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SAFETY BREAKTHROUGH--

REDUCED EXPOSURE MINING SYSTEM (REMS)

By J. J. McClelland, R. F. Randolph,
G. H. Schnakenberg, Jr., and R. S. Fowkes

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

U.S. Department of the Interior
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Safety Breakthrough—
Reduced Exposure Mining System (REMS)

By

J. J. McClelland,[1] R. F. Randolph,[2]
G. H. Schnakenberg, Jr.,[3] and R. S. Fowkes[3]

[1]Computer engineer
[2]Research psychologist
[3]Research physicist

U. S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA

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Executive Summary

The face area of a continuous mining section of an underground coal mine is the most dangerous area in the mine. Workers there are at nearly twice the risk of death or disabling injury than those in other parts of the mine. Despite extensive training of miners and improved equipment and mining methods, fatality and injury rates have remained constant during the past few years. It is clear that advanced research is necessary to apply new technologies or modify work procedures to solve the continuing problem of the loss of lives and the numerous injuries at the mine face.

A U.S. Bureau of Mines research program is developing a Reduced-Exposure Mining System (REMS) that relocates personnel operating the mining machinery at the face away from the hazards to a nearby haven of relative safety. REMS uses proven technologies of computer automation and robotics to help control the operation of the mining machines at the face, while personnel are moved away to a nearby, safe control room. In this protected, well-ventilated environment, they can supervise or control the operation of the machines while viewing what the machine is doing using video and graphic display monitors.

REMS has the potential to be the single most important improvement in the safety and health of underground coal mine workers since the introduction and enforcement of the Federal Coal Mine Health and Safety Act of 1969.

The REMS program is one of the more significant research efforts of the U.S. Bureau of Mines, Department of the Interior, which has been mandated by Congress to "conduct necessary research and development to improve working conditions and practices in coal and other mines...to prevent accidents...to develop new and improved underground and other equipment...which will provide greater safety."

REMS clearly meets the requirements of this Congressional mandate. It has been developed to save lives and to minimize human suffering, and is the only research program to address the safety of the mining system at the mine face. In addition to protecting mine workers, REMS will redefine their roles, allowing them to operate in a more productive, environmentally-safe manner.

REMS technology is also available and is being tried and tested for applications other than underground mining. Various aspects of its system can be adapted to improve productivity and protect workers in industries such as civil engineering and construction, nuclear and hazardous waste detection/cleanup.

Introduction

Between 1986 and 1992, there were 268 deaths and 54,642 severe injuries to workers in underground U. S. mining operations. Clearly, this level of health and safety risk is not acceptable.

Figure 1.- Typical remote control continuous mining machine and its operator.

While most underground coal mining jobs are dangerous, some are much more dangerous than others. Many jobs in an underground coal mine are clustered around the working face—the place where machinery digs coal from the surrounding rock. The hazards in this area are numerous: When the coal is removed, the ground around it becomes unstable and can cave in on the workers. The mining machines used there are large, heavy, powerful, and move in many different directions in a very confined space, presenting danger to workers. Also, the machines churn up coal dust that causes black lung and other ailments. Figure 1 shows a modern radio remote controlled continuous mining machine and its operator.

"The best way to protect an individual is to remove that individual from the hazard."
-Ronald Wooten

In a typical mine, the jobs with the greatest exposure to hazards involve operation of machinery that cuts tunnel-like passages into the coal (the continuous mining machine) and machines that insert supportive steel bolts into the rock above the work area (roof bolting machines).

The workers who endure these hazards are at almost twice the risk of death or disabling injury than co-workers in other safer areas of the mine.

Of the statistics quoted above, 106 of the 268 deaths and 21,552 of the 54,642 severe injuries occurred in jobs involving equipment at the working face.

The operators of roof bolting and continuous mining machines account for only 21% of the work force but suffered 40% of the deaths and 39% of the lost-time injuries during 1986-1992. These death and injury rates are almost twice the rate for workers in other underground mining jobs (see figure 2). The estimated total cost of the 106 fatalities and 21,552 lost-time injuries was $327 million from 1986-1992. On average, each fatality cost over $1 million and each lost-time injury costs in excess of $9,000.

