

THE HUMAN ELEMENT IN MINING - AN OVERVIEW OF BUREAU OF MINES
HUMAN FACTORS RESEARCH

James M. Peay, William J. Wiehagen, and George R. Bockosh

Supervisory Engineering Psychologist
Supervisory Industrial Engineer
Supervisory Electrical Engineer
Pittsburgh Research Center, Bureau of Mines
U.S. Department of the Interior

ABSTRACT

In 1910, the coal industry produced 501 million short tons and 2,821 miners lost their lives. In 1982, the industry produced 812 million short tons of coal and 115 miners were fatally injured.

The greater portion of fatalities in 1910 were the results of mine explosions and fires which could generally be traced to methane or coal dust ignitions. These accidents often resulted in multiple fatalities with scores of miners being killed in one incident. Mine disasters still occur too often; today, however, most fatalities and serious injury accidents occur as single events and usually cannot be attributed to physical parameters of the work place.

Several recent studies have pointed out that while fatalities continue to decline, commensurate progress has not been made in reducing serious lost-time mining injuries, and that a large percentage of industrial-type mining accidents are related to human performance. The same studies have also concluded that if additional progress is to be made in reducing mining accidents, the research emphasis must focus on the human element in the accident chain. Improved training, improved labor management cooperation,

and greater consideration for the man-machine interface are major areas requiring attention.

The solutions to many of these problems lie within the scope of human factors research. The Bureau of Mines has a well-established Human Factors research program which addresses most problems related to training and the man-machine environment interface. This paper describes the current status of that research program, the results to date, and its future direction.

INTRODUCTION

The President's Commission on Coal found that a wide variance in accident rates existed among the largest producers of underground coal in the United States (1).⁴ The data showed that the best performer had maintained an incidence rate (accidents per 100 manyears worked) of 3.02, while the worst performer reported a rate of 21.01. The obvious question is, "What are the reasons for the wide variation in incidence rates?" MSHA has completed a study examining this variance and has concluded the only major differences evident are those concerning how the mines are managed,

⁴Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

that is, the quality of health and safety programs, and management's commitment to enforcing the programs; and the quality of training and other variables associated with "people." A recent study conducted by Consolidation Coal also indicated that the human element is the most significant causative factor in industrial-type accidents (2). The implication of these studies is that unsafe acts and conditions lead to considerable "human error" in the mining work place. Attributing accidents to unsafe acts or unsafe conditions, unfortunately, obscures the real causes of the accident. Human error may have been involved in the accident, but the critical question is what caused the human error; much too often responsibility is assigned to the individual miner and little attention is given to identifying factors which permit the human error to occur. Perhaps more importantly, can this human error be reduced through proper job design, training or other means?

The Bureau of Mines initiated a research program in 1973 that was designed to address and provide technologies to reduce industrial-type, human error injuries. The Human Factors Research effort encompasses work in improving the quality and efficiency of the education and training efforts of the mining industry and improving the human-mine environment interface. The program represents a balanced approach between the redesign of the work place and the expected adaptation of the miner to that environment via training. An example of these trade-offs may be seen in the shuttle car operator's job. Earlier models of this machine were equipped with one steering wheel which was mounted perpendicular to the centerline of the machine. This resulted in a condition where travel in one direction presented the operator with automotive type steering, that is, a clockwise turn of the steering wheel resulted in a right turn of the machine. However, in reversing the direction of travel, the clockwise movement of the steering wheel resulted in a left turn of the machine. This design presented

the operator with a situation where retraining was necessary with each reversal of travel. However, no amount of training would prevail in an emergency maneuver, where the operator would revert to the behavior that has served him or her well in driving an automobile. This example is intended to demonstrate that training is not the entire answer, and that improvement in the miner-machine interface is also in order. Conversely, the mining environment is ever-changing, and the miner must be made aware of the hazards inherent in the work place and methods of dealing with them. It is proposed then, that a dual approach is necessary, an approach that considers efficient use of training and the redesign of working conditions. The Bureau of Mines Human Factors Research Program is addressing this dual approach to reducing accidents attributed to human error by applying what is known about training and human engineering (ergonomics) to the mining environment.

EDUCATION AND TRAINING

Education and training research is directed toward assisting the mine training community in improving the quality of employee training. The purpose is to facilitate the reduction of industrial-type injuries through application of performance-based training methods and through research investigating innovative training and evaluation techniques for developing and maintaining health, safety, and occupational skills. An implication of the goal requires specific attention to the dissemination of research results.

Background

The training of mining personnel is a large and continuing activity for the mineral industries. Health, safety, and occupational training has long been recognized as an essential element for reducing injuries and death. In 1983, the U.S. mineral industries employed over 400,000 miners to whom approximately 4.5 million hours of formalized health and

safety instructions were provided. This training included safety instruction required for newly hired miners as well as annual retraining for the entire workforce. Many of these mandated training topics address the development and maintenance of non-routine skills - performances that are infrequently used but that are critically important under emergency conditions.

In addition, the mining industry provided over 80,000 miners with occupational training to support organizational goals and comply with Federal and State task training and certification requirements. Occupational training involves the development of routine skills that are directly related to task performance and are part of the miner's normal job routine.

Together, new hire, refresher, and occupational training cost over \$200 million yearly.

The current challenge then is one of providing more effective training. Research studies have found the quality of existing mine training is uneven and varies to a considerable degree. To improve the effectiveness of training, performance evaluation and training procedures, successful in measuring and developing necessary behaviors within the work group, need to be documented. The research program is directed toward this end.

New Hire and Refresher Training

A primary purpose of this training is to reduce the potential for mine disasters and to improve the miner's chance of surviving a mine emergency. Examples include training in the use of mine escapeways and evacuation procedures, fire fighting, first-aid, and the use of self-rescue apparatus. Thus, new hire and refresher training involves objectives relating to development and maintenance of contingency-type skills; i.e., skills and behaviors that are not part of a miner's normal or typical daily activity and that are not subject to the same para-

meters of regular practice that support proper performance of more routine activities. To address this issue, Federal and a few State regulations have mandated a prescribed number of training hours for a defined set of categories for non-routine skills. While the regulations placed the industry on equal terms regarding training requirements, discrepancies in quality and effectiveness are a major concern. In fact, the quality of training for non-routine skills is unknown. Traditional measures of training effectiveness utilizing injury data are not appropriate. Other types of data, such as the incidence of mine disasters, utilization of first aid techniques, and emergency evacuation procedures, to name a few, are not often available at the aggregate level to permit "bottom line" assessment. Even if such data were available, methodological problems experienced by other researchers in the conduct of aggregate evaluations would require major attention at both the theoretical and the practical level (3).

Completed Research - Previous research has provided preliminary guidelines for both the conduct and evaluation of new hire and refresher training offered under 30 CFR, Part 48. Developed materials include instructional guides and rather low level assessment tools (e.g., verbal recall) for surface and underground coal, deep metal and non-metal, sand and gravel, underground salt, and all uranium mines (open pit, surface, and underground).

An evaluative study (4) of classroom health and safety training was designed to address two basic questions:

- (1) How effective are trainers in achieving the objectives they adopt for their new hire and refresher sessions?
- (2) What sort of problems make it difficult for trainers to conduct optimally effective training?

The study involved field data collection through pre- and post-

testing of trainees, audio-taping class sessions, and administering short feedback forms to trainers and trainees at 14 sites in West Virginia, Maryland, Kentucky, and Pennsylvania.

Results indicate that goals, methods, materials, and outcomes of existing training programs vary widely among trainers and sites. The study findings also indicated that although many non-routine skills are being taught in new hire and refresher training, there are a number of problems related to the degree of proficiency to which these skills are learned, and that major opportunities exist for upgrading the training from a standpoint of both time efficiency and trainee performance.

