire and retain permanently the specialists in other fields that it needs (the mining industry has not been successful in retaining the specialists in other disciplines in the existing working environment).

Greater mechanization and automation (continuous mining) of rock breakage can only be achieved by replacement of the present drill-blast-muck cycle. It would be particularly advantageous to mining if mechanical breakage could be used for development to replace the present notoriously slow cyclic method using explosives. The successful development of radical rock breakage technology for use by hardrock mines appears to be a bigger challenge than the development of automation technology for the industry.

Monitoring and control of mine ventilation

Monitoring and automation of mine-wide ventilation system would appear to be a reasonable target for mine automation with enormous potential in terms of economic and health benefits. Because of location, almost all underground mines in Canada have to heat mine air for 5 to 6 months a year at considerable cost. Dieselized mines, which are common, require large amounts of air (100 cfm/bhp). Equipment and systems presently exists which can monitor diesel exhaust and pollutants in mine air. MRL/CANMET has installed such ahardwired system in a salt mine to monitor methane.

Further improvements to such systems are required before the automation of mine ventilation systems becomes feasible, in particularly the development of a broader range of rugged sensors to measure pollutants and ventilation control parameters is required. Rugged remote acting ventilation control devices are also required.

There have been several theoretical systems developed for mines ventilation management using knowledge based expert systems, predominantly in the USA and Europe and for coal mines. They could probably be modified to accommodate the needs of hardrock mines. Most of these systems, however, have not been field tested to establish their shortcomings. No effort has yet been made to develop mine door systems specifically for remote control. Therefore the difficulties and the problems which must be overcome to produce suitably reliable remote control door systems are, as yet, unknown.

Monitoring and gathering of supervisory and management information for underground operation

Upgraded information systems for day to-day mine management could contribute to increased mining efficiency. These systems could provide additional information to forepersons, underground super-intendents and captains to assist in man-power deployment, production scheduling, equipment distribution, blast sequences designing, etc.

Before a project to develop such a system could proceed the following preliminary studies would have to be carried out: 1. identification and classification of information to be gathered, (the most important element of the project); and, 2. the availability and assessment of essential sensors and their ruggedness. It is possible that item 2 might establish that the existing level of sensor technology make the project unfeasible.

Power plant "control-room technology" for mine management is a suitable candidate for evolutionary technology development. A very highly automated Swedish mine uses "control-room technology" to control ore transport from mine chute to seaport loading of ore ships. This system is to be expanded to cover other mine operation components/elements in the future incrementally.

It is essential that a computer controlled mining system has as a component, a communication system with the following characteristics and functional capabilities: digital, analog, on-off, voice and video transmission capabilities; mine production centre sub-systems encompassing mobile and stationary office. Compatible sub-systems will permit their integration into a "control-room" type mine-wide management system.

Because of the dynamic nature of mining (daily changes in geometry), the variability of the electromagnetic characteristics of rock formations and the irregularity of mine openings, the communications challenges facing those developing a computer controlled mine system are daunting. It is the authors' view that the industry should establish an expert communications team to determine and address the data, voice and video transfer requirements of a mine-wide computer-controlled management system. It is most probable that no single suitable system exists but that suitable hybrid system could be developed using a limited number of generically different sub-systems. For example, a hybrid system could consist of hard wiring between stationary locations radio linkage to moving and advancing stations. Thus, mobile equipment at a face would be served by an antenna located at the end of the nearest hard wire system component for the purpose of voice and data transfer into the mine communication system. Hardwiring of an entire mine is not feasible and leaky feeder technology has its limitations including signal degradation due to dirt and dust on the cables.

To date, most of the sales of communications equipment made for mines have been for voice com-munication equipment. As a result, Digital Communications Network or Cable companies, who are experts in the field of data, voice and video signal transmission and hard-wire and radio communication systems, have not been actively involved in the development of underground mine communication systems. It is absolutely essential that these companies become involved, even if it involves large financial incentives.

Examples of individual equipment automation were mentioned in the first part of this paper, eg.; DTH drill, driverless truck, cavity surveying etc. In the future this list of automated mining equipment will increase significantly. In the case of many of these highly automated units, full benefits cannot be realized on the basis of the "one man one machine" concept. Highly automated drills provide a good example. There is a need to transfer Computer Integrated Manufacturing technology to underground mining where operations and equipment permit one man to control several pieces of equipment.

Figures 2 and 3 provides a schematic of a computer-controlled mine management system. Although this concept has existed for some time, serious studies to develop it have not been carried out. Completion could only be accomplished by mounting a large and expensive project. If carried out in Canada, however, it would place the Canadian hardrock mining industry in the forefront of computer-assisted mine management technology.

If real progress is to be made in the development of a computer-assisted mine management system in Canada on the control-concept, the mining industry must provide Canadian developers and manufacturers with concrete specifications, direction and assistance.