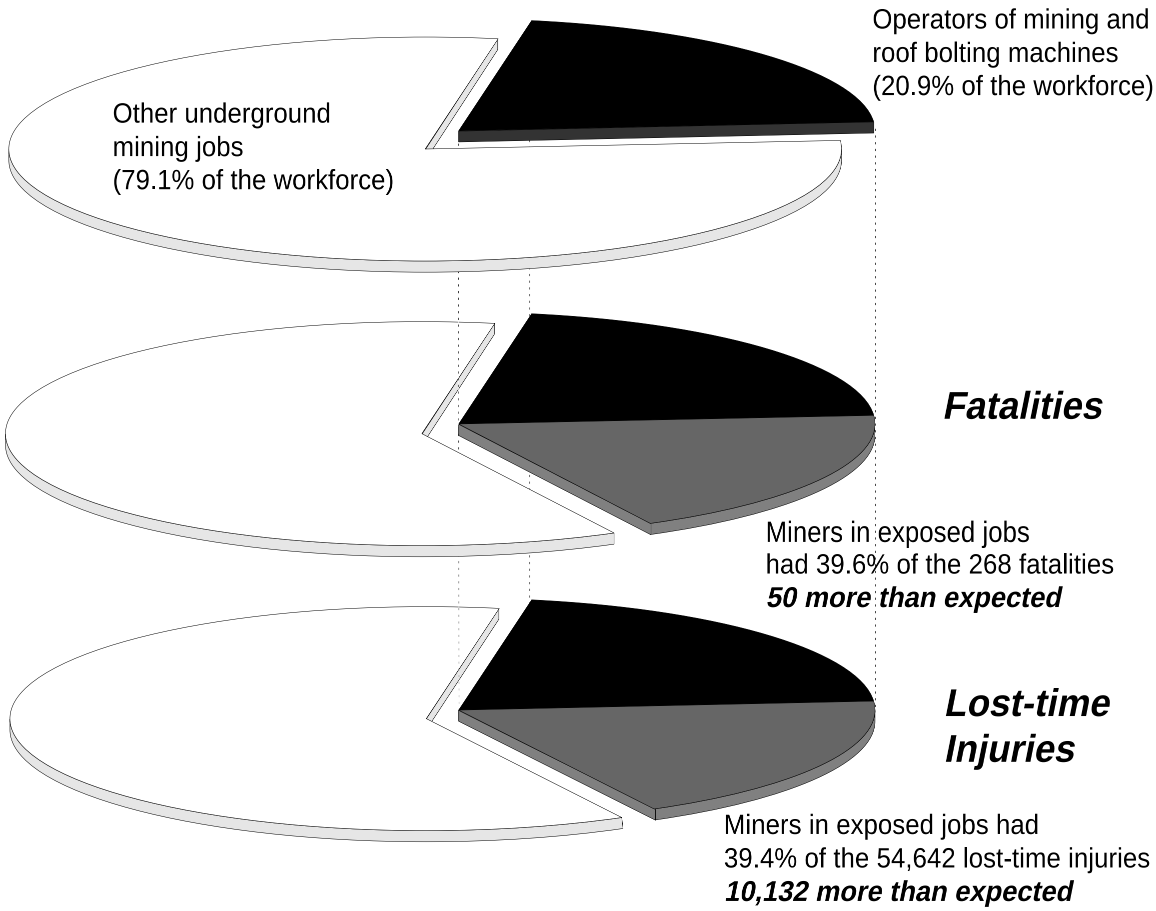

Figure 2.- During 1986-1992, operators of mining and roof bolting machinery had almost twice the expected number of fatalities and injuries.

Figure 3 shows that the improvement in fatality rate has bottomed out over the last few years; the injury rate also shows a flattening trend, the recent upturn due to a more comprehensive accident reporting procedure. Successful research programs will be the ones that attack this problem in a new way—either by the application of new technologies or addressing and modifying work procedures.

When workers are exposed to hazardous conditions, the most effective remedy is simply to reduce their exposure, if possible. In underground coal mining, the hazards revolve around just a few activities in a small area. If workers can be relocated to a safer area where they perform less hazardous jobs, the number of injuries and deaths will be dramatically reduced.

Ronald Wooten, Safety Vice President for Consolidation Coal Co., in testimony on behalf of the National Coal Association (NCA) to Congressional Oversight Hearings in 1990 said, "The best way to protect an individual is to remove that individual from the hazard. This simple and fundamental underpinning is, we believe, at the heart of the [Bureau of Mines'] Automated Mining Systems program."[1]

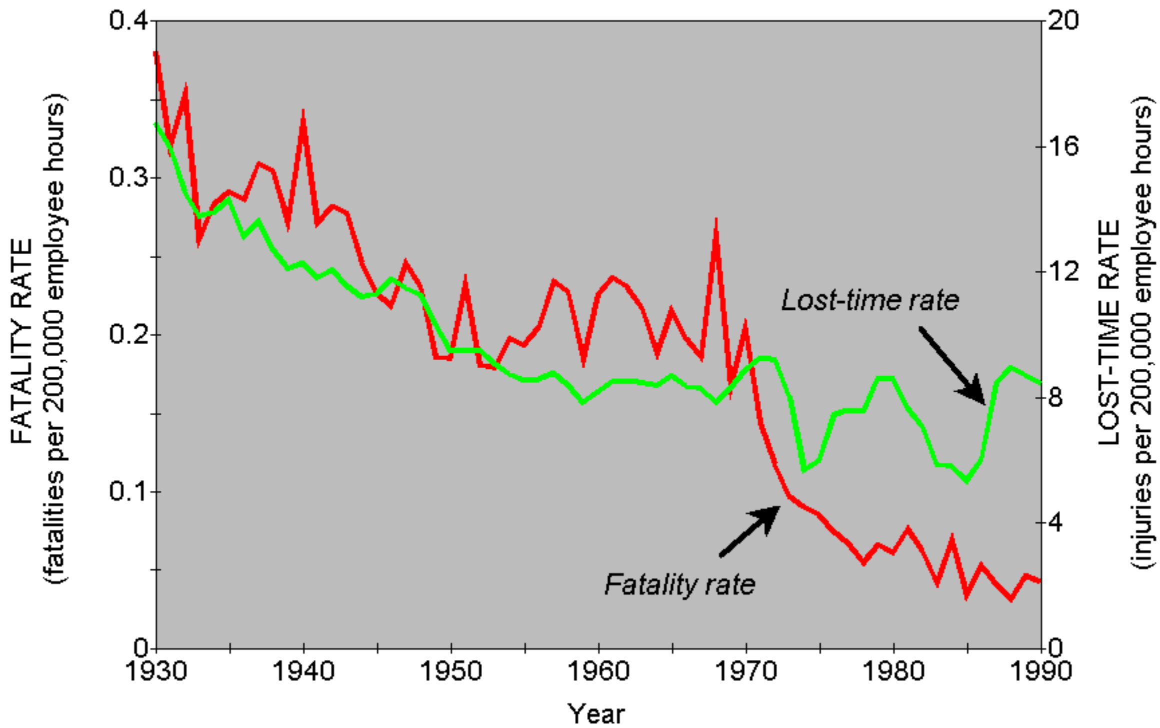

Figure 3.- Trends in underground coal mining fatalities and lost-time rates, 1930-1990.

Until recently, the relocation of workers was impractical because the technologies needed to make the changes were not available. The U. S. Bureau of Mines (USBM) and others have traditionally improved safety through methods such as modifying work procedures, developing and implementing training, and improving machine design. The return from these traditional approaches, while effective, may be diminishing. The historical trend of continuing improvements in fatality and injury rates in the mining industry began to taper off in the 1980's. The next great steps in improving safety will require fundamental changes in the mining system, including the technology, work force skills, and the tasks miners perform. New technologies are making these changes feasible.

