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Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories
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AUTOMATION OF MINING EQUIPMENT – A POSITION PAPER

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Automation of Mining Equipment

a Position Paper

by

J. Pathak *

Background

As background material for the present paper, it was considered important to identify those developments which have occured in mining and other pertinent fields of significance to the application of hi-tech, automation and robotics in mining. The review was carried out in terms of the needs of the Canadian hardrock mining industry and, is therefore, not necessarily germane to the mining industry of other countries or to surface or soft rock mining in Canada. Softrock mining (coal, potash, gypsum, salt etc.), because of its nature, has a long history of successful application of automated mining equipment. However, up to the present, it has not proven feasible and economic to transfer this technology to hardrock mining. As an example, the Remote Operated Longwall Face (ROLF) was developed and applied to coal mining in England in the mid-1960s, but similar concepts for automation of faces (stopes) in hardrock mining are not in the conceptual phase.

Hardrock mining is usually more complicated than soft rock mining: greater occurrence of irregularly shaped ore bodies; multi-level 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.

Mining projects require large front-end capital investment and, compared to projects in other industries, involve long periods before there is a return on this investments. Mining engineers concerned with the technological planning of such projects have little geological and technical information for planning actual operations and risk is involved in selecting specific equipment and mining methods. The investors' risk is compounded by the wide fluctuations in world metal prices that can and do occur. It is quite natural, therefore, for the experienced hardrock miner who has worked in this environment for years to adopt an operational philosophy summarized in the following phrase: "use the technology that works and has been proven". Even so, mine operators

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who are responsible to investors and shareholders for making such decisions are a special breed of mining engineers.

With the recent development of high mineral production in the third world countries and a parallel decline in world market prices Canadian mining companies and their mine planners have had to rethink their attitude towards the application of hi-tech and automation as a long term solution to remaining competitive. Reorganization and cost cutting which has been carried out in the frame work of existing technology and methods and has been responsible to date for maintaining the industry's competitive position can only be viewed as a short term solution. In time, this strategy will be exhausted and the only avenue to further enhance productivity left to the mining engineer will be the use of "new technology".

In the manufacturing industry, a marginal improvement in a product sold at a slight increase in cost can make a saleable item. For example, in the world of PCs, a modification which can make a particular type work faster, or provide with a larger storage capacity or provide it with a sharper colour graphics can result in significant gain in sales at the expense of its competitors. There are few opportunities to improve a mine's end product. Therefore to remain competitive, mine operators have only one choice - reduce unit costs!

Automation of processing and packaging has had a tremendous impact on the manufacturing industry. Production costs across the board have been considerably reduced. That industry is fortunate, however, in that all product parameters are well defined and that the product can be produced using stationary automated equipment or robots. By contrast, in mining the product parameters are not fully known and cannot be moved to suit the present stationary characteristics of automated equipment. In mining the production equipment must go to the product whose parameters are not fully known. When faced with the reality of this situation the scepticism in the mining community about new and unproven technology including robotics is understandable. However, the need to maintain international markets and remain competitive is changing the attitude in the mining industry towards automation increased application of automation and hi-tech mining operations.

Some of the significant events that have fostered this change in attitude are the following:

- 1982 Versailles Summit Agreement;
- 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 MIT sponsored symposium on innovative mining;
- 1985 Meeting of the Versailles Agreement countries to establish 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 and 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 early 1980s to foster the application of hi-tech, automation and robotics in mining. The author of this paper has participated in all the above events in Canada, USA, India and France since, either by presenting papers and/or by serving as a member of the organizing committees.

The author believes that CANMET has played a significant role in changing the attitude of the Canadian industry to advance technology by:

- increasing the industry's awareness of hi-tech, automation and robotics in mining;
- contributing to the development of consensus positions shared by mine operators, R & D organizations, universities, Governments, mining associations, hi-tech companies and mining equipment manufacturers on advanced mine technology;
- bringing together people with expertise in different disciplines with a common objective of solving mine oriented problems through the use of advanced technologies;
- supporting mechanisms to bringing this expertise together, workshop, conferences, symposia, etc.; and,

- financially supporting R & D in this field as well as expertise, software and equipment with export potential.