This study also identified some practices that appeared to increase the effectiveness of training. One was the use of progress checks or other written tests to assess knowledge and skills at the beginning of training, during training, and at the end of the programs. The use of appropriate progress checks and exercises appeared to promote "interest" and "proper attitude" among the miners in training programs and was associated with higher scores on written post-tests and with higher gain scores.

Current Research - One research effort is built upon assessing the potential application of advanced techniques for using progress checks, exercises, and simulations in applications to new hire and refresher training. Skill assessment could potentially encompass a variety of new testing procedures, such as adaptive testing models, criterion-referenced testing, and classroom simulations of problem solving tasks designed to assess a miner's ability to recognize, problem solve, and perform in the event of a mine emergency.

Application of these techniques requires a detailed analysis of skills and proficiencies required under the mandated training topics. This will result in a more useful set of performance criteria that can be more easily

customized to mine environments than the rather broad and general objectives that presently exist.

Another current project is investigating the application of commercially available microcomputers (e.g., TRS-80 and Apple IIe) for assisting mine trainers in the delivery of new hire and refresher training. This in-house project is seeking to integrate computer-based training (CBT) with the Bureau's inhouse mine safety training.

Prior research (5) has indicated the technology for using computers in training has significant potential for reducing training delivery costs (25% to 50% time savings) while maintaining competency levels typically found with conventional classroom or self-paced learning.

The purpose of our CBT work is to develop an appropriate empirical model for industry utilization of this technology and to identify and address technical and cost barriers to the utilization of computer-based training by mine trainers.

Occupational Training

Occupational training at the mine site encompasses a wide variety of activities involved with development of routine skills, such as supervisory skills, equipment operation, etc.

Routine skills are those skills directly related to task performance and which are part of the miner's normal job routine. Many of these skills (behaviors) are readily observable, and performance errors can be tracked to resultant costs (e.g., injuries, downtime, production delays).

As in other industries, the most frequently used training method for routine skills is on-the-job training (OJT). The literature reports that most of this training is unstructured, that is, lacking a clear definition of objectives and training strategies designed to develop and evaluate specific skills required for the task.

The impact of this semi-formal process of developing skills is shown by examining injury data. Accident-injury studies (6,7,8,9,10) have consistently demonstrated a greater risk of injury for the new task performer than for the experienced veteran.

This generally accepted belief has also obtained wide support outside mining. Surry (11), for example, in 1969 reported a steady decrease in injury rates as workers' ages increased. More recently, Keyserling found a similar but more exact relationship in his study of 344 industrial workers (12). Other studies (13, 14) identified a strong correlation between injury rates of high- and low-accident firms with age and job experience of the workforce.

In a recent study by the National Academy of Sciences (15), the importance of formalized training was validated, which resulted in recommendations that Federal and State agencies provide additional consultative services and regulatory requirements for the purpose of enhancing mine safety and training efforts. In this particular study, the research team found that the injury risk of younger workers

(ages 18-24) was nearly twice that of more experienced miners (ages 25-34).

Completed Research - Our research investigations have provided a vehicle for many companies to structure their occupational training. Furthermore, training research has indicated that injury rates can be reduced if (1) the training process is performance-based and (2) management policy and decision making place a high priority on safety.

The Bureau has been engaged in developing generic materials for a wide variety of occupational skills (table 1). These materials generally consist of self- or classroom-administered training materials as well as procedures for conducting on-the-job training. Developed materials have served as a foundation for many industrial trainers to build upon to upgrade their training. By providing basic documentation (task analyses, training objectives, and course material), individual companies can incorporate site-specific information, resulting in a more measurable, performance-based program. Distribution of these materials is provided through MSHA's National Mine Health and Safety Academy.

Our field investigations have shown

TABLE 1. - Occupational training materials

<u>Underground coal equipment</u>	<u>Surface mining equipment</u>	<u>Specialized mining skills</u>
-Shuttle cars	-Pre-shift inspection procedures	-Mine rescue team training
-Roof bolters	-Diesel-electric haulers	-Electrical (surface)
-Continuous miners	-Diesel-mechanical haulers	-Electrical (underground)
-Hoist equipment	-Front-end loaders	-Shaft sinking
	-Scrapers	-conventional
	-Track dozers	-raised drilling
<u>Deep metal/nonmetal</u>	-Rubber tired dozers	-Supervisory and management training
Health & Safety aspects of:	-Graders	-Trolley wireman
-Load-haul-dumps	-Drills	-Blasting surface (coal)
-Jackleg drills	-Cranes	-Electrical hazards
-Track haulage	-Hydraulic excavators	-surface coal
-Mucking machine operation		-underground coal
-Slusher operation		-preparation plants
-Manege tending		-High voltage electrical
-Supply handling with a tugger		-Compressed gas
-Jumbo drills		
-Worksite preparation		

that training that is performance based and incorporates provisions for on-site follow-up evaluation has significant potential for reducing performance errors associated with injuries, downtime, and production loss.

In one case, an experiment (16) was conducted to assess the impact of structured training, using a Continuous Miner Training System (CMTS), on the task performance of both experienced and inexperienced continuous miner operators. Working in cooperation with Inland Steel Coal Co. and Rend Lake College, a total of 39 experienced and 19 inexperienced miner operators were trained. Experienced operators attended a two-day course aimed at standardizing continuous miner operating procedures, and the inexperienced operators attended a three-day course aimed at machine familiarization and operating procedures. Student group sizes ranged from two to six persons. Structured on-the-job training was provided at the mine site by Inland Steel.

The results of the field experiment indicated a significant increase in productivity coupled with reductions in machine downtime and preparation

plant rejects. (Figs. 1,2,3) In addition, structured feedback obtained from both the experienced and inexperienced operator groups indicated a high level of enthusiasm for and applicability of the training.

Current Research - Examples of present work include:

(1) Work Crew Performance Model

This inhouse project is designed to field-test a visual detection model for conducting training and performance evaluations. The model has the potential to overcome some significant problems in both cost-benefit analysis and performance management, both at the initial stages immediately following training and over the long-term performance of the underground equipment operator.

The method employed here prioritizes performance errors relevant to the equipment operator's task by assessing the relationship of potential error to the primary accomplishment of the job. In the case of the shuttle car operator, that accomplishment is to minimize waiting time by the continuous miner operator for an empty shuttle car. Factors that have

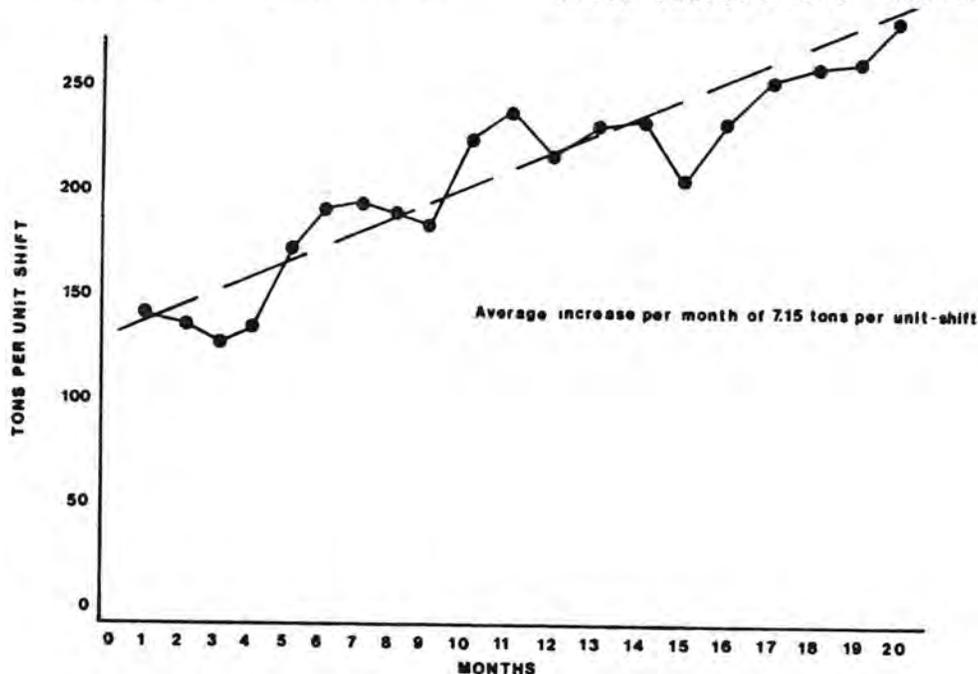


FIGURE 1.- Production rates per machine.