Present Mining Methods

The following is a description of the mining system of a productive room-and-pillar mine:

Two mining methods predominate in producing most of our nation's underground coal—the room-and-pillar method and the longwall method. Both methods are entirely dependent on the same three pieces of equipment—the continuous mining machine, roof bolting machine, and a haulage system—but in different ways. In room-and-pillar mining, a continuous mining machine removes the coal by cutting between three and seven parallel tunnels (called *entries*). These entries are then cross-connected by right angle - or angled - entries, the intersection of which is termed a room. The remaining coal between the entries is called the pillar. In longwall mining, the longwall panel is "developed" by driving two parallel 3-entry room and pillar sections separated by a few thousand feet. The time it takes to establish a longwall section is presently constrained by the time it takes to develop these room and pillar entries. The mining process is described below.

A continuous mining machine is operated either with the operator riding inside a compartment on the machine or by radio remote control, with the operator standing within proximity of the machine. A miner helper may be present to pull the mining machine power cables and water hoses out of the way as the mining machine backs out of the newly mined area. Two additional workers drive the shuttle cars which carry the coal from the output of the mining machine to the conveyor belt a few hundred feet away. In a few more advanced mines a single worker controls the front end of a continuous haulage system that is used in place of the shuttle cars.

Coal is mined by advancing the cutting drum of the continuous mining machine into the coal in a series of sump (forward advance of the cutting drum into the coal) and shear (downward sweep of drum) actions, creating a tunnel (entry). A number of factors limit how far (deep) the machine can advance before having to pull out to allow the roof to be bolted. Presently, the haulage operator cannot go under unsupported ground, limiting the depth to about 12 m (40 ft). In a very few mines, the use of radio remote controlled continuous miner and continuous haulage allows mining to 30m (100 ft). This increases the efficiency of mining by reducing the number of times the machine must be moved from one entry to another.

Any person who is standing near these moving machines is at risk of being pinched between the equipment and the mine walls, as well as exposed to dust and noise. Occasionally, the roof, even though it is supported where the worker is standing, may cave in on the equipment and the worker.

While mining of an entry is going on, two other workers are operating a dual boom roof bolting machine in another nearby freshly mined entry. Here, the machine is maneuvered into the first area of unsupported roof. The roof is first supported temporarily with hydraulic jacks. A worker at each boom then drills a deep hole upward into the ground above the entry. A long bolt is placed in this hole, and tensioned to hold the roof strata together. The jacks are released and the machine is moved further into the entry and the process repeated. In roof bolting, the worker is susceptible to cave-in or getting pinched or injured by the equipment.

Shuttle car drivers are less frequently injured, yet their equipment represents a hazard to others. More progressive mines are using, or are considering using, continuous haulage where feasible.

The Solution: Reduced-Exposure Mining System (REMS)

The technology that can virtually eliminate worker exposure to hazards while performing the mining activities of room and pillar mining is within our grasp.

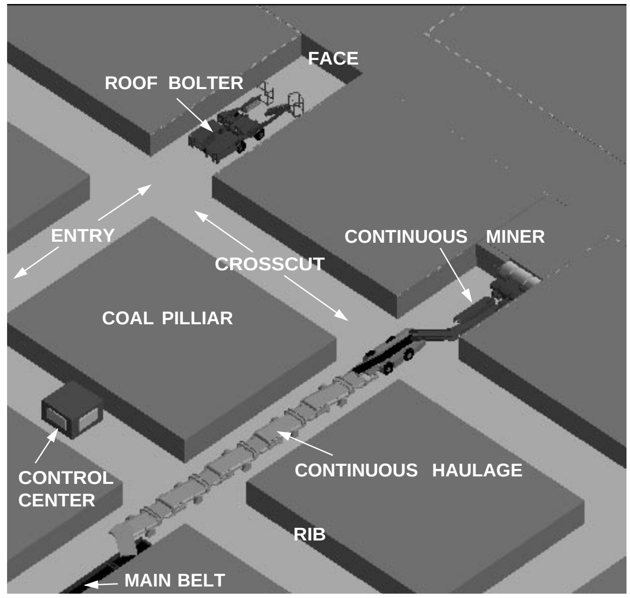

Figure 4.- Underground coal mine work site using the Reduced Exposure Mining System (REMS).

Within the last decade, technology in the form of powerful yet relatively inexpensive computers, sensors, and graphic video displays, has advanced to the point where it can be used with mining equipment to avoid most mine face hazards. **The solution is the relocation of machine operating personnel away from the hazards to a nearby haven of relative safety. This simple statement embodies the purpose of the USBM research program on reduced-exposure mining.**

REMS exploits the technologies of automation and robotics and can also be referred to as computer-assisted mining. REMS uses sensors and computers to control the operation of the mining machines for the most hazardous mining tasks, eliminating the need for a worker to ride on, stand beside, or be within line-of-sight of the machine. The machine operators are instead located in a safe control room nearby, supervising the computer operation of the machines (see figure 4), virtually eliminating their exposure to the hazards that cause death and injury.

The machines involved are the continuous mining machine, a continuous haulage system (or a pair of shuttle cars), and a roof bolting machine.

REMS has the potential to be the single most important improvement in the safety and health of the underground coal mine worker since the introduction and enforcement of the Federal Coal Mine Health and Safety Act of 1969. Thus, the REMS research program is one of the most significant current research efforts of the USBM.

With REMS, workers use a combination of computer and remote manual operation of the mining machines. Video and computer displays are used to monitor mining operations from the control room.

A typical scenario is the following: After the mining machine and haulage system are manually moved into a starting position, the workers walk to the control hut, take a seat, and turn over the mining actions of the continuous mining machine and continuous haulage system to computers. The machine operators view the progress of their machines on a video display terminal. Upon encountering unusual situations, the computer will alert the operator and request manual intervention and control from the operator.

REMS has the potential to be the single most important improvement in the safety and health of the underground coal mine worker since the introduction and enforcement of the Federal Coal Mine Health and Safety Act of 1969.

Similarly, the roof bolting machine will be controlled by computer. Once it has been manually placed into an approximate starting point, the computer will guide it to the proper positions to place the bolts for the entire depth of the entry. As with current practice, mining and bolting occur simultaneously, but in different entries.

