BUREAU OF MINES ERGONOMIC RESEARCH TO REDUCE BACK INJURIES AND IMPROVE ERGONOMICS ASPECTS OF MINING EQUIPMENT

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ABSTRACT

In the past few years, several companies in the mining industry have come to realize that ergonomics is an effective method of controlling costs and improving the health and safety of workers. Benefits that may be derived through the ergonomics approach may include more efficient operation, fewer accidents, lower operating costs, and more effective use of personnel. This paper discusses the use of ergonomics to reduce the cost and incidence of back injuries and to improve the design of mining machinery in underground coal mines.

CONTROLLING THE COST OF BACK INJURIES IN MINING

It is estimated that approximately 25 pct of all injuries in the mining industry involve trauma to the back, and that the cost of back injuries in coal mining alone exceeds $20 million a year. However, the tremendous cost of these injuries is overshadowed by the human disability and suffering experienced not only by the affected miners, but by their families as well.

Unfortunately, the underground coal mining environment presents some uncommon barriers to preventing back injuries. The restricted roof height of many low-seam coal mines (mines with seams less than or equal to 48 inches) forces workers to adopt exceptionally stressful working postures during manual lifting activities, generally stooped or kneeling, which produce a considerable strain on the low back. This may help to account for the high incidence of low-back pain in coal miners. The use of certain types of mechanical-assist devices is also made more difficult by the confined workspace of low-seam mines. In addition, poor illumination and slippery footing serve to compound the problems associated with underground materials-handling.

The traditional approach to reducing the risk of back injuries has been to train miners to cope with the existing conditions. Unfortunately, the effectiveness of this method has been relatively limited and new approaches are needed. This section briefly describes methods that can be used to redesign hazardous materials-handling tasks to reduce the threat of injury to workers.

Additional information may be found in Bureau of Mines Information Circular 9235 (Gallagher *et al.* 1990).

A MODEL FOR REDESIGN OF MATERIALS-HANDLING TASKS

The model in Figure 1 outlines the steps that should be followed (and questions to be asked) when developing alternative materials-handling strategies.

Examining the Current Supply-Handling System

The first step to developing safer materials-handling procedures is to carefully examine the current supply-handling system and to identify materials-handling problems that can be modified. In addition, goals for reduction in materials-handling accidents should be established.

A review of past accident records and a task analysis (usually a videotaped analysis of hazardous jobs or tasks) can be helpful in distinguishing areas where job or task redesign is needed. The analysis of past accidents identifies occupations and activities that lead to injuries, so they can be prevented in the future. Obviously, the occupations or tasks with the highest injury rates are primary candidates for redesign strategies.

After analyzing accident statistics, problem areas should be visited and hazardous tasks should be documented so that alternative materials-handling strategies can be considered. This can be performed using a task analysis that identifies the hazardous components of a job. Videotape, still photography, and portable tape recorders can all be used in this identification process. Videotape is the preferred method, because it can be subsequently reviewed as often as necessary to provide required information to develop alternative strategies. However, videotape equipment is not permissible, and may be used only outby the last open crosscut.

Evaluating Alternative Strategies

Once specific materials-handling problems are identified, it is necessary to consider ways of modifying tasks to increase their efficiency and safety. As seen in figure 1,

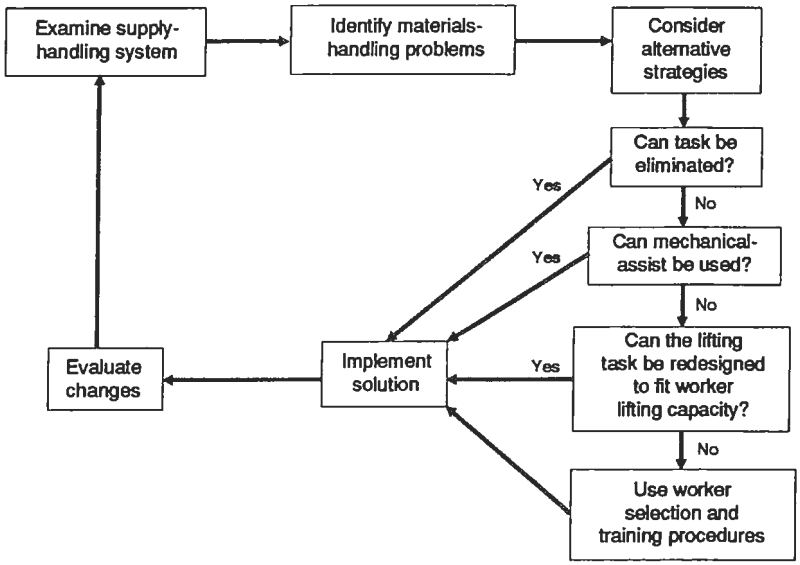

Figure 1. - A simple model for analysis and redesign of materials-handling tasks

the redesign techniques that should be considered (in order of preference) are (1) elimination of the task, (2) use of a mechanical assist device to perform the task, (3) redesigning the manual lifting task according to the physical capabilities of the worker, and (4) using worker selection and training procedures. These techniques are discussed in more detail below.