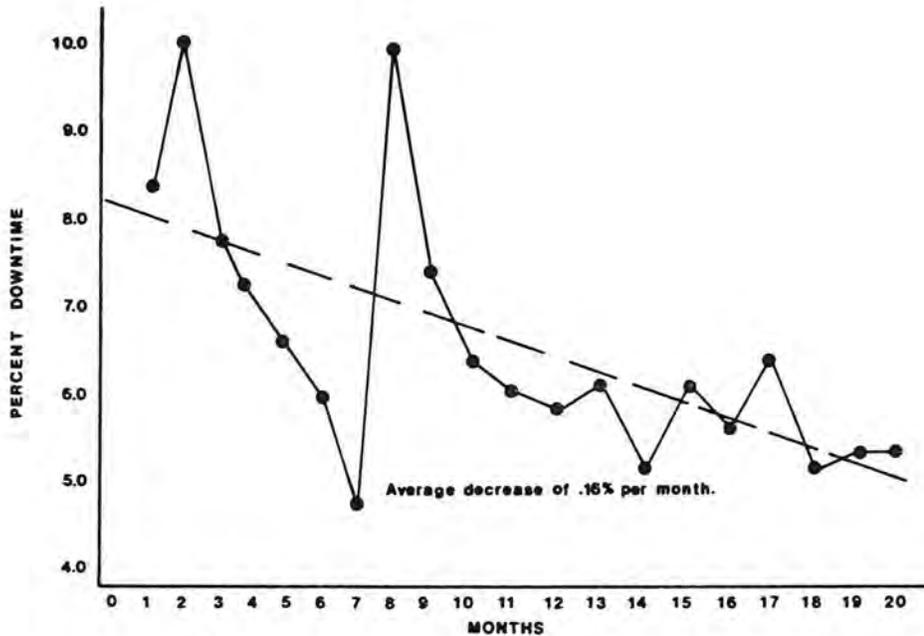


FIGURE 2.- Machine downtime as percent of production time.

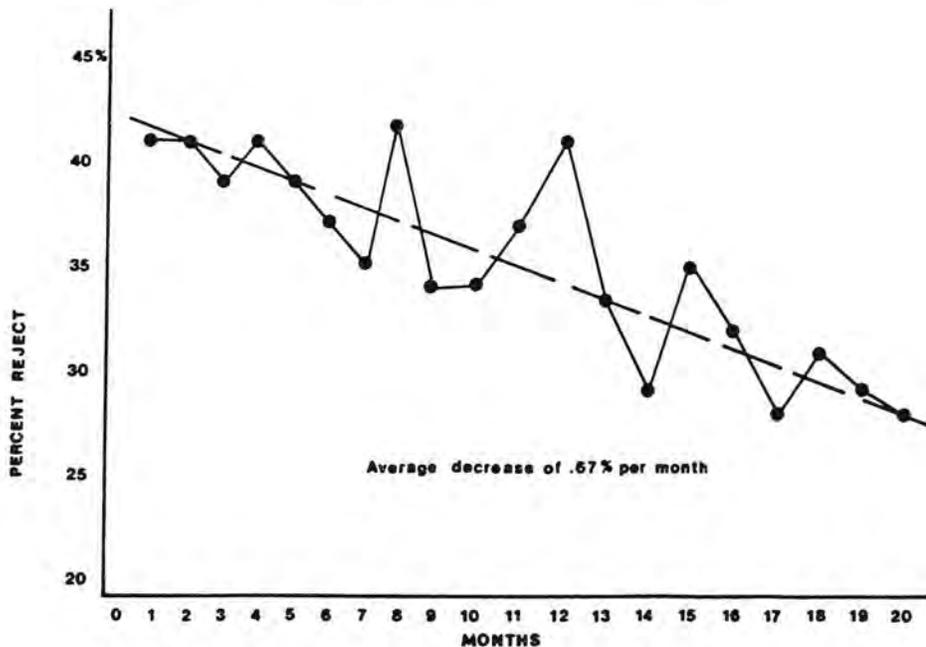


FIGURE 3.- Monthly reject rates.

a negative impact upon waiting time include injuries, down time, excessive maintenance, and property damage. Performance is improved by the visual detection model through (a) enhancing the supervisor's ability to discriminate between significant and nonsignificant performance errors by associating those errors with their cost con-

sequences and (b) designing evaluation measures that allow identification of performance improvement strategies, including training, that reduce the negative impacts of operator error on organizational goals. Field testing of the visual detection model is scheduled for 1985.

(2) Materials Development

The present work extends the development of instructional guides and OJT procedures to address the training of mine workers whose duties include working in and around coal preparation plants, longwall mining sections, underground haulage equipment (belt conveyormen and trackmen), and health and safety aspects of maintenance and repair activities.

(3) Visual Skills Study

The purpose of this in-house study is to ascertain the feasibility of utilizing stereoscopic slides as a discriminatory tool for assessing the visual skills of miners in their ability to recognize safe vs. dangerous roof and rib conditions. Supporting this study, interview guides were developed to assess the attitude and opinions of miners, mine management, and MSHA roof and rib experts concerning the causes of groundfall accidents and preventive measures.

The study is designed to address two questions: 1) To better understand why increasing experience improves a miner's chances of avoiding injury from groundfalls and whether or not this "experience factor" is tied to the perceptual and discriminatory skills of experienced miners, and 2) to identify promising new (behavioral) approaches for the reduction of groundfall accidents.

Information Dissemination

Several studies have attributed some types of mine training and performance problems to the lack of good resources and information on the part of mine training and safety personnel (4,15, 17,18). In many cases these problems cannot necessarily be attributed to a lack of useful training materials but are more likely the result of problems in (1) distributing information about training and performance management resources, (2) informing training and safety personnel about how copies of materials and

programs may be acquired, and (3) distributing accurate and useful safety performance data.

In the past, efforts to inform trainers have been based upon working through training organizations such as the annual Training Resources Applied to Mining (TRAM) conference jointly sponsored by Penn State University and West Virginia University, through the efforts of training support organizations like the WVU Mining Extension Service, through Bureau of Mines Technology Transfer and MSHA Industry Seminars, and through other organizations such as the Holmes Safety Association and the Pennsylvania Mine Educators Association.

Conference and seminar approaches are expensive in terms of preparation and lead time on the part of sponsors, and in terms of time and travel expenses for those who might attend.

Perhaps as a result of the economic recession in the coal industry, some of the major training conferences have experienced important reductions in registered attendance. Even at conferences that are maintaining their registration of participants, there is evidence that smaller coal companies are underrepresented. This is a matter of special concern, especially since the smaller companies are overrepresented in terms of their fatality rates (15,18).