When the mining machine has cut to the depth required - usually 6 to 30 m (20 to 100 ft) - it will withdraw to its starting point. The workers will then manually move the machine to the starting point for the next cut, usually in an adjacent parallel entry. The roof bolting machine is moved to the entry just vacated by the mining machine.

Machine maintenance/servicing will be done under a safe roof between mining activities as is the current practice. Mining machine bits will be changed if needed, drill bits will be inspected and changed, and the bolter loaded up with bolts and anchors. The workers remain in relatively safe areas performing these routine activities. The ventilation will be moved if necessary, but most ventilation air will be provided by an additional system that can be mounted on the continuous haulage system. Once the machines are serviced and set into position, the workers will retreat to the control station and turn their operations over to the computers.

In summary, REMS provides the technology that enables the operators of the mining equipment to operate their machines at a distance, in safety, and as will become clear, with enhanced efficiency.

REMS Benefits

For years, industry, government and university researchers have worked to identify ways to reduce the health and safety risks associated with mining. Significant gains have been realized in many areas, leaving no doubt that our mines are much safer and more productive than the mines in which our forefathers risked their lives. Health, safety, and production statistics support this reasoning. Unfortunately, lives are still lost from dangerous methane ignitions, fires, and cave-ins. Also, workers continue to suffer a disproportionately high percentage of disabling injuries, and long-term debilitating diseases such as pneumoconiosis and silicosis.

Traditional research focuses on identifying methods, procedures, protective equipment, and preventive techniques that will allow mining personnel to work in relative safety, but without removing the worker from the hazardous face area. These solutions keep the worker and machine in a precarious situation where the unforeseeable actions of both can lead to disastrous results.

REMS is a dramatic, yet logical, shift away from a traditional research approach. It does not struggle to find ways to minimize the hazard itself or its effects, but instead physically separates humans from the hazard.

REMS offers tangible benefits in safety, health, the environment, and productivity. The benefits of REMS will accrue to any mine where continuous mining machines are used. This includes longwall mines as well as single- and multiple-section continuous mining operations. The following is a list of the most significant benefits offered by REMS:

REMS offers tangible benefits in areas such as safety, health, the environment, and productivity.

Safety

Relocating the face workers to a control room will have the most dramatic benefit to the industry by its impact on worker safety. No longer will the worker be working in fear of cave-ins, of being crushed by the very machine they operate or one operated by a co-worker, of being hit by debris from a bursting pillar, or of being caught in equipment mechanisms—all hazards of the working face. It is in this area that the roof has not yet been supported or, if it has, still remains unstable and unpredictable as the earth continues to settle around this newly created void. It is here that large, heavy equipment is maneuvered to mine coal in a very confined space, and shuttle cars jockey into position behind the machine to receive the coal. The simple act of relocating the worker from the face area and activities could prevent the loss of about 15 lives annually.

Health

Relocating the face workers will also avoid several serious health hazards present at an underground mining section. Exposure to respirable coal and quartz dust will be reduced to near zero or eliminated, thus leading to a reduced occurrence of the debilitating and often fatal diseases, pneumoconiosis and silicosis. In addition, mining machines working within narrow working areas generate an incredible amount of noise that can lead to permanent hearing loss.

Additionally, there will be less need to manually and physically manage heavy power cables and water lines. The cables will be handled by the continuous haulage system. This will lead to a substantial reduction in back injuries, which account for a significant number of lost-time injuries at the working face, the cost of which is excessive.

Environmental

Coal cutting by the continuous mining machine will be better controlled; deviations out of the coal seam and into roof or floor rock will be greatly reduced resulting in cleaner coal and a minimum of unrecovered resource. Existing mining systems require visual observations and to some extent the trained ear to determine when floor and roof rock is being cut and coal is not. Only the most experienced mining machine operators can minimize the likelihood of cutting rock. When rock is mixed with coal it must be separated and discarded before the coal can be shipped. It is this waste product that is dumped in unsightly heaps at the surface. Coal interface sensors will provide better ways to keep the machine within the seam, resulting in cleaner coal, less waste on the surface, and lower cleaning costs. More accurate cutting of the entries will eliminate the practice of leaving larger than necessary pillars "just in case we cut too much on the last pass or might cut too much on the next entry." More accurate cutting control will enhance resource utilization.

Productivity

With advanced guidance, navigation, and ventilation technology, REMS will increase machine efficiency as deeper cuts are taken with fewer intervening place changes. Existing Mine Safety and Health Administration (MSHA) regulations for mining machines limit the depth of cut to a maximum of 12 m (40 ft) simply because the haulage operator would be under unsupported roof. Deeper cutting places the machine operator at a disadvantage because dust and equipment obscures the view making control of machine less accurate. Ventilation of deep cuts requires special techniques to clear dust and methane and to monitor the methane level. Today, increasing mining efficiency by deep cutting is hindered by lack of adequate technology. Consequently, frequent place changes (the miner leaves, the bolter arrives) are required. These place-changes take time and cost money because the time spent moving means less time cutting coal. **With the REMS, depth of cut may exceed 30 m (100 ft), thus reducing the number of needed place-changes by 60 percent.**

The REMS is ideally suited to longwall development where rate of forward advance is of primary importance. With a herringbone, 3-entry pattern, and a REMS, mining will be highly efficient and almost continuous.

Additionally, it should be pointed out that productive mines are usually large, running several room-and-pillar or longwall sections. The introduction and use of REMS would eventually involve its use in all of the sections of a mine, not just one. Also, REMS would allow small mines to step up to a safer and more efficient technology without the high capital cost of a longwall system.

Cost-Benefit

The cost of a single death to the mining industry and to society is approximately $1 million. However, the loss of a human to his or her family and loved ones is immeasurable. The mine face area, which is addressed by REMS, accounts for approximately 17 fatalities per year. Most, if not all, can be eliminated by using this technology. This represents a savings of over $17 million annually. The annual cost of the research program is less than one-third of that. There are further benefits owing to drastically reduced injury rate and incidents of black lung. Additionally, increased utilization of resources (both labor and capital), increased coal recovery, better mine geometry, and less preparation costs owing to cleaner coal, tend to lower the cost of coal and hence its price to the utilities using it.