Conclusions

The paper proposes that the Canadian hardrock mining industry undertake an expensive and long term project with the objective of developing a mine-wide computer-assisted mine management system based on the control-room concept. Such a system would significantly contribute to the

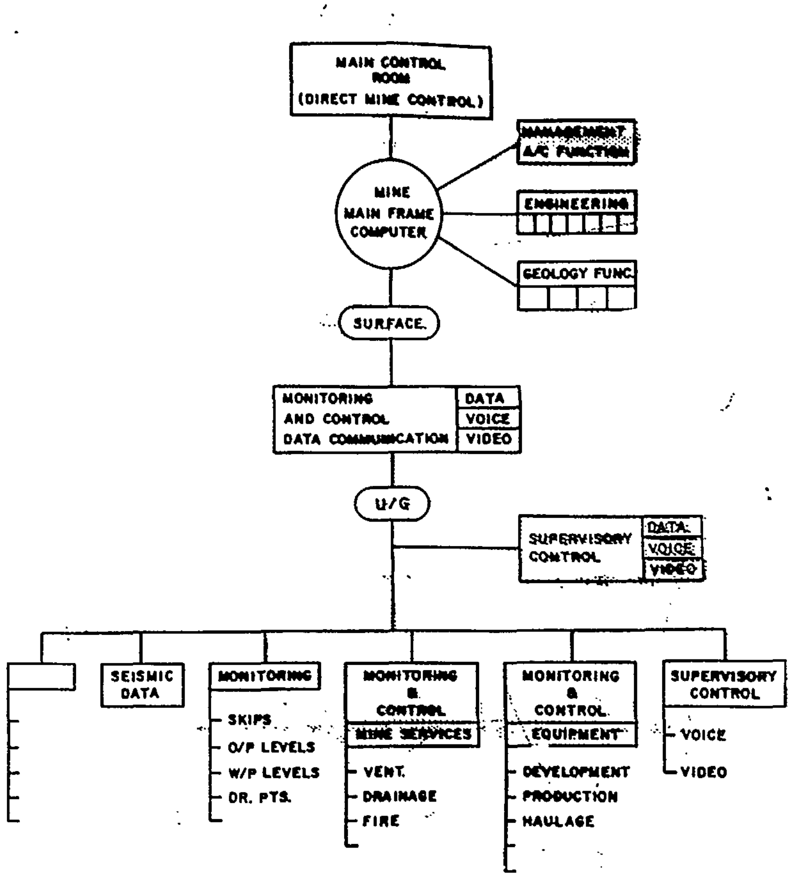

Fig. 2 - Mine-wide monitoring and control system.

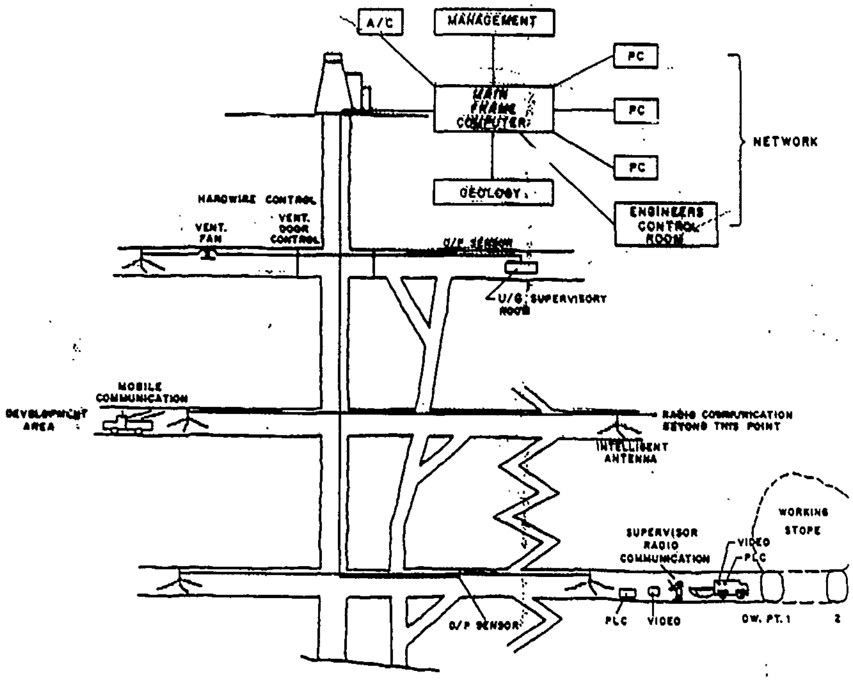

Fig. 3 - Mine-wide hardwire/radio communications system.

competitiveness of the industry as it moves into the 21st century. There will be a large export market for this technology and expertise which could be exploited. As all advanced countries with an R & D capability, Canada must sustain its resource industries, such as mining, through the exploitation of new technologies.

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