In 1982, CANMET financially supported a study to establish the industries awareness of robotics and to identify possible robotics applications. Responses from industry for requests for information were amazing , bearing in mind the objective of the study was not to establish present existing high technology application; but to explore the mining industry's thinking towards the introduction and use of new high technology and robotics. As a side issue it was also planned to use the study to establish possible roles for government agencies such as CANMET in advancing the use of high technology (ref 2 Pathak). The position of a significant section of the mining industry to the future use of advanced technology and robotics in 1982 is summarized in quotes from the survey:

- "...we use only live robots. If I suggest robots for underground operations, they will send me to a nut house" and "if the robots hits a rock in a drift and falls down, who is going to pick him up?"
- "those who gaze into a crystal ball (to use robots underground), usually end up eating the glass!"

There was another quote at the other extreme end of the scale:

- "the mining technology is at the moment at the 'neanderthal' stage.

The last quote came from a person who is not a mining engineer and has never worked in a mine and holds an academic position.

These extreme quotations indicate the fallacy about the application of robotics in mining.

Where do we stand now?

Since CANMETs first initiative in 1982, the Canadian mining industry has made tremendous progress in the use of high technology; particularly 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.

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

Table - 1

The increase in both Canadian and foreign attendance demonstrates the national, as well as international interest in high technology and automation developments that are occuring in the mining 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 1988 symposium held at Montreal in tandem with the IFAC workshop attracted significantly more foreign participants. Almost all the papers were significant in terms of advancing 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 to the Canadian mining industry. The success of these events prompted some American participants to suggest that future mine automation symposia be a joint American-Canadian effort with the site alternating between Canada and the USA. This is of interest considering the failure of their own efforts outlined below.

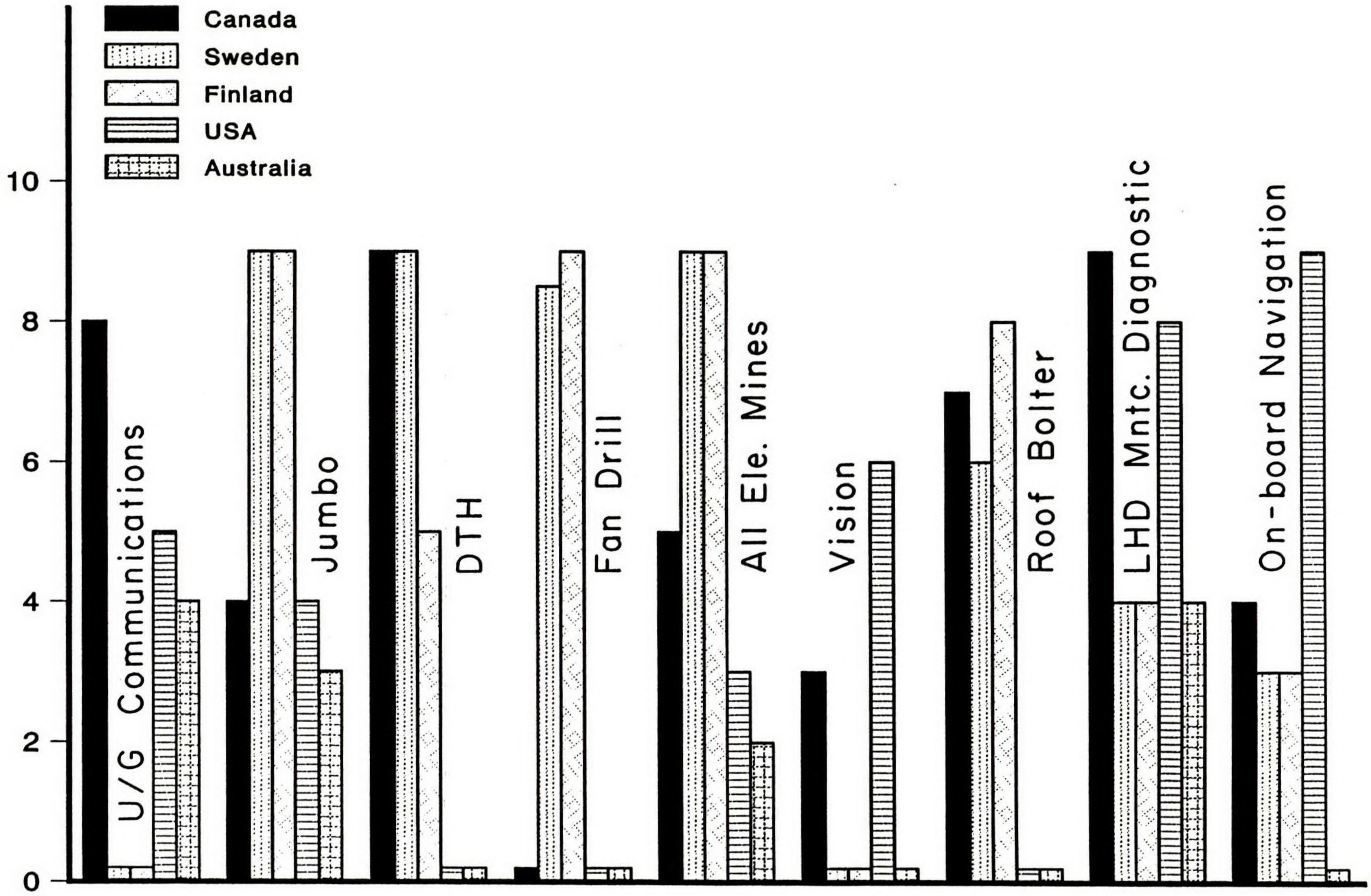
In 1985, MIT and Penn State University organized the first symposium on mining automation at Cambridge, USA, where Canada was represented in large numbers. While there was a tremendous response to this hurriedly organized symposium, attendance and interest in succeeding symposia quickly diminished and they were discontinued after the 3rd symposium held at Rolla, Missouri in 1987. In the 2nd and 3rd sumposia, Canadian participation was limited because of the concentration on coal related papers many of which were not concerned with high tech application and automation in hardrock mining.