This inhouse project is specifically devoted to exploring options for addressing these problems, by supporting, through research and development activities, implementation of a nationally accessible computer-based safety information system. The system has two primary components as it presently exists:

1. The West Virginia Safety Information System
2. The National Safety Information System

West Virginia Safety Information System. The Bureau has assisted the

West Virginia Department of Mines in developing a computer-based information system serving both administrative and research functions. This system, which has been in place since January 1983, has proven its effectiveness for a variety of information management and research tasks. Based upon a Digital Equipment Corporation VAX-11 computer, data management and statistical analysis software, and a telecommunications network, this system serves the Department's main offices in Charleston, WV, the Department's regional offices, and a number of non-Departmental users who access the system through dial-in lines and remote computer terminals for a variety of research purposes. Examples of external users include utility companies who access production and employment information in developing demand projections for electricity, coal consumers who seek suppliers of coal meeting particular quality specifications, and coal companies who access injury and mine inspection reports in support of their safety and training efforts. These users are in addition to Department of Mines personnel who produce many types of reports and data required by the Department in carrying out its statutory responsibilities.

National Safety Information System.

Using a similar approach to file design and user access explored during work on the West Virginia Safety Information System, the first formal component of the nationally accessible network is now in place. The Educational Materials Search System (EMSS) consists of references to mine safety and health training programs and materials developed by Government and private agencies. This data base is available free of charge to anyone who wishes to make use of it. Users Guides for EMSS may be obtained from the Learning Resources Center of the National Mine Safety and Health Academy in Beckley, WV. Similar efforts are underway to design, develop, and implement other widely available components, including a human factors research search system, an on-line mining dictionary, easy access to

accident and injury data, and a State mining agencies network.

The project involves cooperation among the West Virginia Department of Mines, the Bureau of Mines, the Mine Safety and Health Administration, and a number of other public agencies and private organizations.

Organizationally, the Bureau has been responsible for developing state-of-the-art information systems that will facilitate dissemination of information to all types and sizes of operations who may need help identifying and analyzing problems related to employee performance or workplace design.

ERGONOMICS RESEARCH

The discipline of ergonomics, or human engineering, works to define the capabilities and limitations of people, and then apply this knowledge in the design of the workplace to insure that it is compatible with these capabilities and limitations. The Bureau's ergonomics program is concerned with the definition of the capabilities and limitations of the miner, how the miner interfaces with the machines in use, and finally, how those machines and the miner interact with both the physical and organizational environment of the mining work place.

The Miner

Anthropometry - In considering the miner as a component of the complete mining system, some basic information needs to be known concerning the miner's physical size, his or her strength, and finally, how demanding, in terms of physical loading, are common manual mining tasks. In one research project, thin-seam miners and tasks were examined. Anthropometric data for thin-seam miners were collected by Texas Tech University under Bureau of Mines Contract and compared with equivalent measures of both civilian and military populations.

The findings show that there existed some differences in muscular develop-

ment in those body segments that would be expected to be most stressed when working in non-erect or stooped postures, that is, the upper torso, shoulders, and arms. The effect was more pronounced in males than females, but this was attributed to the fact that the male population has worked underground longer than females (18 months vs 9 months). This work also pointed toward some problems associated with a high incidence of back injuries.

Specific measurements are presented in Bureau of Mines IC 8866 (19). Importantly, the defined differences were not significant enough to warrant the maintenance of a separate data base for the mining population. This enables the mining industry to utilize existing data bases that are regularly updated for the general population.

Work Physiology

A number of mining tasks were analyzed to determine the energy expenditure demanded of miners, and also the physical work capacity of the thin-seam mining population. The aerobic capacity comparisons of the current low-coal mining population with nonmining individuals show no significant differences (20). This would indicate that modernization of equipment and improved mining technologies have made the mining of coal less strenuous to the hearts and circulatory systems of the miners. It also indicates that a high level of cardiovascular fitness is not necessary to perform the majority of low-coal mining tasks (an exception to this rule is shoveling). The research also indicates that some female miners and the fifth percentile male may have inadequate strength to perform those tasks requiring the highest levels of cardiovascular fitness, for example, shoveling.

Results also reveal that when performing the activities of timbering and shoveling, current low-coal miners expend more energy than reports from past research have indicated. Typical energy expenditure comparisons show

timbering as 5.995 kcal/min, compared with 5.695 kcal/min; and shoveling as 9.280 kcal/min, compared with 6.878 kcal/min. These activities are the only coal mining tasks available from previous literature. No current coal mining tasks (roof bolting, miner helping, bolter helping) have been examined prior to this study. In reporting the physiological responses to these tasks, it is found that the most strenuous tasks are helping and shoveling. The helping tasks require constant awareness of the machine cables, removing or hanging curtain, handling supplies, rock dusting, or bolt bending. Thus, it would be expected that individuals doing these tasks would show the greatest expenditure of energy.

Roof bolting does not require as high a rate of energy output when compared to the helper tasks. All of the tasks required of low-coal miners are at or above the 5.00-kcal/min value used to signify heavy work. Thus, it can be concluded that on a scale of general guidelines for industrial work, coal mining tasks require above average energy expenditure rates.

Further analyses can be made on the physiological data to estimate working and rest times for the demanding underground tasks. Figures 4 and 5 show a plot of endurance time versus energy expenditure requirements based on the 5th, 50th, and 95th percentiles of male and female miners' aerobic capacities. These figures show the differences in endurance time between males and females for the given tasks. Comparisons can also be made for the other tasks. It should be noted, however, that the females can perform these tasks for a longer period of time if the task parameters are changed (load in shovel and the shoveling rates). This of course would affect productivity, but would increase working time and reduce overexertion.

Additional Anthropometry and Work Physiology Studies - The Anthropometry and work physiology research completed in low coal has now been extended to

include most underground mining situations. A current study is collecting and analyzing data related to conventional coal mining, continuous mining, longwall, metal and nonmetal room and pillar, sublevel open stoping, vein mining, sublevel caving, and block caving.

Table 2 indicates the type of data being obtained and the current number of male and female miners from whom data have been obtained.

This work, like the low-coal research information, will be utilized to make recommendations for task and job redesign, to provide information related to sizing of female personal protective equipment, and to assist operators in selecting miners who have the physical capacity to perform heavy work in underground mines.

Research To Reduce Back Injuries

Back injuries sustained by miners while performing manual materials handling tasks are a major problem in the underground mining industry. MSHA indicates that in 1980, back injuries accounted for 26 pct of all reported coal mining injuries, and a recently completed, well-controlled study estimated that between 30 and 40 pct of a company's compensation cost is related to back injuries.

The Bureau is currently engaged in several research efforts designed to provide information that will be helpful to the industry in reducing the frequency and severity of back injuries.

A Bureau of Mines Information Circular (IC) 8948 entitled "Back Injuries" contains 11 technical papers that discuss and present what is currently known concerning the causes of mining back injuries and the methods by which these injuries can be reduced.

Training, selection, and job redesign are the three basic countermeasures that are detailed in the technical papers. Several papers

point out that training in proper lifting techniques has historically been the primary focus in attempting to reduce back injuries and has generally been found ineffective. However, new training approaches where miners are taught to take responsibility for their own back care appear to have considerable promise.

Dr. Ayoub's paper discusses in detail the benefits to be derived from a well-designed employee selection program. This paper stresses that individual physical lifting capacity is directly related to the likelihood of sustaining a back injury and that lifting capacity of an individual can be determined prior to employment. Thus, those individuals who will be engaged in heavy manual materials handling tasks can be selected on the basis of their ability to lift heavy loads.

Two papers in the IC discuss job design and redesign in reducing injuries. Both stress that job redesign to eliminate or reduce the overall need to lift heavy materials is the preferred countermeasure. Specific examples are given concerning how jobs and tasks can be designed.

Other papers in the IC report on new mechanical devices for use in underground mines, which assist in handling and moving materials.

