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HUMAN FACTORS ANALYSIS OF UNDERGROUND WORK AREAS AND TASKS IN METAL AND NONMETAL MINES

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

PERCEPTRONICS

FINAL REPORT

Contract No. J0387230
Study of Human Engineering
and
Analysis of Work Areas and Tasks
to Establish Illumination Needs
In
Underground Metal and Nonmetal Mines

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T.J. Perry, N.D. Schwalm, W.H. Crooks

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The objective of this study was to identify the human factors problems that are critical to the safety and productivity of underground metal and nonmetal mining, and to propose state-of-the-art as well as research and development solutions to those problems. Analyses of observational and statistical data were performed and human factors problems inherent in metal and nonmetal mining operations were identified. Priorities were established for the solution of these problems according to their perceived criticality to the industry. This report describes the nature of human factors problems in metal and nonmetal mining, and recommends applicable state-of-the-art as well as research and development solutions to those problems.

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FOREWORD

This report was prepared by Perceptronics, Incorporated, Woodland Hills, California, under USBM Contract No. J0387230. The contract was initiated under the Metal and Nonmetal Health and Safety Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. James M. Peay acting as the Technical Project Officer. Mr. William R. Mundorf was the Contract Administrator for the Bureau of Mines. This report is a summary of work completed as part of this contract during the period from April 1, 1980 through September 22, 1980. This report was submitted by the authors on March 11, 1981.

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Appreciation is expressed to the Technical Project Officer, Mr. James M. Peay, for his guidance as well as his technical and administrative support of this contract.

We wish to thank Professor Mark Sanders of California State University at Northridge, whose expertise in Human Factors has affected every aspect of this research. We also express our deepest appreciation to Professor Ben Stone of Drake University for sharing his expertise and experience in the mining industry with us. His contributions in this regard have touched every aspect of the research. The efforts of our three mining engineering consultants, Dr. Robert Lundquist of Acton, MA, and Professors Thys Johnson and William Hustrulid of the Colorado School of Mines also have been invaluable.

Special thanks are expressed to the mine operators and equipment manufactures who participated in this study, and who willingly shared their knowledge and experience with us.

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EXECUTIVE SUMMARY

This report presents the results of a study of human factors problems that affect the safety and productivity of underground metal and nonmetal miners. These problems are those that result from inappropriate interaction or interface between the workers and their equipment, tools, and environment. Included also in this definition are problems resulting from inadequate training in the use of equipment and procedures necessary for performance of underground work activities.

The objectives of the study were to identify the entire range of human factors problems in underground metal and nonmetal mining, to identify those problems that affect significantly the safety and productivity of underground miners, to select human factors problems that are considered critical to safe and productive mining, and to propose state-of-the-art as well as research and development solutions to those critical human factors problems.

Based on statistical, observational, and interview data, the range of human factors problems in underground metal and nonmetal mining was identified. Unit operations performed in underground mining were rated on the basis of the accident frequency and severity associated with the operations. Problems characteristic of these "critical" unit operations were then reviewed and ranked. The result of this ranking was a list of problems considered to be critical to the safety and productivity of underground workers, and whose solutions deserved immediate attention, either by implementation of state-of-the-art solutions or by further research and development efforts.

The problems considered critical to safe and productive underground metal and nonmetal mining include materials handling, detection and removal of loose rock, slips and trips, hazard conspicuity, hand tools, eyewear, and clearing of blocked chutes and raises. Human factors engineering solutions exist for some of these problems, and these solutions are identified in the report. Seven research programs have been recommended to obtain solutions to those problems that are not amenable to state-of-the-art solutions. These programs present the problem backgrounds, define objectives for research aimed at solving the problems, and describe methods for arriving at solutions.

It is suggested that whether solutions already exist or whether research and development efforts are needed to develop them, implementation of these solutions and ideas in the metal and nonmetal industry will depend on miners' and mine operators' awareness of the existence of the problem and its solution, the degree to which the user accepts the proposed solution and integrates it into his or her work, and the means by which solutions or changes are introduced into underground operations.

It is particularly important to note that successful solutions to critical human factors problems will generally involve more than the development of machinery or devices to aid operators in performing their tasks, especially in the case of large problems. For example, materials handling and slips and trips are two problems that are so pervasive in the industry that they demand consideration of the full range of variables (such as equipment needs, job aids, procedural changes, training requirements, etc.) to obtain a productive and acceptable solution. That is to say, those problems involve so many people, are associated with so many accidents, and can occur in so many operational situations that a lack of consideration of all of these elements would surely handicap the effectiveness of any solution developed. To increase the probability that effective solutions will be developed and will be used willingly by the workers, a "systems" approach should be used in the preliminary design, development, and evaluation of solutions. This must include consideration of all system components, such as the jobs and tasks required, the physical and biomechanical demands of the tasks, the environment in which the tasks are done, the characteristics of the user of the system, and the interactions among these components that are essential to safe and effective task performance. Only through this type of evaluation and analysis can adequate solutions to underground metal and nonmetal mining problems be designed and implemented successfully. Obviously, it must be established early whether the problem is significant enough to warrant an effort such as that inherent in the systems approach.

It is concluded that studies aimed at developing and implementing solutions to human factors problems should continue at an accelerated pace, and that the results of such studies will be a well-organized, comprehensive, and useful program of research aimed at improving the safety and productivity of underground metal and nonmetal miners and mining operations.

1.0 INTRODUCTION

1.1 Overview

Underground metal and nonmetal mines have been under great pressure both to increase productivity and to improve safety. With the recent acceleration in prospecting for new ore deposits, and the concommitant opening of new mines, it has become crucial to establish a foundation for human engineering improvements, and to begin practically directed research and development programs. Although some of the research that has been done in coal mines is applicable to metal and nonmetal mines, the technologies, operations, and working environments are so different in metal and nonmetal mining, that for the most part, the application of human factors research must be given a new and revised direction.

A primary goal of human factors research is to improve the performance and safety records of persons working in complex sociotechnical organizations. This goal can be achieved by many different methods, applied separately or in concert, but the methods have a common thread of looking at human performance within the context of the larger system in which the person operates.

An earlier study (Crooks, et. al., 1980) described the activities performed in underground metal and nonmetal mines, the surroundings in which these activities are performed, the equipment used to do them, and the characteristics and needs of the people who actually perform these activities. From the results of that earlier study, it was possible to identify the problems encountered in underground metal and nonmetal mining operations, particularly those that are viewed as being detrimental to miners' safety and productivity. The present study was concerned with defining clearly the nature and sources of those problems from the human factors point of view, and with identifying state-of-the-art and research and development solutions to those problems.

1.2 Objectives and Approach

The specific objectives of the human factors analysis described herein were to:

1. Identify the entire range of human factors problems in underground metal and nonmetal mining.
2. Identify those problems that significantly affect the safety and productivity of underground miners.
3. Rank order the problems identified.
4. Propose state-of-the-art and research solutions to critical human factors problems.

To attain these objectives, it was necessary to identify several dimensions of underground metal and nonmetal mining operations. These dimensions included:

1. The tasks being performed in the mines.
2. The locations in the mines (i.e., the surroundings in which those tasks are being performed).
3. The people who perform those tasks.

The research approach to identifying these dimensions was multi-faceted. That is, several kinds of research methodologies were employed in combination to obtain the most complete and comprehensive data possible on underground metal and nonmetal mining operations. A detailed description of this research approach and its results is contained in the report entitled "Analysis of Work Areas and Tasks to Establish Illumination Needs in Underground Metal and Nonmetal Mines" (Crooks, et al, 1980). However, in the interest of presenting a self-contained report that will facilitate complete understanding of the present research effort, the analyses comprising this multi-faceted approach, as well as their outcomes, are now briefly summarized.

1.3 Summary of Work Site and Task Analysis

The study included analyses of four distinct but closely related matters. The first analysis considered the underground locations where miners perform their jobs. This analysis included identification of the major categories of underground work locations within metal and nonmetal mines, followed by detailed on-site observations and evaluation of a carefully selected sample of work sites. Illumination, sound, and atmospheric measurements were made and the number, type, and locations of luminaires and mining machines were identified at each location. In addition, the work activities being performed at the location were identified. This analysis of work locations provided the basis for the comprehensive description of the illumination characteristics of underground work locations in metal and nonmetal mines.

The second analysis of the study concerned the illumination and visibility characteristics of the rocks and minerals that constitute the majority of the surfaces found in the mines. A Mine Illumination Laboratory was used to determine the directional light distribution (goniophotometric) properties of samples of rocks and minerals from a wide variety of metal and nonmetal mines. This laboratory provided several advantages over field measurements, including: 1) allowed the time necessary for detailed goniophotometric measurements and 2) provided the highly accurate instruments required for these measurements. Analyses of these goniophotometric characteristics provided the basis for identifying the reflectances that are encountered in metal and nonmetal mines.

The third analysis of this study focused on the jobs that underground workers perform in this industry. The intent of this analysis was to identify the specific tasks that are performed by the various workers, especially those tasks that are impacted by the illumination present in the underground work locations. Through both on-site observations of work activities and structured interviews with experienced miners, the tasks and activities that constitute the underground work operations were identified.

The fourth analysis of the study focused on the accidents occurring in underground metal and nonmetal mines and on the employment distribution across this industry. The focus of this latter analysis was to identify the number of people performing the various underground tasks and the accidents that occurred to those underground workers.

We now turn to a discussion of the specific conclusions that may be drawn from the analyses performed in that study.

1.3.1 The Underground Work Environment

Analysis of the underground working environment suggested that the categories of work locations shown in Table 1-1 constitute a useful taxonomy of work stations that encompasses the vast majority of underground work areas in metal and nonmetal mining.

With regard to illumination, analyses of the underground work environment indicate that although some general similarities exist, there is great variability in the many characteristics of work sites in underground metal and nonmetal mining. This variability exists both between different mines

TABLE 1-1. - Categories of underground work locations

- Production Sites
  - Faces
  - Stopes
- Development Sites
  - Faces
  - Exploration
  - Construction
- Haulage Sites
  - Loading Sites
  - Haulage Ways
  - Dump Sites
  - Skip Pockets
- Ore Processing Sites
- Miscellaneous Sites
  - Shaft Landings
  - Maintenance Shops

and within a given mine. In general, we found that underground work environments differ significantly in surface luminances and reflectances, types of luminaires, and other factors that affect the quality of the visual environment.

Production and development sites have lower reflectance, lower output luminaires, lower luminances, and are more likely to have visual impairment due to aerosols or hydrosols, than do permanent work sites such as ore transfer and processing stations and maintenance shops. Additionally, production and development sites are characterized by a significant number of visual impairments, of which direct glare and the scattering of light due to the presence of aerosols and hydrosols appear to pose the greatest problems. Aerosols and hydrosols often obscure the face, and the scattering of light reduces apparent luminance.

Three-fourths of all work sites measured have surface reflectances of less than 30%. Reflectance varied significantly among the nine mines. Direct glare from light sources is a problem when the operator must work between luminaire and task, when luminaire design is poor (e.g., bare lamps), or where two or more workers are in close proximity and glare from cap lamps becomes a problem.

There are also significant differences in the sizes of the openings, ranging from 4' x 4' x 10' development raises to 125' x 150' x 200' open stopes. The height of most underground work locations is relatively uniform, with a median of eleven feet. However, the width and depth of these locations varies greatly between mines and within some mines. These variations in size of openings are positively correlated with the luminances of the surrounding area, probably due to the higher output luminaires generally used in the larger openings.

Perhaps the most significant finding regarding the work environment is the wide variety of operations performed in any given work site. As we will suggest, the work activity being performed, rather than the work site itself should be the primary focus of any illumination standards for underground metal and nonmetal mines.

1.3.2 Reflectance of Metal and Nonmetal Rocks and Minerals

There is no single number which fully describes the reflectance of a surface. For above-ground applications, the use of a single reflectance obtained from a standardized geometry is an acceptable approximation for painted walls or carpeted floors. But the situation underground is far more complex. The gonioreflectance of rocks and minerals varies with the source angle, angle of view, presence of dust or water, and the reflecting characteristics of the surface. The range in gonioreflectance for any given sample can be tremendous. The ratio of highest to lowest gonioreflectance can be more than 10:1 for shale or sphalerite and as little as 2:1 for dolomite. Water is a major contributor to the variance for most rock and minerals. At most viewing angles, water causes a 25 to 50% reduction in the gonioreflectance but at the complimentary angle can increase the gonioreflectance, in some cases to over 100%. Surface moisture can be a significant source of reflected glare if the wet areas are sufficiently large (the surface must also be brightly lit and the operator at the complimentary angle position).

Most dry rocks and minerals are matte diffuse reflectors and when wetted become diffuse and spread reflectors. A few become diffuse and specular reflectors when wet and are the most likely to cause visual impairment due to reflected glare. Gunite and white wash are diffuse reflectors which may be used to improve the visual environment.

Most mines are in a single major rock or mineral type (whose gonioreflectance may be highly variable). A few mines have several major rock or mineral types present. If these types are significantly different in gonioreflectance, that mine will face tremendous difficulties in providing the optimal amount of illumination for any given task. For example, according to the data obtained, the lighting that is adequate for development activities in dry dolomite will have to be increased approximately 400% to achieve the same luminance levels for production work in wet sphalerite. Or, if the equipment lighting is designed to provide adequate luminance production in wet sphalerite (worst case), at other work sites more illumination will be provided than is cost-effective or necessary.

The range of gonioreflectances found within a given mine also has implications for the enforcement of minimal luminance standards. For example, a jumbo drill with a given set of luminaires could be in compliance working in dolomite or feldspar and out of compliance in sphalerite or shale at the same mine. The differences among rock and mineral types are such that it may be cost effective to tailor equipment lighting systems to particular gonioreflectance ranges.

1.3.3 Underground Work Activities

During the course of the current research, we determined that the typical classification of work activities according to job title would not be useful. Analysis of a large sample of job titles revealed that many persons holding different job titles perform the same work activities. Conversely, people having the same or similar job titles often perform entirely different work activities. Accordingly, we chose to consider the unit operations being performed. Analysis indicated that the vast majority of work activities in metal and nonmetal mining are encompassed by the unit operations listed in Table 1-2.

TABLE 1-2. - Categories of unit operations

DRILLING

- Jackleg Drilling
- Raise Drilling
- Jumbo Drilling
- Stoper Drilling
- Ring Drilling
- Rotary Drilling

GROUND SUPPORT

- Rock Bolting
- Timber Post Erection
- Gunnite/Shotcreting
- Timberset Assembly
- Cribbing
- Sandfilling
- Preparing Work Area

LOADING

- LHD Operation
- Slusher Operation
- Overshot Loader Operation
- Manual Shoveling
- Chute Pulling
- Gathering-Arm Loader Operation

HAULAGE

- Train Operation
- Truck Operation
- Shuttle Car Operation
- Conveyor Operation/Maintenance
- Tugger

MAINTENANCE

- Shaft Maintenance
- Machine Maintenance
- Roadway Maintenance
- Track Maintenance

SERVICES

- Pipe Installation/Repair
- Ventilation Control Installation/Repair
- Electrical Installation/Repair

CONSTRUCTION

- Concreting
- Steel Construction
- Timber Construction

BLASTING

- ANFO Loading/Blasting
- Stick Powder Loading/Blasting

EXPLORATION

- Diamond Drilling
- Surveying
- Sampling

CONTINUOUS MINING

- Continuous Miner Operation
- Cutter Bar Operation

HOISTING

- Man Cage Operation
- Ore Skip Operation

SUPERVISION

- Supervising/Coordinating Workforce
- Safety Inspecting

UNDERGROUND ORE PROCESSING

- Ore Crushing

Although we analyzed many aspects of the unit operations performed by underground workers, including physical demands, training requirements, and time requirements, we focus here on the unit operations with inherent exposure to risk and with high visual demands placed on the worker. It will be seen that these activities are also critical in terms of productivity. By these criteria, the critical unit operations are:

Feedleg drilling
Jumbo drilling
Rock bolting
Preparing work area
L.H.D. operation
Slusher operation
Manual shoveling
Train operation
Conveyor operation and maintenance
Machine maintenance
Pipe installation and repair
ANFO loading and blasting
Stick powder loading and blasting
Safety inspecting

The visual abilities most frequently required in the performance of the aforementioned tasks were: depth perception (72%); accommodation (64%); far acuity (43%); near acuity (36%); peripheral vision (36%); and color discrimination (7%). From this listing, it is evident that some critical tasks make very low demands upon the visual system, while others may require the exercise of several visual capabilities in concert. Manual shoveling, for instance, can seemingly be performed satisfactorily under visually disadvantageous conditions, while jumbo drilling, L.H.D. operation, work site preparation, loading and blasting, and safety inspection bring into play the full spectrum of visual discrimination potential. One may conclude, therefore, that certain of these critical operations should be done by trained personnel with intact visual systems if safety and productivity criteria are to be met.

Our analyses have also shown that workers' ratings of the relative degree-of-hazard inherent in a unit operation is significantly and inversely correlated with the amount of luminance associated with that operation. Further, the accidents occurring in specific unit operations are inversely correlated with the amount of luminance. In other words, those unit operations are perceived by workers as being hazardous, and that have higher than average numbers of accidents, are often performed in areas with lower luminance levels.

Moreover, our analyses indicate that there is currently no apparent relationship between the type of luminaire typically used for a unit operation and the visual demands of that operation. Unit operations with high visual demands were just as likely to use only cap lamps as to use high-output types of luminaires. For operations requiring only near acuity, the cap lamp is probably quite sufficient. However, the lack of relationship between luminaire type and visual demand should attract attention when considering unit operations requiring far acuity, depth perception, and wide fields of view.

1.3.4 Critical Mining Activities

We now turn our attention to accidents associated with the critical underground work activities. For purposes of this discussion, "critical" mining activities are defined as those unit operations that are associated with a high accident index. This accident index was based on the degree of exposure of underground workers to particular unit operations and the percentage of accidents associated with those unit operations, as shown below.

$$\text{Accident Index} = \frac{\text{Percent of Accidents Associated With Unit Operation}}{\text{Relative Amount of Time Spent Performing the Unit Operation}}$$

Our analyses indicated that those unit operations with the highest accident indices are concentrated in the drilling, ground support, haulage and loading categories. Table 1-3 presents the most hazardous unit operations in terms of accident frequencies and indices. A significant number of these accidents was found to be associated with the use of nonpowered hand tools, which points up the importance of taking a closer look at the design of these types of tools for use by underground mining personnel. Another important finding was that of all worker activities, "barring down" or "scaling" accounts for the largest percentage of deaths or fatalities in the underground metal and nonmetal mining industry. Thus, it is advised that particular attention be given to the tools, procedures, and illumination associated with that unit operation if the number of underground fatalities is to be reduced.

We stress, however, that although the accident index may highlight some unit operations as being particularly accident prone, serious attention must also be given to those unit operations which account for a large overall number of accidents. For example, maintenance has an accident index of 1.0, indicating that the frequency of maintenance accidents is what would be expected for the number of people performing that unit operation. However, because maintenance is such a widespread activity, 13 percent of all underground accidents in metal and nonmetal mining is associated with maintenance. Thus, efforts aimed at reducing maintenance accidents will go a long way toward reducing the number of people who are hurt every year.

The accident index is, nevertheless, an important step in focusing the attention of future human factors research and development efforts in underground metal and nonmetal mining into areas of significant safety needs. It is apparent from the statistical as well as observational data obtained in this study, that primary research emphasis should be put in the <u>preliminary</u> design of mining equipment for user safety and comfort. It

TABLE 1-3. - Percent of total accidents and accident index for top 20 unit operations from highest to lowest

Unit Operation	Percent of Total Accidents	Accident Index*
Overshot loader operation	4.22%	16.88
Rock/roof bolting	8.65%	3.25
Train operation	8.23%	3.05
Drilling	22.15%	2.52
Gathering arm loader operation	0.72%	2.40
Truck operation	3.84%	1.93
Barring down	9.45%	1.91
Hoist operation	1.35%	1.48
Front-end loader operation	1.73%	1.44
Man cage operation	1.27%	1.27
Timbering	4.35%	1.19
Maintenance	13.67%	1.01
Pipe/vent control, installation, repair	3.08%	0.81
Continuous miner operation	0.17%	0.81
Slusher operation	2.36%	0.81
Manual shoveling	2.41%	0.78
Chute pulling	1.39%	0.77
Track construction/repair	0.84%	0.68
Shuttle car operation	0.97%	0.66
Electrical installation/repair	1.01%	0.66

* A value of 1.00 on the accident index indicates that accident frequency is in accordance with what would be expected for the number of people performing that unit operation. A value greater than 1.00 indicates that accident frequency is more than what would be expected for the number of people performing that unit operation. A value less than 1.00 indicates that accident frequency is less than what would be expected for the number of people performing that unit operation.

appears, from both underground site visits and visits to mine equipment manufacturers, that machines are designed with little if any consideration of the characteristics and expected behavior of users.

The foregoing analyses and their results served as the basis for a detailed investigation of problems encountered by underground mining personnel in performing their tasks. Specifically, we are concerned with identification of those problems that may be solved by a human factors approach. We now turn to a brief overview of the methodology used in identifying those problems.

1.4 Analysis Methodology

The human factors analysis was concerned with a detailed evaluation of human factors problems in underground metal and nonmetal mining. By "human factors problems" is meant those problems in underground metal and nonmetal mining that result from inappropriate interaction or interface between the workers and their equipment, tools, and environment. Included also in this definition are problems resulting from inadequate training in the use of equipment and procedures necessary for performance of underground work activities.