Task Elimination

The optimal solution is to eliminate unnecessary materials-handling tasks. in some cases, this may be as easy as having the supplier deliver items in a different configuration. For example, posts are often delivered to mines as individual pieces. This makes it more difficult to use mechanical-assist devices to handle the loads, which ultimately leads to increased manual handling of these items. However, some mines have found that banding posts into a unit load is an effective method that makes it much easier for mechanical-assist devices to be used both in the surface supply yard and underground. In fact, the post supplier also preferred the banding arrangement and was more than willing to make this change.

Using Mechanical-Assist Devices

If a task cannot reasonably be eliminated, the next best redesign strategy is to use mechanical devices to perform the job, until manual handling becomes absolutely necessary. One problem is that many mines do not keep supplies palletized or in unit loads long enough. Often supplies are delivered on pallets but miners immediately break the pallets and load supplies manually onto supply cars. This increases the chance of back injury. If supplies are palletized longer, the number of times the supplies can be handled mechanically increases (via forklift or front-end loader), and the number of times that materials must be handled manually decreases.

When individual supply items cannot be palletized, specialized tools or devices may be needed to assist in handling them. However, there appear to be virtually no mechanical-assist devices to aid in handling heavy, bulky items in low-seam mines. The Bureau has therefore initiated research specifically addressing the materials-handling problems that occur after supplies have been delivered underground and are being used during mine or equipment maintenance. This research has indicated that inexpensive and easily fabricated mechanical-assist devices can be developed, decreasing the risk of a low-back injury.

Match Job Demands to Worker Capabilities

Unfortunately, some of the supply-handling tasks in underground mines are of such a nature that they cannot be eliminated or mechanized. Even supplies that are palletized or handled as large units may have to be handled repetitively as individual items during their final end uses. In such cases, it is important that the manual lifting tasks that the workers must perform do not exceed their lifting capacity. While a great deal of lifting research has been accomplished in recent years, most of it has been aimed at establishing the amount of weight that can be safely lifted in unrestricted postures. Most of the results are of little use in low-coal mines. Recently, several Bureau studies have examined the lifting capacity of underground miners in both stooped and kneeling postures. Studies in the Bureau's Ergonomics Laboratory have shown that there is a significant reduction in the amount of weight that can be safely lifted in the kneeling posture, compared to a stooped posture. For compact repetitively-handled loads (such as rock dust bags, stopping block, cribbing block, etc.) the recommended weight of lift is 55 pounds in the stooped posture, but only 45 pounds in the kneeling posture.

These results have important implications for the amount of weight that supplies should have when delivered to low-seam mines. Rock dust is typically packaged in 50-pound bags, which is an acceptable weight to lift in the stooped posture; however, it exceeds the recommended weight for the kneeling posture. Serious consideration should be given to packaging rock dust in 40-pound (instead of 50-pound) bags when miners have to repetitively lift rock dust bags in a kneeling posture.

Worker Selection and Training

In addition to the primary redesign techniques described above, there are other methods that involve worker selection and training. While the emphasis of this paper is on redesign of materials-handling tasks, worker selection and training are sometimes the only way to reduce the injury risk. Selection of workers usually includes evaluation of one or more of the following: physical strength, aerobic capacity, or a clinical examination of the individual. It is important that the test or tests administered be directly related to the specific demands of the job in order to prevent accusations of discriminatory selection procedures.

Worker training does not appear to be as effective in controlling injuries as the previously described methods. However, it can assist the worker if the following areas are covered: risks of unsafe materials handling, basic anatomy and biomechanics of lifting, use of mechanical assist devices, and accident avoidance. Active involvement of the worker during the training process is crucial to the success of the program.

Implement Solution and Evaluate Changes

Once a choice for the redesign of the task has been made, the new strategy must implemented. Communication with a number of individuals not influenced by the process until this point may play a very important role in whether inplementation of the strategy is successful or not. Although management may initiate a new method of performing a particular task, implementation will be difficult unless the idea is supported by the miners it affects.

