METHODS TO MINIMIZE INJURIES IN MATERIALS-HANDLING PROCESSES IN UNDERGROUND MINES

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ABSTRACT

Handling materials in underground mines continues to be a major safety problem. To help reduce materials-handling injuries, researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health are investigating those materials-handling tasks in underground mines that appear to generate a high number of injuries. Data from the Mine Safety and Health Administration for the years 1989-1999 were studied to find out if there were any trends in materials-handling accidents and if so, to determine what tasks were involved and the sources of injuries. Several underground coal and metal mines were visited to document innovative materials-handling technologies. Considerations for safety training and mechanization needs for continued reduction in materials-handling injuries are described.

INTRODUCTION

Materials-handling problems in underground mines and injuries associated with materials handling have been well documented (Peay 1983; Gallagher et al. 1990). Given the nature of the underground environment (poor lighting, poor footing, confined spaces, etc.), the amount of supplies and equipment needed daily, and the diversity of tasks, injuries resulting from materials handling will probably never be eliminated. The number of such injuries is directly related to the number of manual tasks. Numerous materials-handling tasks can only be done manually, and hundreds of these tasks are performed in underground mines each day. They involve pulling, hanging, pushing, and lifting objects of different weights, shapes, and sizes. Lifting and re-lifting supplies several times before they are used is not uncommon. In many common tasks, the supplies have to be lifted above the shoulders and the body is twisted during the lift, resulting in overexertion of the back and other body parts. Many times, for reasons of expediency and in the absence of help, a worker tries to lift materials or handle equipment that is too heavy.

The 10 most common materials-handling activities that resulted in reportable injuries numerous times in underground coal and metal mines in 1999 and the approximate number of occurrences are shown in table 1. Some are unique to coal mines, some to metal mines, and some are common to both types of mines. Mine injury records may include more detail than reports submitted to the Mine Safety and Health Administration (MSHA), such as what was lifted and how and why the lift was made. They may also indicate activities other than those listed in table 1 as priority activities that need immediate attention.

Table 1.– Underground materials-handling activities and number of injuries in 1999 (MSHA 2000)

Activity	No. of occurrences
Moving cable (primarily trailing cable)	117
Moving roof bolt supplies	85
Moving conveyor belt parts	69
Loading/unloading supplies in and out of carriers	50
Moving roof support supplies (timbers, beams, cribs, etc.)	25
Construction activities (stoppings, bulkheads, overcasts, etc.)	25
Moving rock dust supplies	23
Lifting, hanging, pulling objects overhead	23
Moving, shoveling rock, coal, debris	16
Moving pumps	11

In 1989, Stobbe et al. conducted an extensive investigation of back injuries in underground coal mines. The authors of that report found “considerable diversity in the situations which produce back injuries. Of the 156 scenarios which produced back injuries, 130 occurred only once, 17 occurred twice, 4 occurred three times, 1 occurred six times, 2 occurred eight times, and 2 occurred 10 or more times.”

It appears not much has changed in underground mines in the last 10 years with regard to materials handling.

Materials-handling injuries are still the leading cause of injuries, and the back is the body part getting injured the most. A review of data from 20 underground mines investigated in this study indicated that, for the year 1999, 25% of 860 reportable accidents at these mines were classified as materials handling. Fifty-two percent were overexertion-type injuries, and 58% of these were injuries to the back (Figure 1).

Materials-handling injuries and incident rates for underground coal and metal/nonmetal have also decreased during the same period (Figures 3 and 4). These figures also show that materials-handling incident rates for underground coal mines are twice as high as rates for underground metal/nonmetal mines. Reasons for this difference may be that coal mines have more confined spaces, are less mechanized, conduct inadequate materials-handling training, and may require more manual tasks. One of the primary tasks of this project is to address these issues and provide useful information to reduce materials-handling incident rates in underground coal mines.

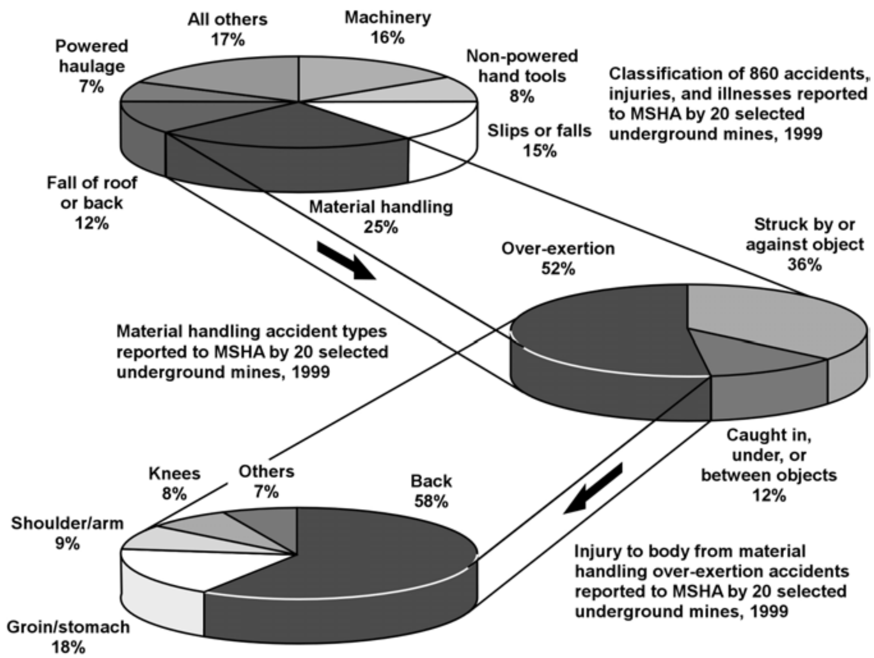

Figure 1.—Materials-handling injuries from 20 underground mines, 1999.