The procedure for identifying critical human factors problems in underground metal and nonmetal mining is presented graphically in Figure 1-1. Based on the accident index, accident frequency, and accident severity data obtained previously, critical unit operations were selected for further analysis. Criteria were then developed to determine the importance or criticality of the problems associated with the critical unit operations to the underground metal and nonmetal mining industry. These problems were rated by human factors experts according to the criteria developed. These criteria included the effects of the problems on the health, safety, productivity, and comfort of underground metal and nonmetal mining personnel. Related problems were logically grouped, resulting in a list of problems that were considered important to underground metal and nonmetal mining operations.

This list of important human factors problems was then distributed to a sample of mine operators, engineers, and safety personnel who were asked to rank them according to their educated and experienced opinion of the criticality of the problems to the industry. Thus, the problems selected as important were verified by the individuals most affected by the problem. The result of these rankings was a more restricted list of problems considered to be critical to the safety and productivity of underground workers, and whose solutions deserved immediate attention, either by implementing state-of-the-art solutions or by further research efforts.

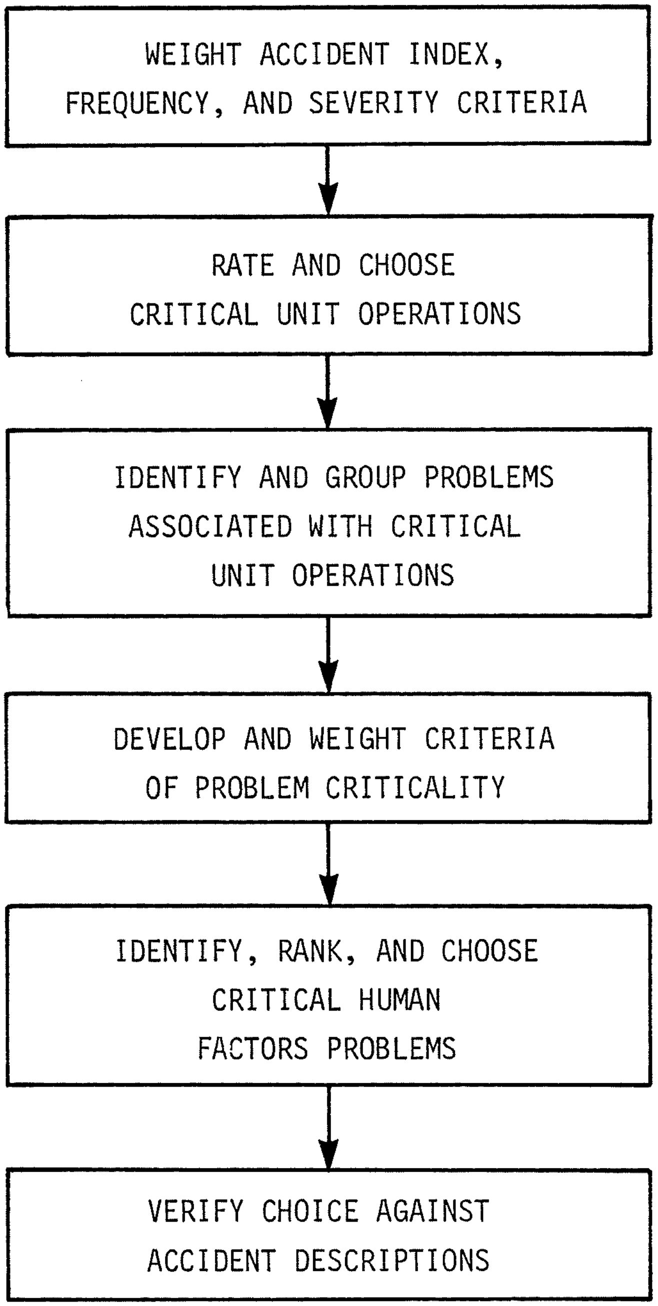

FIGURE 1-1. - Procedure used to identify critical human factors problems in underground metal and nonmetal mining

A random sample of 510 detailed descriptions of accidents that occurred in the underground metal and nonmetal mining industry during 1978 and 1979 was obtained from the Health Safety Analysis Center (HSAC) and was carefully reviewed by the human factors analysts. These accident descriptions were then classified according to the problems most closely associated with the accidents, to verify that these problems were, in fact, critical to the safety of underground miners. A comprehensive literature search was conducted to determine which problems could be solved by state-of-the-art technology, and which problems would require further human factors research and development to arrive at their solution. In cases where state-of-the-art solutions were available, manufacturers of equipment designed to solve the problems were contacted, and details regarding implementation of these solutions were obtained.

1.5 Results and Recommendations

Table 1-4 presents the list of problems determined to be critical to the health and safety of underground metal and nonmetal mining personnel. Also presented in Table 1-4 is an indication of the types and categories of solutions (1=state-of-the-art, 2=research, or 3=demonstration project) to those problems that seem to be most appropriate and have the greatest potential of overall payoff to the underground metal and nonmetal mining industry. These results are expanded and fully detailed in Chapters 3 and 4 of this report.

1.6 Report Organization

Chapter 2 presents a detailed description of the methodology used in the Human Factors Analysis, and preliminary results of that analysis.

Chapter 3 presents a discussion of State-of-the-Art Solutions to some of the important human factors problems in the industry. Also provided are the results of our discussions with mining equipment manufacturers on impediments to the implementation of state-of-the-art solutions to these problems.

Chapter 4 deals with the specific problems considered to be critical to the safety and productivity of underground mining personnel, and with state-of-the-art and research and development solutions to those problems.

And, Chapter 5 presents a general set of conclusions that integrates the information presented in the previous chapters. Also

TABLE 1-4. - Types and categories of solutions to critical human factors problems in underground metal and monmetal mining

SOLUTION CATEGORIES

	HUMAN FACTORS									ENGINEERING			
	ENVIRONMENTAL DESINGN			EQUIPMENT DESIGN			TRAINING						
CRITICAL PROBLEMS IN UNDERGROUND METAL & NONMETAL MINING	Improved Visibility and Illumination	Vibration Attenuation	Protection from Geological, Atmospheric, and Physical Hazards	Design for Safety	Design for Anthropometric and Other Characteristics for User Population	Design for User Acceptance	Job Procedures	Biomechanics	Safety Awareness	Mechanized Sealing Devices	Lifting & Handling Aids	Rock Characteristic Sensor Devices	Chute Clearing Devices
Materials Handling			2,3	2,3	2,3	2,3	2,3	2,3			2,3		
Detection of Loose			2,3	2,3	2,3	2,3	2,3					2,3	
Removal of Loose			2,3	2,3	2,3	2,3	2,3	2,3		2,3			
Slips and Trips	1,3		1,3			1,3							
Hazard Conspicuity	1,3		1,3			1,3							
Hand Tools		2		2	2	2	2	2					
Eyewear					1,3	1,3			1,3				
Clearing Blocked Chutes & Raises			2,3	2,3	2,3	2,3	2,3	2,3					2,3

1 = State-of-the-Art Solution 2 = Research Solution 3 = Demonstration Project

discussed is the problem of technology transfer, which we feel is a significant issue in both the implementation of state-of-the-art solutions and the definition of research solutions to the human factors problems in underground metal and nonmetal mining.

2.0 HUMAN FACTORS ANALYSIS

2.1 Overview

In this chapter the methodology and procedures that led to the selection of the most critical human factors problems in underground metal and nonmetal mining are detailed. First, the way in which the entire range of human factors problems in underground metal and nonmetal mining was delineated is reviewed. Second, the process by which both critical unit operations and critical problems were evaluated is presented. Third, the selection and verification procedures used to arrive at the final list of critical human factors problems is discussed. Fourth, the methods used to identify state-of-the-art and research solutions to those problems are outlined. And finally, the means by which the applicability and potential payoff of recommended solutions were verified with manufacturers of underground mining equipment is discussed.

2.2 Taxonomy of Problems in Underground Metal and Nonmetal Mining

In a previous phase of research under the present contract (Crooks, et al, 1980), in-depth interviews were conducted with 135 underground miners to determine the nature and characteristics of their work. An important aspect of these interviews dealt with identifying the problems and hazards encountered by the miners in their everyday work activities. These data were obtained for a total of 43 unit operations.

To describe the full range of problems in underground metal and nonmetal mining activities, the data from each interview were carefully reviewed and all problems reported by the workers in their day-to-day work activities were listed. This review produced a list of 94 unique problems encountered by the sample of miners in the metal and nonmetal mining industry. These problems were then classified into three major and classical human factors categories: environment, equipment, and tasks. The problems were reviewed further and were assigned to several more specific taxonomic groups so that the problems would ultimately be considered as part of a larger and more useful conceptual framework. The final taxonomy is presented in Table 2-1. Examples of some of the human factors problems

TABLE 2-1. - Taxonomy of human factors problems

- ENVIRONMENT
  - Visibility and Illumination
  - Noise and Vibration
  - Geological Hazards
  - Atmospheric Hazards
  - Physical Hazards
  - Toxic and Caustic Material Hazards
- EQUIPMENT
  - Operator-Equipment Interface
  - Unsafe Design
  - Anthropometry
  - Personal Equipment and Tools
- TASKS
  - Job Procedures
  - Biomechanics
  - Communication
  - Information Transmission

subsumed under these taxonomic groups will facilitate an understanding of the nature of the problems encountered in underground metal and nonmetal mining operations.

2.2.1 Environment

Problems of the environment include those problems inherent in the worker's surroundings that may impede performance or create a safety hazard. These include problems of visibility and illumination, noise and vibration, geological, atmospheric and physical hazards, and hazards associated with toxic and caustic materials.

Subsumed under the category of visibility and illumination are problems such as obscuring of the face and back by aerosols and hydrosols, hazards on train tracks, the detection of low back and hazards protruding from back and ribs, etc. One particular problem, although not one identified as critical, is that of miners' difficulty in locating shelter holes. Shelter holes are those openings used by miners for refuge to provide enough clearance when trains move through haulageways. In most cases, these shelter holes are not well marked and are difficult to locate. This increases the probability that miners will not locate them fast enough and get hit or pinched against the rib by a train. Other important problems in visibility and illumination include those of detecting mechanics working on machines onsite, and detecting of hoses, cables, and pipes at the underground work site, both of which may cause accidents.

Problems of noise and vibration include, among others, the noise of feedleg and jumbo drills (which is frequently above 110dB), high frequency vibration from hand-held drills, and noise of diesel powered equipment. These problems can produce long-term disabilities in hearing and touch.

Geological hazards are those hazards inherent in the physical characteristics of the rock, such as fall of back, flying and falling rock.

Atmospheric hazards include those of hot and cold temperatures in the mine (which may interfere with task performance), and dust and gasses in in the air (which may produce respiratory ailments).

Physical hazards are basically those presented by obstacles (such as holes, hoses, cable, pipes, etc.) present at the worksite. These hazards contribute significantly to the incidence of slips and falls in the mine.

Finally, toxic and caustic materials hazards include those stemming from the use of chemicals, lubricants, and blasting powders.

These substances are often associated with skin and eye irritations and "powder headaches."

2.2.2 Equipment

Subsumed under the category of equipment are problems relating to operator-equipment interface, dangers inherent in the equipment, anthropometry, and personal equipment and tools.

Operator-equipment interface problems are those problems that create difficulty for the operator in using his equipment effectively. Inappropriate and confusing control layouts, and inappropriately designed hand tools are two common operator-equipment interface problems.

Many pieces of underground equipment have inherent dangers. The overshot loader is a good example. Operators may be hit by flying rocks, slip off the platform, or be pinched against the rib while loading with the OSL. Other such dangers are inadequate safety screens at slushers, and pinches or crushes to the hands suffered while miners attempt to remove bound steel.

Anthropometric problems are concerned with the difficulty in getting in and out of the operator's compartment, seating comfort, and control reach envelopes.

Examples of problems with personal equipment and tools include the design of the tool used for barring down, and inadequate design of ear, eye, and respiratory protection that often prevents miners from using it. Another problem that is continually annoying to miners is that of the cap lamp cord catching on protrusions and pulling off the hard hat. Although not a critical problem, this situation may increase the probability of head injury.

2.2.3 Tasks

There are also a series of problems that are inherent in the tasks performed by underground metal and nonmetal workers. These include inappropriate or inefficient job procedures, biomechanical problems encountered in performing various tasks, difficulties in communication, and problems of information transmission. Specifically, the procedures used for removing loose rock, rerailing cars, and maintaining machines should be analyzed and safer job procedures developed.

Heavy lifting and other physical demands associated with materials handling operations present biomechanical problems that may result in strains, pulled muscles, or chronic back pain.

Missed or confused communication may result in production delays and accidents. For example, while pulling chutes, it is important for the chute puller to communicate effectively with the motorman of the train to load ore cars properly and to prevent accidents associated with this operation.

The information transmission problems noted were those that concerned proper documentation of sample location, and difficulties encountered in inter-supervisory communication regarding location of miners, equipment status, and work progress. Although these problems are rarely associated with accidents, they have profound and sometimes critical effects on productivity.

The problems just described comprise a sample of the range of human factors problems encountered in underground metal and nonmetal mining. A wider range of human factors problems, categorized according to this taxonomy, appears in Appendix A.

2.3 Evaluation of Critical Unit Operations

2.3.1 Criteria of Criticality: The Multi-Attribute Utility Model

The results of the Unit Operation and Task Analysis and the Work Safety Analysis discussed in Chapter 1 provided several items of information that were crucial to the selection of critical unit operations in underground metal and nonmetal mining. These items were:

1. A list of 43 unit operations that described the work done in underground metal and nonmetal mining.
2. Accident frequency data, i.e., data on the number of accidents associated with particular unit operations.
3. Accident severity data, i.e., data on the consequences of the accident to the worker.
4. Accident index data, i.e., an indication of the relative danger of performing particular unit operations, taking into account the number of accidents associated with the unit operations, the frequency with which any particular worker performs that unit operation, and the number of workers in the industry that perform the unit operation.

To select those unit operations whose associated problems deserve primary attention in terms of their solution, it was necessary to determine the criticality of each unit operation to the underground metal and nonmetal mining industry.

A recently popularized technique known as Multi-Attribute Utility (MAU) offers a useful approach to making quantitative assessments involving multiple criteria (e.g., Keeney and Raiffa, 1976). MAU methods can decompose a complex overall evaluation problem into more manageable subproblems through scaling, weighting, and combining operations applied to specific criteria.

The MAU model was developed in four steps:

1. Decomposing and structuring the evaluation problem.
2. Defining the element relationships.
3. Establishing element boundaries.
4. Determining element weights.

The major task in the development of an MAU model is the identification and definition of appropriate evaluative attributes and their configuration into attribute clusters or categories. This might be difficult since the attributes and their classification are somewhat arbitrary; they are subject to differences of opinion and there is probably no such thing as a "best" set. A reasonable approach, therefore, is to use an iterative procedure, involving consultation with relevant literature and expert opinion, to distill a "good" set of general evaluative criteria that are broad in scope yet are meaningful, practical, and internally consistent. More specifically, an attempt is made towards satisfying the desirable properties of an attribute set as suggested by the framework of MAU theory (Keeney and Raiffa, 1976): namely, that it be complete, so that it covers all aspects of the problem; operational, so that it can be meaningfully used in analysis; decomposable, so that the evaluation process is simplified by breaking it down into parts; nonredundant, so that double counting of attribute impact is avoided; and minimal, so that evaluation dimensions are kept to a minimum.

These guidelines, with some modification to make them adaptable to the present evaluation, were followed in the definition of a set of attributes or criteria for evaluating the criticality of unit operations and (as explained in Section 2.4.1) human factors problems.

The MAU approach improves upon intuitive techniques of unit operation and problem assessment in the following ways: (1) it makes explicit what are conventionally implicit considerations; (2) it quantifies what are usually qualitative descriptions; (3) it simplifies the representation and integration of what are often complex configurations and interrelations among relevant information; and (4) it provides an objective and general method for rating the unit operations and problems.

Based on the Multi-Attribute Evaluation methodology outlined above, and on lengthly discussion with our consultants, we determined that the best criteria for assessing the criticality of unit operations were the accident index, accident frequency, and the accident severity data obtained as a result of our previous Work Safety Analysis. It became apparent, however, that these three criteria might not be considered equally important in determining the criticality of unit operations. Thus, as dictated by the MAE model, a criteria weighting procedure was employed where each criterion was weighted by each of four mining engineering and Human Factors consultants. In this manner, the relative importance to the selection of critical unit operations of each of the three criteria was determined. This criteria rating for unit operation appears in Figure 2-1 along with the average of the weights assigned by the four consultants to each of the three criteria.

2.3.2 Ratings of Unit Operations

Having established the criterion weights, each unit operation was rated on each of the three criteria. A 5-point scale was employed for this purpose, as seen in Figure 2-1. Scale values were assigned on the basis of accident frequency, severity, and index values obtained in our previous research. Figure 2-1 presents this 5-point rating scale as applied to the unit operation "overshot loader operation." As shown in the figure, the scale rating for each criterion was multiplied by the associated criterion weight to produce a coefficient of criticality for that criterion. The three coefficients of criticality were then summed to produce a value designating the overall criticality of that unit operation, as shown below.

$$OC = \sum_{i=1}^{3} R_i W_i$$

where:

OC = overall criticality of unit operation

R_i = criterion rating by HF analysis team for criterion i

W_i = criterion weight determined by consultants for criterion i.

Criterion	X	Weight	=	Coefficient of Criticality

Accident Index

Frequency of accidents associated with the unit operation weighted by the number of people performing the unit operation in which the human factors problem appears.

1	2	3	4	5				
				X	X	0.400	=	2.000
BELOW .5	.5- .75	.75- 1.00	1.00- 3.00	ABOVE 3.00				

Accident Frequency

Frequency of accidents associated with the unit operations in which the human factors problem appears.

1	2	3	4	5				
				X	X	0.375	=	1.875
BELOW .25%	.25- .50%	.5- 1%	1- 4%	ABOVE 4%				

Accident Severity

Severity of accidents associated with the unit operations in which the human factors problem appears.

1	2	3	4	5				
		X			X	0.225	=	0.675
NO DEATH LOST OR RESTRICTED ACTIVITY DAYS	<5 LOST OR RESTRICTED ACTIVITY DAYS	>5 LOST OR RESTRICTED ACTIVITY DAYS	PERMANENT TOTAL OR PARTIAL DISABILITY	FATAL				

OVERALL CRITICALITY OF UNIT OPERATION 4.550

FIGURE 2-1. - Criteria, weights, & rating scales for evaluating criticality of unit operations

2.3.3 Critical Unit Operations

Upon obtaining an overall criticality value for each unit operation, a mean value of overall criticality was calculated. All unit operations above the mean ($\overline{X} = 2.81$) were designated as critical, in terms of the criteria developed previously. Thus, a total of 18 unit operations were considered critical to the safe performance of underground metal and nonmetal mining operations. These unit operations are listed in Table 2-2 with their overall criticality values.

2.3.4 Human Factors Problems Associated with Critical Unit Operations

The present study attempted to identify those problems in underground metal and nonmetal mining that were the most significant or "critical" to the industry. The aim was to concentrate on problems whose solutions would prove to be most effective in reducing accidents and lost-time expenses while increasing productivity. Thus, a process of elimination was employed to narrow the range of human factors problems to those that were the most important and most relevant to the safety and productivity of underground metal and nonmetal miners. The identification of critical unit operations was the first step in this narrowing process, and led directly to a delineation of those human factors problems that were associated with critical unit operations. Appendix B lists the 70 human factors problems associated with the critical unit operations, according to the taxonomy previously established. It should be noted that the subcategory "information transmission" was thus eliminated from the taxonomy, since none of the problems listed thereunder were associated with any critical unit operations.

2.4 Evaluation of Human Factors Problems Associated with Critical Unit Operations

2.4.1 Development of Criteria of Criticality

To evaluate adequately the importance of the problems associated with critical unit operations to the underground metal and nonmetal mining industry, it was essential to develop logical criteria of criticality upon which to base such evaluation. The multi-attribute utility model explained in Section 2.2.1 was again employed toward this end. Four criteria of problem-criticality were developed based on discussions with mining engineering and human factors experts. Again, on the assumption that these criteria might not be equally important to the evaluation of problem

TABLE 2-2. - Critical unit operations (in order of decreasing overall criticality) (scale range: 1-5)

Unit Operation	Overall Criticality
Rock Bolting	4.55
Overshot Loader	4.55
Train Operation	4.55
Feedleg Drilling	4.15
Stoper Drilling	4.15
Prepare Work Area	4.15
Timber Set Assembly	3.77
Truck Operation	3.77
Machine Maintenance	3.70
Jumbo Drilling	3.55
Ring Drilling	3.55
Mancage Operation	3.55
Chute Pulling	3.37
Manual Shoveling	3.37
Timber Post Erection	3.00
LHD Operation	2.97
Pipe Installation/Maintenance	2.92
Slusher Operation	2.92

criticality, each criterion was weighted according to the mining engineering and human factors expert opinions of its relative importance to determining the overall criticality of a particular problem. The criteria weighting for problem evaluation appears in Figure 2-2, along with the average of the weights assigned by the four consultants to each of the four criteria.

2.4.2 Ratings of Human Factors Problems

Before rating each problem, all the problems associated with critical unit operations were reviewed. It became apparent that some problems could be combined with others in a logical manner, to produce problems of a wider, more inclusive scope containing related elements. For example, regarding the unit operation "overshot loader operation," problems such as "operator pinched against rib," "pitched off platform," "hit by flying rock," and "loader tipping over or derailing" were each listed separately when originally classified (see Appendix B). However, all are concerned with the operation and use of overshot loaders and were therefore listed together for evaluation as one set.