Evaluation of the newly implemented materials-handling strategy is another essential step. Occasionally, the strategy used to redesign a task may overlook important unintended consequences. Therefore, it is crucial to get feedback on how the changes are working and how well the miners are accepting the new procedures, and suggestions on how the new plan might be made more effective can be solicited. Evaluation should consist of a systematized method of determining if the redesign strategy has fulfilled the desired goal of reducing the worker's risk of injury. An excellent method of establishing the effectiveness of a job design change is to perform a second task analysis, and to document the reduction in back injury risk factors compared to when the job was initially analyzed.

The Role of Management in Reducing Costs

Despite the benefits that can be derived from the redesign techniques described above, management must realize that not all back injuries are preventable. When they do occur, management's policy for dealing with the injury may have a significant role in determining the duration of the disability, and the costs to the company. Often, management often does not respond properly. The injured worker may be suspected of malingering; this, in turn, causes the workers to try to "get back" at management. As adversary situations develop, costs of the injury may increase significantly for both the worker and management. However, enlightened management can often reduce and perhaps even prevent the disability associated with low-back pain through a program of positive acceptance of low-back

pain, early intervention, good communication and follow-up, and early return-to-work programs.

This section has briefly recommended practices that can reduce the incidence of back injuries and other musculoskeletal injuries. Redesign techniques such as task elimination, use of mechanical-assist devices, designing manual-lifting tasks to worker lifting capacities, and worker selection and training procedures have been discussed; the role of management has also been considered. If correctly implemented, these can have a significant impact in reducing the cost and incidence of back injuries in low-seam coal mines.

EQUIPMENT DESIGN PROBLEMS IN UNDERGROUND MINING

Designing crewstations for underground mining equipment is a formidable task. Massive machinery is required to meet production goals while the confined environment imposes severe space restrictions in every direction, most critically in height. As a result, operator compartments are frequently cramped and poorly designed. In fact, crewstations which provide operator accommodations of less than 30 inches in height and 24 inches in width are not uncommon. In these cramped quarters, visibility is often severely impaired, forcing operators to lean outside of the protection of their crewstations in order to see. When lighting systems are provided, they may be positioned where they cause excessive glare, which further restricts the visibility of those working on or around the machines. Critical controls are often placed where they are difficult for some operators to reach in the awkward seating postures which they must assume. In panic situations, the wrong control may be activated, which can lead to an accident.

To effectively meet the challenges of underground equipment design, manufacturers must address a variety of human factors issues. However, studies indicate that this is rarely the case. A study of 44 design engineers conducted during the 1970's concluded that: "One of the most consistent findings of our research, confirmed in each study with all subjects regardless of sophistication, years of experience, or design problem, is that the typical design engineer does not consider human factors in his design" (Meister, 1971).

Although this study was conducted twenty years ago, the problem still exists today. An informal survey conducted in 1986 at a Bureau sponsored seminar on mine equipment design found that none of the participating design engineers from a major mining equipment manufacturer had ever received formal training in either the design process or in human factors design. In fact, most admitted overwhelming reliance on designs that had been used before rather than on development of novel approaches.

PROMOTING AWARENESS OF HUMAN FACTORS DESIGN

Given the mining industry's lack of expertise in human factors engineering, the Bureau has been attempting to provide it with products to assist in the equipment design process. Several guidelines have been developed, including a maintainability design reference manual and a textbook on human factors in mining. In addition, a database containing abstracts of human factors research applicable to mining was developed and made available to anyone with a Digital Equipment Corp. VAX compatible terminal and modem. One recent Bureau research project that shows promise of impacting how engineers think about the mining equipment design process is the development of the Crewstation Analysis Programs package. CAP is a set of computer programs that can

be used to analyze some of the human engineering aspects of crewstation design that have particular significance in underground mining. These programs include assessments of visibility, illumination, and glare in the surrounding work area. Other work is focusing on seating design with respect to operator comfort. The following sections provide more information on some of these equipment related projects.

CAP VISIBILITY ANALYSIS

Visibility is a significant problem in the underground mining environment. During the early 1980's, the Bureau of Mines sponsored research to determine minimum visibility requirements for three classes of underground mining machines: shuttle cars, scoops, and continuous miners. Using structured interviews and on site task analyses involving approximately 100 subjects, the researchers first identified the tasks involved in the operation of each class of vehicle, such as loading, hauling or unloading. Then, the machine operators were interviewed to identify the visual information required to perform each of these tasks. For example, a shuttle car operator performing a loading task would need to see the positioning of the shuttle car under the tail boom of the continuous miner. While hauling, the location of the shuttle car and any obstacles in the roadway would be required. Following the interviews, the operators were observed while performing the tasks to verify the visual information requirements established in the interviews (Sanders and Kelly, 1981).