As noted, most back injuries occur while miners are engaged in manual materials handling tasks. Therefore, the Bureau has an ongoing systematic program of research concerning human factors of manual materials handling (MMH) in the coal mining industry. This program is directed toward accomplishing the following objectives:

1. Completing a literature search to collect, analyze, and review the state-of-the-art in MMH.
2. Surveying MMH activities in coal mining to gather data on characteristics of MMH system components i.e., miners, materials, methods, and environment).

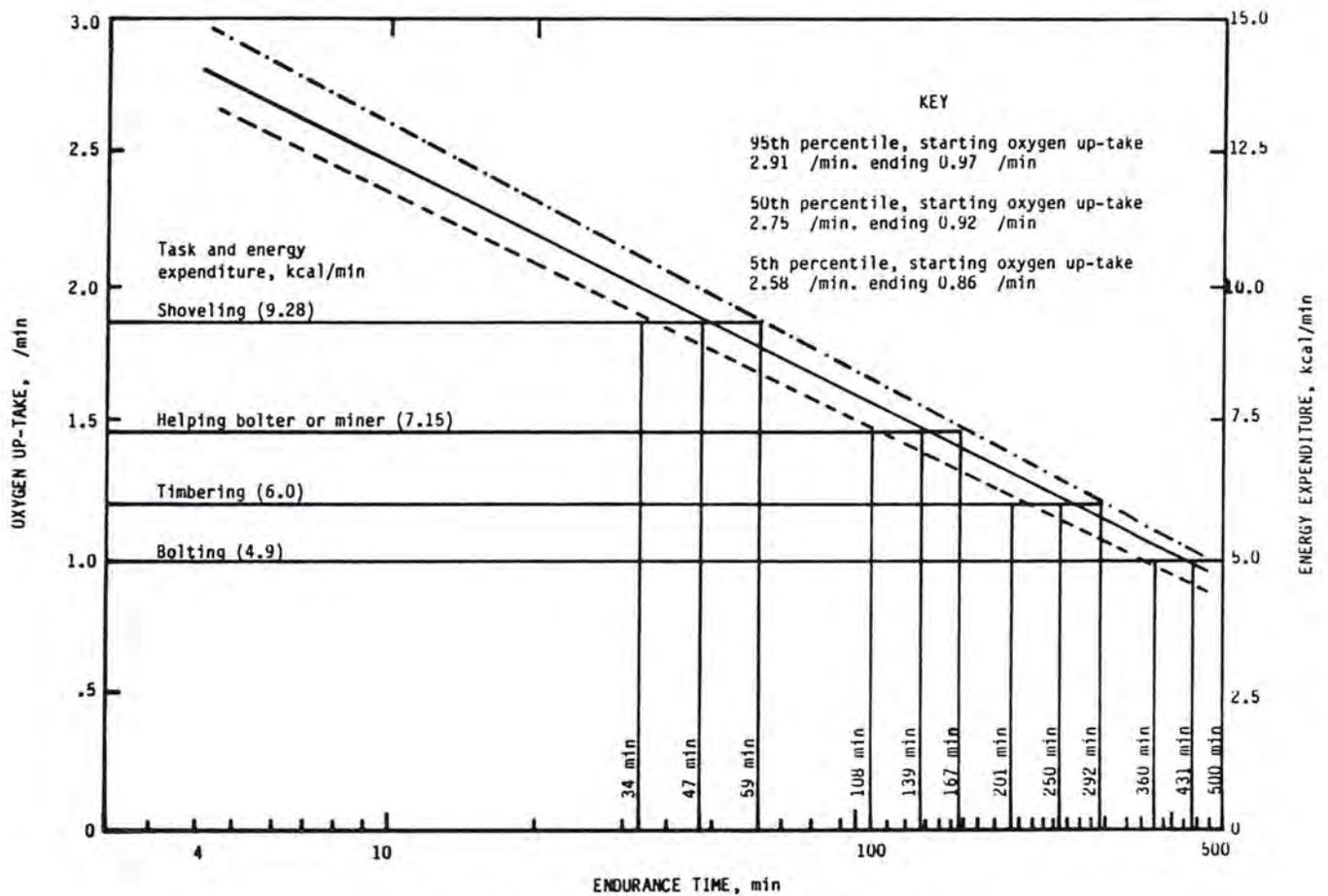


FIGURE 4. - Predicted endurance times for male low-coal miners.

Table 2

Summary of data collected

	Males	Females
Anthropometry	320	86
Physical Work Capacity	243	72
Isometric Strength	276	83
Nutrition Survey	177	62
Task Analysis	179	45
Underground Ventilation Volume	343	10

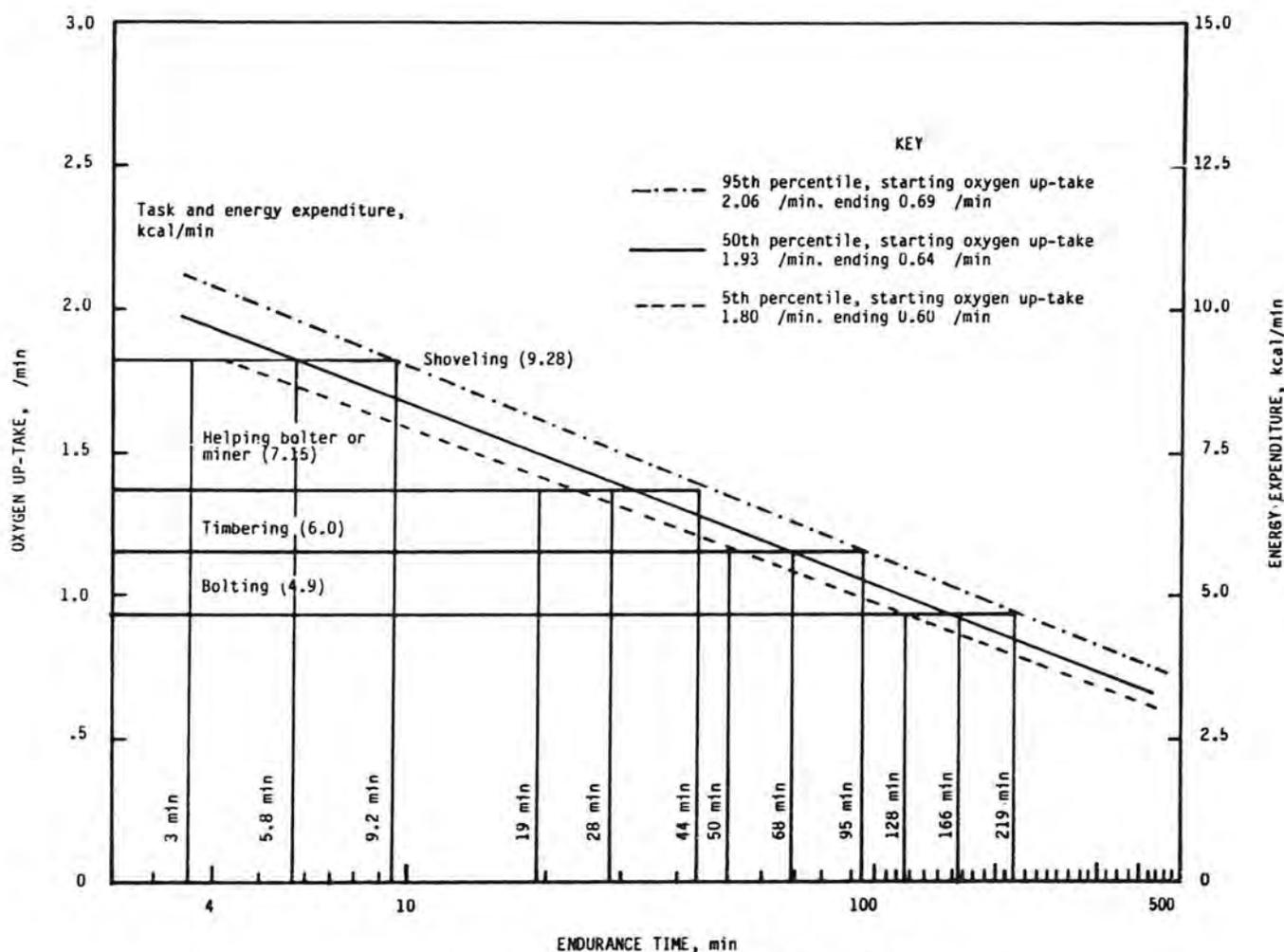


FIGURE 5. - Predicted endurance times for female low-coal miners.

