OVERVIEW OF U.S. RESEARCH ON THREE APPROACHES TO ENSURING THAT COAL MINERS WORK SAFELY: MANAGEMENT, WORKPLACE DESIGN, AND TRAINING

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ABSTRACT

This paper was commissioned by the Japan Technical Cooperation Center for Coal Resources Development. It is to be published in a proceedings following a series of presentations to Japanese coal officials in February 1997. The paper focuses primarily on summarizing the past 20 years of U.S. research on promising techniques for ensuring that underground coal miners work safely. These techniques can be grouped into three major categories: management, workplace design, and training. Each technique is described, and the results of efforts to apply the technique at underground coal mines are summarized. Recent statistics on accidents and productivity in U.S. underground coal mining operations are presented before the overview of research findings is given. Because Japanese coal mines are using the longwall method of coal extraction, separate statistics are given for U.S. longwall versus room-and-pillar coal mining operations.

INTRODUCTION

How can employees be encouraged to avoid hazards and follow safe work practices? The usual techniques appear to be limited to verbal warnings made during safety talks about the dangers of various unsafe acts and conditions, and in some cases, threats concerning disciplinary actions that might be taken if employees violate certain safety rules. However, these techniques have some significant drawbacks. The effects of verbal warnings to avoid dangerous acts or conditions are often of short duration. After employees have heard these warnings a couple of times, further repetitions of the warning probably have little or no impact. Supervisors are often reluctant to use formal disciplinary actions because they wish to avoid interpersonal conflicts and various other undesirable responses. Also, due to the physical layout of many mining operations, it is very difficult for supervisors to be able to closely monitor whether their employees are complying with the safety rules. This suggests that admonitions and the creation of regulations or policies that threaten employees with punishment for violating safety rules are not a totally sufficient answer. Other options need to be considered. The intent of this article is to review

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U.S. research concerning the use of three approaches to ensuring that coal miners work safely: (1) management, (2) workplace design and (3) training. However, a few statistics on the safety and productivity of the U.S. coal industry will first be provided.

U.S. UNDERGROUND COAL STATISTICS

Just slightly over 1 billion tons of coal are mined each year in the U.S. Approximately 40% of that coal comes from underground operations. Data on the underground coal mining industry will be reviewed for the period 1986 to 1995. During those 10 years, underground coal production fluctuated between 315 million metric tons to 380 million metric tons, and productivity increased from 1.93 to 3.51 metic tons per employee hour. In 1995, the rate of fatalities at underground coal mines was 0.038 per 200,000 hours, and the rate of non-fatal lost time injuries was 10.75. Table 1 shows that the highest fatality rate occurred in the year 1989. Since 1989, the rates have been steadily decreasing. Similarly, the highest lost time injury rate occurred in 1988, and, with the exception of one year, these rates have also been steadily decreasing each year since.

TABLE 1. -- Annual rates of fatal and lost time injuries during 1986 - 1995.

Year	Fatality Rate[1]	Lost Time Injury Rate[1]
1986	0.063	N.A.[2]
1987	0.052	12.77
1988	0.038	13.51
1989	0.065	13.12
1990	0.064	12.76
1991	0.064	12.96
1992	0.060	12.31
1993	0.053	11.99
1994	0.040	11.87
1995	0.038	10.75

[1] Number of incidents per 200,000 hours worked by underground employees.

[2] Not Available. Because the Mine Safety and Health Administration modified their injury reporting requirements during 1986, it is not possible to make valid comparisons of injury rates from before versus after 1987.

There are several substantial differences between mines that use longwalls versus those that do not. Since the Japanese coal industry is primarily based on the longwall mining method, the remainder of the statistical information presented in this section focuses on the performance of U.S. longwall mines, and how these mines compare to room and pillar operations. The longwall method of coal extraction appears to be safer than the room and pillar method, especially in terms of fatality rates. For example, during 1994 and 1995, the rates of fatalities at longwall mines were, respectively, 0.026 and 0.015 fatalities per 200,000 hours. The corresponding rates for the non-longwall mines were 0.049 and 0.055 fatalities per 200,000 hours. Table 2 summarizes several of the differences between longwall versus room and pillar mines based on data from 1995.

Table 2. -- Differences between U.S. longwall versus room-and-pillar coal mines.

	Longwall	Room and Pillar
Number of mines	70	872
Ave. number of tons per mine	2,416,123	216,620
Ave. number of underground employees per mine	260	33
Ave. seam height (cm)	203	127
Fatality rate	0.015	0.055
Lost time injury rate	10.4	11.04
Productivity (tons per employee hour)	4.4	3.4

In comparison to room and pillar mines, mines using longwalls are larger, safer and more productive (per hour of labor).