Attendance at all the high tech mining symposia earlier listed has provided the author with an excellent world overview of research pertinent to automation of hardrock mining operations. With this background knowledge it has been possible to make a subjective comparison of the status of research and application of high technology in hardrock mining in Canada with that in other countries, notably Sweden, Finland, USA and Australia. These, with 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 in Figure 1 as a barchart. A 0 to 10 scale has been used for comparison purposes with highest advanced state indicated by 10. Several independent mining industry specialists concerned with advanced mining technology were asked to indicated individual nation status in the subject areas using the 0 to 10 scale (eg. Inco research mine, Noranda Technology Centre personnel etc.). Australia has a large underground hardrock mining industry and competes with Canada in several mineral commodities. Distances and, as a result, the lack of frequent communication with this country limit knowledge about technology thrusts and changes that might be underway. Thus, status with respect to the subject areas under consideration in figure 1 for the Australian industry is based on personal contacts, literature searches and AMIRA/CSIRO reports. There is no evidence of major thrusts or initiatives with respect to mine automation except in the area of computer modelling of ore bodies and computer mine design. However, a more thorough review of the Australian mining industry initiatives on advanced mine technology is merited, if funds and time become available. It is worth noting that in 1982 Canada would not have been significant contributor to such a barchart.

Canada's Position with Respect to Other Countries

Various Mine Automation Related Fields



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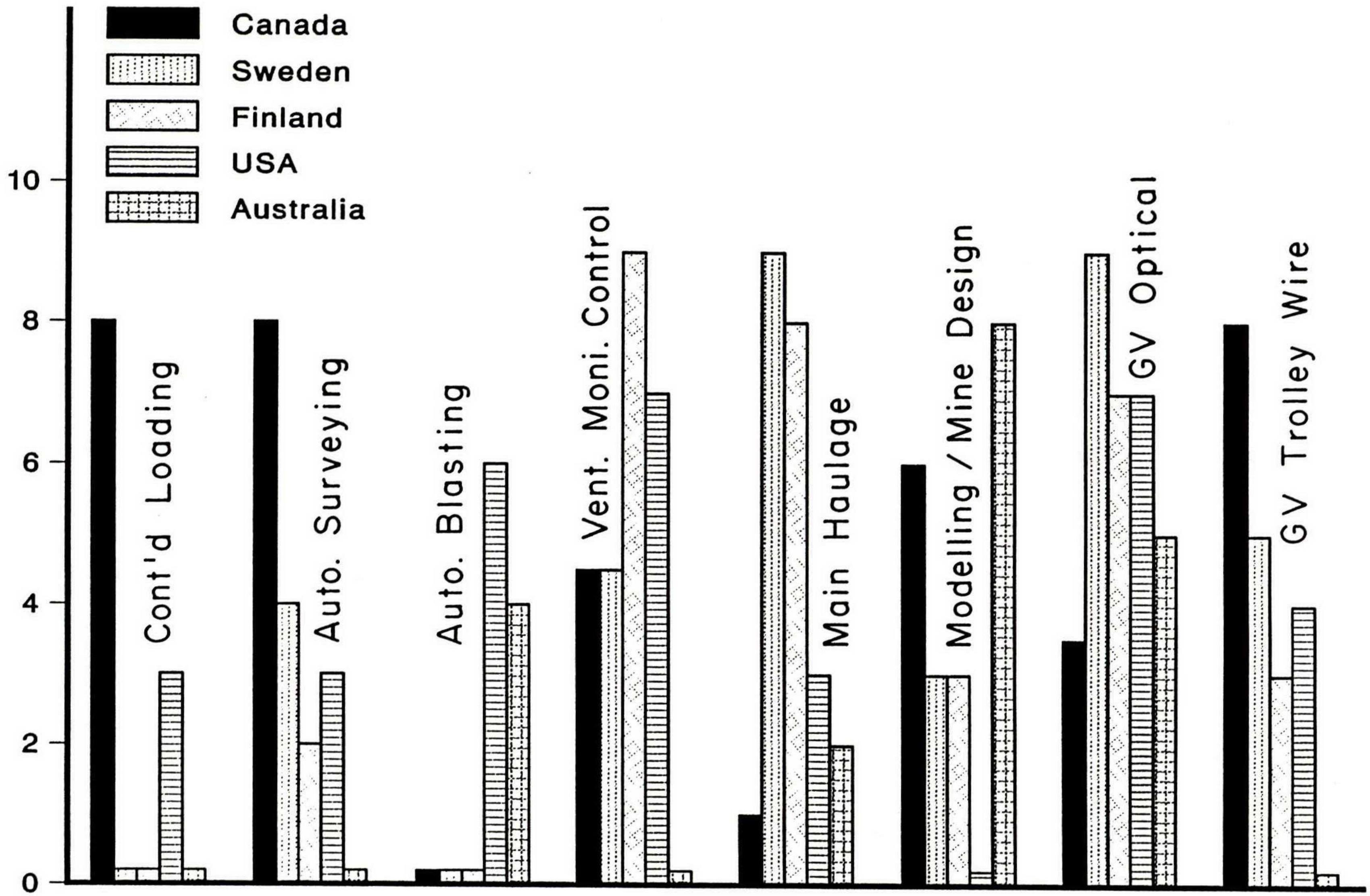