The effects of USBM research are permanent; once reduced-exposure mining is established, savings will continue to be realized **every year thereafter**.

In summation, REMS will significantly reduce accidents, fatalities, and injuries occurring at working sections of underground coal mines; decrease incidence of black lung and hearing loss; improve overall efficiency of mining equipment through an increase in equipment utilization; and have a positive environmental impact through increased mineral recovery.

The payoff of this research is high and is much greater than its cost. To the companies who adopt REMS, the payback will be realized in a short period of time.

Reallocation of Human Resources and Training

As to the effect that automation will have on jobs, Frantz and King[2] did an in-depth analysis of four stages of automation in a continuous mining section in terms of safety, productivity, and employment. They then compared their results with those of a present continuous mining section. Their investigation showed that the automation of a continuous mining section improved the health and safety of mine workers, increased section productivity, decreased mining costs, and led to increased employment. The increased efficiency of the automated systems made the mine more productive and led to increased hiring.

> *A company or industry that fails to modernize cannot remain competitive with other companies or industries that do adopt this technology.*
>
> *-Uday Kumar*

The authors present tables for the present system and the systems in various stages of automation, which give a detailed breakdown of underground and surface employees by job title.

Other tables in this report show that for the mine using the present system, 400 employees are required and productivity is 11.3 clean tons per person-shift. Of the four stages analyzed by Frantz and King, the fourth closely approximates REMS; that is, production personnel are removed from the working face with the only workers in that area being there for emergency service and planned maintenance. Stage IV automation involves 618 employees, and produces 21.8 tons per person-shift. Thus, the move from the present system to REMS will increase the number of employees from 400 to 618 while increasing productivity from 11.3 to 19.6 clean tons per person-shift.

In terms of safety, the authors present detailed tables showing the frequency of accidents due to a variety of causes (cave-ins, face or rib falls, haulage, bumps or bursts, etc.) for the present system and for each of the four stages of automation. In brief, the overall accident frequency per million person-hours for the present system is 42.8, while for Stage IV automation (REMS) it is 24.0; thus reducing the possibility of accidents by almost 1/2.

> *The impact of automation and robotics on employment in mining, construction, transportation, communications, and agriculture will not be drastic.*
>
> *-Ayres and Miller*

In a paper dealing with mine mechanization and automation, Uday Kumar[3] asserts that advanced technology is needed to save jobs. According to Kumar, a company or industry that fails to modernize cannot remain competitive with other companies or industries that adopt this technology. And although mechanization and automation alter the nature of human involvement at various levels of operations in mines, humans are still and always will be needed to monitor, supervise, and execute mining operations.

Ayres and Miller[4] claimed that the impact of automation and robotics on employment in mining, construction, transportation, communications, and agriculture will not be drastic. These fields will continue to use human workers in essentially the same types of jobs that they presently perform.

The U. S. Bureau of Mines—Developing Technology for Health, Safety, and Industry Support

The USBM has been involved in electrical systems and instrumentation research for over half a century. During the last 12 years, it has enhanced its research staff to include specialists in computer software programming, and specialized mechanical systems. The Bureau's Pittsburgh (PA) Research Center, where a Mining Robotics Development Laboratory was recently dedicated, is the lead center for REMS research. The facility features offices adjacent to an enclosed high bay area where mining equipment and systems can be tested. Additionally, the Bureau's Spokane (WA) Research Center is performing research specifically on the complex problem of the autonomous roof bolting machine, a critical component of the REMS.

In the late 1980's, a progressive mining company sought out the USBM automation research group at the Pittsburgh Research Center and proposed that working together would be beneficial. They offered a test area in a mine, while utilizing the research skills of the USBM. They came to the conclusion that they would ultimately benefit from the Bureau's research on REMS. Under a Memorandum of Agreement (MOA) the USBM used the test site for two years, in which great progress was made toward computer-assisted machine guidance and control. At that point, the mine changed ownership and the machine was returned to the Pittsburgh Research Center for technology updates and additional surface testing.

Recently, several other mining companies and machine manufacturers have made inquiries to the USBM about possible joint ventures on REMS research.

Joy Technologies, Inc. and the USBM have a Cooperative Research and Development Agreement (CRADA) to investigate and develop technology for advanced computerized mining systems. The initial area of the cooperation has been for the development of a proximity warning system for human safety around mobile mining equipment. This system has been made commercially available by Joy.

Joy has also requested assistance to investigate the development of automatic cutting for a highwall mining machine. It wishes to incorporate coal-overburden boundary detection, rib thickness sensors, and automatic cutting cycle into a control system for its Addington highwall mining system. The USBM will apply their expertise to help solve these problems. This effort was initiated in 1993.

The incorporation of REMS technology into the mining industry will be gradual and evolutionary. Cooperative research agreements are being established that apply machine guidance technology (both heading and in-seam) and visualization systems to increase productivity of highwall operations. At least three highwall mining operations or suppliers of equipment are actively requesting information on REMS.

Impacts of Advanced Technology in Parallel Industries

Smelting

Because of hazards associated with smelting, steel mills have introduced filtered control rooms for workers in these areas. This is done in order to remove workers from the smelting area itself, which contains hazardous fumes. The control rooms have clean air pumped in, enabling the workers to perform tasks while increasing health and safety on the job.

Tunneling

Tunneling is an underground operation similar to underground coal mining in that a material is cut and transported and, if the roof is not substantial, it must be supported. Thus, while there has been some use of automation in tunnel-boring machines in large tunneling operations, there is potential application of REMS to tunneling. The U.S. Bureau of Labor Statistics found that the accident rate per 200,000 person-hours for underground workers in tunneling was **twice** the accident rate of workers in manufacturing and almost twice the accident rate of aboveground construction workers.

Recently, a mini-miner used in underground mining was modified and is being used in tunneling projects. The technology developed for REMS should have some application to tunneling equipment like the mini-miner and possibly to haulage of waste and roof support.

Removing workers from the hazardous face area is as important in tunneling as it is in underground coal mining. Glover[5] claimed that tunneling has a higher proportion of accidents than any other branch of civil engineering. The equipment developed under the REMS project will contribute to safety in this environment.