There are several differences in the types of injuries that occur at longwall versus room and pillar mines. During the three year period 1993 to 1995, 63 fatalities occurred at underground locations of U.S. coal mines. Eight of those were at mines using longwalls. Of those 8, three were caused by groundfalls, two were caused by electric current, two were caused by machinery, and one was caused by powered haulage. During the three year period 1993 to 1995, 16,623 lost time injuries occurred at underground locations of U.S. coal mines. Of those, 6,017 injuries occurred at mines using longwalls. Table 3 summarizes the types of accidents that caused those injuries. Accidents associated with handling materials are, by far, the most common type at longwall mining operations. These usually involve strains, sprains, or overexertion to the musculoskeletal system--especially the lower back. The next three most common types of accidents responsible for injuries at longwall mines are: slips and falls, machinery, and powered haulage.

Table 3 -- Accidents causing lost time injuries at longwall mines (N = 6,017)

Type of Accident	Number of Injuries	Lost Time Injury Rate[1]
Handling material	2,218	3.97
Slip or fall of person	1,223	2.19
Machinery	651	1.17
Powered haulage	564	1.01
Hand tools	446	0.80
Groundfalls	422	0.76
Stepping or kneeling on object	125	0.22
Striking or bumping	110	0.20
All others	258	0.46

[1] Number of injuries per 200,000 hours worked by underground employees.

OVERVIEW OF HUMAN FACTORS RESEARCH

This section attempts to summarize the past 20 years of U.S. research on approaches to ensuring that coal miners work safely. Much research has been conducted to improve mine safety, but only a portion of it is related to human factors. The following interventions have been selected for discussion because there is evidence to suggest that they positively influenced the performance of safety-related employee behaviors at underground coal mines. They have been grouped under three headings: I Management, II Workplace Design, III Training. The management techniques described in this paper are: conducting employee surveys, forming ergonomics committees, creating autonomous work crews, establishing better labor-management relations, and providing feedback and incentives tied to safety performance. Efforts have been made to improve workplace design in the following areas: redesigning manual lifting tasks; improving the illumination and maintainability of mobile mining equipment, redesigning the controls on roof bolter machines, and providing a safe method for restoring power to continuous mining machines. Three techniques for improving miners' safety training are reviewed: interactive problem solving stories, fear messages, and the 3 + 3 method of emergency breathing apparatus donning.

I. Management

A great deal of research evidence has accumulated which, not too surprisingly, indicates that good coal mine safety performance is difficult, if not impossible, to achieve without management's commitment to this goal [DeMichiei et al. 1982; Gaertner et al. 1987; National Academy of Sciences 1982; Pfeifer et al. 1976]. More specifically, research suggests that mine safety performance is influenced by three factors that mine managers are in a position to influence: the extent to which the workforce is actively involved in identifying safety problems and solutions; the extent to which labor-management relations are favorable; and the use of safety incentive plans. The research evidence regarding each of these three factors is reviewed below:

A. Workforce Involvement

Using structured interview guides and questionnaires DeMichiei et al. [1982] collected information from miners, mine managers and safety officials at 21 underground coal mines with an exceptionally high rate of accidents, and from the same personnel at another 19 mines that all had an exceptionally low accident rate. He found that mine managers and safety officials were significantly more likely to report that good ideas fostered by miners get more serious consideration from management at low-rate mines than at high-rate mines. He makes the following observations based on his interviews with miners: (1) At several low-rate mines, miners indicated that individuals in key management positions were receptive and responsive to miner requests, and frequently solicited input from the miners concerning mine policies and procedures, and that management earnestly encouraged interaction between themselves and labor representatives. (2) Miners at several high-rate mines believed management to be one-sided, since they had little input into the decision making process. Questionnaire responses indicated that miners in low-rate mines reported safety and health hazards to their foreman more often than miners in high-rate mines.

To effectively receive input from their employees, management must work at cultivating a different kind of attitude among workers--a perception that management thinks their ideas are important and takes them seriously. Various techniques for obtaining greater input and involvement from coal miners have been studied. The better ways involve regularly setting aside time to hold in-depth discussions about safety issues with those who work at the mine. Three examples are presented.