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The backbone of any mine-wide automation is a suitable mine-wide communication system. Information has to be transferred between sensors, processors and controllers with the precision and speed required for adequate operational control and decision making. Two way transmission of data for some monitoring function is not required, e.g. ore-pass levels. Table 2 provides the present status of radio communications system 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 with short distance transmission. Most mines will need hybrid systems. If one compares the number of installations to number of Canadian underground hardrock mines, however, the percentage installations of radio communications 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 the use in mine-wide automation. However, the successfully introduction and use of voice communications in underground mines should not be under rated in terms of its utility per se and as step towards the introduction of mine-wide information transfer communication system.

Wireless 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	1	1	0	0
Quebec	2	0	1	0
Ontario	9	7	9	4
Manitoba	3	5	3	1
Saskatchewan	2	0	1	1
Alberta	0	0	0	0
B.C.	2	0	0	0
Yukon / N.W.T.	2	1	0	0
Total	21	14	14	6

Table - 2

The subject of radio communication system will be discussed in detail in a subsequent section of this paper.

Some Canadian achievements in the field of mine automation

It is appropriate here to mention some specifics on Canadian automated equipment developments where, in the opinion of the author, Canada has excelled:

1. DTH drill automation:

In 1981/82 Atlas Copco of Sweden developed a sophisticated PROMEC M-188 DTH drill. It has two novel features: 1. it could change the drill rods, retract and place them in a storage drum automatically, and 2. it could accurately collar the drill bit with the aid of an operator using laser positioning system.