Once the requirements were determined, a methodology was developed to identify specific points in the front-to-back, side-to-side, and vertical planes that must be visible to the operator to satisfy the visual requirements. These points, called Visual Attention Locations (VALs), were defined in reference to generic locations on the machine. This allowed the VALs to apply to all configurations of a particular equipment class. For instance, during a hauling task, a shuttle car operator must be able to spot an obstruction on the ground while there is enough time to stop the vehicle. The location of one of the VALs associated with this requirement is described in figure 2.

Using this methodology, the procedure involved in computing the location of the VAL is the same even if the length of the equipment, the operator's position, or the height of the equipment is modified. Therefore, the VAL is applicable to all equipment in the shuttle car class.

The results of this VAL research have been incorporated into the CAP package. The CAP visibility model automates the task of determining whether or not the required VALs are visible to a selected human operator, currently either a fifth percentile female or ninety-fifth percentile male. The output is a relative visibility rating for the

Coordinate Plane	Position of VAL
Front-to-Back	Front Edge of machine + Necessary Stopping Distance
Side-to-Side	Machine Center Line
Vertical	Floor

Figure 2.-Visual attention location positioning

machine which can be compared with results of alternative machine designs. CAP also provides both graphical and tabular output to pinpoint any machine parts which obstruct visibility.

CAP ILLUMINATION AND GLARE ANALYSIS

Due to the perpetual darkness of the underground environment, illumination and glare are factors which must be considered when designing equipment for optimal visibility. Federal regulations specify that certain surfaces within a miner's normal field of vision must be illuminated to 0.06 footlamberts while self-propelled mining equipment is being operated. The 0.06 footlambert level is a measure of luminance, or photometric brightness. It is a product of the level of illumination (incident light) impinging on a surface, and the reflectivity of the surface. Bureau research has shown that the 0.06 footlambert level is adequate for most mining tasks and is low enough so that operators will not experience severe adaptation problems when moving from illuminated to non-illuminated areas of the mine (Lewis, 1986).

Unfortunately, in attempting to meet these illumination standards, mine equipment designers often aggravate another mine lighting problem - glare. There are currently no standards related to glare in underground mining. The regulations state only that designers should attempt to minimize glare when developing machine illumination systems. Obviously, performing all of the calculations required to compute glare for a multitude of machine and lamp types, with the possible combinations running into the thousands, is too tedious and costly to be practical using manual methods. The result is that the designer is impeded significantly in solving for an optimal illumination system that minimizes glare.

The CAP illumination model eliminates these problems by turning the computational portion of the lighting design task over to the computer. The software allows the lighting designer to concentrate on adjusting the configuration of the illumination system to minimize the potential for glare while still providing enough illumination to conform to the Federal regulations.

Specifically, CAP generates a three dimensional representation of the digitized mining machine, allows the user to input a lighting system, and then calculates the level of illumination in designated areas surrounding the machine. Using these values of illumination, the user may perform Disability Glare comparisons by calculating the luminance contrast of objects of interest along selected lines of sight. The luminance contrast is the relationship of the luminance of an object to its immediate background. In an underground coal mine, the background is usually the walls, floor or roof of the tunnel being mined, which has a known luminance value.

MAINTAINABILITY DESIGN GUIDELINES

Forty years ago underground coal mining equipment consisted of relatively simple machines maintained by miners equipped with a basic knowledge of hydraulics, electricity, and mechanical design. These miners were expected to maintain all of the equipment at the mine site using only simple hand tools.

Today, the basic mining machine has been transformed into powerful, complex mining systems. To increase throughput, continuous miners, long and short wall systems and continuous haulage were introduced. To boost productivity, machines were designed to perform multiple functions, such as miner/bolters. To reduce injuries, safety features such as illumination systems have

been added to the machine. To protect the miners' health, environmental control systems such as dust scrubbers have been tacked on.

With few exceptions, however, little improvement in the basic design of equipment for maintainability has been made. In many cases, equipment maintainability has been sharply decreased. Many of the above design changes were achieved by simply modifying existing machine designs. On certain mining machines, sharp reductions in maintainability, and consequently, maintainer safety, were experienced as a result of added-on safety and environmental systems designed only with the machine operator in mind.