1. Employee surveys

Because miners are very familiar with their working environment, they are probably in the best position to understand what types of situations arise that make it difficult to follow safety rules. Most safety experts agree that they should be asked to identify such situations, and to suggest what might be done to prevent these situations from occurring. Employee survey results may help to reveal aspects of equipment, work procedures, or policies that may be inadvertently encouraging employees to violate safety rules. Peters and Randolph [1992] conducted structured interviews with 297 underground coal miners to discover the reasons miners violate safety rules that lead to injuries and deaths from roof fall accidents. These miners made many valuable suggestions for redesigning equipment and work procedures such that the temptations to violate safety rules are eliminated or reduced. These recommendations are being communicated throughout the U.S. coal industry through publications and seminars. The number of deaths caused by roof collapses has been reduced from about 50 per year in the early 1980s to less than 10 in recent years. Several improvements in the design of mining equipment and methods have been made since 1980 which have had a significant impact on reducing the rate of roof fall fatalities. These improvements include: new regulations requiring automated temporary roof supports systems on roof bolting machines; new regulations requiring overhead canopy protection for the operators of mobile face equipment (except in very low seam heights); and the introduction of remote control continuous mining equipment.

2. Ergonomics committees

Another form of employee participation that appears successful at coal mining companies is ergonomics committees [Hamrick and Gallagher 1994]. Although ergonomics committees can be used to reduce the incidence of several types of injuries, they usually focus primarily on the prevention of occupationally related musculoskeletal injuries. These committees should include representatives from management, labor, engineering, maintenance, personnel, and the medical and safety departments. Imada [1991] believes that it is particularly important to include representatives from the front-line work force because they possess many good insights based on their first hand experience, and because the likelihood of successful implementation of ergonomically based changes is increased if the worker has some ownership in the ideas. Various analysis techniques can be used to identify ergonomic problems throughout the mine. Once hazards have been identified, then solutions can be formulated and implemented. The preferred strategy is to redesign the job by eliminating the hazard, removing the worker from exposure, or mechanizing the task. If these strategies are infeasible, then the job should be designed so that it can be performed within the workers' capabilities. After any ergonomic solution is implemented, a follow-up analysis should be performed to ensure the effectiveness of the change and to guard against the introduction of any new ergonomic or safety hazards. Physical fitness programs and training are sometimes used to supplement job redesign.

Ergonomics committees are similar to Quality Circles in several respects. The committees meet on a regular basis (e.g., monthly) to generate new ideas for preventing accidents, and then oversee their implementation and evaluation. One large U.S. coal corporation (American Electric Power) began using this approach in the late 1980s to reduce the costs and incidence of back injuries among their underground coal miners. The program has been highly successful. O'Green et al. [1992] report a 41% reduction in back injuries over a 4-year period after ergonomics committees were established.

3. Autonomous mining crews

The results of an experiment at Rushton Mining Company suggests that the creation of autonomous mining crews may have been responsible for improvements in safety performance at a room and pillar continuous mining operation [Goodman 1979; Trist et al. 1977]. Although this intervention entailed making a number of changes to the organization, one of the most notable changes was the creation of self-managing coal mine face crews. These crews were given the entire responsibility for making all the decisions pertaining to the day-to-day production of coal from their sections. Crew foremen were no longer involved in making production decisions. Their primary responsibility was to maintain the safety of the crew. Changes that could have been responsible for the observed safety improvements were: (1) The experimental group received more formal training about safety practices and federal safety regulations. (2) New mechanisms were introduced for motivating miners in the experimental section toward good safety practices. The work group was restructured to provide the men greater opportunities for feelings of responsibility and accomplishment if safety levels improved. Periodic meetings with the miners provided them with formal feedback on how safety behavior matched safety goals; they were a problem-solving arena where new safety practices were developed, and, offered a direct opportunity to reinforce good safety behavior. (3) The foremen in the experimental section were no longer caught in the conflict between production and safety. They could expend all their energies on safety. Foremen in the non-experimental sections had to continually balance production and safety demands.

Safety was measured by the number and type of accidents, the number and type of violations, ratings on the quality of safety made by independent observers as well as by the union and management, and by qualitative reports from the on-site observers. The performance of crews in the experimental section was compared to that of crews in two control group sections on these measures of safety both before and after the intervention. The accident data was not a particularly good measure of the intervention's effectiveness because the experimental section exhibited a very low accident rate before the intervention even began. All other measures of safety performance clearly indicated that the intervention had substantial positive effects on the safety of those who worked in the experimental section. During this experiment, the productivity of the experimental section was observed to increase by a slight amount relative to the control groups.