Having established the criterion weights, each problem (or problem set) was rated on each of the four criteria by the human factors analysts. A 5-point scale was employed for this purpose. Scale values were determined on the basis of the degree of impact the solution of the problem would have on that particular criterion. In the case of payoff, the scale values were based on the perceived likelihood that the problem could be solved by a human factors approach. To clarify, a problem that was perceived as one having a strictly engineering oriented solution, for example, would be rated very low on payoff. Conversely, a problem that was perceived as one whose solution necessitated extensive consideration of the characteristics of the man as part of the system would be rated very high on payoff.

Figure 2-2 presents this 5-point rating scale. The scale rating for each criterion was multiplied by the associated criterion weight to produce a coefficient of criticality for that criterion. The four coefficients of criticality were then added to produce a value designating the overall criticality of that problem or problem set, as shown below:

$$OC = \sum_{i=1}^{4} R_i W_i$$

Criterion	X	Weight	=	Coefficient of Criticality

Payoff

Likelihood of satisfactory solution through human factors analysis.

1	2	3	4	5
			X	
LOW LIKELIHOOD		50-50		HIGH LIKELIHOOD

X 0.225 = 0.79

Safety & Health

Probable impact of solution on safety & health (including near misses and unreported minor accidents).

1	2	3	4	5
				X
NO IMPACT		SOME IMPACT		SIGNIFICANT IMPACT

X 0.413 = 2.06

Productivity

Probable impact of solution on productivity.

1	2	3	4	5
	X			
NO IMPACT		SOME IMPACT		SIGNIFICANT IMPACT

X 0.275 = 0.55

Comfort/Convenience

Probable impact of solution on worker comfort and convenience in task performance.

1	2	3	4	5
		X		
NO IMPACT		SOME IMPACT		SIGNIFICANT IMPACT

X 0.087 = 0.26

TOTAL: 1.000

OVERALL CRITICALITY OF PROBLEM: 3.66

FIGURE 2-2. - Criteria, weights, and rating scales for evaluating criticality of problems where:

OC = overall criticality of problem or problem set

R_i = rating by HF analysis team for criterion i

W_i = weight determined by consultants for criterion i

Thus, a value of overall criticality was established for each problem or problem set.

2.5 Selection and Verification of Critical Human Factors Problems

2.5.1 Problem Selection

After each human factors problem was rated, problems were again reviewed to establish their inter-relatedness. Those problems that could be logically related were grouped together and a title of greater generality was assigned to them. The intention was to create sets of problems that would be viewed by the mining community as general enough and inclusive enough to warrant research and development attention. This focused attention on larger problems rather than on specific problems that, although perhaps important, were too small and specific to justify the expenditure of time, effort, and funds that would be required for their solution.

In this manner, twenty human factors problems were identified as important to the underground metal and nonmetal mining industry. (The word "important" was chosen to distinguish it from "critical," which was used to refer to the problems that were ranked subsequently as crucial to safe and productive work in the underground metal and nonmetal mining industry). Table 2-3 presents the twenty important problems and the human factors areas with which they are associated. The value of this table becomes apparent by way of the following example. It is important to note that few problems are associated with only one human factors area, and this has profound implications for approaches to their solution, as will become evident later. For example, Table 2-3 shows that the materials handling problem falls primarily into three categories of human factors problems. This reflects that the materials handling problem is made up of physical hazard, job procedure, and biomechanical components. Thus, as we will subsequently explain, any comprehensive attempt at solving the materials

TABLE 2-3. - Important problems and human factors categories with which they are associated

	APPLICABLE HUMAN FACTORS CATEGORIES												
	ENVIRONMENT						EQUIPMENT				TASKS		
IMPORTANT PROBLEMS IN UNDERGROUND METAL AND NONMETAL MINING	*Visibility & Illumination*	*Noise & Vibration*	*Geological Hazards*	*Atmospheric Hazards*	*Physical Hazards*	*Toxic & Caustic Material Hazards*	*Operator-Equipment Interface*	*Unsafe Design*	*Anthropometric Considerations*	*Personal Tools & Equipment*	*Procedures*	*Biomechanics*	*Communication*
Materials Handling					X						X	X	
Detection of Loose	X		X							X	X	X	
Removal of Loose			X				X		X	X		X	
Slips and Trips	X				X					X			
Hazard Conspicuity	X				X								
Hand Tools		X					X	X	X	X	X	X	
Eyewear	X								X	X			
Clearing Blocked Chutes and Raises			X				X		X	X	X	X	
Drill Noise and Mist	X	X											
Communication													X
Failure to Secure for Maintenance											X		
Derailment	X							X			X	X	
Respiratory Protection				X		X			X	X			
Truck/L.H.D. Operator Position		X					X		X				
Overshot Loader Accidents							X	X					
Burns During Welding										X			
Vibration		X											
Rock Bolter Controls							X	X					
Removing Bound Steel								X					
Inserting Resin Cartridges										X			

handling problem should include at least those three elements. Table 2-3 becomes even more meaningful when reviewed in light of the information given in Table 2-4, which presents a verbal description of the components of each of the twenty important human factors problems selected. For example, looking at the materials handling problem in Table 2-4, it can be seen that "handling and lifting heavy objects such as pipe, timber, and rail" falls into the category of "biomechanics" in Table 2-3; "hoisting and transporting such objects from shaft to worksites and between worksites in all parts of the mine" falls into the categories of "procedures" and "physical hazards" (such as obstacles in haulageways or drifts, for example) as indicated in Table 2-3. This type of categorization and detailed explanation was done for each of the 20 "important" human factors problems.

2.5.2 Statistical Verification of Problem Selection

To verify the selection of important human factors problems in the underground metal and nonmetal mining industry, Health Safety Analysis Center (HSAC) accident data were examined to see if, in fact, the problems selected were associated with high numbers of accidents. As described in the Work Safety Analysis of our recent report (Crooks, et al, 1980), much difficulty is encountered when attempting to determine the exact cause of accidents from the HSAC accident statistics. Classifications of accidents and injuries often overlap, and the conditions precipitating accidents are often indeterminable. Therefore, it was decided not to use those data for statistical verification of the problems selected. Instead, a random sample was requested from HSAC of accident records that verbally described activities in which the victim was engaged at the time of the accident.

A sample of 510 25-word accident descriptions from 1978 and 1979 was provided by HSAC; 238 records from 1978, and 272 from 1979. These records were carefully reviewed and classified, where possible, into the problem area with which they were most closely associated. A full 65 percent (329) of the 510 accident descriptions were classified into the problem areas we selected as "important" to the underground metal and nonmetal mining industry. Table 2-5 presents the results of this classification; the problems are ranked according to the percent of the total number of accident descriptions associated with them. It is worthy of note that about 83 percent of the total number of classifiable accident descriptions are attributable to the top six problem areas. These included:

TABLE 2-4. - Detailed explanation of 20 most important HF problems in underground metal & nonmetal mining

		Coefficient of Criticality
Vibration	Problems resulting from vibration of hand-held equipment such as stoper and feedleg drills; includes long-term disabilities such as decreasing tactile sensitivity in the hand.	4.23
Respiratory Protection	Problems resulting from inadequate and unacceptable design of respirators for use during performance of heavy work, especially in hot or humid environments.	4.23
Slips and Trips	Problems in slipping or tripping on wet/oily machine surfaces and wet worksites; includes tripping over obstacles at or around the worksite.	4.23
Derailment	Includes problems of detecting hazards on the track, detecting half-cocked switches that can lead to derailment; also includes problems of rerailing ore cars after derailment.	3.97
Drill Noise and Mist	Problems resulting from noise of air-powered percussive drills; includes obscuring of vision due to aerosols and hydrosols produced by most drills.	3.71
Truck/L.H.D. Operator Position	Problems resulting from restrictive operator compartment especially for larger operator; includes seat and compartment design to reduce effects of buffeting and to provide for rapid emergency egress.	3.90
Removing Bound Steel	Problems encountered in the use of existing steel pullers by operators of feedleg and stoper drills.	3.79
Inserting Resin Cartridges	Problems of inserting long, flexible resin cartridges in high back during rock bolting.	3.77
Hand Tools	Problems associated with use of hand tools; use of inappropriate tools for certain purposes; strains and discomfort from using badly designed tools, including long-term disability problems.	4.64

		Coefficient of Criticality
Materials Handling	Problems of handling and lifting heavy objects such as pipe, timber, and rail. Includes problems of hoisting and transporting such objects from shaft to worksites and between worksites in all parts of the mine.	4.55
Clearing Blocked Chutes and Raises	Problems of clearing blocked chutes and finger raises resulting in strains, slips, and falls from operator platforms, and operator exposure to falling rock.	4.10
Detection of Loose	Problems of detecting loose slabs of rock on face, ribs, or back	4.46
Eyewear	Problems of discomfort and reduced visibility due to ill-fitting and dirty or fogged safety glasses or goggles.	4.13
Communication	Missed or confused communications during chute pulling, sandfill, tugger operation at raises and any other situations requiring communications beyond the range of the human voice.	4.07
Hazard Conspicuity	Problems in the visual detection of potential hazards such as other workers, machinery pipes, hoses, cables, low back and protrusions from rib or back.	3.96
Removal of Loose	Problems resulting from working under unsupported back and the strenuous nature of barring down to remove loose.	3.89
Burns During Welding	Problems of burns to ears and neck when welding beneath mining machinery and in other confined spaces	3.68
Overshot Loader Accidents	Operator pinched against rib, pitched off platform, hit by flying rock; includes loader tipping over or derailing.	3.66
Failure to Secure for Maintenance	Problems resulting from failure to secure mine machinery, lock-out power, and relieve pressure in hydraulic systems prior to beginning maintenance.	3.28
Rock Bolter Controls	Problems resulting from layout of controls and response to activation, includes operator mistakenly engaging rotation while holding drill steel in chuck, as well as lurching of bolter during tramming causing operator to be pinched against rib.	3.90

TABLE 2-5. - Ranking of problems according to percent of classifiable and percent of total number of accident descriptions

RANK	PROBLEM	TOTAL NUMBER OF ACCIDENT DESCRIPTIONS ASSOCIATED WITH THIS PROBLEM	PERCENT OF TOTAL NUMBER OF CLASSIFIABLE ACCIDENT DESCRIPTIONS ASSOCIATED WITH THE PROBLEM	PERCENT OF TOTAL NUMBER OF ACCIDENT DESCRIPTIONS ASSOCIATED WITH THE PROBLEM
1	Materials Handling	85	25.84	16.67
2	Slips and Trips	82	24.92	16.08
3	Hand Tools	49	14.89	9.61
4	Detection of Loose	21	6.38	4.12
5	Removal of Loose	21	6.38	4.12
6	Hazard Conspicuity	15	4.56	2.94
7	Overshot Loader Accidents	10	3.05	1.96
8	Clearing Blocked Chutes and Raises	8	2.43	1.57
9	Derailment	7	2.13	1.37
10	Failure to Secure for Maintenance	7	2.13	1.37
11	Eyewear	6	1.82	1.18
12	Removing Bound Steel	6	1.82	1.18
13	Truck/L.H.D. Operator Position	3	0.91	0.59
14	Burns During Welding	3	0.91	0.59
15	Communication	2	0.61	0.39
16	Respiratory Protection	2	0.61	0.39
17	Rock Bolter Controls	2	0.61	0.39
18	Drill Noise and Mist	0	0.00	0.00
19	Inserting Resin Bags	0	0.00	0.00
20	Vibration	0	0.00	0.00
		TOTAL: 329	100.00	64.52

* 1978 and 1979 data

1. Materials Handling.
2. Slips and Trips.
3. Hand Tools.
4. Detection of Loose.
5. Removal of Loose.
6. Hazard Conspicuity.

Additionally, more than half (54%) of the total number of our sample of accident descriptions were attributable to these same problem areas. These findings offer some support for the accuracy and appropriateness of the selection of important human factors problems.

2.5.3 Problem Rankings

To identify the problems that are perceived to be not only important but critical to the safe and productive performance of underground metal and nonmetal operations, the list of twenty "important" problems was sent to a sample of 14 underground mine operators and 4 consultants. This sample covered five different mining methods. These methods and the percent of mines sampled from each method are listed in Table 2-6.

The operators were asked to rank these twenty problems in accordance with their opinions of the criticality of the problem to the underground metal and nonmetal mining industry. Careful instructions were given to increase the probability that mine operators would rank the problems according to their importance to the entire industry, not only according to the importance of the problem to their own particular operation, since several of the problems were not applicable to certain mining operations.

The problem ranking sheet appears in Figure 2-3. Mine operators and consultants were asked to assign ranks from 1 to 20 to each of the problems, with 1 indicating the most important problem and 20 indicating the least important problem. Note the "Other" category; mine operators were given the opportunity to enter and rank any problem they thought was important but did not appear on the list. All of the mine operators and consultants who received the list of problems responded to the ranking request, either by mailing the list back or through follow-up phone conversations.

TABLE 2-6. - Mining methods and percent of total number of mines sampled for problem ranking

METHOD	Percent sampled of total number of mines of this method in U.S. that employ over 100 people*
Room and Pillar	14.3
Vein	26.7
Sublevel Open Stoping	14.3
Modified Random Room and Pillar	12.5
Caving	10.0

* Taken from 1977 HSAC data.

Please rank in order of decreasing significance to the entire metal and nonmetal industry (1 = most significant, 20 = least significant). Write in under the OTHER category any additional problems you feel are important and were not included in the list. Please include them in the ranking.

PROBLEM	RANK
Vibration Problems resulting from vibration of hand-held equipment such as stoper and feedleg drills; includes long-term disabilities such as decreasing tactile sensitivity in the hand.	____
Respiratory Protection Problems resulting from inadequate and unacceptable design of respirators for use during performance of heavy work, especially in hot or humid environments.	____
Slips and Trips Problems in slipping or tripping on wet/oily machine surfaces and wet worksites; includes tripping over obstacles at or around the worksite.	____
Derailment Includes problems of detecting hazards on the track, detecting half-cocked switches that can lead to derailment; also includes problems of rerailing ore cars after derailment.	____
Drill Noise and Mist Problems resulting from noise of air-powered rotary percussive drills; includes obscuring of vision due to aerosols and hydrosols produced by most drills.	____
Truck/L.H.D. Operator Position Problems resulting from restrictive operator compartment especially for larger operator; includes seat and compartment design to reduce effects of buffeting and to provide for rapid emergency egress.	____
Removing Bound Steel Problems encountered in the use of existing steel pullers by operators of feedleg and stoper drills.	____
Inserting Resin Cartridges Problems of inserting long, flexible resin cartridges in high back during rock bolting.	____
Hand Tools Problems associated with use of hand tools; use of inappropriate tools for certain purposes; strains and discomfort from using badly designed tools, including long-term disability problems.	____
OTHER (Please describe):	
______________________________ ______________________________	____
______________________________ ______________________________	____
______________________________ ______________________________	____

PROBLEM	RANK
Materials Handling Problems of handling and lifting heavy objects such as pipe, timber, and rail. Includes problems of hoisting and transporting such objects from shaft to worksites and between worksites in all parts of the mine.	____
Clearing Blocked Chutes and Raises Problems of clearing blocked chutes and finger raises resulting in strains, slips, and falls from operator platforms, and operator exposure to falling rock.	____
Detection of Loose Problems of detecting loose slabs of rock on face, ribs, or back.	____
Eyewear Problems of discomfort and reduced visibility due to ill-fitting and dirty or fogged safety glasses or goggles.	____
Communication Missed or confused communications during chute pulling, sandfill, tugger operation at raises and any other situations requiring communications beyond the range of the human voice.	____
Hazard Conspicuity Problems in the visual detection of potential hazards such as other workers, machinery, pipes, hoses, cables, low back and protrusions from rib or back.	____
Removal of Loose Problems resulting from working under unsupported back and the strenuous nature of barring down to remove loose.	____
Burns During Welding Problems of burns to ears and neck when welding beneath mining machinery and in other confined spaces.	____
Overshot Loader Accidents Operator pinched against rib, pitched off platform, hit by flying rock; includes loader tipping over or derailing.	____
Failure to Secure for Maintenance Problems resulting from failure to secure mine machinery, lock-out power, and relieve pressure in hydraulic systems prior to beginning maintenance.	____
Rock Bolter Controls Problems resulting from layout of controls and response to activation, includes operator mistakenly engaging rotation while holding drill steel in chuck, as well as lurching of bolter during tramming causing operator to be pinched against rib.	____

FIGURE 2-3. - Human factors problem ranking sheet

2.5.4 Critical Human Factors Problems in Underground Metal and Nonmetal Mining

Table 2-7 presents the results of the problem rankings. The numbers in the body of the table represent the problem ranks by the mine operators and consultants. Row "R_j" represents the sum of the ranks for any given problem. As is apparent, the lower this sum, the greater the importance of the problem to the metal and nonmetal mining industry. To identify the critical human factors problems, a tally was taken to determine the number of raters that ranked each problem among the top ten (or upper 50%) of all "important" problems. Critical problems were defined as those problems that were ranked among the top 10 problems by at least 2/3 of the raters. Those problems to the left of the heavy broken line in Table 2-7 were thus chosen as most critical to the safe and productive performance of underground metal and nonmetal miners. These included, in final order of criticality, the following 8 problems:

1. Materials Handling.
2. Detection of Loose.
3. Removal of Loose.
4. Slips and Trips.
5. Hazard Conspicuity.
6. Hand Tools.
7. Eyewear.
8. Chute Pulling.

To verify statistically the results of these rankings, it was decided to determine whether mine operators and consultants were basing their rankings on similar criteria. Kendall's Coefficient of Concordance (W), a measure of the relation among several sets of rankings, was used for this purpose. The result of this analysis was a Coefficient of Concordance $W = 0.49$, which proved to be significant ($P < 0.001$). This indicates that the raters applied essentially the same criteria in ranking the problems, or, alternately, used the same bases for ranking the human factors problems (Siegel, 1956, p. 237). Appendix C presents the calculation of Kendall's Coefficient of Concordance and the measures used to test the significance of this coefficient.

TABLE 2-7. - Problem ranks

Rater \ Problem	Materials Handling	Detection of Loose	Removal of Loose	Slips and Trips	Hazard Conspicuity	Hand Tools	Eyewear	Clearing Blocked Chutes and Raises	Drill Noise and Mist	Communication	Failure to Secure for Maintenanc	Derailment	Respiratory Protection	Truck/L.H.D. Operator Position	Overshot Loader Accidents	Burns During Welding	Vibration	Rock Bolter Controls	Removing Bound Steel	Inserting Resin Cartridges
Consultant																				
1	3	1	2	7.5	5.5	12	5.5	4	11	10	20	16	9	18	7.5	15	13	19	17	14
2	15	2	1	7	12	3	14	6	9	10	5	11	8	18	4	13	20	19	16	17
3	7	3	6	1	2	9	10	8	17	5	12	16	11	4	20	13	14	18	15	19
4	1	6	2	3	4	7	14	16	5	9	13	12	15	11	19	17	10	8	18	20
Mine Operator																				
1	2	6	8	5	12	13	7	10	1	11	15	18	9	3	14	20	17	16	4	19
2	3	1	2	8.5	18	11	14.5	6.5	12.5	17	8.5	4.5	12.5	14.5	6.5	16	10	4.5	9	20
3	3	12	13	1	2	4	6	8	9	11	7	20	17	10	16	5	14	15	19	18
4	3	1	2	4	7	6	8	15	16	10	12	17	13	11	18	14	19	5	20	9
5	3	4	8	1	7	2	5	17	13	6	11	18	15	10	14	9	16	12	19	10
6	2	4	3	1	10	6	9	5	7	16	13	8	15	11	17	12	18	20	14	19
7	1	4	2	3	10	5	13.5	13.5	8	13.5	10	10	6	7	17.	13.5	16	19	18	20
8	3.5	1.5	1.5	14.5	13	14.5	3.5	7	7	7	5	9.5	11.5	17	11.5	18	20	9.5	19	16
9	3.5	1.5	1.5	10	7	9	14.5	5	17	6	11	3.5	13	14.5	12	18	8	16	19.5	19.5
10	3	2	1	5	6	9	8	4	11	15	10	7	12	18	19	17	16	13	14	20
11	1	4	12	15	16	11	3	17	2	13	10	9	5	8	14	18	7	20	6	19
12	4	3	6	11	5	14	7	2	8	9	12	1	10	20	17	13	15	19	16	18
13	1	2	5	3	4	8	10	9	16	6	12	7	14	13	17	15	19	18	11	20
14	2	7	6	8	1	9	3	15	4	16	10	13	12	11	5	17	14	23	18	19
R_j	61	65	82	108.5	141.5	152.5	155.5	168	173.5	190.5	196.5	200.5	208	219	248.5	263.5	266	271	282.5	326.5
No. of Ranks in Top Ten	17	17	16	15	13	12	13	12	10	10	8	8	6	6	4	2	4	4	2	1

It was also important to determine the extent of the relationship between the ranks of human factors problems selected by the mine operators and consultants and the ranks determined in the previous analysis of the 510 detailed accident descriptions. Spearman's rank correlation coefficient, which represents a measure of association of two sets of ranks for a given set of objects (in this case, problems), was used. The results of this analysis indicated a correlation of rho = 0.74, which was significant at the 0.01 level. These results indicate that there is substantial agreement between the ranks of human factors problems arrived at by subjective (raters) and objective (accident records) measures. Appendix D presents the detailed calculations of Spearman's rho, and the measures used to test its significance.