Even with all of these changes, the maintainer is still expected to service and repair these ever more complex machines. This must be accomplished in a setting providing little in the way of new maintenance tools, procedures, automatic test equipment, or other technology-based maintenance aids, and in an environment that usually lacks proper lighting and clearances. All in all, there has been little concern directed at the well being of the maintainer. It is no wonder that equipment maintenance has traditionally accounted for one-third of all lost-time injuries in underground mines. This injury rate persists in spite of concerted efforts on the part of mine management to minimize accidents, Mine Safety And Health Administration (MSHA) efforts to enforce health and safety rules, and Bureau of Mines efforts to conduct safety research.

A review of current mining equipment design suggests that considerable improvements in safety, as well as substantial cost savings, could be achieved with relatively simple design improvements. For example, by relocating difficult to access but frequently replaced hydraulic valves and hoses on certain roof bolters, this one hour plus Removal and Replacement (R/R) task is reduced to a five minute operation. Improved component accessibility and increased ease of R/R reduces the maintainer's risk of injury. Numerous other maintenance improvements could be realized with minor design changes on new or existing equipment.

Equipment users and manufacturers recognize the need for improved design for maintainability. Many mines, in fact, are currently modifying or rebuilding equipment to facilitate maintenance. Several mining Original Equipment Manufacturers (OEM) contacted as part of a Bureau of Mines project are actively seeking ways to improve the maintainability design of their equipment. Two of these OEMs have impressive research efforts directed at incorporating new maintenance technology into their designs. At least one mining OEM is exploring innovative new technologies in an effort to enhance the overall maintenance process. Most end users and manufacturers admit, however, that additional maintainability design improvements are warranted.

The Bureau of Mines conducted a research project to analyze the design of underground mining equipment with respect to ease of maintenance and maintainer safety. The work included a review of maintainability design literature, an analysis of maintenance related accident data, field reviews of equipment designs, and interviews with mine maintenance personnel and equipment manufacturers. Based on the findings, a set of maintainability design recommendations have been prepared. The final recommendations document includes maintainability engineering information for equipment designers, as well as a buyers' guide to aid purchasers of mining machinery in evaluating the maintainability of equipment (Conway, 1988).

SEATING DESIGN

The effects of shock and vibration experienced while operating mobile equipment is a growing concern in the underground mining industry. During some informal tests in a low seam coal mine,

Bureau researchers found that riders on a typical 30 minute mantrip were exposed to nearly 35 percent of the 8 hour exposure limit set by the International Standards Organization (ISO) for vertical whole body vibration. This limit is intended to protect workers from physical injury or disease caused by daily exposure at work. Another Bureau research program conducted a limited evaluation of the exposure of underground coal mine equipment operators to whole body vibration. The data indicated that 33% to 39% of the operators are exposed to vibration levels that exceed the ISO fatigue decreased proficiency level, which is intended as a measure to insure worker efficiency. They also found that 7% to 14% of the operators exceeded the exposure limit. Compounding the vibration problem are the height restrictions in many underground mines which force operators to assume awkward seating postures. These postures, when coupled with a lack of vibration isolation on the machine, can lead to increased levels of fatigue and stress.

The Bureau of Mines has an ongoing effort underway in an attempt to better understand the effects of whole body vibration on miners and to improve seating design. A laboratory study to determine the transmissibility of various seating materials used for mining equipment was conducted and the results are currently being analyzed. The knowledge of the transmissibility of the tested materials may aid in the improvement of equipment seating and the reduction of vibration and shock exposure to equipment operators.

Field data collection to further quantify the extent of worker exposure to whole body vibration is ongoing. The data collection is focusing on frequency spectrum assessment. The spectrum must be well defined if engineering solutions are to be found to reduce the exposures to harmful whole body vibration.

The Bureau is also cooperating with mining companies to aid in the reduction of worker exposure to whole-body vibration. At one mine data was collected to test the effect of foam filled tires as compared to air filled tires on shuttle cars. Another company is working with the Bureau on improving seating suspension and padding on shuttle cars through field and laboratory experiments.

SUMMARY

The underground mining environment presents relatively unique barriers to proper design of supply-handling systems and underground equipment. However, the rapid emergence and continuing development of mining ergonomics provides mines with new and innovative solutions that can reduce the risk of accidents and injuries, with a concomitant cost reduction. This article has briefly summarized ergonomic methods that can be helpful in controlling costs associated with back injuries and accidents that result from poor equipment design.

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