B. Management-Labor Relations

Quite a bit of evidence indicates that a favorable management-labor relationship has positive effects on coal mine safety performance. Gaertner [1987] compared five coal companies with a relatively good management-labor relationship to five other coal companies experiencing a relatively poor management-labor relationship. He observed a striking difference in the safety records of these two groups; the average injury rate for companies with a negative labor relations climate was almost double that of the companies with a positive climate. The two groups of companies were also compared in terms of the average annual rate of Mine Safety and Health Administration (MSHA) citations per mine for "significant and substantial" safety violations. He found that the rate of violations for companies with positive labor relations was only about a third as high as the rate for companies where labor relations were relatively negative.

Similar results were obtained from an independent study performed by the National Academy of Sciences [1982]. Researchers collected data from 12 large underground coal mines. Seven of these mines had very low injury rates and five had very high injury rates. The researchers noted that: "at all seven mines with low injury rates there appeared to be a cooperative attitude between management and labor; an antagonistic attitude was observed in three of the five mines with high injury rates."

How can management cultivate a positive relationship with labor? This is a complex issue. Although there are no guaranteed formulas for maintaining a good relationship, it is probably safe to say that effective lines of communication are a prerequisite. These research findings suggest that open lines of communication need to exist between all levels of management and labor so that unsafe conditions or practices can be corrected, and employees can feel free to discuss and resolve safety issues without fear of adverse action. Management and labor representatives should take the lead in cultivating a cooperative atmosphere at the mine via joint informational meetings, safety inspections of work places, and increased interaction with the general work force.

C. Incentives and Feedback

Incentives have been found to be effective in improving employee compliance with safety rules in a rather large number of studies conducted in several types of U.S. industries [McAfee and Winn 1989; Sulzer-Azaroff 1982]. However, the research evidence relating to underground coal mining is rather limited. Rhoton's [1980] study is perhaps the best example of an incentive plan that was highly effective at reducing hazardous conditions at an underground coal mine. The purpose of this study was to determine the effects of an incentive plan on the rate of MSHA (federal government) safety inspector ventilation violation notices. The experimenter's goal was to receive zero violation notices during the intervention phase. On a random basis, there was one inspection every week. During each inspection, 5 critical performance variables were monitored: (a) making a methane gas check at the working face every 20 minutes; (b) maintaining a flow of at least 85 cubic-meters-per-minute of intake air behind the line brattice; (c) maintaining proper calibration of equipment methane monitors; (d) keeping the line brattice to within 3 meters of the working face; and (e) keeping the area behind the line brattice free of accumulation of loose coal dust.

When the target behaviors were in compliance, the crew members and the foremen were praised. Furthermore, graphic feedback of the ventilation violation notices were presented in the mine office. To supplement these graphs, verbal feedback was delivered biweekly by the experimenter during regular safety meetings with the foremen. When a section was found to be non-compliant, the experimenter would stop production of coal until the hazardous condition was corrected. During a three-month baseline period, the mean number of ventilation citations issued per month was 2.6, based upon a mean of 13.3 inspection days per month. During the intervention phase, the mine operated for 10 consecutive months without a single ventilation citation. The results of this study suggest that compliance with safety requirements can be increased with the use of frequent observation, contingent positive feedback, and praise.

Through research funded by the U.S. Bureau of Mines, Goodman [1987] performed an assessment of safety incentive programs in use at four underground coal mines during the mid-1980s. He found that none of the programs he examined were properly designed, and that they did not appear to produce any improvements in mine safety performance.

Although incentive plans have been found to be extremely effective in motivating many types of self-protective employee behavior, there are some limitations to this approach. For incentives to affect behavior, it is important that people see a close connection between their actions and the receipt of a positive outcome (or avoidance of a negative outcome) as a result of their action. One must be able to consistently and accurately measure the employee behavior that one wishes to change. Sleet and Geller [1986] and Cohen et al. [1979] recommend doing the following to maximize the effectiveness of incentive plans:

- Find a baseline for the behavior or the condition (e.g., presence of a hazard) one wants to change. This is usually done by looking at data from prior time periods, e.g., last month.
- Establish a specific criterion of success for earning the reward. Give rewards for small, but significant improvements in performance. Rewards should be relatively small and should be given relatively often, e.g., monthly.
- Supplement the incentive program with education. Explain why it is important to avoid the unsafe act, cite accident statistics, show how to perform various tasks without exposing oneself to a hazard, etc.

The use of safety incentives can arouse increased worker and company interest in job safety. However, incentive plans are no substitute for hazard control programs having well-established safety training, housekeeping, safety inspection, and reporting functions. Rather, the incentive approach is most effective when used to provide an added spur to an already well-designed hazard control program.