2.6 Identification of State-of-the-Art and Research Solutions to Critical Human Factors Problems

Having determined which problems are most critical to the safe and productive performance of underground metal and nonmetal mining operations, a careful review of government documents, reports, and mining journals was conducted to identify solutions to those problems. In some cases, prior research was found that identified solutions to some of the critical problems we selected. In many cases, however, no off-the-shelf or state-of-the-art solution to the critical problems could be found. Therefore, the literature was further reviewed to identify research that had been performed in attempting to solve the critical problems that had been identified. In addition to the literature, mining engineering and human factors consultants were queried regarding their knowledge of a) state-of-the art solutions to the critical problems and b) areas related to these problems in which research had been done or was ongoing. This information provided the background for proposing state-of-the-art solutions, and for research plans aimed at solving the remaining problems. The results of the literature review and inquiries made of the consultants appear in Section 3, Results and Recommendations.

2.7 Verification of State-of-the-Art Solutions With Mining Equipment Manufacturers

As mentioned, there are some problems for which equipment and technological developments appeared to be available. In those cases, the manufacturers of that equipment were contacted to determine:

1. Whether the solution was commercially available;

2. The extent of its sale to the metal and nonmetal mining industry;

3. Problems encountered in user (miner) acceptance of the equipment (need, cost, and practicality);
4. Manufacturer's plans regarding development of new equipment to solve the problem;
5. Feasibility of developing new equipment to solve the problem;

and other general questions about the particular problem. In most cases, equipment manufacturers were very helpful and willing to discuss the specific nature of their products, their applicability, cost, and problems with or impediments to implementation of the products in the underground metal and nonmetal mining industry. The results of those conversations appear and are fully discussed in the conclusions of this report (see Chapter 5).

We now turn to a detailed discussion of the results of the Human Factors Analysis.

3.0 APPLICABLE STATE-OF-THE-ART SOLUTIONS

In this chapter we discuss human factors engineering solutions that are applicable to several important problems previously identified. We also present the results of our discussions with mining equipment manufacturers regarding impediments to the implementation of those solutions in underground metal and nonmetal mines.

The problems for which current solutions exist include:

1. Removal of rock.
2. Slips and Trips.
3. Hazard Conspicuity.
4. Eyewear.
5. Clearning Chutes and Raises.
6. Drill Noise and Mist.
7. Respiratory Protection.
8. Inserting Resin Cartridges.

Many of the solutions proposed to alleviate these problems are already in use in some underground metal and nonmetal mines often, widespread implementation of these solutions is impeded by (1) high cost, (2) lack of proper procedures for introducing the solution and adapting the work force to the system changes imposed by it, (3) slow rate of replacement of certain types of equipment in the industry, (4) lack of user acceptance. Where applicable, these issues will be discussed in relation to each of the proposed solutions.

It should be noted that comprehensive solutions to some of these problems will entail additional research and development as well as implementation of the recommended solutions. Thus, some of the problems listed above will also be found in the discussion of research and development needs (see Chapter 4).

We now turn to a discussion of state-of-the-art solutions to the problems listed above. In each of the following sections, a brief description of the problem is given, followed by one or more proposed solutions, and a brief discussion of the impediments to implementing these solutions.

3.1 Removal of Loose Rock

There are two major safety hazards for miners who remove loose rock: (1) the danger of being hit by falling rocks, and (2) the strain and chronic back pain resulting from the barring down procedure.

Both of these problems are virtually elminated by the use of a rubber-tired, diesel powered mechanized scaler, which is available and in use in some larger mines. The machine uses a claw-like mechanism to dig into fractures and cracks to peel off loose rock. It can scale effectively up to a height of 24 feet, although its optimal scaling height is 20 feet. The operator position is at the rear and is protected by a canopy.

The advantages of the mechanized scaler are that:

1. The operator no longer works directly under loose back and is protected by a canopy.
2. The physical demands on the operator of loose removal are greatly reduced.
3. Slips and falls are largely eliminated, since the operator sits in the machine.
4. One worker is able to scale high backs and ribs quickly and safely.

There are, however, several disadvantages to the mechanized scaler. These include its high cost, limited range of application, and mine operator reservations as to its efficacy. For example, many mine operators feel that a mechanized scaler cannot do a thorough job and that manual scaling will still be required following use of the mechanized scaler. Reliable data on this question are not yet available. These disadvantages impose significant impediments to more widespread use of mechanized scalers.

Injuries associated with removal of loose rock are severe enough to warrant increased use of mechanized scalers wherever the physical layout of a mine permits. It is suggested that the cost of the mechanized scaler will be compensated for by significant savings from reductions in man-hours lost and increases in productivity. An economic feasibility study of the costs and benefits of implementing mechanized scalers in underground metal and nonmetal mines would be helpful in determining the overall usefulness of the mechanized scaler. Favorable results of such a study would encourage mine operators to use mechanized scalers, thus decreasing the number of accidents associated with the removal of loose rock.

3.2 Slips and Trips

Slips and trips have been defined as those problems associated with slipping and tripping on wet or oily machine surfaces and wet and muddy worksites (see Table 2-4). Included also is tripping over obstacles at or around the worksite, specifically hoses and cables. Taken together, slips and trips are among the most common sources of accidents in the underground metal and nonmetal mining industry. Several state-of-the-art solutions exist to help minimize the occurrence of slips and trips. These are now discussed with regard to the source of the slip or trip.

Machine Ingress/Egress

Slips and trips that occur while climbing on and off machinery can be minimized by providing steps and hand holds designed to provide adequate footing for the operator. Most large machines are fitted with several hand holds and inset steps to help the operator get into or onto the machine. However, a significant number of slips and trips occurs while attempting to step down from the machine. Inset steps do not serve this purpose well and operators frequently prefer to jump off the machine, which results in sprained or broken ankles, damaged knees, etc. Alternative designs of hand holds and steps that would facilitate egress as well as ingress should be developed and included in the design of new machinery, as in the case of surface mining machinery (Gavin, et al, 1979). However, owing to design differences between some surface and underground machinery, a separate study aimed at determining optimal designs for underground machinery is clearly indicated.

Oily or Wet Machine Surfaces

In addition to slips and trips that occur when getting on and off machinery, there is also a problem slipping or tripping on wet and oily machine surfaces. The operation of many mining machines often produces a water or oil mist that settles on the machine platform, thus creating a slippery and hazardous surface. The operator also frequently gets mud on his boots and this contributes to slips. Many slips and trips occur while workers are moving drill rods or steel from the storage area to the drill chuck on the wet or oily platform of a ring or rotary drill.

One solution to this particular problem is the use of non-skid surfaces to help the operator maintain proper footing on wet and oily machine surfaces. Many of the available "non-skid" surfaces are of the "raised diamond" type, which are effective so long as the surface is dry. However, they are largely ineffective for wet or oily surfaces. Other types of non-skid surfaces, such as serrated grating or sandpaper-like coverings are available, but are generally not provided unless specifically requested by mine operators. Unfortunately, mine operators seldom request such surfaces because of the additional cost.

Wet and Muddy Worksites

Another type of solution to the slips and trips problem is the use of special bootwear. For softer rock types, excellent grip is provided by carbide studded boots, which contain patterns of carbide studs imbedded in the rubber sole of the boot. However, these boots are inappropriate for most types of rock found in metal and nonmetal mining. Also, the rubber sole of these boots tends to wear out around the studs, allowing the studs to fall out, and the cost of insertion of the studs is relatively high.

A soft rubber, waffle-soled boot exists that provides very good gripping of a wide variety of rock surfaces. A problem with boots of this type is that the soft rubber construction reduces the strength of the toe cap, which renders the boot inadequate in terms of accepted standards for toe caps. Hard rubber boots, on the other hand, have toe caps that meet safety standards, but they do not provide the grip that soft rubber boots provide.

The Bureau of Mines is currently sponsoring research on bootwear under Contract No. J0387213. This research will test new molded patterns for boot soles that will provide improved traction and secure footing. The new boot sole pattern is square, as opposed to the conventional oval pattern, and shows some potential for reducing the number of slips and trips.

The general feeling of bootwear manufacturers is that they could produce whatever the safety standards might require, but that the cost of the product usually far exceeds what mine operators (or miners) would be willing to pay. Basically, well-designed bootwear is not purchased because it's too expensive.

Since slips and trips are so pervasive and such large sources of injuries in metal and nonmetal mining, it appears that the number of lost time accidents could be significantly reduced if the three solutions outlined above were implemented, in concert, in underground metal and nonmetal mines. The provision of steps, hand holds, effective non-skid surfaces, and well-designed bootwear would no doubt reduce the number of slips and trips considerably.

Because these solutions are apparently not perceived by most mine operators as cost-effective, an economic feasibility study is recommended again, to determine the relative costs and benefits of their implementation. Favorable results from this type of study might provide a financial incentive to mine operators to accept and use these solutions. The alternative, although not popular with miners or mine operators, is to institute a regulation for the use of non-skid surfaces and special bootwear that provide maximum protection from the slips and trips hazard.

3.3 Hazard Conspicuity

The problems associated with hazard conspicuity are concerned with the visual detection of potential hazards, such as other workers (in haulage-ways, intersections, or working under machinery onsite), machinery, pipes, hoses, cables, low backs, and protrusions from ribs or back. The inability of workers to detect such hazards vastly increases the probability of accidents and injuries.

Solutions to these problems should address how the detectability of workers, machines, and obstacles can be improved, and how early warning systems for approaching hazards can be provided.

An inexpensive and quick solution to the problem is the use of retroreflective materials and paints such as those used on cars' bumpers, traffic officers' apparel, and at construction sites. This type of material can be affixed to various surfaces and objects to increase their conspicuity and increase the probability that these surfaces and objects will be detected before an accident occurs.

Hoses and cables with high visibility also exist and can provide miners with more easily detectable cues as to the positions of the hoses and cables. These high visibility hoses and cables are not used often. And, when they are used, it is generally not because of the improved visibility afforded, but because of their excellent quality.

With regard to early warning systems, the major concern is with providing motormen, truck, and LHD operators with advance notice of low hanging or protruding obstacles so that these operators will not impact those objects while traveling down a haulageway or drift. A retroreflective line or marker could be hung some distance before an obstacle (such as a low hanging timber set or a "chinaman" chute). This would give the operator advance notice that he is about to encounter the obstacle and would reduce the probability of an accident. This solution should be used, of course, in addition to applying retroreflective paint or materials to the hazard itself.

An alternative approach to reducing the severity of injuries resulting from motormen impacting chinaman chutes is to minimize the consequences of such an accident. The part of a chinaman chute extending into the haulageway could be constructed of soft rubber rather than steel. Thus, although the accident could still occur, the consequences to the operator would be reduced greatly.

The proposed solutions to the hazard conspicuity problems should be implemented in concert. Most of the solutions outlined above are inexpensive and may be instituted very quickly. Regulations requiring the systematic marking of potential hazards, guidelines for recommended practices in marking hazards, and the provision of inexpensive early-warning systems such as those described above, are sorely needed.

3.4 Eyewear

Protective eyewear is mandated by Federal regulation to offer miners protection from flying rock and small particles that could damage the eye. There are numerous jobs in underground metal and non metal mining in which the potential for eye injury is great, for example, feedleg drilling, slushing, rock bolting, and shotcreting.

The regulations requiring eyewear state:

> "All persons shall wear safety glasses, goggles, or face shields or other suitable protective devices when in or around an area of a mine or plant *where a hazard exists* which *could* cause injury to unprotected eyes."[1]

The range of interpretations that can be given to the italicized words in the above regulation appears to allow miners not to wear eye protection where they feel it unnecessary without being in violation of the regulation. This, coupled with the disadvantages and discomforts of currently used protective eyewear, results in less frequent use of eye protection in underground metal and nonmetal mining than should be the cas

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[1] Italics ours.

The reduction of eye injury that accompanies the use of eyewear is significant, but the design of protective eyewear has itself introduced several problems into underground metal and nonmetal mining. In general, the biggest problem is that miners do not like to wear eye protection. There are several reasons for this. First, the design of currently used eye protection is such that it is uncomfortable to wear. Second, eyewear gets dirty very quickly in underground mining operations, and miners complain that "it's harder to see with them than without them," or "it's harder to do the job wearing safety glasses."

The two types of eyewear most often purchased by mining companies are standard safety-glasses, which look like regular eyeglasses but offer plastic guards for the "corners" of the eye, and safety goggles, which fit over the eyes entirely and fasten around the head with an elastic strap. Both types of eyewear are very inexpensive and would serve the purpose for which they were intended, <u>if</u> they were worn.

Safety glasses are made with universal bridges and temple pieces that do not fit comfortably a large number of workers. The glasses put pressure on the nose and the backs of the ears, and tend to slide down the miner's noses when they perspire. Safety glasses also fog easily. Safety goggles offer a greater area of protection for the face. The pressure on the ears that is characteristics of safety glasses is eliminated because goggles have no temple pieces. The problem with goggles seems to be that they cover too much of the face and feel restrictive. They are also made with universal bridges and therefore do not fit comfortably many miners. Goggles also fog, but not as quickly as safety glasses.

In response to the fogging problem, several manufacturers offer "anti-fog" compounds or solutions that are intended to minimize or eliminate fogging of the lenses. However, these solutions and compounds are effective only for short periods of time, and constant reapplication is necessary to keep lenses clear throughout any given work shift.

The problem of eyewear accumulating dirt, mist, oil and other impediments to vision is inherent in the nature of underground work. There does not seem to be an adequate, quick-fix solution to that particular problem in the mining industry outside of wiping off the glasses or goggles. However, if eyewear were designed so that miners would be more willing to use it, the problem of wiping off accumulated dirt might be tolerated more easily.

Due to the fact that most types of eye protection are not comfortable to wear and get dirty easily, miners claim that the available eye protection creates more problems than it solves. One approach to solving this problem is to offer miners a greater variety of sizes and shapes of protective eyewear from which to choose more comfortable safety glasses or goggles. Another approach would be to mandate that eyewear be fitted to the miner by a trained safety officer, to obtain the most comfortable fit.

It is apparent that the biggest impediment to the more frequent use of protective eyewear in underground metal and nonmetal mining is lack of user acceptance. Thus, it is suggested that a user acceptance study be done to identify problems that miners might have with eyewear and to develop methods for alleviating those problems.

It is apparent also that mine operators and purchasing agents generally buy the eyewear that is least expensive, with little consideration of whether or not the miners will wear it. It is therefore imperative that the values and cost-effectiveness of using protective eyewear be demonstrated to those responsible for purchasing safety glasses and goggles, as well as to those responsible for wearing them.

3.5 Clearing Blocked Chutes and Raises

A significant problem in the chute pulling operation is the removal or clearing of blockages or "hangups" so that the rock resumes flowing. In general, blockages in chutes or raises are cleared by the operator by prying loose the jammed rocks with a metal bar. Occasionally the blockage will not yield and explosives must be used to break the oversize causing the blockage. In some mines it may be necessary to drill the oversize with a stoper or feedleg drill prior to blasting.

These operations are extremely hazardous, since rock may fall down the chute and hit the operator, sometimes causing serious injury. Clearing blocked chutes and raises has been noted as one of the most hazardous of underground mining operations (e.g., Barry, 1974).

Impact rock breakers are available from several manufacturers in either pedestal-mount or mobile configurations. The operator controls the breaker from a remote position or from inside a protective cab. Despite their initial cost, these breakers are proving to be cost-effective in breaking oversize rock at grizzlies. They would also be very effective in breaking oversize in chutes and raises, if the hangup is within the reach of the breaker. However, the jam point is frequently beyond 4 to 5 feet from the opening and hence cannot be reached by commercially available impact breakers. This, combined with their high cost, precludes the use of impact breakers in clearing blocked chutes and raises in most metal and nonmetal mines. Suggestions for the development of better equipment that would be useful in clearing hangups are presented in Section 4.7 of this report.

3.6 Drill Noise and Mist

Subsumed under this problem area are hearing disabilities resulting from the noise of air-powered percussive drills, and obscuration of vision due to the aerosols and hydrosols produced by most drills. These problems are now discussed in turn.

Noise

It is not uncommon for percussive drills to operate at 110-120 dB, which is 20 to 30 dB higher than the maximum sound level allowed by MSHA for the unprotected ear over an 8 hour shift. Consequently, underground workers, exposed to percussive drills are subject to loud noise over long time periods. This situation can produce hearing disabilities, such as temporary or permanent threshold shifts and nerve deafness.

Ear protection is mandated by the Federal Metal and Nonmetallic Mine Safety and Health Regulations where noise exposure exceeds the levels permissible. This solution to the noise problem is effective, as long as underground workers use it. From observational data, it is apparent that most underground personnel do wear ear protection when drilling, slushing, or doing other work in high noise areas. However, the ear protectors are often uncomfortable and there are still a number of workers who would rather not wear ear protection and who claim that they're "used to the noise." This poor attitude is reinforced by the fact that hearing losses are not apparent until after several years. It therefore seems to miners as if there are no consequences to working under those noisy conditions. Also, the idea that "you get used to it" is readily accepted without consideration of the fact that "getting used to" loud noise really means losing the ability to hear certain sound frequencies. Thus, one "gets used to" loud noise levels by losing some hearing capabilities.

Another approach to noise reduction is to isolate operators in enclosed cabs in large mobile drills like jumbos. However, user acceptance of enclosed cabs is reportedly poor. Miners apparently do not like the feelings of confinement and restricted egress. Enclosed cabs also limit the extent of communication possible between miners. Additionally, machines equipped with enclosed cabs are much more expensive than those not so equipped.

The aforementioned approaches to noise reduction are "fail-safe" approaches, the aims of which are to allow the undesirable condition to exist but to minimize the consequences to the worker. That is, high levels of noise are permitted to exist in the underground environment, but the workers are provided with ear protection to minimize the consequences of the noise to the workers' hearing.

The preferred approach to noise reduction, however, is to minimize the noise emitted from the source. That is, to reduce the amount of noise that is emitted by air-powered percussive drills. This can be done in several ways:

(1) Purchase new hand held drills (e.g., feedleg and stoper drills) with integral noise mufflers, and retrofit older equipment with appropriate mufflers;

(2) Use hydraulic instead of air-powered drills where possible.

These two approaches can reduce the noise level considerably.

The problems in implementing these solutions in the underground metal and nonmetal mining industry are as follows.

With regard to integral mufflers, miners perceive that the less noise the drill makes, the less power it generates. Hence, they feel that work progresses more slowly with drills that are fitted with mufflers. For contract miners, this is perceived as direct dollar loss due to reduced productivity. In actuality, the reduction in power is insignificant and productivity is not actually affected.

The result of this inaccurate perception of the muffler reducing the power of hand-held drills is that the drills are ordered with integral mufflers and when they underground, miners disconnect the mufflers and operate the drills without them. The consequence of this action is that mine operators will order drills without mufflers next time, since they feel they shouldn't pay for muffled drills if the mufflers are going to be removed.

One drill manufacturer will soon offer a drill that cannot oeprate if the muffler is disconnected. It is felt that this is an excellent solution to the muffler removal problem. Another option that might be considered is to mandate the use of muffled drills in underground mining. This is already done in several other countries.

The use of hydraulic drills is increasing, especially in hardrock mining. These drills have several advantages, including reduced noise, more power and automatic steel binding detection. Productivity increases have also been noted in mines that use hydraulic drills. Unfortunately, a hydraulic hand-held drill is not yet available and only carriage mounted hydraulic drills (jumbo, for example) are now in existence. Also the initial cost of hydraulic jumbo drills is high. Additionally, although hydraulic-powered drills reduce the intensity (dB level) of the noise, the noise they generate is of higher frequency, and could still damage hearing.

Despite these disadvantages, hydraulic drills are being accepted eagerly by the mining community, reportedly due to their related ease of operation and associated increases in productivity.

Aerosols and Hydrosols

There are two solutions to the obstruction-of-vision problem created by the aerosols and hydrosols that are generated by most large percussive drills. First, hydraulic jumbo drills may be used, since they are devoid of air exhausts and thus create no hydrosol problems. As previously mentioned, the cost of such drills is relatively high, but would probably be saved in increased productivity over time. Second, operator cabs offer protection from aerosols and hydrosols, but they must be equipped with adequate windshield wipers or vision will still be obstructed by dirty windows. The operator acceptance and cost issues presented earlier are also applicable here.

3.7 Respiratory Protection

The solutions to the problems of respirable dust that have been implemented in the underground mining industry are generally in the form of half-face respirators. These may be either replaceable filter cartridge models or mask-like, single-use "throwaway" types. Although these are effective in some mines, they are generally not accepted, and therefore not worn by underground mining personnel.

There are several reasons for poor acceptance of these respirators. First, they are extremely uncomfortable, especially in hot and humid conditions. Second, they offer inadequate protection because they do not seal properly. Finally, they restrict breathing considerably. Consequently, miners will not wear them if they can avoid it. When they do wear respirators, the filters are often removed to permit easier breathing. The advantages associated with these throwaway and filter type respirators are that they are inexpensive and require minimal maintenance. It is felt that this is the reason that they are purchased.

Another type of respirator exists that is much more comfortable, does not restrict breathing, and offers better sealing properties than those discussed above. These are the "air-curtain" type. These respirators come in helmet form such that they protect the eyes as well as the nose and mouth. They offer integral head protection, eliminating the requirement for a separate hard hat. This "air curtain" type respirator contains a small motor in the helmet that blows cool, clean air over the face. It cools in hot environment and imposes no restrictions on free breathing.