- Conducting laboratory and field experiments to evaluate hazards and establish recommended job requirements, such as required physical lifting capacity for miners engaged in MMH tasks.
- Develop a MMH program (guidelines) specific to the needs of the coal mining industry.

To obtain information useful in the study of MMH, a comprehensive literature search is being conducted. Computer searches are being made to identify pertinent information. Several computer data bases are being utilized, as follows:

Dissertation Abstracts
 Engineering Index
 National Technical Information Service
 Safety Science Abstracts Journal
 Science Citation Index

Social Science Citation Index

All articles that are deemed relevant are being abstracted. The literature review will assist in identifying some areas where research should be directed. This activity will result in defining the current state-of-the-art in MMH research and will result in a publication that will be made available to the mining industry.

An analysis is also being conducted to identify all MMH activities and materials handled in mining. The emphasis is on the characteristics of the materials handled, such as size, shape, and weight, as well as the methods used by the miners in handling these materials. The data are being obtained through interviews and observation of the MMH tasks and activities that miners routinely perform.

Current job descriptions in the mining industry are inadequate indicators of potential stresses of the job. An extensive task analysis to identify the functional requirements of the MMH tasks is also being undertaken. These include such task characteristics as load handled, frequency of handling loads, postures, pace, and environmental conditions.

Other activities also involve the design of the specific research methodology and testing of miners for measuring or otherwise depicting the performance of the human body or body parts during manual lifting tasks. The operational criteria will relate to the performance of body parts in making specific types of movements, such performance generally falling into the following groups: range of motion, force applied during the activity (i.e., strength), endurance, and speed. For measuring these, various techniques will be used, such as motion pictures, strength tests, dynamometers, and metabolic measurements.

Muscular strength is the most significant requirement for jobs involving the manual handling of heavy materials. From the biomechanical viewpoint, the assessment of static muscular strength of a worker can provide a method of predicting whether the person is capable of performing a physical act in a job without incurring injurious strain.

The wealth of data derived from the research work described above will be used to develop recommendations for MMH in the coal mining industry. Numerous recommendations will be presented in the form of a guide, specific to the needs of coal mining, to control the hazards associated with MMH. Quantitative recommendations regarding the safe load, weight, size, location, and frequency of MMH handling will be provided. Additional factors will also be discussed (e.g., worker training, strength, workplace layout, etc.). The guide will include recommendations on the selection and training of miners who must perform

MMH activities, and will present some engineering guidelines for the design of workplaces where MMH is performed.

Personal Protective Equipment

While much work has been done to reduce industrial-type hazards in the mining environment, the individual worker still must depend on articles of personal protective equipment (PPE) to provide that extra margin of safety so necessary in the mining environment. Personal protective equipment is a multimillion-dollar-a-year business, cutting across virtually every industry in the United States. As such, many items are designed for general use rather than for the unique problems associated with mining.

Miners are equipped with an extensive array of protective equipment including ear protection, safety glasses, respirator, hard hat, cap lamp and battery, overalls, gloves, safety boots, self-rescue devices, and in low-seam mines, knee pads. The various protective equipment items have often been designed without giving proper consideration to human factors and unique environmental situations encountered in the mining environment. The current designs of this PPE have been reviewed by the Canyon Research Group under Bureau of Mines Contract J0387213, and a broad range of recommendations for their improvement was reported by Sanders, et al. (20). Also, significant progress has been made in the personal lighting system, knee pads, slip-resistant boots, and personal protective equipment for female miners.

Personal Lighting System

The present-day miner's cap lamp and battery system has been a highly reliable and indispensable aid to miners for many years and had undergone few changes since its general acceptance in the 1930's. Recent developments in battery technology, however, have made several improvements possible.

Over the past several years, the

Bureau has been working with outside contractors to develop a new cap lamp and battery system. The new battery is based on nickel-cadmium technology and features significant improvements in performance when compared to the conventional lead-acid battery presently in use.

Among the more significant improvements are a 48-pct reduction in battery weight and a 15-pct reduction in battery volume. The weight reduction should be an attractive feature to miners who must carry the battery while performing their work. Battery capacity has been increased from 12 to 15 A.h and will provide a greater margin of safety and cap lamp burning time that may be required in emergency situations. Charging cycle life has been also increased, and although testing has not been completed, it is expected to be in the 1,000-cycle range. This will extend the usable life of the battery to 2-1/2 times that of the present lead-acid battery, providing 3 to 4 years of normal use. The extended battery life should more than offset the higher cost of the nickel-cadmium system.

The battery has undergone testing at MSHA's Approval and Certification Center, and approval is expected shortly. Ongoing research is investigating methods of making the battery maintenance free so that periodic water addition will not be necessary. Research efforts are also focusing on the development of a new cap lamp bulb. Efforts to date have led to the development of prototype lamps based on tungsten halogen technology. The new lamp has dual filaments and marks the first time that a low voltage, dual-filament tungsten halogen bulb has been successfully designed. The new bulb offers approximately 30 pct more light output than the conventional lamp while operating at the same input power levels.

Knee Pads

Approximately 30 pct of underground coal miners work in mines with a vertical work clearance of less than

48 inches (121.9 cm). These miners must work in a crawling or kneeling posture most of the working day. An ailment affecting such workers is "miner knee" (pre-patellar bursitis). The bursa is a sac between the skin and the uppermost forward part of the shin bone. Repeated pressure between the bone and an outside surface, such as the ground, causes the bursa to fill with fluid to provide a cushion to protect the bone. The bursa can swell and become quite painful.

An improved knee pad was developed to reduce or eliminate the problems inherent in the currently available pads. This design is shown in figure 6. It consists of a tough rubber, high-rim outer shell and a contoured inner foam pad. A single nylon strap and belt buckle are used to secure the pad. Two models are being field-tested; one will have a chambered air cushion (18 psi) embedded in the inner foam, and the other will not. Table 3 compares the physical dimensions of the prototype pad with the unitized design shown in figure 6.

The contoured prototype pad distributes the forces over a greater surface area and provides greater comfort. The contour also stabilizes the knee in the pad, thus reducing abrasions. The higher side walls reduce the intrusion of rubble between the knee and the pad. The strap is positioned so it will not cut into the back of the knee. The use of a standard single-prong belt buckle with a nylon strap provides infinite adjustability without slippage. This reduces the need to retighten the strap during work. The pad extends farther down the shin than does the commonly utilized pad, thus providing additional protection to the user.