II. Workplace Design Interventions

It is often easier to eliminate threats to workers' safety through manipulations of their environment rather than attempting to persuade or train them to alter their work habits. Therefore, it is important that injury prevention programs first seek to identify the reasons employees might deviate from safe work practices, and then redesign the tasks and work environment (e.g., tools, equipment, physical surroundings) so as to eliminate these reasons. U.S. Bureau of Mines researchers have significantly enhanced mine safety through several improvements in the design of the underground coal miners' workplace. Several examples are described below.

A. Redesigning Manual Lifting Tasks

The coal mining process often requires heavy labor that can exceed miners' physical capabilities. Manual handling of supplies, roof support materials, and equipment has resulted in a high incidence of musculoskeletal injuries, particularly back injuries. Low back pain consistently ranks as the leading cause of lost work days in coal mining. Recent research suggests that seam height may be an important contributor to miners' back injuries. In 1995, about half of all underground coal miners worked in coal seams lower than 1.5 meters in height, and about one fourth worked in seams lower than 1.25 meters. Low seam heights cause miners to assume awkward postures, and prevent miners from using their leg muscles to lift heavy loads, as workers in other industrial settings are taught. U.S. Bureau of Mines researchers have conducted laboratory experiments to determine the maximum loads that miners can safely lift in stooped and kneeling postures. For example, Gallagher [1992] found that worker lifting capacity was decreased by 13-20% when lifting in the kneeling posture compared with upright lifting.

Recommendations based on the laboratory findings are being applied in several ways. For example, suppliers of rock dust now offer the product in 18 kilogram bags rather than heavier units. In concert with the laboratory research on back strength, a number of inexpensive, easy-to-construct materials handling devices for underground mines have been developed by U.S. Bureau of Mines researchers. Several of these materials-handling devices have been used successfully in underground operations to decrease worker exposure to hazardous manual lifting tasks [Unger and Conway 1994a]. As mentioned previously, a few mines have formed ergonomics committees to guide the process of developing and implementing new ways to reduce the amount of materials that have to be moved manually, and these mines have been successful at reducing the incidence of back injuries.

B. Illumination

Poor visibility in underground work areas contributes to many serious accidents. Restricted fields of vision are a common problem with underground mining equipment, particularly in lower seams. Also, when manufacturers provide lighting systems underground, they occasionally position them where they may cause glare. This restricts the visibility around the machines even further. To help address these problems, U.S. Bureau of Mines researchers have developed CAP (Crewstation Analysis Programs), an easy-to-use PC-based software package to aid in the analysis of the visibility aspects of mining equipment design [Unger 1994]. The software is available for use by mine operators and equipment manufacturers for design work on new machines, and for evaluating proposed modifications to machines already in use.

With CAP, one can build a virtual environment containing objects typically found in an underground mine. One can then perform different types of analyses using this environment. CAP currently contains two analysis programs that address operator visibility: the Statement of Test and Evaluation (STE) Illumination model and the Visual Attention Location Line-of-Sight model. The CAP STE Illumination model is a computerized method for evaluating mine illumination systems. This permits modification of lighting designs without using the time-consuming method of building physical mockups and taking light readings manually. The CAP STE Illumination model uses an analysis technique developed by Bureau researchers that greatly increases the accuracy of near field illumination calculations [Gallagher et al. 1996]. The CAP Visual Attention Location Line-of-Sight model assesses visibility from the operator's compartment for three classes of mining machinery: shuttle cars, scoops, and continuous miners. This analysis program is based on research that determined the visual requirements associated with the operation of these types of equipment. The model determines the extent to which the machine design meets the visual needs of the operator, given a geometric model of the machine, and information about the size of the operator. CAP has been purchased by all the mine lighting manufacturers in the U.S. and is being used by MSHA (the certifying agency) for evaluating mine lighting systems submitted for approval.

C. Equipment Maintainability

"Maintainability" can be defined as the ease with which one can repair equipment safely in the least amount of time. Equipment maintenance operations account for a persistently high percentage of mining injuries. The most recent review of injury data on this topic showed that, during 1978-88, maintenance accounted for over 25% of underground coal mining injuries. Thirty-two percent of all machine-maintenance injuries involved the lower back, and 38% of all machine-maintenance injuries were the result of overexertion [Conway and Unger 1988]. These numbers strongly suggest that mine equipment designers need to focus more attention on how to ensure the safety of maintenance workers and minimize the costs of performing maintenance while they are in the early stages of designing a new machine. Maintainability should be a designed-in capability and not an add-on option. The following list is based on research funded by the U.S. Bureau of Mines. It is a list of typical design problems on underground mobile mining equipment that could be addressed by incorporating maintainability into the original design of the equipment:

- Inadequate access openings causing maintenance personnel to be unable to access failed or suspected components to inspect or remove and replace them
- Poor layout of components in a compartment, necessitating removal and replacement of unaffected parts to access the failed units
- Inability to access mounting bolts or connectors or to use required tools
- Installing components in inaccessible interior cavities
- Running cables inside the frame or chassis where you cannot reach them
- Locating fasteners and mechanical interfaces where you cannot reach them physically unless the machine is partially or completely disassembled
- Inadequate component handling capability and component machine interface design
- Inadequate design for routine maintenance, such as the inability to quickly remove and replace leaking hydraulic hoses and water lines, remove and replace failed hydraulic valves, do routine lubrication, and perform visual and physical inspections
- Inadequate fault isolation capability, such as difficulty determining the precise cause and location of a failure, reaching components to do visual inspections and to perform checks, limited or no designed-in fault diagnostic capabilities, lack of effective failure indices
- Increased maintenance burden resulting from poor design and placement of components, subjecting them to damage
- Poor design with respect to resources available, such as the need for maintenance personnel to build tools, handle 45 to 450 kilogram components, or use brute human strength to overcome poor component interface design or lack of needed tools
- Equipment complexity resulting from poor layout, such as the crowding of components into compartments without regard for the need to maintain or replace individual items, overlaying hoses and power cables, and making removal and replacement difficult
- Multiplying the number of valves, connectors, and other high-frequency replacement components as a design convenience

Conway and Unger [1988] conclude that the successful application of maintainability design principles to underground coal mining equipment could reduce preventive maintenance and corrective maintenance time by 40% to 70%, maintenance labor costs by 10% to 25%, and maintenance risk significantly. NIOSH researchers are currently developing a detailed set of guidelines to assist those who wish to ensure that maintainability principles are applied to the design of mobile equipment for underground mines [Unger and Conway 1994b].

D. Redesigning Roof Bolting Machine Controls

During the past decade, several roof bolting machine operators have been caught and crushed to death by the powerful hydraulic drill boom. In 1994, a team of U.S. Bureau of Mines researchers performed a study of the hazards that exist during the roof drilling and bolt installation procedures. Particular emphasis was placed on hazards associated with the fast feed lever and movement of the drill head boom or mast. In addition to reviewing reports of roof bolter fatalities, researchers videotaped miners operating roof bolting machines, interviewed roof bolter operators, held discussions with manufacturers of roof bolting equipment, and reviewed past research on roof bolter safety.

The research team developed a list of seven solutions which were then ranked based on their ability to protect the operator, the time needed to develop and carry out the solution, and cost. The solutions, ranked in descending order of importance, are: (a) use an interlock device to cut off power to the controls when the operator is out of position, (b) provide fixed barriers at pinch points and other dangerous areas, (c) provide better control guarding, (d) reduce the speed of the fast feed, (e) use automatic cutoff switches for pinch points and dangerous areas, (f) redesign the control bank to conform to accepted ergonomic principles, (g) use resin insertion tools and resin cartridge retainers. The leading roof bolter manufacturer in the U.S. has adopted the project team's first recommendation. The other solutions have been carried out to various degrees by mining companies and manufacturers [Turin 1995].

E. Safe Methods for Restoring Power To Continuous Mining Machines in Extended Depth Cuts

Over the past decade, there has been a dramatic growth in the number of U.S. mines using radio remote control continuous miners to take longer cuts of coal. Using this technology, it is usually possible to double the depth of cuts--from 6 to 12 meters. Unfortunately, after the machine advances beyond the first 6 meters, it begins to go beyond the protection of roof supports. Continuous miner operators are killed by falls of unsupported roof each year. During interviews with 297 miners who work in continuous mining face crews, continuous miner operators frequently reported that it is very tempting to go under unsupported roof to restore power to the miner [Peters and Randolph 1992]. They usually just have to reset a circuit breaker on the continuous miner. The time and effort required to do that is minimal compared to the time and effort it takes to set temporary roof supports. Unfortunately, it is also very dangerous. Therefore, the U.S. Bureau of Mines has developed two remote reset systems for use in deep-cut coal mining [Brautigam and Kwitowski 1995]. They provide a way to remotely reset tripped electrical circuit breakers.