The problems associated with these respirators are that they restrict mobility somewhat, require maintenance, the visor occasionally fogs, and they weigh more than a conventional hard hat and half-face respirator. Some miners who have used the "air-curtain" helmet respirator complain that the noise of the air motor precludes their hearing the roof "talk" (i.e., precludes their hearing important cues and sounds that inform them of roof conditions). However, the biggest impediment to widespread implementation of this solution is, again, its high cost.

Since the degree of respiratory problems varies greatly in the mining industry, an economic feasibility study should be established to determine in which types of mines (i.e., which commodities) the air-curtain helmet respirator would be both accepted by the user and cost-effective. For example, it would appear that these respirators would be appropriate in trona and potash mines, where dust is a severe problem, and in uranium mines, where inhalation of radon daughters is a significant hazard. They would be less appropriate, perhaps, in hardrock mines such as copper, lead, and zinc, where respirable dust is generally not as big a problem.

3.8 Inserting Resin Cartridges

A problem of somewhat less criticality is the insertion of resin cartridges into rock bolt holes before the insertion of the actual bolt. It is difficult to reach the hole, especially in high backed mines. The operator often will stand or climb on the rock bolter boom to reach the hole to insert the resin cartridge. This creates a significant hazard.

Even if the bolter operator can reach the hole, it is difficult to insert the long flexible resin cartridge into the hole because the cartridges tend to bend and fall over.

A fairly inexpensive device exists to aid in the insertion of resin cartridges. Essentially, it is a long plastic tube in which the cartridge is placed. The operator then aligns the tube with the hole and pushes a plunger upward, which inserts the resin tube into the hole.

It is believed that if this solution was publicized more widely, it would be eagerly accepted by the industry. It is felt that lack of knowledge of the existence of this device is the major impediment to its use in the industry. Its cost-effectiveness could be demonstrated by increased speed and subsequent productivity in the rock-bolting operation.

Having discussed some of the currently available human engineering solutions to the problems in underground metal and nonmetal mining, we now turn to a discussion of suggested research programs for solutions to critical problems.

4.0 RECOMMENDED HUMAN FACTORS R&D PROGRAMS

The following sections contain recommendations for research and development programs aimed at solving some of the critical problems identified earlier. These programs are written in the form of finished requests for proposals (RFP's). Therefore, reference is made frequently to the present report.

4.1 Materials Handling

4.1.1 Background and Discussion

Materials handling, i.e., the movement of materials and supplies from surface to point of use, is one of the most pervasive activities in underground metal and nonmetal mining operations. Ten to fifteen percent of the underground work force is involved in the movement of supplies and materials (Barry, 1975).

The nature of present systems for moving supplies and materials in most mines is such that production is often slowed or delayed owing to lack of materials availability and the removal of men and equipment from production tasks. Another source of reduced productivity is the reliance of most mines on manual means of materials handling.

Materials handling in general has been identified as the largest single source of nonfatal injuries in underground metal and nonmetal mining (Chugh, et al, 1974; Crooks, et al, 1980). A recent sample of mine operators and mining engineering consultants also identified materials handling as the most critical safety problem in underground mining (Perry, et al, 1980).

Specifically, manual handling of heavy objects exposes the worker to local muscular as well as systemic fatigue due to the requirement for high degrees of physical exertion, mostly linked to lifting and handling activities. The effects of this requirement are to increase back injuries, and the likelihood of slipping and falling.

In a review of industrial back injury problems (incurred during lifting, carrying, pushing, and pulling) Brown (1972) found that 32 percent of lifting injuries were sprains of the lower back, 12 percent were hernias, and 6 percent were slipped disks. Additionally, 60 percent of all reportable injuries were caused by lifting objects which were beyond the "physical capability" of the worker. The worker is also exposed to hazards of falling objects. The manual handling of materials, use of defective or inadequate equipment, and worker ignorance or disregard of safety rules for materials handling are prime hazards (Barry, 1975).

Materials handling procedures and problems vary among mines and mining methods. Some mines have made significant efforts toward mechanizing materials handling systems. For example, some mines have made efforts to transport materials in "modules" or "packages," where the nature of the materials permits. In some mines surface-to-cage and cage-to-haulageway movement of supplies is done by forklift machines and pallets. This eliminates much physical labor. However, handling materials at or near the point of use remains a problem. This is especially true for mines that require a final vertical movement of supplies. For example, timbers in unitized bundles may be transported by rail to the bottom of a raise to a stope. There, because no mechanized means exists to unload the rail cars, the unitized bundles are opened and individual timbers are manually unloaded and stacked along the tracks. Then each timber is hoisted up the bin line of the raise using a tugger. This requires a minimum of two workers and is a difficult, hazardous task. Each timber must be moved to the raise and manually lifted into the stope supply basket. The haulage level worker then signals (usually by cap lamp) to the worker on the level above who operates a tugger to hoist the basket and its contents. The timber then is unloaded manually and stacked by the second worker. In this procedure, the haulage-level worker performs heavy lifting and is exposed to falling objects at the bin line. The stope-level worker performs heavy lifting around the open hole of the bin line. Missed or confused communication between the two levels also adds to the hazards involved in the task.

The materials handling problem is pervasive in that it appears in many parts of a particular mine and in connection with many activities. Due to the fact that the problem is so widespread, it is impacted by many variables, including mining method used, size of openings, means of haulage, and activities performed. Thus, the most appropriate approach to solving the materials handling problem is to conduct detailed analyses of the effects of these variables on the problem.

The systems approach is useful in achieving this end. In general, the systems approach is one that considers the characteristics of the personnel, the task, the equipment (hardware and software) and the environment, as well as all the interactions between these system "components," in determining the nature of the problems that lead to system degradation. This "system degradation" may be manifested in increased accidents and injuries, lower productivity, etc. Specifically, it is essential that the characteristics of the men who move and store materials in underground mining (e.g., their training, physical characteristics, abilities, limitations), the equipment (e.g., job aids, machines, information displays), the task (e.g., physical energy requirements, biomechanical characteristics), and the environment (e.g., temperature, humidity, obstacles to unencumbered movement) be considered if the critical problems in the entire materials handling system are to be identified and solved adequately.

4.1.2 Objectives

The objectives of the proposed research are to define the critical materials handling problems found in the major types of underground metal and nonmetal mines, to develop appropriate solutions for those problems, and to determine their efficacy in demonstration projects.

4.1.3 Research Plan

General

The work should be accomplished in the following phases:

Phase I

1. Task I - Perform Detailed Human Factors Systems Analysis of Present Materials Handling Operations.
2. Task II - Propose Design Changes for Materials Handling Systems and Assess Feasibility of Implementation.

Phase II

1. Task I - Develop Selected Materials Handling System Changes.
2. Task II - Institute Materials Handling System Demonstration Projects.

Scope of Work

Phase I

1. Task I - Perform Detailed Human Factors Systems Analysis of Present Materials Handling Operations.

    a. A survey of materials handling systems and their associated problems should be made in mines representative of the range of commodities and methods (including vein, sublevel open stoping, room and pillar, and caving) in underground metal and nonmetal mining. The outcome of this survey should be a clear and systematic identification of materials handling procedures and problems, specifically those associated with:

        (1) Handling and loading of materials for conveyance into the mine.

        (2) Movement and storage within the mine.

        (3) Movement to the final point of use.

        (4) "Choke points" in the movement of materials.

        (5) High accident frequencies.

        (6) Delays in production operations.

    b. Classes of materials handling systems should be identified. Criteria for classifying materials handling systems should be established. Factors to be considered in the classification of such systems should include, among others:

        (1) Degree and types of mechanization.

        (2) Degree and types of manual tasks required of individual workers.

        (3) Degree and types of materials haulage and storage requirements.

        (4) The frequency with which each system occurs in the sample of mines.

        (5) The potential payoff of system redesign.

c. The need for human performance evaluation and subsequent redesign of equipment, procedures, and training for each class of materials handling system should be assessed. Those classes having a critical need should be selected. Selection criteria should include:

   (1) Hazards associated with each system class.

   (2) Productivity associated with each system class.

d. Materials handling procedures used in those classes of systems identified as having a critical need for redesign should be analyzed and problems identified. Critical problems should be selected for solution through redesign of relevant system components or training procedures. The selection criteria should include:

   (1) Impact on safety (including long term or chronic disability).

   (2) Impact on productivity.

   (3) Impact on operators' comfort and convenience.

   (4) The likelihood of cost-effective solutions.

2. Task II - Propose Designs for Materials Handling Systems and Assess Feasibility of Implementation.

   a. Major systems design changes should be proposed for the critical problems identified in Task I. Alternative design changes should also be proposed. These might include:

      (1) Development of equipment or aids to reduce manual handling requirements.

      (2) Redesign of existing equipment to match operator characteristics.

      (3) Redesign of procedures to reduce hazards and increase productivity.

      (4) Training packages in biomechanically sound procedures for lifting, carrying, pushing and pulling.

      (5) Establishment of standards for maximum acceptable weight of lift in underground metal and nonmetal mining.

b. Proposed system design changes should be assessed for feasibility of implementation and potential payoff. Design changes which are both feasible and have a high potential payoff should be selected. Selection criteria should include:

    (1) Impact of the design change on materials handling safety.

    (2) Impact of the design change on materials handling productivity.

    (3) Estimated time and cost for development of the proposed design changes.

    (4) Estimate of technical risk involved in development of the design change.

    (5) Estimated time and cost for implementation in U.S. mines.

Phase II

1. Task I - Develop Selected Materials Handling System Changes.

    a. Design change proposals selected as being feasible and offering high potential payoff should be developed for test and evaluation in operating mines. At a minimum, the following should be done:

        (1) At least one working prototype of any new materials handling machine, device, aid, or tool shall be prepared.

        (2) At least one working prototype shall be prepared for each machine, device, aid, or tool identified as requiring redesign to match operator characteristics determined in Phase I.

        (3) Job procedures developed shall be evaluated for their contribution to the safety of and appropriateness with regard to the performance limitations of the operator(s).

        (4) Training packages shall be prepared in a form suitable for implementation.

   b. Those design changes that would increase significantly the safety and productivity of materials handing systems shall be identified. The feasibility of testing each redesigned materials handling system in a demonstration project shall be assessed. Those redesigned systems deemed feasible to test and found to offer significant potential "payoff" shall be selected for demonstration projects.

2. Task II - Institute Materials Handling System Demonstration Projects.

   a. This phase shall consist of materials handling system demonstration projects in the underground metal and nonmetal mining industry. Each system selected during Task I shall be operationally tested in at least one cooperating mine.

   b. Reliable and valid means for assessing the efficiency of the materials handling systems must be developed. The results of the demonstration projects shall provide a measure of the "payoff" of implementing each system.

   c. All aspects of the projects shall be carefully documented with the intent of widely distributing the program results.

   d. The final report shall document the impact of each redesigned materials handling system, make recommendations for instituting each system in other mines where appropriate, and specify how this can be accomplished.

4.2 Detection and Removal of Loose Rock

4.2.1 Background and Discussion

Failure to detect and remove loose rock exposes workers to an increased likelihood of rock falls, which are the largest single source of fatalities. The data show that 35 percent of all fatalities and 16 percent of nonfatal accidents are associated with rock falls (Chugh, et al, 1974). As part of an effort to reduce the incidence of rock falls, Federal regulations require that miners "examine and test the back, face, and rib of their working places at the beginning of each shift and frequently thereafter." Haulageways and travelways also are to be examined periodically. Loose rock must be taken down or supported before any other work is done (30 CFR 57.3-22).

An analysis of a random sample of 510 accidents that occurred in 1978 and 1979 found that 4.1 percent of the accidents could be attributed to a failure to detect (and remove) loose rock (Perry, et al, 1980). A recent South African report (Blignaut, 1979) indicated that perceptual failure was the most important source of error underlying the failure of mine workers to avoid accidents caused by rock falls, and that inexperienced miners were the most vulnerable, particularly during their first four months on the job.

The requirement to examine and test the back, face, and rib for loose rock is typically met by a combination of visual inspection and testing of suspect areas by sounding with a scaling bar. Visual inspection requires far acuity, depth perception, accommodation, and peripheral vision, yet the worker's cap lamp is usually the only illumination source. This task is time consuming and requires a high level of experience and judgement. In most cases, workers learn the necessary skills through on-the-job training, usually while paired with a more experienced worker.

The procedure most often used to remove loose rock is termed "scaling" or "barring down." The worker typically rams the flat end of an 8 to 12 foot pole (scaling bar) into the fracture line between a loosely attached slab and firm rock. The worker then exerts pressure on the end of the scaling bar to pry down the loose slab.

Barring down is a hazardous task. Crooks, et al (1980), found that barring down was the worker activity associated with 5 percent of all accidents during 1978, many of which were severe. Barring down was found to be associated with more fatalities and permanently disabling accidents than any other worker activity. Removal of loose rock from a high back is especially hazardous. The efficacy of the scaling bar is limited by the worker's strength and skills in controlling it. Additionally, because of the limited length of the bar, when scaling a high back, the worker is forced to stand closer to the slab of loose rock than may be safe. Thus, he is susceptible to being hit by rock fragments or, in some cases, being crushed when the slab falls.

Slips and falls are also common occurrences while barring down. The worker is especially likely to slip when ramming the bar into a difficult to reach crack. Slips and falls are caused also by the bar slipping from the crack or the loose rock suddenly giving way during the prying activity.

Barring down is also extremely physically demanding. The constant lifting and maneuvering of the bar, and the prying itself were cited by miners in recent interviews as among the most "backbreaking" tasks in the underground mining industry (Crooks, et al, 1980). This description is very accurate, since the activity involves maneuvering a heavy metal bar, often at full body extension and with less than optimal footing, in most cases. The immediate consequences of such activities are strained, pulled, and "thrown out" backs. The long term consequences are chronic back disorders -- one of the most frequent and expensive types of claims for workman's compensation. It is apparent that biomechanically optimal procedures and tools that would reduce the physical demands and improve human performance are not being employed in the industry.

It is also important to note that since removal of loose rock must be completed prior to beginning other work, it is also a potential source of delay and inefficiency in the mining process, and therefore may have a significant detrimental effect on a mine's overall productivity.

While loose rock can occur at any point in a mine, the majority of removal activities occur at production or development headings as part of the conventional mining cycle. Mechanization of loose rock removal at those sites should be practical and offer a significant payoff in reduced accidents and increased productivity. Removal of loose rock is also required in haulageways, travelways, and other active work sites. In most cases the amount of loose rock to be removed is small and manual removal with a scaling bar may continue to be the standard practice.

Improvement in the safety and productivity of the loose rock detection process is a high priority need and a variety of approaches should be explored. The development of a practical, low-cost detection system would bring tremendous benefits, especially when coupled with the use of a mechanized scaler. Such a system should be capable of detecting loose rock at the back, face, and ribs quicker and with fewer errors than an experienced worker can perform the task with a scaling bar. Research is ongoing or has been completed in the development of roof fall warning systems in coal mining. Both, infrared an seismic systems have been developed. Potential for application of systems developed for coal mining to metal and nonmetal mining should be evaluated.

It is anticipated that the conditions found in underground metal and nonmetal mining may differ enough so that use of detectors developed specifically for coal applications may be impractical. Because of this, a separate research and development effort should be mounted to develop loose rock detection systems for metal and nonmetal application. Detection systems developed should be compatible with either mechanized or manual removal of loose and appropriate to the limitations and characteristics of the operator.

The Bureau of Mines is currently sponsoring research to develop a hand-held, light-weight, mechanical scaling bar and a vehicle-mounted scaler suitable for use in smaller openings. Additional research and development efforts in both areas should be undertaken to ensure that all feasible alternatives are fully considered and that the best possible systems that are applicable to many ore types be made available to the mining industry.

Even after most scaling has been mechanized, workers will still occasionally have to remove loose rock by barring down. Thus, research aimed at increasing the safety and productivity of visual inspection, sounding, and manual removal is clearly indicated.

A "systems" approach to the solution of the scaling operation is suggested. Presently used procedures for visual inspection, sounding, and barring down should be identified, and predominant patterns of scaling particular types of rock determined. Biomechanical and hazard analyses should be made of these procedures, and common unsafe practices should be identified.

The limitations of the operator, in terms of physical characteristics (e.g., height, weight, visual characteristics, maximum functional reach envelope, static strength capacity, etc.) must also be investigated and compared to data from a detailed job analysis of the barring down operation. Sounding properties and maneuverability of the barring tool itself should also be determined, in terms of operability by and acceptability to the workers.

These analyses should provide the basis for:

1. Developing loose rock detection aids and procedures.

2. Suggesting biomechanically sound and safe alternative procedures for removing loose rock.

3. Recommending specific design criteria for a more useful, efficient and lightweight barring tool that will enhance human performance and reduce accidents and the probability of long-term disabilities.

4. Integrating the above with the development of a complete training package for detection and removal of loose rock, which should be tested as a demonstration project in a representative sample of mines.

A comprehensive research plan for solving the problems inherent in detection and removal of loose rock would involve three essential components. To facilitate understanding of the aims of each component, we present them here as separate research plans.

4.2.2 Objectives

The objective of the three research programs is to increase the safety and productivity of present methods of detection and removal of loose rock at the back, face, or ribs through training programs and equipment redesign and to develop practical and low-cost systems for the detection and removal of loose rock to augment or replace present practices, as necessary.

4.2.3 Research Plan A: Improvement of Current Detection and Removal Equipment and Procedures

General

The work should be accomplished in the following phases:

Phase I

1. Task I - Perform Human Factors Evaluation of Existing Equipment and Procedures for Detection and Removal of Loose Rock.
2. Task II - Develop Alternative Equipment or Procedures for Detection and Removal of Loose Rock.
3. Task III - Develop Training Packages for Detection and Removal of Loose Rock.

Phase II

Demonstrate Utility and Safety of Equipment and Procedures Developed in Phase I.

Scope of Work

Phase I

1. Task I - Human Factors Evaluation of Current Procedures and Equipment for Detection and Removal of Loose Rock.

    a. A survey of current loose rock detection and removal procedures should be made of mines representative of the range of commodities, mining methods, and geological conditions in underground metal and nonmetal mining. A limited number of site visits may be required. The outcome of this survey should be a clear and systematic identification of loose rock detection and removal procedures and problems. Specifically, the areas to be included in the survey are:

(1) Visual inspection procedures.

(2) Testing procedures.

(3) Scaling or barring procedures.

(4) Hazard analysis of all aspects of the task -- the relative safety of all procedures should be assessed and unsafe practices identified.

(5) Biomechanical analysis of all aspects of the task.

(6) Characteristics of the loose rock that impact on detection by the worker (including visual and sounding cues).

(7) Characteristics of the loose rock that impact on removal by the worker.

(8) Characteristics of the scaling bars that impact on worker performance in detection and removal of loose rock.

(9) Characteristics and limitations of the operator that impact on performance of the task.

2. Task II - Develop Alternative Detection and Removal Procedures and Equipment.

a. Optimal visual search procedures should be developed. Included in the development should be consideration of what to look for and how to identify suspect ground. Procedures appropriate to time-sharing with production tasks should be included (See Blignaut, 1979, for a discussion of the time-sharing requirements of the barring task).

b. Optimal testing procedures (sounding, prying with bar) should be developed.

c. A low-cost, improved scaling bar should be developed for use with the detection and removal procedures identified in

Task Ia and Ib. It is anticipated that because of the range of conditions found in metal and nonmetal mining, more than a single bar design may be required.

3. Task III - Develop Training Packages for Detection and Removal of Loose Rock.

    a. A training package based on the optimal procedures of loose rock detection and removal identified in Task II should be developed. Included in the package should be a description of visual search skills appropriate for use in time-sharing with production tasks.

    b. The range of conditions found in metal and nonmetal mining may impose a requirement for the development of more than a single training program.

    c. Each training package should be prepared in the form suitable for implementation and testing in demonstration projects.

Phase II

Demonstrate Utility and Safety of Equipment and Procedures.

a. This phase should consist of demonstration projects in the underground metal and nonmetal mining industry. Each training package developed during Phase I should be operationally tested in at least one cooperating mine.

b. An assessment plan should be devised that would provide a reliable and valid mechanism for assessing the efficacy of the training. Every effort should be made to determine the "payoff" of subsequent implementation of each training package.

c. All aspects of the project should be carefully documented with the intent of widely distributing the program results.

d. The final report should document the impact on miners' health, safety, and productivity of each training package, and make recommendations for instituting each system in other mines.

4.2.4 Research Plan B: Detection of Loose Rock

General

The work should be accomplished in the following phases:

Phase I

1. Task I - Perform Needs Analysis for Loose Rock Detection System.
2. Task II - Determine Characteristics of Loose and Firm Rock.
3. Task III - Develop Loose Rock Detection System.

Phase II

Demonstrate Utility of Loose Rock Detection System.

Scope of Work

Phase I

1. Task I - Perform Needs Analysis for Loose Rock Detection System.
    a. A survey should be made of the needs and performance requirements of loose rock detection systems. Mines representative of the range of commodities, mining methods, and geological conditions in underground metal and nonmetal mining should be surveyed. A limited number of site visits may be required. The survey should include identification of:
        (1) Areas within a mine that have a high need for loose rock detection activities.
        (2) Other mining activities that occur in these areas.
        (3) Limitations and characteristics of the operators and the human performance requirements of a loose rock detection system.
        (4) Human factors and training considerations that these characteristics and performance requirements impose upon the design of the system.
        (5) Environmental conditions impacting design of the system.