In the opinion of the author, the system had a serious drawback which significantly reduced the advantages it provided to the operation and operator. The aligning of 40 to 50 feet long equipment within 6 inches of the target collar with the help of a laser beam was a very difficult task. To provide precise alignment the drill needed to be mounted on an adjustable table. (Obviously this drill system in no longer in production).

In 1985, MRL/CANMET sponsored an alternative solution to the Swedish DTH drill machine and bit placement using retrofit accessories which would perform the following function:

- guide the operator in accurate placing 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 of 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 system has been licensed by CANMET and is being developed for commercialization.

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. At present it is undergoing surface trials; underground trials will commence in September 1989.

3. LHD monitoring and maintenance system:

The 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.

4. Automated surveying.

Surveying instruments have become very sophisticated in design, and are accurate and very 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, 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 Research 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 man-less surveying instrumentation.

Beside the above four examples, there are many others that could have been selected. However, these represent areas where Canada is leading and 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 near 100 % with little dilution. Similarly, USBM has extensive programs to develop autonomous coal mining equipment, which would not depend on the perception of the operator to guide and control it.

Where do we go from here?

Until the recent past, technical management of mines was entirely in the hands of generalists. For example, in the coal mining industry competitive examinations were held for those wishing to become eligible for mine manager positions. University degrees with specialization in mining engineering were not sufficient. Until recently, examinations were also held to establish competency in the following areas related to mining: mechanical/electrical engineering; surveying; mining methods; mine regulations. Mining engineering as a 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 author's 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 vein, since 1982 interdisciplinary seminar, and workshops have been held to promote expose 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 they require to remain competitive into their operations. Technology changes which are already taking place will be increasingly be felt in terms of personnel requirement and qualifications as well as financial expenditures.

Some of the 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 entirely 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 computer science graduates;

- the universities should do more to sensitize university facilities 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).

Evolutionary or revolutionary development of mine automation?

The argument continues as to whether an evolutionary or revolutionary approach to the introduction of automation in mines is best. The author believes in the evolutionary approach involving initially the automation of individual pieces of equipment and operations and leading to ultimately, mining systems automation. With the present level of digital, voice and video communications available for use in underground hardrock mines, automation requiring mine-wide communication is not feasible. It must also be recognized that some mining operations which are intermittent in nature are not amenable to automation.

However, revolutionary changes have occurred in the recent past in hardrock mining which have not been related to mining automation. The author considers the introduction and use of VCR mining as one of the these revolutionary changes. Another was introduction of use of LHD equipment for loading and short haulage. Because of the intermittent nature of these two revolutionary changes neither is readily automated.

Blasting systems are becoming ever more sophisticated with considerable improvement in the explosives and detonators available. However, blasting operations will never be suitable for mechanization much less automation. Within these limits, though, revolutionary changes are still possible. The present activity by Sandia Laboratories and the University of Albuquerque to develop a microchip (Solid State Bridge - SSB), detonator is an example. Its successful development and ultimate use would permit the accurate delay times in blasting needed to improve fragmentation significantly.

However, greater mechanization and automation (continuous mining) of rock breakage can only be achieved by replacement of the present drill-blast-haul 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.

There are several tools/equipment being developed to permit the mechanical breaking of rocks:

- Robbins/Mt. Isa Mobile Miner;
- Falconbridge/Boretec TBM;
- Roger continuous mining machine;
- USBM ripper miner;
- HP water rock fragmentation tool, (Fluid Jet International Inc.); and,
- USBM Axial rock splitter.

The first four are continuous excavating machines and lend themselves to automation. The last two, which are still at an experimental stage, involve intermittent processes and are not suitable for automation.

It is author's opinion that R & D efforts should be concentrated on the development of continuous mining machines and not on the development of intermittent rock breakage technology except to replace secondary blasting. 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 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 amount of air (100 cfm/bhp). Presently, equipment and systems exists which can monitor diesel exhaust and pollutants in mine air. MRL/CANMET has installed such hardwired system in a salt mine for the purpose of monitoring methane.

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

When the paper industry began mill automation, they found that they lacked the necessary special sensors. A period of 2 1/2 years was required to develop these sensors which caused a serious delay to mill automation projects. Mining has not yet systematically established what sensors it requires for various possible automation initiatives much less set standards for them or initiate their development. The author is of the opinion that this industry short sightedness could seriously delay in future automation efforts with respect to ventilation control and in other areas. It is considered essential that the industry, mining associations and governments take action to effectively address this situation as quickly as possible.