Slip-Resistant Boots

In 1980, MSHA recorded 2,400 non-fatal, days-lost injuries due to slips and falls of persons in underground mines, with 79 pct of those occurring in coal mines. The magnitude of the slip and fall problem suggests that perhaps improvements could be made in

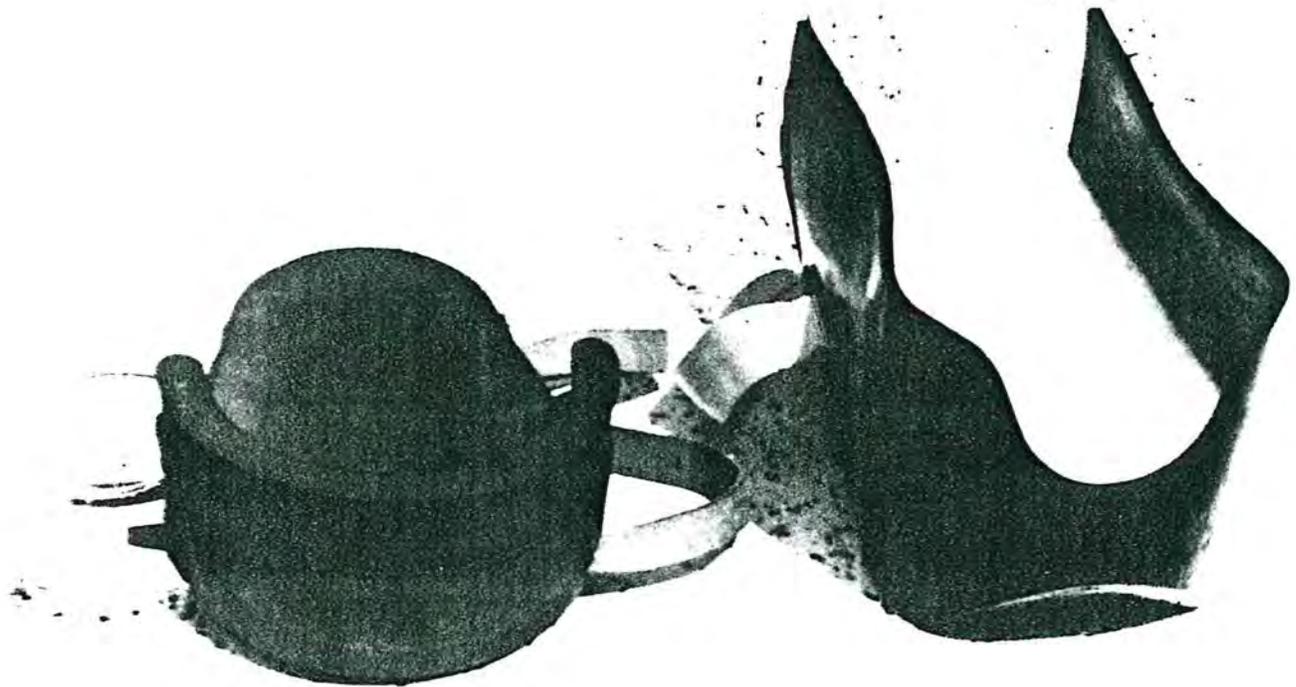


FIGURE 6. - The new knee pad design (left is compared with an existing product.

Table 3

Comparison of Unitized and Prototype
Knee Pad Designs

<u>Physical dimensions</u>	<u>Design</u>	
	<u>Unitized</u>	<u>Prototype</u>
Weight..... gm	495.3	509.4
Outer length..... cm	20.7	22.9
Inner length..... cm	19.3 ¹	22.5
Outer width..... cm	14.9 ¹	11.4
Height..... cm	7.3	11.0 ²
Pad thickness..... cm	2.5	2.5-5.0 ²

¹Tapered.
²Contoured.

the design of boot soles to increase the coefficient of friction between the sole and the floor.

Wet conditions usually prevail underground; this necessitates the use of rubber boots to keep the workers' feet dry. The sole of steel-toe rubber boots is made by one or two processes. The most common type of sole is calendered or rolled. The sole pattern is cut into a roller (like a rolling pin) and rolled into the sole material while it is curing. The resulting pattern usually consists of zigzag bars running laterally across the bottom of the boot with the outer edge rounded up to meet the upper part of the boot. This process provides a shallow tread pattern, typically 4 to 5 mm (0.16 to 0.2 in) above the sole base.

The second type of sole is molded. A metal mold is made in the shape of the sole with the pattern cut into the mold. The liquid sole material is poured into the mold and cured. This typically produces a deeper tread pattern (approximately 8 mm (0.315 in) above the sole base) and sharp, squared-off edges.

Although there has been considerable research on coefficients of friction, there has been virtually no information on the effect of the sole design (pattern) on slip resistance. The American Society of Testing and Materials (ASTM Method D 2047-75) recommends the testing of a 7.6- by 7.6-cm (3- by 3-in) specimen of the material on a horizontal plate. The small specimen does not fully allow for sole pattern effects to become evident. Further, the machine does not test slip resistance for walking across a slope.

A slip resistance tester was built that used the entire boot for testing and included a test for slip while walking across a slope. Results from the laboratory tests clearly showed that the sole pattern did affect slip resistance, and that a critical design factor was the existence of edges perpendicular to the slip vector.

Molded soles with sharp, squared-off edges were found to be more slip resistant than calendered soles. A limited field test comparing the molded and best models of calendered soles confirmed the superiority of the molded sole in preventing slips and falls.

A problem with molded soles currently used on rubber boots is that they collect and hold mud, thus reducing their slip-resistance qualities. Based on experiences from both laboratory and field tests, a molded sole pattern with sharp edges oriented perpendicular to both fore-aft and lateral slip vectors was designed. The sole was designed to reduce the accumulation of mud by using a lug design and open channels. Figure 7 shows the prototype boots. The tread, or lug depth, is approximately 7 mm (0.28 in).

During field observations and discussions, many miners complained that their foot slipped inside the boot. It was believed that this "false slip" sometimes caused the worker to attempt a recovery and may have actually increased the probability of an actual slip or fall; the prototype boots, therefore, were designed with laces over the instep. This permits the wearer to tighten the laces and provides a more snugly fitting boot. This should reduce false slips and add stability during locomotion. Iron Age has produced 25 prototype boots which were successfully field tested over a 5-month period and is presently offering them commercially.

Personal Protective Equipment for Female Miners

Over the past 10 years significant numbers of females have become employed as underground miners. It appears that in the coming years the number of females working underground will increase. One major problem faced by female miners has been the unavailability of properly fitting personal protective equipment.

Essentially, the female miner has



FIGURE 7. - A slip resistant boot tread (center) compared with typical miners' boots.

been required to adapt and make do with equipment that was sized for males. In many instances, this has led to females being required to wear equipment that is ill-fitted and uncomfortable. In fact, only about 50 pct of the female miners can be properly fitted with clothing that has been sized for males.

In an attempt to begin solving this problem, the Bureau has developed sizing data for female miners and has developed and tested a prototype outer garment. The basic features that distinguish this garment from typical overalls are a design that properly fits the female population and has an inseam zipper to more easily allow the wearer to perform bodily functions. A

summary of some female sizing data is contained in figure 8.

In a field assessment, where female miners wore and evaluated the experimental coveralls, it was determined the new design was superior to conventional underground work clothing along the safety, comfort, work productivity, and fabric suitability parameters selected for assessment. In addition, several low-coal miners interviewed during the comfort assessment portion of the clothing design study indicated that the inseam zipper was relatively easy to utilize and was preferable to conventional coveralls in terms of performing bodily functions.

PERCENTILE

	<u>5th</u>	<u>30th</u>	<u>50th</u>	<u>70th</u>	<u>95th</u>
Height (inches)	59.48	61.10	63.61	66.13	67.75
Chest Circumference (inches)	31.18	32.77	35.22	37.68	39.27

Size Categories

Size	Height, in	Chest Circumference, in
Small Short	58.0 - 60.9	30.0 - 32.9
Regular Short	58.0 - 60.9	33.0 - 35.9
Large Short	58.0 - 60.9	36.0 - 38.9
X-Large Short	58.0 - 60.9	39.0 - 41.9
Small Medium	61.0 - 63.9	30.0 - 32.9
Regular Medium	61.0 - 63.9	33.0 - 35.9
Large Medium	61.0 - 63.9	36.0 - 38.9
X-Large Medium	61.0 - 63.9	39.0 - 41.9
Small Long	64.0 - 66.9	30.0 - 32.9
Regular Long	64.0 - 66.9	33.0 - 35.9
Large Long	64.0 - 66.9	36.0 - 38.9
X-Large Long	64.0 - 66.9	39.0 - 41.9

FIGURE 8. - Sizing standards for female work clothing based on anthropometric data.