        (6) Anticipated maximum acceptable cost of the system.

    b. The survey results should form the basis of the system design parameters of a loose rock detection system. It is anticipated that those parameters will include:

        (1) The system be lightweight and easily portable by a single operator.

        (2) The system operator should always be working under safe roof.

        (3) Operation of the system should be possible within the limitations and characteristics of the operator.

        (4) The system should be useable under the range of conditions found in a large proportion of all possible worksites.

        (5) The system should be cost-effective.

        (6) Operation of the system should be compatible with use of any mechanized or manual loose rock removal system.

2. Task II - Determine Characteristics of Loose and Firm Rock.

    a. The characteristics that distinguish loose rock from firm should be determined for the range of ore types and geological conditions found in underground metal and nonmetal mining. Those characteristics that distinguish loose and firm roof in a substantial number of mines should be selected for further study.

    b. The technical feasibility of developing detection systems for the characteristics identified in subtask "a" should be evaluated and those systems judged to be technically feasible should be identified.

3. Task III - Develop Loose Rock Detection System.

    a. The design parameters of technically feasible systems should be evaluated (including man, task, equipment, and environmental components). Those systems that meet the performance requirements outlined should be selected for development.

b. Working prototypes should be developed and undergo preliminary testing in a representative sample of mines.

Phase II

Demonstrate Utility of Loose Rock Detection System.

a. This phase should consist of demonstration projects in the underground metal and nonmetal mining industry. Each detection system developed during Phase I should be operationally tested in at least one cooperating mine.

b. A plan should be devised that would assess the efficacy and potential payoff of the detection systems developed.

c. All aspects of the project should be documented for wide distribution of the program results.

d. The final report should document the impact of each detection system on miners' health, safety, and productivity, and make recommendations for instituting each system in other mines.

4.2.5 Research Plan C: Removal of Loose Rock

General

The work should be accomplished in the following phases:

Phase I

1. Task I - Perform Needs Analysis for Loose Rock Removal System.
2. Task II - Determine Characteristics of Loose Rock.
3. Task III - Develop Loose Rock Removal System.

Phase II

Institute Rock Removal Demonstration Project.

Scope of Work

Phase I

1. Task I - Perform Needs Analysis for Loose Rock Removal System.

    a. A survey should be made of the needs and performance requirements of loose rock removal systems. Mines representative of the range of commodities, mining methods, and geological conditions in underground metal and nonmetal mining should be surveyed. A limited number of site visits may be required. The survey should include identification of:

        (1) Areas within a mine that have a high need for loose rock removal activities.

        (2) Other mining activities that occur in these areas.

        (3) Limitations and characteristics of the operators and the human performance requirements of a loose rock removal system.

        (4) Human factors and training considerations that these characteristics and performance requirements impose upon the design of the system.

        (5) Environmental conditions impacting design of the system.

        (6) Anticipated maximum acceptable cost of the system.

    b. The survey results should form the basis of the system design parameters of a loose rock removal system. It is anticipated that those parameters will include:

        (1) The system should be lightweight and easily portable by a single operator.

        (2) If a vehicle mounted system is required, it should be small and maneuverable to allow use in mines with small openings.

        (3) The system operator should always be working under safe roof.

        (4) Operation of the system should be possible within the limitations and characteristics of the operator.

(5) The system should be cost-effective.

(6) Operation of the system should be compatible with use of any loose rock detection system.

2. Task II - Determine Characteristics of Loose Rock.

a. The characteristics of the loose rock to be removed by the system should be determined for the range of ore types and geological conditions found in underground metal and nonmetal mining. It is expected that those characteristics will include:

(1) The dimensions and mass of the rock.

(2) The force required to remove the rock.

(3) The optimal methods of removing loose rock under various conditions.

b. The technical feasibility of developing a variety of systems for loose rock removal should be evaluated. Those systems judged to be technically feasible should be identified.

3. Task III - Develop Loose Rock Removal System.

a. The design parameters of technically feasible systems should be evaluated (including man, task, equipment, and environment components). Those systems that meet the performance requirements outlined should be selected for development.

b. Working prototypes should be developed and undergo preliminary testing in a representative sample of mines.

Phase II

Demonstrate Utility of Loose Rock Removal System.

a. This phase should consist of demonstration projects in the underground metal and nonmetal mining industry. Each removal system developed during Phase I should be operationally tested in at least one cooperating mine.

b. A plan should be devised that would assess the efficiency and potential payoff of the removal systems developed.

c. All aspects of the projects should be documented for wide distribution of the program results.

d. The final report should document the impact of each removal system on miners' health, safety, and productivity, and make recommendations for instituting each system in other mines.

4.3 Slips and Trips

4.3.1 Background and Discussion

A large proportion of the accidents occurring in underground metal and nonmetal mining are a result of workers slipping, tripping or losing their balance and falling, Chugh, et al, (1974) reported that 13.6 percent of nonfatal injuries and 10.6 percent of fatalities from 1969-70 were due to slips and falls. Those accidents were further classified into (1) slips and falls from elevation and (2) slips and falls on the same level. Ninety-seven percent of the fatalities were due to falls from elevation while 57 percent of the nonfatal injuries were due to slips and falls on the same level. Slips and falls from elevation occurred while handling materials (21.9%), due to failure of scaffolds, ladders or other support (19.3%), while operating or moving machinery (5.2%), and during a variety of other activities. Slips and falls on the same level are associated most strongly with materials handling (37.1%), the use of hand tools, and moving machinery (14.5%).

These data are supported by the findings of Perry, et al, (1980). A study of a random sample of 510 detailed accident descriptions in 1978 and 1979 found that 16.1% could be attributed to slips and trips, making it the second largest cause of accidents in underground metal and nonmetal mining.

Accidents caused by slipping and tripping can occur anywhere in a mine and are associated with virtually all worker activities. An almost limitless variety of factors can cause a worker to slip or trip. However, some circumstances can be identified as significant contributors to the likelihood of an accident. These are the presence of slick surfaces, inadequate provisions for operator ingress and egress, and the presence of obstacles in the worker's path.

The hazard posed by slick surfaces may be reduced by either changing the surface or by using specialized footwear. When the slick surface is located on mining machinery or at permanent work sites, the surface should be modified to provide more secure footing. Effective non-skid surfaces should be required on all machine surfaces to provide secure footing for all worker activities. Non-skid surfaces should also be provided on all ladders, stairways, and landings. Wherever possible, non-skid surfaces should be used at permanent work sites such as shops, shaft landings, and skip sites. All non-skid surfaces should retain their effectiveness when wet or muddy.

There are significant differences between boots in resistance to slips. the design and composition of the sole appear to be the determining factors. Optimal boot designs should be determined for the range of surface conditions and activities encountered in underground metal and nonmetal mining. Use of approved footwear should be mandated following testing of their efficiency.

Climbing on and off mining machinery increases the likelihood of slipping and tripping. Inset steps and hand holds are usually provided for ingress to large machines. However, even if adequate for ingress, insets are difficult to use when climbing down from the machine, and operators prefer to jump off the machine. Adequate systems of hand holds and steps should be developed for all large mining machinery. Following sufficient testing to determine their efficiency, adequate provision for ingress and egress should be mandated for all new mining machinery.

Obstacles in the worker's path cause trips, slips and falls. The incidence of slips, trips, and falls may be reduced by either eliminating the hazard or by increasing the likelihood the worker will detect and avoid the obstacle. Better housekeeping practices should reduce the incidence of workers tripping over lumber, pipe, tools, and other materials left lying about the site. Better roadway maintenance should also reduce the likelihood of tripping over rocks or stepping into unseen holes.

Where the hazard cannot be eliminated, efforts should be devoted to increasing the likelihood of detection and avoidance. Improved illumination is one approach. The minimal luminance requirements of mining tasks are yet to be determined but it is anticipated that a requirement for increased illumination of the worksite, including the floor, will result from further research efforts in this area. Another approach to increasing the likelihood of detection is to increase the conspicuity of the hazard by using retroreflective and other high visibility materials (see 4.4 Hazard Conspicuity). Present equipment design frequently requires the presence of trailing hoses and cables at the dimly lit rear of the machine. These hoses and cables are typically coated with black rubber and are very difficult to detect in dim light. Use of high visibility or retroreflective hoses should reduce slips and trips of workers as well as the costly incidence of cables and hoses being cut, ripped out or otherwise damaged when run over by other machines. Alternative methods to increase the conspicuity of hoses and cables should be tested and a standard promulgated for application to all new hoses and cables.

Solutions are available that should significantly reduce the numer of accidents attributable to slips and trips. Those solutions should be operationally tested and standards for their application established. Finally, for those solutions found to be sufficiently efficient, regulations should be promulgated requiring their implementation on all new purchases.

4.3.2 Objective

The objective is to evaluate alternative solutions to the problem of accidents attributed to slips and trips.

4.3.3 Research Plan

General

The work should be accomplished by the following tasks.

1. Task I - Secure the Cooperation of Mines and Equipment Manufacturers.
2. Task II - Perform Human Factors Evaluation of Operator Access and Position.
3. Task III - Develop Test Programs.
4. Task IV - Operationally Test Programs.
5. Task V - Recommend Design Standards for New Equipment.

Scope of Work

1. Task I - Secure the Cooperation of Mines and Equipment Manufacturers.
   a. The cooperation of mines to participate in the study should be secured. The mines should be representative of the range of methods and equipment found in underground metal and nonmetal mining.
   b. The cooperation of applicable equipment manufacturers must be secured.

2. Task II - Perform Human Factors Evaluation of Operator Access and Position.

   a. Data relevant to slips and trips accidents should be collected at mine sites. These data should include:

      (1) The machinery in use at each mine.

      (2) Detailed descriptions of slips and trips related accidents at each mine.

      (3) Characteristics of work station layouts that contribute to slips and trips.

      (4) Characteristics of the machinery that contribute to slips and trips.

      (5) Characteristics of the worker's personal equipment, i.e., boots, that contribute to slips and trips.

      (6) Characteristics of the work station environment that contribute to slips and trips.

   b. Manufacturers of the equipment in use in the mines should be visited. A human factors evaluation should be made of each machine type. This study should focus on identifying problems of ingress/egress and slips and trips at the operator's work station.

   c. Existing solutions to the problem of reducing slips and trips should be compiled. These should include ingress and egress requirements, alternative surface materials and treatments, boot designs, and high visibility and retroreflective coating of surfaces.

   d. Specific programs to reduce accidents due to slips and trips should be formulated for each cooperating mine. These programs should be based on application of technology appropriate to the specific situation at each mine.

   e. Plans for each program should be reviewed with the mine operators and agreements reached on operational test procedures.

3. Task III - Develop Test Programs.

    a. Retrofit packages should be developed in cooperation with equipment manufacturers to enable in-mine modification of existing equipment.

    b. In cooperation with mine operators, the retrofit packages should be installed and prepared for operational test.

    c. Working with the mine operators, specific changes in work station design, housekeeping procedures, or other changes required by the test plan should be identified and implemented.

4. Task IV - Operationally Test Programs Developed.

    a. Each program should be tested in a cooperating mine.

    b. A plan should be devised that would assess the efficiency and potential payoff of each program developed. Accident data should be supplemented with a measure of "near-miss" incidents.

    c. All aspects of the project should be documented for wide distribution of the program results.

5. Task V - Recommend Design Standards for New Equipment.

    a. Make specific recommendations for implementation of those program components found to be effective.

    b. The final report should document the impact of each recommendation on miner's safety and productivity. The cost and time to implement each recommendation in the mining industry should be assessed. Recommendations specifying how implementation can be accomplished should be included.

4.4 Hazard Conspicuity

4.4.1 Background and Discussion

The underground environment is characterized by the presence of numerous hazards which must be detected and avoided by the worker. These hazards assume many forms and may be either fixed (protrusions, hoses, cables) or in motion (other workers, machinery). They appear at most locations in the mine; on the floor, at the back or ribs, or within the opening.

In general, a worker depends on visual discrimination to detect a given hazard. Yet this visual discrimination is performed in an environment characterized by low levels of illumination. The ability of individual workers to make the visual discriminations necessary to detect and recognize hazards is, of course, dependent upon their visual skills (especially acuity) and their prior experience. Aside from these individual differences, however, McCormick (1970) stated that there are certain variables, external to the individual, that affect visual discriminations. These are:

1. Luminance contrast. The greater the difference in luminance (brightness) of the hazard and the surrounding surfaces, the greater the likelihood of detection.

2. Amount of illumination. Provision of adequate levels of illumination increase the likelihood of detection.

3. Movement. Acuity generally deteriorates as a direct function of the angular speed of movement of either the object or the observer.

4. Glare. The presence of direct or reflected glare reduces the likelihood of detection.

5. Luminance ratio. The luminance ratio is the ratio between the luminance of any two areas in the visual field (usually the area of primary visual attention and the surround area). The greater the ratio, i.e., the more uneven the lighting of the worksite, the more difficult the visual discrimination.

6. Time. Within reasonable limits, the longer the viewing time, the greater the likelihood of detection of the hazard.

Crooks, et al, (1980) reported that many tasks are performed by cap lamp or machine-mounted sealed beam luminaires. These lamps have a narrow beam distribution pattern and do a relatively poor job of illuminating the periphery where hazards are located frequently. Crooks, et al, found median luminance levels of the floor, back and surround were 0.1 to 0.3 foot-lamberts. Assuming the median range of reflectance of 15 to 31 percent reported by Crooks, et al, for metal and nonmetal mines, the incident light on the floor, back and surround ranged from 0.3 to 2.0 foot-candles. For comparison, the IES Lighting Handbook (1972) recommends illumination levels of 10 to 50 foot-candles for most tasks in iron and steel manufacturing.

If the underground worker's ability to detect and recognize hazards can be enhanced, it follows that the safety of the workers will be increased. This goal may be approached in a variety of ways. One approach is to focus on the worker. He may be trained in the pattern recognition of hazards and with experience will develop expectancies of hazard locations. Training should increase the safety of the inexperienced miner but is a relatively expensive approach for the benefits derived.

Another approach is to increase the conspicuity of the hazard -- to make it easier to detect and recognize. This may be done through changes in the variables affecting visual discrimination described previously. Mining conditions limit the practicality of changing some of those variables. For example, there is relatively little that can be done to either reduce the movement of the hazard and the worker or increase the time allowed for visual discrimination.

Three other variables are direct functions of the quantity and quality of illumination provided in the underground environment. Standards for illumination of underground mining tasks are yet to be determined, but it is anticipated that the standards will be minimal rather than optimal ones because of the high costs of implementing optimal levels. Based on the experience of minimal lighting regulations in underground coal mining, it is anticipated that improvements in the amount of illumination, the evenness of the illumination (luminance ratio), and reduced glare, will be required for many metal and nonmetal tasks. But these improvements await completion of the necessary research to determine minimal luminance requirements for metal and nonmetal mining.

The remaining approach is that of increasing the luminance contrast of the hazard. Applying retroreflective surface treatments or affixing retroreflectors on or near the hazard offers substantial increase in detectability, especially given the low levels of illumination available. This approach is feasible for hazards that are relatively permanent and have a known location. For example, retroreflective materials may be applied to machinery, pinch points on machines, protrusions from the back, ribs, or floor, cables and pipes, low points at the back, etc. Retroreflective materials may also be affixed to apparrel to increase the conspicuity of the underground worker. Other hazards occurring at irregular intervals or at variable locations (e.g., loose rock at the back) are not amenable to this approach.

Excessive or inappropriate use of retroreflective materials could cause confusion and actually interfere with the detection of hazards. Guidelines for their use should therefore be developed and evaluated in an operational test in one or more mines. The results should provide a reliable and valid basis for recommending necessary regulatory changes.

In some cases the consequences of failing to detect a hazard are so dire that increasing the conspicuity is not a sufficient solution. An example of such a hazard is the extension of a metal "chinaman chute" into the haulage way or a low hanging timber set. In either case, if the motorman fails to detect the hazard and doesn't duck to avoid it, the likely result is a fatal accident. Of course, the conspicuity of these hazards should be increased but two additional approaches should be explored.

The first is the application of a simple "early warning system" to alert the motorman. One way to do this would be to hang a retroreflective sign or other marker some standard distance before the hazard. This marker should be extended into the haulage way the same distance as the hazard that follows it, and should be constructed so that if the motorman hits it, no injury will result. Guidelines for the design and application of such early warning systems should be developed and operationally tested.

The second approach is to reduce the consequences of the failure to detect the hazard. In the example of the "chinaman chute" extending into the haulage way, use of flexible rubber rather than steel for the chute extension would not eliminate the accident but it could reduce the severity of the injury. Hazards amenable to this approach should be identified and the approach tested.

4.4.2 Objective

The objective is to reduce the frequency and severity of accidents associated with failures to detect and recognize hazards by increasing the conspicuity of those hazards, using early warning systems, and minimizing the consequences of accidents when they occur.

4.4.3 Research Plan

General

The work should be accomplished by the following tasks:

1. Task I - Secure the Cooperation of Mines.
2. Task II - Perform Human Factors Evaluation of the Conspicuity of Hazards.
3. Task III - Develop Programs for Enhancing the Conspicuity of Hazards.

4. Task IV - Develop Early Warning Systems and Redesign Equipment and Worksites to Reduce Accident Severity.

5. Task V - Perform Testing at Mine Sites.

6. Task VI - Make Recommendations for Implementation.

Scope of Work

1. Task I - Secure the Cooperation of Mines.

    a. The cooperation of mines to participate in the study should be secured. The mines should be representative of the range of methods and equipment found in underground metal and nonmetal mining.

2. Task II - Perform Human Factors Evaluation of the Conspicuity of Hazards.

    a. A study should be made to identify problems of hazard conspicuity in each cooperating mine.

    b. The study should identify those hazards that the underground worker must detect visually and recognize those that are amenable to conspicuity enhancement. These hazards may include:

        (1) Protrusions from the back, ribs, and floor.

        (2) Low back, low hanging timber sets, chute extensions, etc.

        (3) Hoses, cables, and pipes on the floor or other locations at the worksite.

        (4) Holes, raises, and chutes in the back or floor.

        (5) Haulage equipment.

        (6) Pinch points or other equipment related hazards.

        (7) The presence of other workers at the worksite or in the haulage way.

    c. Identify hazards for which early warning systems can be used.

d. Identify equipment and worksites that are amenable to changes that will reduce the consequences of a failure to detect and avoid hazards.

e. A human factors evaluation should be made of the hazards identified in subtasks b, c, and d. This evaluation should include identification of:

    (1) Worker characteristics and capabilities.

    (2) Worker activity at the time the hazard must be detected.

    (3) Characteristics of the hazard that impact on detection (size, location, contrast with background, motion, any other cues affecting the probability of detection).

    (4) Environmental conditions impacting on hazard detection (illumination, sound, vibration, motion of worker, etc.).

    (5) Criticality of detection. Those hazards that are most critical to the safety of the worker should be identified.

    (6) Time available for detection.

3. Task III - Develop Programs for Enhancing the Conspicuity of Hazards.

    a. Identify different methods of enhancing hazard conspicuity.

    b. A program for enhancing the conspicuity of hazards should be developed for each mine.

    c. Materials necessary for testing the program in cooperating mines should be obtained.

    d. Training packages should be prepared for the workers in each cooperating mine.

4. Task IV - Develop Early Warning Systems and Redesign Equipment and Worksites to Reduce Accident Severity.

    a. Early warning systems should be developed for the hazards requiring them, which were identified in Task IIc.

   b. The systems developed should be inexpensive, of general applicability, and should not create hazards themselves to the underground worker.

   c. Equipment and worksites identified in Task IId should be redesigned to reduce the severity of accidents resulting from a failure to detect hazards.

   d. Early warning systems and redesigned equipment should be prepared in a form ready for operational testing.

   e. Training packages should be prepared for the workers in each cooperating mine.

5. Task V - Perform Testing at Mine Sites.

   a. Each hazard conspicuity program should be operationally tested in a cooperating mine.

   b. A plan should be devised that would assess the efficiency and potential payoff of each program. Accident data should be supplemented with a measure of "near-miss" incidents.

   c. Worker acceptance of each program component should be assessed.

   d. All aspects of the project should be documented for wide distribution of the results.

6. Task VI - Make Recommendations for Implementation.

   a. Recommendations should be made for implementation of those program components found to be most effective.

   b. The final report should document the impact of each recommendation on safety and productivity. The cost and time to implement each recommendation throughout the mining industry should be assessed.

4.5 Hand Tools

4.5.1 Background and Discussion

The hand-held tool establishes a direct physical contact between the worker and his machine. A tool can be viewed as a means for extending and adapting the worker's capabilities to better suit the task and work environment. For example, tools are used to expand reach and force capabilities, to increase precision and efficiency and to enhance the workers safety and well-being. A "good" tool can protect a man from electrical shocks, toxic substances, and from physical damages. Conversely, a "bad" tool when used for extended periods of time can lead to discomfort and local muscle fatigue; when this occurs, the probability of errors and consequent accidents is increased (Ayoub, 1974).

Chugh, et al (1974) reported that 8.9 percent of nonfatal injuries in underground metal and nonmetal mines during 1961-1970 were related to hand tools. This high incidence of hand tool accidents was confirmed by Crooks, et al (1980). Eleven percent of all accidents reported during 1978 involved nonpowered hand tools. It was found that while few fatalities were associated with hand tool accidents, 48.6 percent of all hand tool accidents resulted in lost or restricted activity days. The use and misuse of hand tools are also associated with a variety of long term disabilities, the extent of which depends on the time and degree of exposure to the improperly designed or used tool (Ayoub, 1974).