Spin-off Technologies Both for Mining and Other Industries

Since the inception of the research program on REMS, USBM researchers recognized the potential benefits of spin-off technologies that evolve from this work. As technologies are developed and refined to achieve computer-controlled mining, industry can begin to apply them to existing underground mining methods and equipment. Thus, short-term gains from a long-term research program can be realized.

Listed below are several of the more important and most beneficial spin-off technologies that will be available within three years:

Coal Interface Detection Sensors

In recent years, the Coal Interface Detection (CID) research program has developed a number of methods for determining the thickness of coal left on the roof, the coal roof-rock or coal floor-rock boundaries, and the thickness of coal pillars.

In situations where all of the coal is taken—but it is undesirable to cut and remove the roof or floor rock—a different technique for detecting the coal-roof interface and controlling the cutting of coal is needed. The USBM has developed an infrared technique to detect this coal-rock boundary under these conditions. An infrared viewing camera and image-processing intrusion alarm have been successfully used to indicate the point where the host rock is just barely being touched by the mining machine bits. This infrared system is ready for application now and several mining companies have shown an interest in adopting it. An alternative would be to use electronically detected vibration picked up by a roof bolt.

Highwall mining requires accurate control of the pillar wall of coal between adjacent entries. The deeper one can penetrate into the coal seam, the more efficient the operation becomes, enabling more coal to be removed. Coal is wasted if the separations are too wide, and mines can collapse on the machine if the walls are too thin.

The USBM has successfully modified a commercial pulse radar system to perform measurements of the coal wall thickness. The output can be used as feedback for the operator so that the direction of the machine can be altered to maintain a parallel entry at the correct minimum thickness. Highwall mining companies are actively engaged in working with us to get this product on their machines.

In the near term, the mining industry will have a device to aid it in making consistent and repeatable roof and floor cuts, as well as a device to measure rib thickness between cuts. Advantages of equipping a machine with seam-tracking capability include higher coal-bed extraction, reduced dilution by minimizing roof/floor material taken, increased coal-cutting rates, reduced machine maintenance (due to reduced rock-induced vibration), and reduced respirable quartz-dust concentrations (due to the reduced cutting of roof and floor rock).

The USBM research program is also developing a novel radar technique that can identify differing strata layers or objects for distances of up to 9 m (30 ft) into the ground. With this system one will be able to look ahead of mining operations to detect voids, gas well pipes, etc. It can be used to investigate strata layers to determine proper roof bolt lengths.

It also has the ability to examine concrete roads, bridges, walls for structural changes, and can provide a general-purpose, through-the-earth imaging instrument for detecting unexploded ordnance and nuclear waste as well as for imaging the condition of our nation's highways, locks, dams and bridge structures.

The USBM has conducted an extensive study of coal and host rock properties, especially for their gamma emission rates. Armed with this information, researchers are able to offer mine companies guidance in determining whether the now-commercially available natural gamma coal thickness sensor will work for them and how the systems can be implemented in their mine.

Machine Diagnostics

The USBM has been actively pursuing the development and application of expert system technology to diagnose and predict maintenance for mining equipment. Equipment maintenance accounts for a significant portion of lost production in underground mining operations. Discussions and feedback from industry experts rank this as a top priority for increasing equipment efficiency and utilization.

Implementation of REMS will introduce a new level of machine complexity that will require special skills for maintenance and support. By using well-designed, on-board diagnostics systems, less training will be required to maintain REMS. The time to identify the cause of malfunctions and repair the systems will be greatly reduced. Most importantly, diagnostic systems will permit scheduled and preventive maintenance in safe areas of the mine.

Two prototype expert systems have been completed. A hydraulic diagnostic maintenance expert system analyzes data from machine-based sensors to diagnose system component problems and failures. An electrical diagnostic expert system was developed as a user-interactive troubleshooting guide for mine electricians. Both systems provide a powerful means for improving equipment maintenance by allowing maintenance personnel to quickly diagnose malfunctions and recommend appropriate repairs.

The concept and benefits of this research are applicable to all machines, regardless of how they are operated. Because REMS provides an onboard data communications network, acquisition and analysis of sensor data will be even easier, but the network is not a prerequisite to implementation of diagnostic systems.

Another diagnostic system, able to predict the failure of the large electric motors used in mining equipment, is being perfected. Current and voltage sensors are placed on the power wires leading to the motor, allowing signals to be analyzed and the condition of the motor to be assessed. Motor failure is a leading cause of machine downtime, and early detection of impending failure will allow preventive maintenance to be scheduled, increasing machine availability.

Worker Safety Devices

USBM experiments with REMS during the research and testing phases require a person to handle the mining machine cable while the machine is under computer control. The USBM concern for that person's safety and the need for him or her to be able to stop the machine or indicate readiness of the coal haulage system, led to the development of a remote control system. This uses an MSHA-approved, two-way voice radio equipped with a touch-tone controller. The handheld device provides override control of several critical continuous mining machine functions, including the ability to pause or terminate machine operation instantly. In addition, it allows the operator to talk to the researchers located in the section control center, thus providing an added layer of safety. The device can be retrofitted to most underground mining machines and used as a safety mechanism to prevent accident and injury to face personnel.

Also, because of the increased use of radio remote-controlled mining machines, and because of the safety issues of persons being around computer-controlled equipment, the USBM research team developed a proximity warning and machine shut-down system. This system detects when a person is too close to the mining machine and prohibits the machine control until he or she gets safely away from the machine.

Navigation and Mine Mapping Technology—Cyclone Sensor

Developed with the intention of detecting local obstacles and navigating/mapping mine geometries for guidance, it is receiving interest as a post-mining survey and mapping tool. Software development to support representation of cyclone sensor data is ongoing. Eventual use would be for semi-automated generation of accurate maps of mine workings. This will make for better recovery of valuable mineral resources and prediction of mine boundaries, faults, wells, and other anticipated seam obstructions.