There have been several theoretical systems developed for mines ventilation management using knowledge based expert systems, predominantly in the USA and Europe. for coal mines. They could probably be modified to accommodate the needs of hardrock mines. Most of these program 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 foremen, underground superintendents and captains to assist in man-power deploying, production scheduling, equipment distribution, blast sequences designing, etc. Some of the improved information that could be provided by these upgraded systems would be:

- ore/waste pass levels;
- number of cars trammed (LHD with ID numbers) and tonnages moved;
- ore/waste source and dumping points, levels and mine sections;
- skips hoisted with tonnages;
- availability of equipment; conveyor statistics;
- on-line radiation levels (where applicable); etc.

An upgraded system could be based on the use of a hard-wire communication system but it would be desirable to have the flexibility afforded by a radio communication because of the dynamic nature of mining. Mine operators do not like wire systems because they are messy, expensive to install and prone to damage which seldom gets reinstalled if damaged.

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.

A successful system would send all needed information to a central processor for the scheduled reports. It could also produce summary daily, weekly or monthly reports regularly, demand or flag-out warnings basis. This mine management information system could be linked to other existing information systems on ventilation, hazard warning, fire warning, control programs etc. The projects success could lead to computer controlled mining and communications.

Management and computer controlled mining and communications

"Control-room technology" for mining?

Most underground mine managers and superintendents would appreciate having a wide screen display system in their office (say 5 ft by 15 ft) showing the status of various aspects of their mine level by level. It would represent a quantum advance in information available which would greatly assist them in managing the dynamic process of mining. The availability of computerized mine plans regularly updated by new survey data, would greatly assist the development of 3-D graphics packages which is basic to the provision of such large screen displays. Mine graphics technology and large video screen would make the construction of 3-dimensional (plastic) mine models obsolete.

However, the detailed current mine status information that such a screen could provide a mine manger or superintendent is limited because of the lack of instrumentation and sensors to gather pertinent information. As well, a suitable mine-wide data, voice and video communications to transmit is not available. By contrast such display systems for the control and management of large complex operations are an essential element in many other industries, such as the operation of nuclear plants in the utilities industry. System concepts such as presently used in utilities industry in the control of power stations must be successfully introduced and used in large Canadian mines possessing world level deposits if the industry is to remain healthy in the 21st century.

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 incrementaly.

The principal segments of such systems are the following:

- an integrated data, voice and video communication with mobile and stationary equipment;

- equipment capable of computer control;

- intelligent sensors and actuators.

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 stations link to the engineering 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 author's 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-system. For example, a hybrid system could consist of hard wiring between stationary locations and linkage to moving and advancing stations using radio links. Thus, mobile equipment at a face would be served by an antenna at the end of the nearest hard wire 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. Despite claims made by mine communication system manufacturers, published papers by hardrock mine users indicates that the communications technology does not exist for mine-wide automation and equipment control. A new start is required on mine communication system development with emphasis on the sub-system concept and provision for miniature scale trials.

To date, most of the sales of communications equipment made to mines have been for voice communication 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, like IBM, 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 if 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.

The initial step for a particular piece of equipment will be the development of monitoring sensors for essential control functions and a one way data transmission system. Remote control will ultimately require a suitable two way data system and necessary actuators.

Figure 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 systems.