The manual reset systems are very simple devices designed to give mine operators an easy means to remotely reset circuit breakers. A worker controls the reset from beneath supported roof by pulling on handles. The handles attach to cables that lead, through a protective conduit and over pulleys, to the circuit reset lever. The second remote reset method is an electrohydraulic system. It may be best suited for incorporation into new machines by continuous miner manufacturers. It could also be applied to machines in the field, particularly during a rebuild. A reset is controlled through a radio remote-control system that activates a hydraulic solenoid valve. Both reset system designs have been tested at the Pittsburgh Research Center and have been successfully demonstrated to the Mine Safety and Health Administration.

III. Training Interventions

Unfortunately, the underground coal miner's work environment is often innately hazardous, constantly changing, and difficult to predict. This makes it very difficult to fully protect the employee by the types of environmental manipulations described in the prior section. Therefore, it is important that miners receive effective training in safety procedures to be followed in performing various routine tasks as well as how to respond to various types of mine emergencies. Since 1969, Federal regulations have required that mine operators provide 40 hours of new miner safety training and 8 hours of annual refresher training [U.S. Code of Federal Regulations 1995]. Several significant deficiencies were soon identified concerning the methods and materials typically used to conduct mine safety training [Adkins et al. 1976]. Fortunately, during the past 20 years, many of these deficiencies have been overcome through the development of new forms of training. Three examples of successful new techniques for training U.S. miners will be described: interactive problem solving stories, fear messages, and emergency breathing apparatus donning.

A. Interactive Problem Solving Stories

With help from Universities, mining companies, MSHA, and other providers of miner training, the U.S. Bureau of Mines has developed over 70 interactive problem solving stories on a wide variety of safety and health topics. The exercises are based on authentic mine injury, fatality, or disaster reports and the problems and predicaments encountered in these real-life events.

Each problem solving story is presented in a booklet as an unfolding story with a plot, characters, predicaments, goals, and obstacles. The people working the exercise usually play the role of one of the characters and interact with each other and the story events while making a series of choices among good and bad alternatives at critical decision points. Because the problem solving exercises are interactive stories about real people and authentic events, they are engaging and memorable. Bruner [1990] argues that representing one's own and others' motives and behavior in terms of coherent stories is a universal way by which we learn and remember the things needed to survive.

The story for each training exercise is told a page at a time with short text passages, accompanying diagrams, schematics, equipment diagrams, mine maps and other illustrations. The initial scenario often begins before the emergency situation develops. Subsequent decision points in the exercise sometimes allow workers to recognize the impending development of a serious problem and take corrective actions to prevent an injury event or disaster. Other exercises place the workers in a superficially safe and placid mining environment that suddenly turns dangerous. As they progress through the exercise the miners gather information and debate which actions they will take and why. The miners simulate their actions by choosing among a list of decision alternatives presented in the problem booklet. Next, they mark a special answer sheet with a developing pen that immediately reveals a hidden or latent message that was previously invisible. The message provides information about the consequences of the action, as well as immediate feedback about whether it was a wise or unwise response. Both the good and bad alternatives listed for each decision point in the simulation exercise are taken from the responses of miners involved in the actual emergency situation depicted in the exercise.

When training miners to prevent and cope with mine emergencies, it is important to have them collaborate and work as teams. To promote collaborative learning and problem solving, the simulation exercises are usually presented to small groups of three or four miners. As they interact with the story and each other, the miners usually have lively discussions about the predicaments and decision alternatives.

The interactive problem solving stories have been found very effective through field tests with 3,658 miners in 8 states. The exercises have changed the way miner annual refresher safety training is conceptualized and practiced. Greater emphasis is placed upon learning that requires collaboration and active problem solving. Trainees must integrate their practical knowledge and experience with the mandatory safety and health content presented in miner training classes. To date, more than 500,000 copies of these exercises have been distributed by MSHA's mine training academy.

B. Fear Messages

Fear messages are a commonly used strategy for encouraging self-protective behavior. Fear messages may emphasize threats to physical safety, health, social functioning, financial well-being, or other risks. Fear messages usually include an alarming description or portrayal of the way someone could be harmed, followed by an explanation of appropriate self-protective actions. Those who make use of fear messages hope that employees will perceive the recommended self-protective actions as leading to a reduction of the threat, and that they will begin following the recommendations. Research shows that these messages often produce significant changes in attitudes and intentions to perform self-protective acts or avoid unsafe acts [Leventhal 1970; Sutton 1982]. However, only a small number of studies have shown that they have a long-term impact on behavior. All too often, training designed to increase employees' fear of a particular type of accident has, at best, only a short-term effect on behavior.