Multipurpose Underground Teleoperated Tracked (MUTT) Scout and Survey Vehicle

A small remote-controlled vehicle was built to take video equipment and other types of instrumentation into areas where it is unsafe for humans to travel. It is receiving interest by highwall miners who want to inspect entries for voids, coal seams, environmental conditions, and the like. It is also seen as a vehicle to assist mine rescue teams in mine inspection and recovery efforts.

Roof Bolter Technologies—Bolter Module

Roof cave-in in production sections of a mine is the largest contributor to worker deaths and injuries. Today's bolter operators must be located at the point of operation of the roof bolting machine, a location particularly vulnerable to this hazardous condition. The bolter operator is also exposed to injury while manipulating the drill rod, resin cases, and bolts.

One critical component of the REMS is the computer-assisted roof bolter. An interim development will be the radio or tethered remotely controlled bolter. Remote control eliminates the necessity of workers near an unsupported roof and eliminates the need to handle bolts, drill steel, etc., all of which carry risk of injury. The operator will have to be within line-of-sight of the roof bolting machine in order to control its operation. The advantage is that the bolter operator can perform his or her job function at a safe distance from the unsupported roof. The computer-assisted bolter can operate as a stand-alone piece of hardware. The most difficult research, the automated bolter module, is currently under intensive development.

Smart Drill

Manual control over the drilling of roof bolt holes has been shown to be less than optimal by all but the most experienced roof bolter operators. Also, with the drive to remove the worker from the vicinity of the bolter, a means must exist to provide the drill with the proper thrust and speed control as differing layers of strata are encountered.

The Smart Drill monitors drilling thrust, torque, and rotational speed. This information is processed and the thrust and speed are controlled to maximize drill bit life and drilling efficiency. The measured parameters are also being used to identify boundaries and types of immediate strata. Strata knowledge will be used to improve bolting patterns and length selection.

Although essential for computer-assisted bolting, the Smart Drill can aid manual bolting as well, since it provides better drill control than humans and measures strata properties hidden from the human operator.

The drilling control elements for a Smart Drill will be available within 2 years; the strata identification feature will be available in 3 years.

Miner-Following Haulage

The REMS will couple the continuous haulage movements with the mining machine. A spin-off will be a system that will connect the haulage to a standard remote-controlled continuous mining machine. This will reduce the need for handling heavy power cables and water lines. Cable handling is a leading cause of back injuries in underground mining. In addition, it will increase equipment mining efficiency and production since time will not be lost waiting for haulage vehicles.

Ventilation Systems for Deep-Cut Mining

Ventilation systems with the ability to bring fresh air to the working face when the mining machine and continuous haulage systems are performing deep cuts, is a stand-alone technology. It is applicable when the mine chooses to perform deep cuts or break-to-break cuts, an increasingly popular mining practice. Its development has been accelerated owing to its use in the REMS.

Environmental Monitoring

Deep-cut mining methods are compelling the USBM to develop airflow and methane monitoring systems to ensure adequate dilution of methane at the face and adequate airflow. The dust scrubbing systems found on continuous mining machines are effective in moving air across the face and diluting methane. As they become plugged with dust, the airflow decreases.

The USBM has developed technology alerting operating personnel when the dust scrubber becomes clogged. Also being developed are dual-head methane monitoring systems, which provide a better measure of face methane concentration and a more effective ventilation system to dilute methane encountered while mining. With the probability of reduced exposure systems on the horizon, such monitoring technology becomes essential, and its development has been accelerated for this reason.

Summary

The advent of advanced computerized technology is inevitable. The REMS is in a unique position compared to other industrial automation; its major emphasis is to save lives and minimize permanent human suffering. Its effect on the number of mine jobs will be minimal; the major effect will be redefining the job of a face worker. USBM research efforts serve to bring this technology to the mining industry more promptly than if left to the industry itself, with minimal resources for research. USBM research also brings this technology openly and equally to all manufacturers of mining equipment. Through cooperation with manufacturers, the USBM ensures that the technology is sound and meets the needs of its customers.

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ADDENDUM

The Pittsburgh Research Center: History and Scope

Mining Robotics Development Laboratory

The Pittsburgh Research Center: History and Scope

In 1910, THE NEWLY CREATED U.S. BUREAU OF Mines (Act of Congress 36, Stat. 369, March 16, 1910) acquired a 38-acre tract of land at Bruceton, PA, about 13 miles south of Pittsburgh. This property included a small coal mine, later to be known as the Experimental Mine. The objective was to use this mine for the large-scale underground research needed to support one of the Bureau's main initial functions—to provide the mining industry with safer coal mine explosives. In 1917, when the Center's headquarters moved from the Government Arsenal in the Lawrenceville section of Pittsburgh to the Central Experiment Station at 4800 Forbes Avenue, Pittsburgh, PA, the explosives research and testing activities were transferred to Bruceton. Subsequent land acquisitions increased the area of the Bruceton Explosives Testing Station to nearly 250 acres. However, for many years the Center's activities remained headquartered at Forbes Avenue.

Passage of the Federal Coal Mine Health and Safety Act of 1969 marked a major broadening of the Center's mission. To the longstanding programs on fires, explosions, and explosives, research was added or expanded to control respirable dusts and other atmospheric pollutants encountered in underground mines, reduce noise exposure of miners, decrease methane emissions, protect against roof and rockfalls, improve mine ventilation, eliminate a wide range of industrial safety hazards, and develop new technology for postdisaster survival and rescue. Conservation and reclamation of mined lands became another major activity, aimed at such environmental problems as acid mine drainage, fires in abandoned mines and waste dumps, and ground subsidence. New mining technologies were investigated to meet the needs of an industry producing under increasingly difficult conditions while remaining compatible with health, safety, and environmental concerns. This expansion in program goals was reflected in a series of administrative mergers that began in 1969 and ultimately led to the formation in August 1979 of the present Pittsburgh Research Center.

With these rapid programmatic changes came the centralization of all activities at Bruceton, where space was available for new installations. Today, the Pittsburgh Research Center is headquartered at Bruceton, PA. The Experimental Mine has been expanded considerably and the Safety Research Coal Mine has been added, where new mining equipment and procedures are evaluated before transferring them to industry. Lake Lynn Laboratory, located about 60 miles southeast of Pittsburgh, became operational in early 1982. Lake Lynn is a highly sophisticated laboratory that provides an isolated setting for large-scale explosion trials and mine fire research.