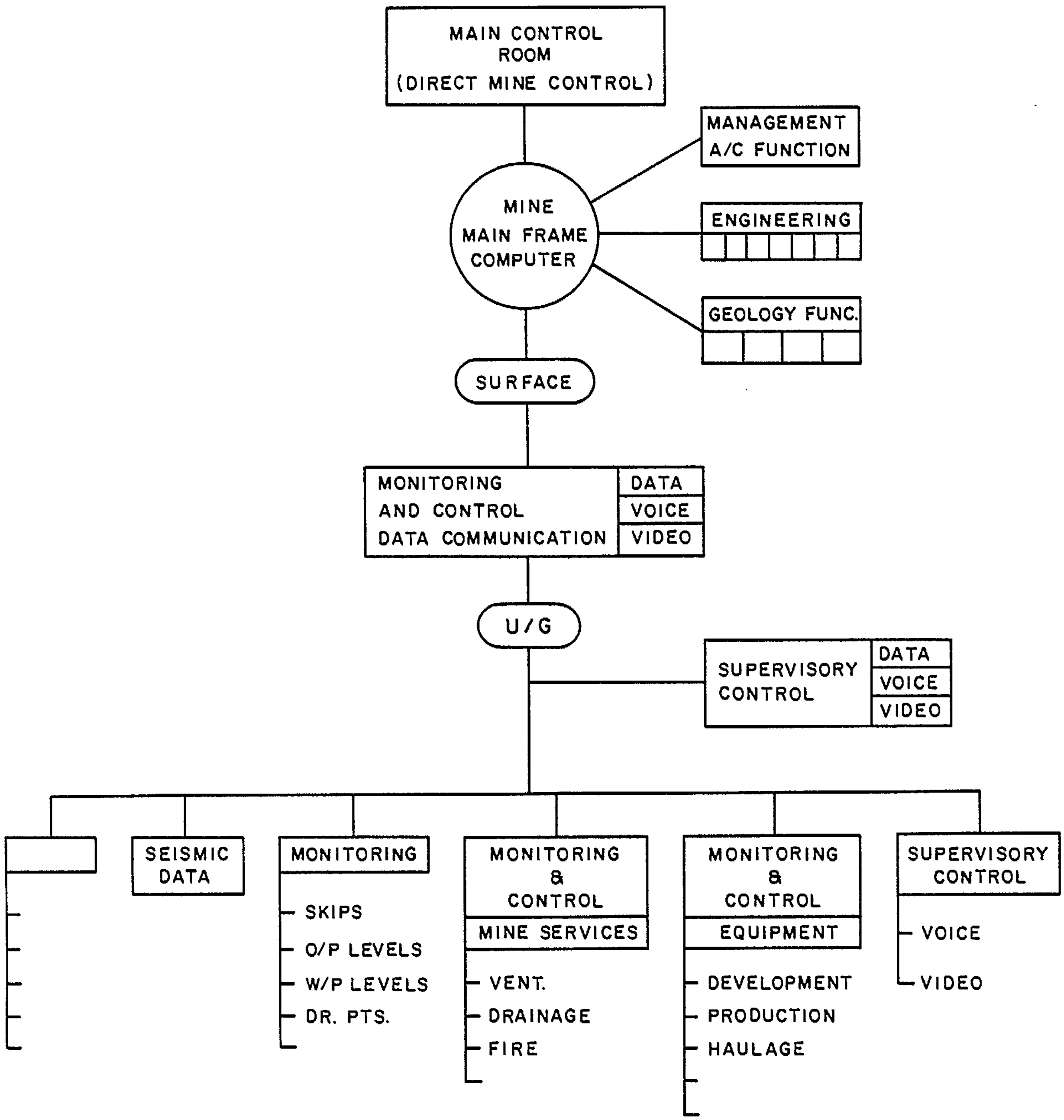

Fig. 2 - Mine-wide monitoring and control system.