One should not rely solely on fear messages as a means of preventing employees from performing unsafe acts. It may be more advisable to use fear messages with new employees than those who have been employed for a time and have had a chance to form various unsafe work habits. It seems especially important that new employees fully appreciate the risks and the severity of the potential consequences of following unsafe work practices. Once an unsafe habit has formed, it is difficult to break. Rather extreme forms of influence must be used to stop the habitual behavior, and if the influence is not applied long enough for the new safe work habit to become well established, the old habit will soon return.

Cohen et al. (1985) suggest that the following are likely to maximize the effectiveness of fear communications: (a) the message should attempt to evoke a high (versus low) level of fear--high fear of personal injury or death due to a particular type of accident and high fear of the consequences of one's death or disability on one's family; (b) the suggested preventive actions should be relatively detailed and specific, © the message needs to show exactly what types of tasks are considered dangerous and how these tasks can be performed without making oneself vulnerable to an accident; (d) it should be made clear that the suggested preventive actions are an effective deterrent to being harmed; (e) the source of the communication should have high credibility; (f) face-to-face, two-way forms of communication should be employed (as well as other forms).

During the past decade, U.S. Bureau of Mines researchers have videotaped a series of short interviews (10-15 minute) with coal miners who have either been victims or eyewitnesses to serious mining accidents such as fires and roof collapses. Along with each video, an instructor's guide was prepared containing questions that could be used to encourage discussion among trainees about why these tragedies happen, and what needs to be done to ensure that similar disasters do not occur at their mine (available from National Mine Health and Safety Academy, U.S. Department of Labor [1996]). These materials have been very well received by trainers.

C. Emergency Breathing Apparatus Donning

Should a fire occur in an underground coal mine, workers may be forced to travel a few kilometers on foot in order to reach the outside. Many times their escape routes will become smoke-filled and toxic. Oxygen generating breathing devices, called "self-contained self-rescuers (SCSRs)" have been mandated for the use of miners during escape attempts. Bureau of Mines researchers investigated three fires in which miners had to evacuate through smoke. Forty-eight of these workers were interviewed and recounted a number of problems that indicate they were not proficient in donning the SCSR. Some reported problems included difficulty in activating oxygen and getting the mouthpiece inserted properly. Additionally, roughly half of all those interviewed indicated that they did not perform all steps necessary to secure their apparatus once they had it on. Workers also recounted problems in using their SCSRs during escape. Approximately 63% of the miners interviewed said that, for one reason or another, they had trouble breathing from their device. As a result, 29 individuals indicated that they either took the mouthpiece out to breathe, or "cheated" by breathing around the mouthpiece while in smoke. A sizable portion of all respondents also said that, although in smoke, they took their mouthpiece out in order to talk.

Bureau of Mines researchers have been instrumental in the development and validation of: (1) a standardized donning procedure (the "3+3") that can be used with all SCSRs currently being marketed in the U.S., (2) a standardized evaluation protocol, (3) training packages consisting of an instructional videotape and instructor's manual, and (4) low-cost SCSR training simulators. They also conducted skill retention studies, which showed that the forgetting curve for SCSR donning approximates the normal forgetting curve for other seldom-practiced motor tasks: within three months people have forgotten most of what they were taught.

The Mine Safety and Health Administration used the Bureau's research findings to support the promulgation of a federal regulation requiring that all individuals entering an underground coal mine for the first time must have hands-on SCSR training. In addition, working miners must be retrained, hands-on, once a year. Since two original equipment manufacturers (CSE and MSA corporations) have formally adopted the 3+3 donning method and delivery techniques for inclusion in their training packages, the industry is very close to a standardized procedure [Vaught et al. 1993].

CONCLUSIONS

Research conducted at U.S. underground coal mines suggests that various techniques of management, workplace design, and training can be effective tools for ensuring that miners work safely. Although each tool is somewhat effective on its own, the best way to attack most mine safety problems often entails a combination of these approaches. The best combination for a specific work setting depends on several factors including: the nature of the work performed; cultural, social and physical aspects of the work environment; the availability of resources; the cost of the intervention; and management and labor's attitudes and priorities.

It is usually easier to change employee behavior through manipulations of their environment than through appeals, threats, or other attempts to persuade them to alter their behavior--especially if the behaviors in question are longstanding habits. Therefore, the following steps are generally recommended for ensuring that coal miners work safely: (1) diagnose what is motivating unsafe behaviors, (2) redesign the environment to eliminate situations from arising that tempt miners to perform unsafe actions, (3) if the problem cannot be totally solved through redesigning miners' equipment or work procedures, then various forms of training, incentives or disciplinary action may need to be considered. The workforce should be involved as much as possible in the process of identifying hazards and unsafe behaviors, diagnosing the reasons for their occurrence, and developing and implementing effective ways to eliminate them.

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