This last finding is of particular importance since a safety feature that is not employed is functionally useless. The combination of these factors provides the experimental coveralls with the potential to avoid many needless mining injuries or fatalities.

Also of importance is the finding that the experimental coverall design received higher ratings in terms of comfort by low coal miners than did standard coveralls. This is not only a function of the specific comfort features incorporated into the experimental coveralls (action pleat in shouldlers, etc.) but also points out that present sizing standards being used in coverall designs are inadequate in providing proper fitting for certain populations, in particular, the female population.

Miner-Machine

The major machinery used at the face in an underground coal mine

includes face drills, cutting and loading machines, continuous miners, boring machines, roof bolters, shuttle cars, and scoop and/or tractors. In general, the design of these machines has stressed technical and engineering aspects related to productivity over consideration of the human operator. This has resulted in machines that strain the capabilities of the operators, require lengthy training periods, and contribute to the high accident rate among mobile equipment operators.

When considering the miner-machine interface from a human factors viewpoint, one must consider compartment envelope (Will it safely accommodate both 5th and 95th percentile persons?), protection from the physical environment, psychological loading, controls design, and visibility. The Bureau's research program continues to address these concerns. Thus, two research efforts, Development of SAE Human Factors Design Guidelines for Operator Compartment of Underground Equipment and Computer Modeling of

Mining Crewstations, are now underway.

Development of SAE Human Factors Design Guidelines

The first effort addresses concern through a joint effort with the society of Automotive Engineers (SAE). Historically, many standards and design guidelines have been established for above-ground equipment which aid industry in establishing consistent man-machine interface systems. This accomplishment toward achieving more consistent placement of controls from machine to machine, as well as accommodating a wide range of population extremes, does not exist for underground mining equipment.

The preparation of these design guidelines, to be presented to industry as SAE Recommended Practices, is being accomplished by organizing a Machine Task Group for each of the selected machine types and charging the task leader of each group with the performance of the research and data gathering necessary to develop the design and performance goals that would produce a safe and efficiently operated work station. This effort includes the compilation of accident histories, preparation of task and hazard analyses, definition of minimum envelope dimensions, recommendation on the location and direction of activation of controls, development of minimum visibility envelopes, and description of minimum criteria for operator ingress-egress and seating. Additionally, examples of work station design are being developed to demonstrate the potential application of the SAE Recommended Practices in developing new equipment designs.

This Bureau of Mines-SAE project will result in the development of SAE Recommended Practices for 10 different mining machine types during the two-year program schedule. By way of contrast, the voluntary efforts of the SAE technical committee have resulted in the preparation of two SAE Recommended Practices (not yet balloted and approved) in two years. This will accelerate the development of these

SAE Recommended Practices and provide the industry with those guidelines far sooner than would be accomplished through the current voluntary efforts conducted by the SAE working group.

Thin seam machines present a difficult challenge that is being addressed in a series of projects that attack work station design for specific classes of machines. One such effort, by the Jeffrey Manufacturing Co. under contract to the Bureau of Mines, has developed a cab and canopy design for thin-seam carriers. The cab is designed to float on the bottom for maximum seam height utilization. It is designed to accommodate both the 5th and 95th percentile person comfortably and safely in seams with a minimum thickness of 36". Visibility is improved by placing the operator at a 16° angle to the machine centerline, permitting a view of both the inby and outby conveyors. While no standards exist for bridge carrier controls, human factors principles were followed in their design. The cab has successfully completed a 6-month in-mine evaluation, and the manufacturer is now marketing it as an option on their latest design of bridge carrier. Similar efforts for thin-seam shuttle cars and loading machine are underway.

Computer Modeling of Mining Crewstations

Using a computer to model crewstations is becoming an increasingly popular method to analyze the human factors aspects of a particular machine design. However, none of the models presently available can handle the unique needs of machines designed for the mining industry. For the Bureau and the mining industry to take advantage of these new techniques, available models are being adapted for modeling mining crewstations. In addition, past and present Bureau research into miners' anthropometry and visibility needs are being incorporated into the model. This will serve to consolidate all the Bureau's research in this area into a package that will be valuable to both the industry and the Bureau.

In 1983, an analysis was done of various computer models suitable for mine vehicle crewstation design. The results indicated that, with modification, the CAR model, developed by the U.S. Navy, could address the major design issues of mine vehicle crewstations. Based on this study, the current work was begun in 1984.

Some previous work includes determining the Visual Attention Locations (VALS) for operating continuous miners, shuttle cars, and scoops (Contract J0388213, Canyon Research Group, Inc.). The information collected during that project is a first step toward describing minimum visibility recommendations or requirements for shuttle cars and continuous miners.

The objective of this project is to develop a comprehensive computer model that can be utilized for designing mine vehicle crewstations. As such, the model will be extremely useful for work ongoing and planned, and for designing advanced operator compartments for underground vehicles. The model will be able to perform visibility assessments using VALS and accommodation analysis much more quickly and cheaply than current methods (mockups, etc.).

Miner-Environment

While much of the Bureau's research program has addressed the physical environment, such as dust and noise control, mine illumination, etc., there exists a project that examines the effects of organizational variables.

The work consists of a demonstration to assess the usefulness and cost effectiveness of organizational development (OD) approaches for increasing safety and productivity in mining. Organizational development efforts typically examine the primary goals of management and then provide some proven methods to assist a company in solving its major problems and achieving these goals. The techniques used basically improve communications throughout the organization and include such activities as team building,

training in leadership and supervisory skills, coaching, and establishing definite channels to provide feedback of information concerning the status of the organization. Details of how these tools were utilized at the demonstration sites, Hecla Mining Co.'s Star Mine and Texas Gulf's Trona Operations, are discussed by Cecil R. Bell, et al. (21). The demonstrations are presently being completed, and preliminary results indicate dramatic improvements in both safety and productivity. It appears the OD instrumentation holds promise for improving accident rates in the mining industry.

CONCLUSION

In examining reported non-fatal lost-time injuries over the preceding decade, it is obvious that there was a substantial increase in absolute numbers. Normalized data indicate that the annual risk of personal injury to the general coal mining population is only slightly less today than it was in the late 1960's. The growth in the absolute number of disabling injuries coincided with a marked growth in new hires, due in part to increased coal demand, and also with a dramatic drop in productivity. The fact that a miner's annual risk of personal injury today is slightly less than it was 10 years ago is little consolation for the additional 3,000 to 5,000 lost-time injuries experienced annually in recent years.

The significant reduction of the individual risk of fatal injuries and the overall reduction in absolute fatalities over the last decade are principally the result of improvements in the physical environment of, or of protection provided to, the worker that minimizes the impact of environmental disturbances. The fact that a similar trend was not evidenced over the same time period for industrial-type non-fatal injuries is cause for concern.

The application of human factors and training research is viewed as an important approach to future reduction

of non-fatal injuries. The achievement and maintenance of downward trends in non-fatal injuries should follow the implication of permanent design solutions, with training acting in a supporting capacity as a planned component to industry efforts to improve safety.

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EDITED BY:

Michael Karnis
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

William H. Sutherland
Mine Safety and Health
Administration
U.S. Department of Labor

David R. Forshey
Bureau of Mines
U.S. Department of the Interior

J. Richard Lucas
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

Gavin J. Faulkner
Department of Mining and
Minerals Engineering
Virginia Polytechnic Institute
and State University

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