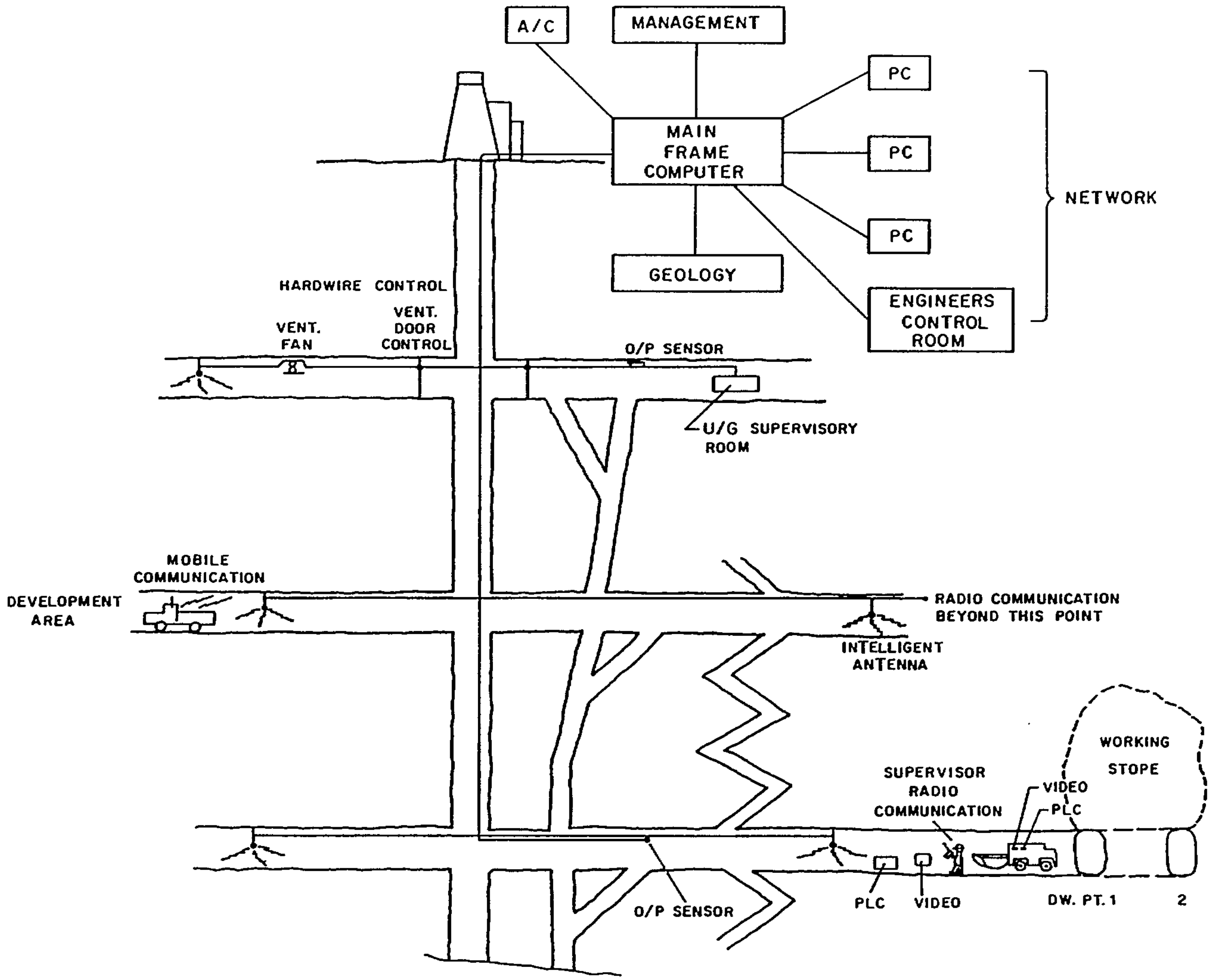

Fig. 3 - Mine-wide hardwire/radio communications system.

Existing and potential mining industries suppliers of equipment and high technologies are reluctant to take initiative with respect to the development of a computer assisted mine management systems (control-room technology) for the previously mentioned reasons: size and cost of project. The Canadian mining and manufacturing industries should keep in their mind and attempt to emulate the enterprise shown by the Swedish and Finnish industries in the area of automated mine equipment: computer controlled jumbos; roof bolters, etc. With much smaller domestic mining industries, (10 - 15 %), they are able to export such units worldwide.

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

- identify parameters to be sensed;
- develop intelligent mine-rugged sensors and electronics;
- provide and assist in mine testing of system components;
- develop standardized communications protocol, (consider foreign developments for easy adaptation to Canadian systems);
- decide on necessary number of component system for hybrid broadband communications systems, hardwire systems for stationary areas and radio links for mobile equipment and dynamic areas of the mine;
- develop interfaces for communications equipment and equipment controls;
- develop underground sub-systems trials and surface networking;
- carry out integration of the whole system.

It is estimated that this project would cost around $ 10 million over a period of 5 years.

It is crucial that companies with the requisite research development and manufacturing expertise and experience be requested to participate in this project particularly: data, voice and video communication companies, automated equipment companies, high-tech oriented mining companies. As mentioned earlier, suitable specialist companies would need to be given substantial incentive to become involved in the mining industry.

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 competitiveness of the industry as it mines into the 21st century. There will be a large export market for this technology and expertise which should be exploited. As all advanced countries with an R & D capability, Canada must sustain its status by development and use of new technologies.

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