Tool design and mode of use are known to affect productivity. Kaplan (1968) listed some of the benefits from applying biomechanics to tool design. These included: (1) minimizing the required physical demands on the worker, (2) reducing or eliminating muscle strain, and (3) increasing the safety of the task. Kaplan emphasized that most of the power generated by an individual comes from the body rather than the hand. Therefore, to maximize power transfer, the linkages between the hand and the tool must be effective. Thus, an effectively designed tool not only eliminates possible injury, but also increases the amount of power a person can generate from the tool and hand combination.

In an examination of any man-tool system, three components, two interfaces, and four interdependencies should be considered. The components are the man (with his attendant capabilities), the tool, and the task to be performed. Two direct interfaces relate man to tool and tool to task. The man-tool interface is concerned with the operator's manipulation of the tool. The tool must be designed so it can be suitably manipulated and still "feel good" to the user. The tool-task interface relates the tool and task objects and is usually of a mechanical nature.

The quality of task performance is partly determined by how well the tool engages the task and partly by how well the user manipulates the tool. User satisfaction and system performance are strongly determined by characteristics related to the man-tool interface.

The first of the four interdependencies is that the task tends to dictate the nature of the tool manipulation required. Removing loose rock from the back takes considerable physical force; this requirement determines how the worker manipulates the scaling bar. The second is that the task tends to dictate the nature of the tool engagement. Testing the back for loose rock calls for the bar to be tapped against the suspect rock while removing the loose requires that the bar be forced into a crack between the loose rock and firm ground. The third interdependency is that the tool design influences the nature of the manipulation. In prying loose rock from the back the flexibility of the scaling bar limits the force the worker can apply. The least that can be asked of tool design is that it does not hinder the required manipulation. The fourth interdependency is that the tool design influences the nature of the engagement with the task. The tool should be designed to select the best engagement and manipulation characteristics required by the task.

In the example of the detection and removal of loose rock by scaling or barring down, the task requirements change continually between the detection and the removal of loose rock. Detection calls for a bar with good sounding properties while removal requires a bar which can be forced into a crack and then used to apply the necessary force to break the loose rock away from the firm ground. These changing task requirements dictate either the use of an adaptive multi-purpose tool or the use of several single-task tools.

It is apparent from the above that a system approach is useful in providing the basis for improvements in hand tool design.

Impetus for the design of new tools or the redesign of old ones can stem from health and safety considerations, from the lack of suitable tools for new tasks, and from a desire to increase productivity. Any or all of the system components can be redesigned. "Redesign of the man" is achieved through selection or training. At least a part of what is referred to as "on-the-job training" consists of the worker learning techniques to compensate for inadequacies of the system design.

While redesign of the task is possible, in many situations the task is specified prior to the designer's entry into the problem. Whenever tasks are redefined, the impact of those changes on the complete system must be considered.

Redesign of tools should be based on a complete understanding of the problem, the task objectives, and the human capabilities and characteristics that are relevant to the problem. User response to the design must be assessed and user feedback should be an integral part of the tool design process.

4.5.2 Objective

The objective is to identify the need for hand tools in the underground metal and nonmetal mining industry, to determine which man-tool systems require redesign, to perform the necessary redesign, and to test the resulting systems.

4.5.3 Research Plan

General

The work should be accomplished by the following tasks:

1. Task I - Identify and Describe the Range of Tasks Performed with Hand Tools in Metal and Nonmetal Mining and Identify Problems Therein.
2. Task II - Select Hand Tools that Require Redesign.
3. Task III - Perform Research to Define Requirements for Hand Tool Redesign.
4. Task IV - Develop and Test Prototypes of Redesigned Hand Tools Used in Metal and Nonmetal Mining.
5. Task V - Select Redesigned Hand Tools for Future Implementation.

Scope of Work

1. Task I - Identify and Describe the Range of Tasks Performed with Hand Tools in Metal and Nonmetal Mining and Identify Problems Therein.
    a. A study should be made of current hand tool uses and practices. in the underground metal and nonmetal mining industry. Visits should be made to a sample of mines selected as representative

of current mining methods. Observations of ongoing work with hand tools should be thoroughly documented. Both still and motion picture photography should be used to supplement the findings of trained observers. Underground workers should also be interviewed. Items to be identified should include:

(1) Tasks performed using hand tools, frequency of performance and importance to the mining operation.

(2) Location in the mine in which the task is performed.

(3) Conditions of use for each tool, i.e., other activities occuring at the time; the physical position of the worker, the environmental conditions, space constraints, etc.

(4) Uses and misuses of tools.

(5) Capabilities and characteristics of the tool user.

(6) Worker-developed or worker-modified tools being used.

(7) Tools perceived by underground workers as requiring redesign; tasks perceived as requiring the development of new tools.

(8) Hazards and accidents associated with each tool and its common use or uses.

(9) Performance problems associated with the use of each tool.

(10) Biomechanical analysis of the use of tools that are likely to produce discomfort, local muscular fatigue, hand trauma, and disabilities.

2. Task II - Select Hand Tools that Require Redesign.

   a. The hand tool systems in greatest need of redesign should be identified based on the results of Task I.

3. Task III - Perform Research to Define Requirements for Hand Tool Redesign.

   a. For those systems selected for redesign in Task II, the following research should be completed:

(1) Examples of each tool should be acquired. Where variations in tool design exist, examples of each type should be procured.

(2) Anthropometric and biomechanical characteristics of the user population should be defined.

(3) A literature search of relevant studies should be performed.

(4) Laboratory simulation of the tasks associated with each man-held tool system should be performed as needed. Subjects for laboratory simulation of the tasks should be trained to use the hand tools in the ways identified in Task I. Proper uses, misuses, and inappropriate uses of each tool should be included in the task simulation.

(5) Measures of the tool-task interface will be required. Objective performance measures of trained subjects using the tool in the simulated task situations should be the standard test procedure.

b. The research should allow the design team to identify the component(s) of each man-held system requiring redesign and the changes, additions, or deletions that should be made.

c. It is anticipated that a variety of redesign approaches will be found necessary. For some systems, redesign of the man through training or selection may be appropriate. Redesign of the task may offer the greatest payoff for a few systems (mechanization of the scaling process is an example of redesigning the task). For other systems redesign of the tool may offer the greatest benefit. An example is the development of a multipurpose tool for feedleg drill operators, which can be used as both a wrench and a hammer to replace the 12-inch "crescent" wrench currently used for a variety of tasks. For some systems, redesign of two or more components may be indicated.

4. Task IV - Develop and Test Prototypes of Redesigned Hand Tools.

a. Alternative designs should be developed for each system component selected for redesign during Task III.

b. Where redesign of the man is indicated, the necessary selection criteria, training curriculum, or procedural changes should be developed.

c. Where task redesign is indicated the complete man-tool system should be developed to fit the changed task.

d. Where tool redesign is indicated, a prototype should be developed.

e. All redesigned tools should be evaluated and compared to the results of Task III to see if improvements of a significant order have been made.

f. User acceptance and satisfaction, and objective tool performance must be considered as part of the system performance evaluation.

g. Redesign of the prototype system based on the results of "f" above may be required.

5. Task V - Select Redesigned Hand Tools for Future Implementation.

   a. Those hand tools that offer a significant improvement should be recommended for future implementation. The following criteria are important:

      (1) Impact of the redesigned system on safety and health including long term disability.

      (2) Impact of the redesigned system on productivity.

      (3) Cost of implementing the redesigned system.

      (4) User satisfaction with the redesigned system.

4.6 Eyewear

4.6.1 Discussion and Background

Regulation requires miners to use safety glasses, goggles, or face shields wherever a hazard exists that could cause eye injury (30CFR # #57.15-4). Mine operators vary in their interpretation of this rule. Some require all underground personnel to wear safety glasses at all times.

Others require the use of protective eyewear only for specific tasks in which the potential for eye injury is great. Obviously, to afford the needed protection, the worker must be wearing the protective eyewear. Yet, in all too many cases, the eyewear remains in his or her pocket.

The protection afforded by present eyewear appears to be adequate. However, the lack of user acceptance constitutes a major impediment to effective sight conservation programs in underground metal and nonmetal mines.

There are two common user complaints. The first is related to the fit of the eyewear. The protective eyewear most often supplied to miners are inexpensive safety glasses with universal bridges and temple pieces that often do not fit comfortably. They put pressure on the nose and the ears and tend to slide down the miner's nose when he perspires. Sometimes safety goggles are used. Goggles offer protection of a greater area of the face, but tend to restric the miner's peripheral vision. They are also made with universal bridges that are often uncomfortable.

The second area of user complaint is related to visual impairments caused by protective eyewear. Both safety glasses and goggles tend to fog, especially when going from a cold area to a warm area. Commercial products intended to minimize or eliminate fogging (i.e., anti-fogging solutions) are available but they are ineffective for long periods of time.

Severe visual impairment is caused by eyewear accumulating dust, mud, water and oil mist, all of which are common in the underground mining environment. The only solution to this problem appears to be to wipe off the glasses or goggles as necessary. For high concentrations of dirt, it is often impossible to keep the glasses clean. For example, the operator of a stoper drill is exposed to flying rock fragments and airborne grit from the drilling process and finds that his eyewear becomes dirty almost immediately. Thus, many times the workers who need eye protection the most will complain that "it's harder to do the job wearing safety glasses," or "it's harder to see with them than without them."

To promote effective sight conservation programs in underground metal and nonmetal mines, a model program for eye safety should be developed. This program should center on increasing user acceptability of protective eyewear and convincing mine operators and workers of the necessity and cost-effectiveness of providing and wearing appropriate eyewear.

4.6.2 Objective

The objective is to identify problems in user acceptance of protective eyewear and to develop a program to increase acceptance and use of appropriate eyewear.

4.6.3 Research Plan

General

The work should be accomplished by the following tasks:

1. Task I - Conduct Study to Identify Problems in User Acceptance of Protective Eyewear.
2. Task II - Develop Model Sight Conservation Program.
3. Task III - Test and Evaluate Model Sight Conservation Program.

Scope of Work

1. Task I - Conduct Study to Identify Problems in User Acceptance of Protective Eyewear.

    a. A study should be made to identify problems in user acceptance of protective eyewear. A number of mine visits may be required. Mines selected for visits should be representative of the range of methods, equipment, and environmental conditions found in underground metal and nonmetal mining.

    b. During mine visits observations should be made of the range of underground work performed in each mine. Data to be collected should include:

        (1) Detailed description of protective eyewear observed in use.

        (2) Environmental conditions at time of use.

        (3) Worker activity at time of use.

        (4) Hazardous conditions requiring use.

        (5) Frequency and means of cleaning eyewear.

        (6) Other personal equipment in use, i.e., respirator, ear muffs, etc.

        (7) Any problems operator is having with eyewear.

    c. Underground workers should be interviewed at each mine. The same data should be collected as in "b" above, with the following additions:

        (1) Detailed description of source and fitting procedure for eyewear.

        (2) Attitudes of worker toward protective eyewear and requirement of its use.

        (3) Suggestions of worker to improve acceptability of protective eyewear.

    d. Compile data on existing solutions, including:

        (1) Identification of optimal eyewear types for specific hazards.

        (2) Solutions to problems of fitting comfortably the anthropometric range and characteristics of underground workers.

        (3) Solutions to problems of fogging of protective eyewear.

        (4) Solutions to problems of maintaining clean eyewear in the mining environment.

2. Task II - Develop Model Sight Conservation Program.

    a. Findings of Task I should form the basis for development of the Model Sight Conservation Program.

    b. The Model Program should address the user acceptance problems identified in Task I.

    c. It is anticipated that elements of the Model Program will include:

(1) Education in the importance of using protective eyewear.

(2) Training in recognition of hazards and conditions requiring use of protective eyewear.

(3) Training in use and maintenance of protective eyewear.

(4) Selection of optimal protective eyewear for the specific hazards encountered by each worker.

(5) Fitting of optimal protective eyewear by trained personnel.

d. Procedures for assessing the effects of the Model Program should be incorporated in the program design.

3. Task III - Test and Evaluate Model Sight Conservation Program.

a. The efficacy of the Model Program should be tested in at least one cooperating mine. Efforts should be made to determine the utility and cost-effectiveness of the program.

b. Test results should be documented for wide distribution of results.

c. Recommendations should be made for implementing the Model Sight Conservation Program in other mines.

4.7 Clearing Blocked Chutes and Raises

4.7.1 Background and Discussion

The clearing of blocked chutes, transfer raises, and draw points has been identified as a major cause of reduced operator productivity and safety (Barry, 1974). Pieces of rock, especially if oversize, become jammed in the chute, raise, or draw point and stop the flow of ore causing delays in ore haulage.

Minor hangups are barred loose by the underground worker. In some mines, this is an activity that occurs constantly during the chute pulling operation. Barring is done from alongside the chute or raise opening. The worker breaks up the jam by prying with a 4 to 8 foot bar. Federal regulation specifies that the work space be designed so that the men pulling chute are not required to be in a hazardous position (30 CFR 57.9-64). Yet, to better see or reach the blockage with his bar, the worker often must lean into the rock fall line. A sudden release of the rock in the chute can hit the worker and result in serious injury or death. Chugh, et al (1974) reported that five percent of all fatalities in noncoal mines in 1968-72 occurred during attempts to clear blockages.

Major hangups are usually blasted. One or more sticks of blasting powder are lashed to a long wooden pole. The worker then wedges the pole into the jammed rock so that the explosion will break up the jam. The explosives are then ignited from a safe distance. In a few mines, the ore characteristics may require than the oversize block causing the jam be drilled prior to blasting. Vibration of the drill can cause a sudden release of the jammed rock, which then may fall onto the drill operator.

Clearing blockages is also physically demanding. Safety considerations dictate that the worker stand to the side of the opening. Yet the jam is frequently at the limits of the worker's reach envelope. At a car loading chute, the worker stands on a small platform beside the chute mouth. To reach the jam with his bar, the worker must lean off balance in front of the chute holding on with one hand and manipulating the bar with the other. His position is thus precarious. The jammed rock may hit him or he may slip and fall from the platform. Muscle strains and local muscle fatigue are also significant problems resulting from this difficult operation.

Improvements in the safety and productivity of the chute and raise clearing process are clearly indicated. Present procedures and equipment used in the range of metal and nonmetal mines should be identified. Biomechanical and hazard analyses should be made of chute clearing activities. Operator characteristics and limitations should be identified as should specific hazards inherent in the process. The work space layout characteristic of chute and raise clearing operations should be evaluated and design changes developed with special consideration given to the operator's needs. The feasibility of mechanizing certain aspects of the clearing process should be assessed. Alternative tool designs, workplace layouts, and procedures should be developed that are appropriate to the needs and limitations of the operator. Training packages should be prepared that integrate information about the use of new tools and procedures for chute clearing operations. Finally, the redesigned chute and raise clearing system (incorporating changes in work space, equipment, and procedures) should be tested in a demonstration project.

4.7.2 Objective

The objective is to increase the safety and productivity of the work space, equipment, and procedures used to clear blocked chutes, raises, and draw points.

4.7.3 Research Plan

General

The work should be accomplished in the following phases.

Phase I

1. Task I - Perform Human Factors Evaluation of Current Chute and Raise Clearing Procedures and Equipment.
2. Task II - Develop Alternative Clearing Procedures and Equipment.
3. Task III - Develop Training Packages for Chute and Raise Clearing.

Phase II

Institute Chute and Raise Clearing Demonstration Projects.

Scope of Work

Phase I

1. Task I - Perform Human Factors Evaluation of Current Chute and Raise Clearing Procedures and Equipment.
    a. A human performance evaluation should be made of current procedures in mines representative of the range of ore types and mining methods in underground metal and nonmetal mining. Several site visits may be required. The outcome of this evaluation should be a clear and systematic identification of chute and raise clearing procedures and problems. Specifically, this evaluation should include:
        (1) The location of the blocked chute or raise.
        (2) Other activity at the site.

    (3) Environmental conditions at the site.

    (4) The work station layout.

    (5) The procedures used to clear blocked chutes and raises.

    (6) Hazards analysis of all aspects of the task -- the relative safety of all procedures should be assessed and unsafe practices identified.

    (7) Biomechanical analysis of the physical demands of the task.

    (8) Characteristics of the chute or raise design which impact on formation of blocks and subsequent clearing by the operator.

    (9) Characteristics of the jammed materials that affect clearing of the chute.

    (10) Characteristics of the bar and any other clearing equipment that affect worker performance.

    (11) Characteristics of the operator that affect performance of the task.

  b. The human performance evaluation should form the basis of the system design parameters (including man, machine, and environment components) for subsequent redesign of the chute and raise clearing task.

2. Task II - Develop Alternative Clearing Procedures and Equipment.

  a. A safer and more productive system for clearing blocked chutes and raises should be developed. It is anticipated that variance in conditions among mines will require development of alternative systems appropriate to specific commodities or mining methods. Each system design should be developed on the basis of the parameters (including operator, task, equipment, and environment components) identified during the Human Factors Evaluation performed during Task I.

  b. Two system redesign approaches should be developed. The first is to improve the safety and productivity of current manual methods of clearing blocked chutes and raises. The second is to mechanize the clearing process.

c. Redesign of manual clearing systems should incorporate changes as necessary in:

    (1) The work station, i.e., the operator position, the chute or raise.

    (2) The equipment used to clear the blockage.

    (3) The procedures employed to clear the blockage.

d. Desirable design characteristics of a mechanized chute and raise clearing system should include:

    (1) If portable or mobile, control and movement of the mechanism should be within the limitations of various operator characteristics (e.g., reach, strength).

    (2) If fixed, the mechanism should be transportable to a new location after the productive life of the original site is over.

    (3) The mechanism should be remotely controlled or operator protection provided.

    (4) The mechanism should be compatible with existing chute and raise designs.

    (5) Operation of the system should be compatible with other activities performed at the work site.

    (6) The system should be cost-effective.

e. Working prototypes of equipment for both manual and mechanized chute and raise clearing should be developed.

3. Task III - Develop Training Packages for Chute and Raise Clearing.

    a. Training packages should be developed for the safe and productive operation of specific chute and raise clearing activities that are associated with various mining methods and layouts.

    b. Training packages developed should include new procedures and equipment ensuing from the results of Tasks I and II.

    c. Each training package should be prepared in a form suitable for implementation in Demonstration Projects.

Phase II

Institute Chute and Raise Clearing Demonstration Projects.

a. This phase should consist of demonstration projects in the underground metal and nonmetal mining industry. Each chute and raise clearing system developed during Phase I should be operationally tested in at least one cooperating mine.

b. An assessment plan should be devised that would provide a reliable and valid mechanism for assessing the efficiency of the system. Efforts should be made to determine the utility and cost-effectiveness of each clearing system. This would entail a comparison of newly developed and established chute and raise clearing procedures as well as an assessment of the training program's efficacy.

c. All aspects of the project should be documented for wide distribution of the program results.

d. The final report should document the impact on miners' safety and productivity of each chute and raise clearing system, make recommendations for instituting each system and associated training packages in other mines where appropriate, and specify how this can be accomplished.

5.0 CONCLUSIONS

5.1 Overview

In this chapter we present a summary of the results of the human factors analysis. We will highlight suggested directions for future research and will stress the utility of demonstration projects. We will also discuss the benefits of 1) publicizing and transferring ideas and new developments for mining equipment, procedures, and training; 2) evaluating user acceptance of new mining technology; and 3) the planned introduction of changes in technology (including equipment, procedures, and training) into the underground metal and nonmetal mining industry.

5.2 Summary of Results

The research presented in this report has identified problems that are considered to be critical to the safe and productive operation of mines by key members of the underground metal and nonmetal mining community. These problems of safety and productivity are associated with:

1. Materials handling.
2. Detection and removal of loose rock.
3. Slips and trips.
4. Hazard conspicuity.
5. Hand tools.
6. Eyewear.
7. Clearing blocked chutes and raises.

Several other problems that were considered less critical but nevertheless important were drill noise and mist and respiratory protection.

Human Factors Engineering solutions exist to some of these problems. These solutions were identified, along with indications from mining equipment manufacturers of the problems encountered in implementing those solutions in the industry. For those problems that are not amenable to state-of-the-art technology, research and development efforts were outlined that are considered appropriate and useful.

It is apparent that whether solutions already exist or whether research and development efforts are needed to develop the solutions, there is a more general problem that impedes the implementation of solutions and ideas in the underground metal and nonmetal mining industry. This is the problem of technology transfer--the means by which technological developments make their way from the production stage to actual application in the areas where they can be most useful in ameliorating problems.

Through the Technology Transfer Program, the Bureau of Mines mounts a continuing effort to keep the mining industry abreast of developments resulting from their many research programs. But this information is available to mine operators only by request. That is, mine operators or representatives must request technology transfer films, newsletters, and seminars if they are to become aware of new developments that will solve the problems they encounter in their operations.

Thus, although information regarding technological solutions to problems is available, it is still conceivable that the information may never make its way into the industry. There are several reasons for this:

1. Mine operators may not be aware of the impact of a problem on safety and productivity and thus do not seek a solution, which may also exist.

2. Mine operators or miners may not accept or use the solution.

3. The manner in which the solution is introduced into the mine may inadvertently create greater problems than the ones solved by the change.

We now turn to a brief discussion of each of these components of the technology transfer issue.

5.3 Awareness of Problems and Solutions

Most mine operators pay particular attention to the needs of their workers in performing their jobs. Upper management is constantly involved in determining the inadequacies of the health and safety aspects of the mine, and attempts to implement changes that are necessary to increase worker safety and productivity.