Effective September 1982, the U S. Department of Energy's coal mining technology program was reassigned to the Bureau, including the Mining Equipment Test Facility (METF), a 9-acre installation unique in the United States. A major feature of the METF is the mine roof simulator, capable of 3 million pounds of force for load tests of various roof supports. The Wire Rope Research Laboratory became operational in FY84. Here, research is conducted to improve safety and economy in the hoisting of personnel and materials in underground mines. FY92 was marked by the completion of the Mining Robotics Development Laboratory, with state-of-the-art equipment and instrumentation for microcomputer, mechanical, radar, navigation, and strata sensor development. It also contains a large, open high-bay area for full-scale evaluations of computer-assisted mining systems.

It has been a long path from the Center's first tentative approach to coal mine fires and explosions, but is has been a steady and consistent one. It promises to remain so, well into the 21st century. ■

Mining Robotics Development Laboratory

The U.S. Bureau of Mines has taken the lead in the development of high technology to enhance the safety and health of mineworkers and to improve mining efficiency.

THE MINING ROBOTICS DEVELOPMENT Laboratory (MRDL) was established to provide the advanced robotics technology needed to maintain a viable mining industry for our Nation in the future. Located at the U.S. Bureau of Mines Pittsburgh Research Center, MRDL is the only facility of its type in the world dedicated to mining robotics research.

FACILITIES

The MRDL contains state-of-the-art equipment and instrumentation for microcomputer, mechanical, radar, navigation, and strata sensor system development. A large, open high-bay area allows full-scale evaluations of mining systems. A block of simulated coal is also available for cutting tests.

Computers—including PC's and 3-D graphic workstations—and software are used to soft-prototype new technology so that it can be analyzed and refined before development. Simulation and animation allow researchers to conduct experiments in software in advance of full-scale tests. Computers are also used to synthesize complete mining systems before actual integration. Standardized hardware and software allow concurrent engineering of technology at multiple research centers.

RESEARCH GROUP

The MRDL has a multidisciplinary group of researchers providing capabilities in sensor development, artificial intelligence, computer-aided design, computer system development, system integration, and machine modification.

Computer-assisted mining will reduce injuries and increase mining efficiency.

Partnerships with Carnegie Mellon University's Field Robotics Center and the National Institute of Standards and Technology's Robot Systems Division allow exchange of ideas, technology, and human resources.

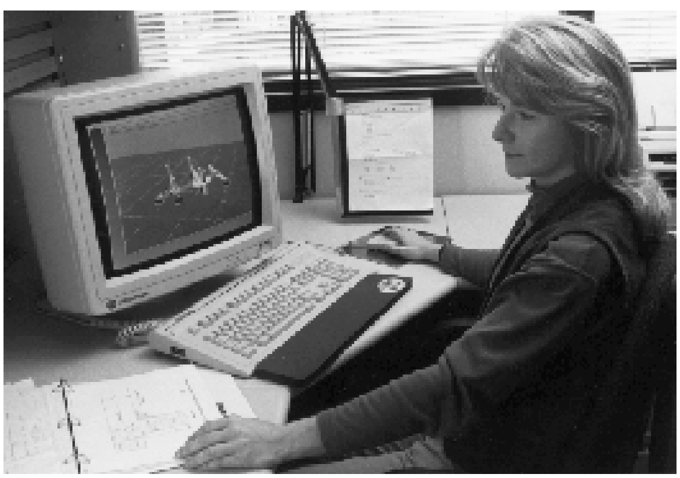
TECHNOLOGY DEVELOPMENT

MRDL research is developing essential technologies for computerized mining:

Computer-assisted mining systems allow the relocation of workers from the hazardous mineral extraction area to a safe, protected location.

Strata Sensing. Strata sensors are required to keep the cutting of a mining machine within the desired boundaries of a mineral reserve and to accurately assess mine roof conditions for placement of roof support. Technology under development involves machine vibration, natural gamma radiation, synthetic doppler radar, and infrared thermography.

Navigation and Guidance. Information on the location of mining equipment within mine passageways is needed to control its movements. A laser-scanner and a laser gyroscope system are being developed. The laser gyro is a high-technology guidance system successfully applied in the military. Ultra-sonic sensors are used to detect obstacles.



Computers are used for modeling and simulation of robotics technology.

Machine Health. Computerized maintenance systems utilizing expert systems and adaptive learning networks are being developed for the hydraulic, electrical, and electrical motor systems of mining equipment.

Computer Systems. Computer systems that coordinate the actions and motions of mobile mining machines are being developed using standardized techniques used in the U.S. space program.

Research is also being conducted on other technologies, including voice recognition, stereoscopic visions systems, teleoperation, and automated roof bolting modules.

RESEARCH HIGHLIGHTS

Research has led to the first ever hands-off, computer-controlled, underground coal extraction system.

The prestigious R&D 100 Award was received for the development of a radar strata thickness sensor.

A Cooperative Research and Development Agreement (CRADA) with Joy Technologies, Inc., allows efficient transfer of robotics technology to the mining industry

CAPABILITIES

Unique facilities and researchers experienced in the development of robotics technology for mining bring capabilities that can be applied to other industries, including infrastructure improvement, hazardous waste cleanup, and extra-terrestrial mining.

We technically represent the Federal Aviation Administration on a grant to Mellon Institute to develop a robot for aircraft skin inspection, and Westinghouse Hanford Co. on robotics technology for waste removal and remediation at the U.S. Department of Energy's Hanford facility.

Research has led to the first ever hands-off, computer-controlled, underground coal extraction system.

FOR MORE INFORMATION

For more information on MRDL, please contact:

Research Supervisor
Electrical and Electronics Systems
U.S. Bureau of Mines
Pittsburgh Research Center
Cochrans Mill Rd.
P.O. Box 18070
Pittsburgh, PA 15236-0070

Phone: (412) 892-6633
Fax: (412) 892-6764