Often, however, the worker's needs in terms of safety and health are not made clear to mine operators. The major reason for this appears to be that miners have adapted to the problems they encounter underground. Miners express this by indicating that a particular problem is "part of the job" or that they "can live with it." The work gets done but at the hidden expense of increased health and safety problems and perhaps lower productivity. Thus, information relating health and safety problems encountered underground may never reach the mine operator, and, consequently, nothing is done to solve these problems.

This situation can be remedied by several means used in concert. 1) a third party, trained in the identification of health and safety problems, could be engaged to identify problems to which miner's have adapted, and could make recommendations for their solution; 2) communication networks between miners and upper management could be upgraded to transmit information about these problems on a regular and constant basis; 3) incentive systems may be set up so that miners perceive that some reward will be associated with making their superiors aware of safety issues and needs.

In cases where mine operators and miners are aware of health and safety problems in the underground environment, they may still be unaware that solutions to those problems are available. It's important that better communication of the existence of solutions (as well as problems) take place, and mining equipment manufacturers should play a key role in this communication. More often, however, it seems that mine operators are reluctant to bring in new technological developments in health and safety because the cost-effectiveness of these developments has not been demonstrated. New equipment has no "track record" and its initial cost may appear prohibitive.

It is recommended that soluations to critical problems be implemented as demonstration projects in cooperating mines. The results of the projects should be measured in terms of their initial cost, effects on accident frequency, effects on productivity, appropriateness (i.e., Does the solution do what it's supposed to do?), etc. Wide distribution of the results of these demonstration projects would provide the basis for mine operators to make well-informed decisions as to whether or not a particular solution (in the form of new equipment, training programs, etc.) should be adopted.

5.4 User Acceptance

Even in cases where solutions to problems in underground metal and nonmetal mining are adopted by upper management, it is frequently found, later on, that the miners do not use the new equipment or procedures. And, when questioned, the miners will report "it's harder to do the job with it than without it" or that they are "used to dealing with the problem in another way." Frequently, the solution creates more problems than it solves, and thus is viewed by miners as "making their lives difficult" instead of simplifying or making their job easier. This problem is known as that of user acceptance.

A case in point is the use of hearing protection. Miners are called upon to wear ear plugs or some sort of ear protection when working in noisy environments. However, many types of ear protection are uncomfortable and annoying, and miners choose not to wear them. Thus, there exists a solution to the problem of hearing loss, but the user does not accept the system that brings about the solution. A similar situation accompanies the solutions developed in the past for eye protection (protective eyewear) and protection from inhalation of respirable dust (air-purifying respirators).

It is essential that mining equipment manufacturers consider the issue of user acceptance before or during the preliminary design of personal equipment, machines, or tools, etc. It is equally important that mine operators try out solutions that they would like to implement on a test sample of miners before adopting the solution and purchasing it on a large scale.

A greater effort on the part of equipment manufacturers in this regard would increase the probability that customers would buy their products. A greater effort on the part of the mine operators to assess the acceptability of the solution to miners before a large scale purchase was made would save the mining company the money that otherwise would be wasted if the solution was purchased and not utilized.

Here, again, demonstration projects provide a means by which user acceptance of a system could be assessed. Necessary modifications of the equipment or procedures could be identified that would increase its acceptance by the user. These issues could be passed on to the manufacturers of that technology, who would have a vested interest in improving it. This would increase the probability that solutions would be integrated successfully in the industry.

5.5 Introducing Change in Underground Metal and Nonmetal Mines

A third problem, beyond those discussed above is that of successful introduction of solutions or changes into the workplace. This problem deals with the way in which the solution is integrated and the way in which changes are handled that ensue from the implementation of the solution.

An example of a situation that may require substantial efforts toward introducing change into a mine concerns automation. Frequently, new and safer machines are introduced into the industry that allow a single operator to perform the work of several. The direct results of using the machine are better productivity and the elimination of several hourly workers, both of which may result in increased earnings (or decreased overhead) to the organization.

However, there are also negative effects of this change. The machine may impose demands on other workers that were not required prior to its integration into the system. The use of machines may be perceived generally as a sign that the mine is tending towards mechanization, and miners may become concerned with their job security. The machine take-over of certain functions may disturb the informal network of communication under which the miners have been working. All of these possibilities may have real effects on the job satisfaction and morale of the miners, and may take their toll perhaps not in direct losses in productivity, but in indirect losses through increased absenteeism and turnover.

A solution to these problems is to institute change into the organization with due consideration given to the effects that the change may have on the workers. First, management should notify workers of potential changes in equipment or procedures before they actually are instituted, and thoughts and opinions of the proposed changes should be elicited. This procedure might bring to light some problems of which upper management was not aware. Second, the changes should be instituted, as much as possible, by the workers who will be affected by them most directly. Third, alternative jobs should be found for the individuals whose functions are being usurped by the change (if that is the case). Finally, proper training should be provided in the use of the new equipment or procedures that are being integrated into the system, so that individual workers will be comfortable using them and will be able to do so productively.

Concluding Remarks: The "Systems" Approach

In this report we have described the critical problems in underground metal and nonmetal mining. Where possible, we have suggested the use of available human factors engineering solutions to eliminate or minimize those problems. We have also presented detailed descriptions of research and development needs that will lead eventually to the solution of other problems. We have advised the use of legislation or regulation for changes that are badly needed and are now available to the industry. Finally, we have suggested the use of demonstration projects to evaluate the relative cost and benefits of implementing solutions to various problems.

It is particularly important to note that successful solutions to critical human factors problems will generally involve more than the development of machinery or devices to aid operators in performing their tasks, especially in the case of large problems. For example, materials handling and slips and trips are two problems that are so pervasive in the industry that they demand consideration of the full range of variables (such as equipment needs, job aids, procedural changes, training requirements, etc.) to obtain a productive and acceptable solution. That is, those problems involve so many people, are associated with so many accidents, and can occur in so many operational situations that a lack of consideration of all of these elements would surely limit the effectiveness of any solution developed. To ensure that effective solutions will be developed and will be used willingly by the workers, a "systems" approach should be used in the preliminary design, development, and evaluation of solutions. This includes consideration of the jobs and tasks required, the physical and biomechanical demands of the tasks, the environment in which the tasks are done, and the characteristics of the user of the system. Through this type of evaluation and analysis, adequate solutions to underground metal and nonmetal mining problems can be designed and implemented successfully. Obviously, it must be established early on whether the problem is significant enough to warrant an effort such as that inherent in the systems approach.

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APPENDIX A

ENTIRE RANGE OF HUMAN FACTORS PROBLEMS IN UNDERGROUND METAL AND NONMETAL MINING

ENTIRE RANGE OF HUMAN FACTORS PROBLEMS IN UNDERGROUND METAL AND NONMETAL MINING

ENVIRONMENT

Visibility and Illumination

Face or back obscured by aerosols and hydrosols.

Detection of bending drill steel.

Realigning boom with drilling hole to insert rock bolts.

Detection of low back and protruding hazards.

Shelter holes hard to locate.

Hazards on track, especially cocked switches and other cars.

Detection of train when cars are being pushed.

Illumination for shaft maintenance.

Illumination for onsite machine maintenance.

Illumination in grease pit.

Detection of presence of mechanics working on machines onsite.

Blind spots to opposite side, rear, and forward on underground machinery.

Failure to detect presence and position of hoses, cables, and pipes.

Worker conspicuity.

Noise/Vibration

Noise of feedleg & jumbo drills.

Vibration (Raynauds syndrome) from hand-held drills.

High pressure hose couplings loosened by machine vibration.

Noise of diesel powered equipment.

Whole body vibration on drills, continuous miners, and haulage vehicles.

Geological Hazards

Fall of back.

Flying rocks during collaring and drilling.

Working under unsupported while rock bolting.

Atmospheric Hazards

Wet environment in shaft; often cold in winter, hot in summer.

Respirable dust and radon daughters.

Physical Hazards

Obstacles, holes, hoses, pipes, cables, and insecure footing, causing slips, trips and falls when at worksite and in transit to and from worksite.

Toxic and Caustic Material Hazards

Skin and eye irritation.

Skin and eye irritation caused by exposure to abrasions from sand and water mixture in sandfill operations.

Grease flings off slusher drums onto operator.

"Power headaches."

EQUIPMENT

Operator-Equipment Interface

Control confusion, inappropriate layout, control-response incompatibility.

Handling rods (pinches, crushes, strains) in raise boring and large hole rotary drilling.

Muscle strain and back-lash maneuvering OSL.

Control of ANFO flow through lance.

Inappropriate use and design of hand tools.

Inherent Dangers

Pinch point between feedleg and drill.

Feedleg slippage.

Operator exposed to hot hydraulic fluid from leaks and burst hoses.

Slips on machine surfaces.

Stoper drill steel stays in hole and falls unexpectedly.

Pinches and burns changing rods in ring drilling.

Strains, pinches lifting wrench to hold rods while unscrewing them on large hole rotary drills.

Rock bolter lurches during traming.

Operator pinched against rib while traming rock bolters and loading with OSL's.

Operator hit by rocks thrown up by rock bolter tires.

Rock bolter boom can drop onto foot of operator.

Control of shotcrete hose.

Sandpipe ruptures on sandfill equipment.

Heat buildup at operator position.

Inadequate safety screens on slushers.

Operator slips and falls off OSL platform.

Operator pinched or hit by OSL bucket or its contents.

Operator exposed to hot particles from bursting pellet exhaust of trucks.

Operator caught in feed screw mechanism on diamond drills.

Pinches and crushes while removing bound steel.

Anthropometry

Access/egress to operator position.

Short operator can't reach controls.

Restrictive operator compartment.

Seat design.

Fixed length levers on slushers used where operator position is variable.

Personal Equipment and Tools

Resin cartridges difficult to insert, especially in high back.

Barring tool design.

Removal of bits on continuous miner.

Failure to attach safety harness.

Failure to use respiratory protection.

Failure to use eye protection.

Inadequate hand protection, resulting in splinters, lacerations, pinches, toxic and caustic material burns & irritation.

Head lamp cord catches on protrusions, due to fixed length.

Burned appendages welding under machinery and in other confined spaces.

TASKS

Job Procedures

Balancing when drilling high and low holes with feedleg drills.

Failure to connect safety chains on high pressure hoses.

Detection of loose.

Difficulties encountered in the location of materials used for various blasting patterns at the face.

Rerailing cars and motors.

Pinches, crushes while coupling cars.

Improper loading of conveyor belts.

Inadequate safety inspection/maintenance of conveyors.

Failure to lock-out power, relieve pressure in hydraulic systems prior to beginning maintenance.

Securing mine machinery for onsite repairs.

Biomechanics

Listing and manhandling rail during track construction and maintenance.

Loading and hauling of heavy timbers.

Heavy lifting, especially overhead.

Strains while clearing blocked chutes and raises.

Handling of replacement conveyor belts.

Lifting and manhandling heavy pipe.

Strains while barring down, especially in high back.

Carrying heavy tools, equipment, and samples long distances, frequently over rough terrain.

Communication

Communications among crew and with surface operator of sandfill pumps.

Missed or confused communication while pulling chute.

Missed or confused communication between motorman and other workers (chute puller, brakeman).

Communication with tugger operator (working in raise).

Errors and missed signals in cager/miner to hoistman communications.

Errors and missed signals to hoistman and skip tender.

Information Transmission

Documentation of sample location.

Inadequate inter-supervisory transmission of information re: location of miners, equipment status, delays, work progress.

APPENDIX B

HUMAN FACTORS PROBLEMS ASSOCIATED WITH CRITICAL UNIT OPERATIONS

HUMAN FACTORS PROBLEMS ASSOCIATED WITH CRITICAL UNIT OPERATIONS

ENVIRONMENT

Visibility and Illumination

Face or back obscured by aerosols and hydrosols.

Detection of bending drill steel.

Realigning boom with drilling hole to insert rock bolts.

Detection of low back and protruding hazards.

Shelter holes hard to locate.

Hazards on track, especially cocked switches and other cars.

Detection of train when cars are being pushed.

Illumination for onsite machine maintenance.

Illumination in grease pit.

Detection of presence of mechanics working on machines onsite.

Blind spots to opposite side, rear, and forward on underground machinery.

Failure to detect presence and position of hoses, cables, and pipes.

Worker conspicuity.

Noise/Vibration

Noise of feedleg & jumbo drills.

Vibration (Raynauds syndrome) from hand-held drills.

High-pressure hose couplings loosened by machine vibration.

Noise of diesel powered equipment.

Whole body vibration on drills, continuous miners, and haulage vehicles.

Geological Hazards

Fall of back.

Flying rocks during collaring and drilling.

Working under unsupported while rock bolting.

Atmospheric Hazards

Wet environment in shaft; often cold in winter, hot in summer.

Respirable dust and radon daughters.

Physical Hazards

Obstacles, holes, hoses, pipes, cables, and insecure footing, causing slips, trips and falls when at worksite and in transit to and from worksite.

Toxic and Caustic Material Hazards

Grease flings off slusher drums onto operator.

EQUIPMENT

Operator-Equipment Interface

Control confusion, inappropriate layout, control-response incompatibility.

Muscle strain and back-lash maneuvering OSL.

Inappropriate use and design of hand tools.

Inherent Dangers

Pinch point between feedleg and drill.

Feedleg slippage.

Operator exposed to hot hydraulic fluid from leaks and burst hoses.

Slips on machine surfaces.

Stoper drill steel stays in hole and falls unexpectedly.

Pinches and burns changing rods in ring drilling.

Rock bolter lurches during traming.

Operator pinched against rib while traming rock bolters and loading with OSL's.

Operator hit by rocks thrown up by rock bolter tires.

Rock bolter boom can drop onto foot of operator.

Heat buildup at operator position.

Inadequate safety screens on slushers.

Operator slips and falls off OSL platform.

Operator pinched or hit by OSL bucket or its contents.

Operator exposed to hot particles from bursting pellet exhaust of trucks.

Pinches and crushes while removing bound steel.

Anthropometry

Access/egress to operator position.

Short operator can't reach controls.

Restrictive operator compartment.

Seat design.

Fixed length levers on slushers used where operator position is variable.

Personal Equipment and Tools

Resin cartridges difficult to insert, especially in high back.

Barring tool design.

Failure to use respiratory protection.

Failure to use eye protection.

Head lamp cord catches on protrusions, due to fixed length.

Burned appendages welding under machinery and in other confined spaces.

TASKS

Job Procedures

Balancing when drilling high and low holes with feedleg drills.

Detection of loose.

Rerailing cars and motors.

Pinches, crushes while coupling cars.

Failure to lock-out power, relieve pressure in hydraulic systems prior to beginning maintenance.

Securing mine machinery for onsite repairs.

Biomechanics

Loading and hauling of heavy timbers.

Heavy lifting, especially overhead.

Strains while clearing blocked chutes and raises.

Lifting and manhandling heavy pipe.

Strains while barring down, especially in high back.

Communication

Missed or confused communication while pulling chute.

Missed or confused communication between motorman and other workers (chute puller, brakeman).

Communication with tugger operator (working in raise).

Errors and missed signals in cager/miner to hoistman communications.

APPENDIX C

ESTIMATING AGREEMENT AMONG THE SAMPLE OF MINE OPERATORS AND MINING ENGINEERING CONSULTANTS

Kendall's "W" or Coefficient of Concordance may be used to estimate the agreement among a group of raters. A significant value of W may be interpreted as meaning that the raters are applying essentially the same standard in ranking the objects under study (in this case the Human factors problems). The raters pooled ordering may serve as a "standard," especially when there is no relevant external criterion for ordering the objects.

Kendall suggests that the best estimate of the "true" ranking of the objects is provided, when W is significant, by the order of the various sums of the ranks. If one accepts the criterion which the various raters have agreed upon in ranking the objects (as evidenced by the magnitude and significance of W), then the best estimate of the true ranking of those objects according to that criterion is provided by the order of the sums of ranks.

The computation formula for Kendall's "W" and the results of its calculation are presented below:

$$W = \frac{\sum (R_j - \frac{R_j}{N})}{1/12\ k^2\ (N^3 - N)}$$

where:

W = Kendall's Coefficient of Concordance

k = Number of raters

N = Number of objects to be rank ordered

R_j = Sum of ranks for object j

In the present calculation:

$k = 18$

$N = 20$

R_j = Sum of ranks for problem j (listed in Table 2-9)

$$W = \frac{105{,}925}{1/12\ (18)^2\ [(20)^3 - 20]} = 0.49$$

The probability associated with the occurrence by chance of any value as large as an observed W may be determined by finding χ^2 by the formula given below.

$$\chi^2 = k\ (N - 1)\ W$$

For the calculated W,

$$\chi^2 = 168.36$$

The critical value of χ^2 with N - 1 or 19 degrees of freedom at the 0.001 level equals 43.82. Therefore, W is found to be significant ($p < 0.001$).

APPENDIX D

SPEARMAN RANK-ORDER CORRELATION (rho) OF MINE OPERATOR AND CONSULTANT RANKS AND ACCIDENT DATA RANKS

Spearman's "rho" is used when an experimenter wishes to determine whether two sets of rank-ordered data are related. In this example, the first set of ranks is the set of 20 human factors problems ranked by the mine operators and mining consultants. The problem with the lowest sum of raters' ranks was assigned a rank of one; the problem with the second lowest sum of raters' ranks was assigned a rank of two and so on.

The second set of ranks was determined by the percentage of accidents associated with each problem from a random sample of 510 accidents during 1978-1979. The problem with the largest percentage of associated accidents was assigned a rank of one; the problem with the second largest percentage was assigned a rank of 2, and so on. Tied problems were assigned a rank equal to the average position they occupied.

Table D-1 presents the two sets of ranks for the 20 human factors problems.

The general formula for computation of Spearman's rho is:

$$\text{rho} = \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum x^2 \sum y^2}}$$

where:

d = the difference between the two sets of ranks for each problem.

$\sum x^2 = (X-\overline{X})^2$

$\sum y^2 = (Y-\overline{Y})^2$

and:

X = Rank of each problem in first set.

$\overline{X}$ = Mean rank in first set.

Y = Rank of each problem in second set.

$\overline{Y}$ = Mean rank in second set.

TABLE D-1. - Human factors problems ranked by raters and by percentage of accidents*

Problem	Raters Sum of Ranks	Raters Rank Order	Percentage of Accidents	Accident Rank Order
Materials Handling	61	1	16.7	1
Detection of Loose	65	2	4.1	4.5
Removal of Loose	82	3	4.1	4.5
Slips and Trips	108.5	4	16.1	2
Hazard Conspicuity	141.5	5	2.9	6
Hand Tools	152.5	6	9.6	3
Eyewear	155.5	7	1.2	11.5
Clearing Chutes and Raises	168	8	1.6	8
Drill Noise and Mist	173.5	9	0.0	18.5
Communication	190.5	10	0.4	15.5
Failure to Secure for Maintenance	196.5	11	1.4	9.5
Derailment	200.5	12	1.4	9.5
Respiratory Protection	208	13	0.0	18.5
Truck/L.H.D. Operator Position	219	14	0.6	13.5
Overshot Loader Accidents	248.5	15	2.0	7
Burns During Welding	263.5	16	0.6	13.5
Vibration	266	17	0.0	18.5
Rock Bolter Controls	271	18	0.4	15.5
Removing Bound Steel	282.5	19	1.2	11.5
Inserting Resin Cartridges	326.5	20	0.0	18.5

* Percentage of a random sample of 510 accident descriptions for 1978 and 1979.

If no ties are present, $\sum x^2$ and $\sum y^2$ both equal the value of $(N^3 - N)/12$ where N equals the number of pairs of ranks. The effect of the tied ranks in the second set of ranks is to reduce the sum of squares, $\sum y^2$, below the total value, that is,

$$\sum y^2 < \frac{N^3 - N}{12}$$

Therefore, it is necessary to correct the sum of squares, taking ties into account. The correction factor is T:

$$T = \frac{t^3 - t}{12}$$

where t = the number of observations tied at a given rank. When the sum of squares of the second set of ranks is corrected for ties, it becomes:

$$\sum y^2 = \frac{N^3 - N}{12} - \sum T_y$$

where $\sum T$ indicates that we sum the various values of T for all the various groups of tied observations.

Substituting into the formulas:

$$\sum T_y = 5\left(\frac{2^3 - 2}{12}\right) + \left(\frac{4^3 - 4}{12}\right) = 7.5$$

$$\sum y^2 = \frac{N^3 - N}{12} - \sum T_y$$

$$\sum y^2 = \frac{20^3 - 20}{12} - 7.5 = 657.5$$

No ties are found in the first set of ranks, thus:

$$\sum x^2 = \frac{N^3 - N}{12} = 665.0$$

$$\text{rho} = \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum x^2 \sum y^2}}$$

$$\text{rho} = \frac{665.0 + 657.5 - 339.5}{2\sqrt{(665)(657.5)}}$$

$$\text{rho} = 0.74$$

When N, the number of pairs of ranks is 10 or larger, the significance of an obtained rho may be tested by:

$$t = \text{rho}\sqrt{\frac{N - 2}{1 - \text{rho}^2}}$$

That is, for large values of N, the value defined above is distributed as Student's t with degrees of freedom equaling N - 2. Thus the probability that the computed value of Spearman's rho could have occurred by chance may be determined by computing the t associated with that value and then determining the significance of that t by referring to a table of the student's t distribution.

Substituting:

$$t = 0.74\sqrt{\frac{20 - 2}{1 - (0.74)^2}}$$

$$t = 4.67$$

For 18 degrees of freedom and a significance level of 0.001, the critical value of t for a two-tailed test is 3.92. Therefore, rho is significant ($p < 0.001$).