From 1995 through 1999, the highest percentages of reportable lost-time accidents in underground coal, metal, and nonmetal mines were classified by MSHA as materials-handling accidents. In that 5-year period, 33% of all lost-time injuries in underground coal mines, 24% in underground metal mines, and 31% in underground nonmetal mines were due to materials handling.

Although lost-workday injury rates related to materials handling in mines decreased between 1988 and 1997 (MSHA 1999; National Institute for Occupational Safety and Health [NIOSH] 2000), the number of lost workdays was still significant, and the cost to the mining industry each year was tremendous. During that time, 58,661 lost-workday cases resulted in an average of 34 days lost (including restricted days) per case. Over 21,000 of the lost-workday cases were in underground mines.

The good news is that overall lost-time injuries and injury rates have steadily decreased (figure 2). The number of lost-time injuries in underground coal has decreased from 8,553 in 1990 to 3,351 in 1999, a 61% reduction, and lost-time injury rates have decreased from 12.7 per 100 full-time equivalents (FTE's) to 8.7 per 100 during the same period.

The first step to reducing materials-handling injuries further is to determine the activities and actions that cause injuries. By keeping good daily records, each mine can track injury-causing activities and actions. Record-keeping is also important for tracking increases in incident rate. Consecutive incident rate increases need to be investigated and causes determined.

Causes of materials-handling injuries will be different at each mine, depending on mine size, type of mining, equipment used, and other factors. Safety personnel need to focus on priority activities, that is, activities that result in numerous accidents, and make changes to the activity or the way that activity is performed. Close communication with miners who perform these activities is essential.

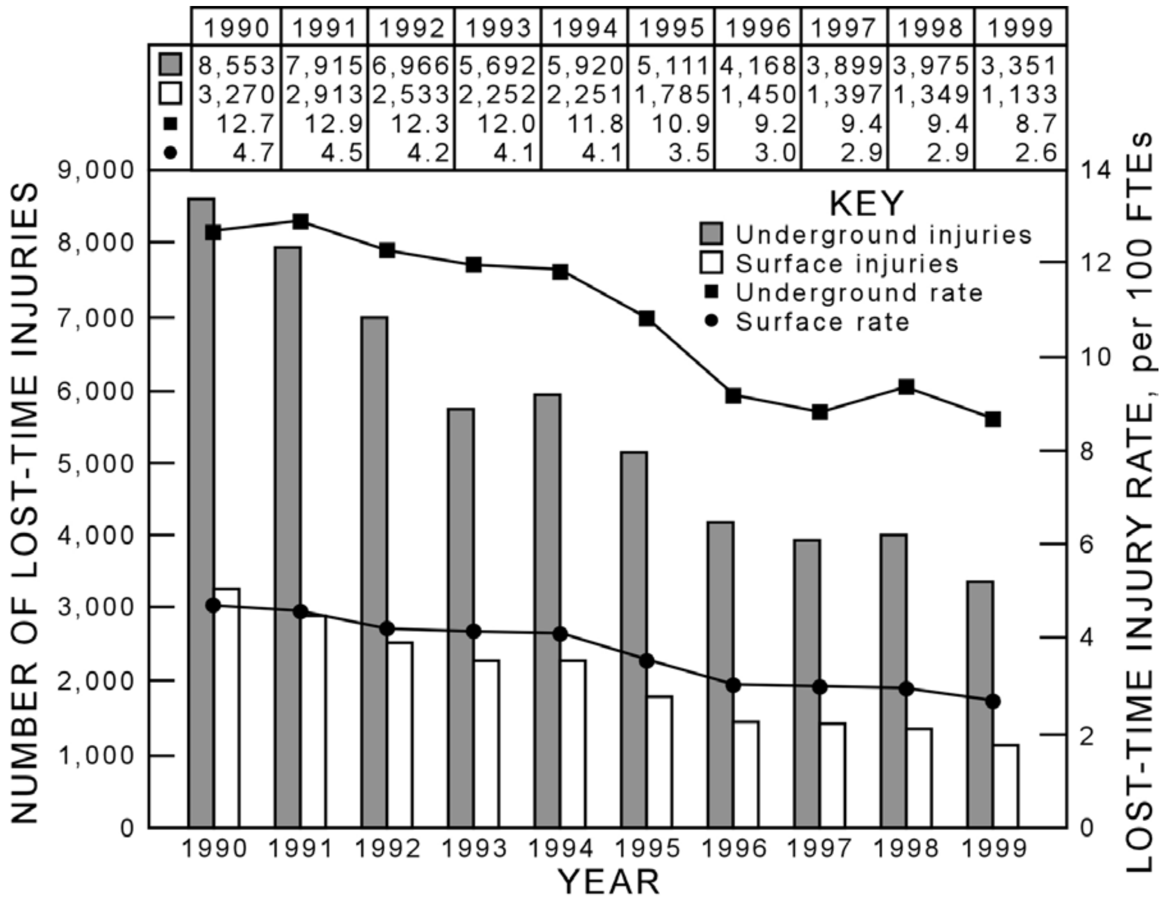

Figure 2.– Coal mining operator lost-time injuries, 1990-1999.

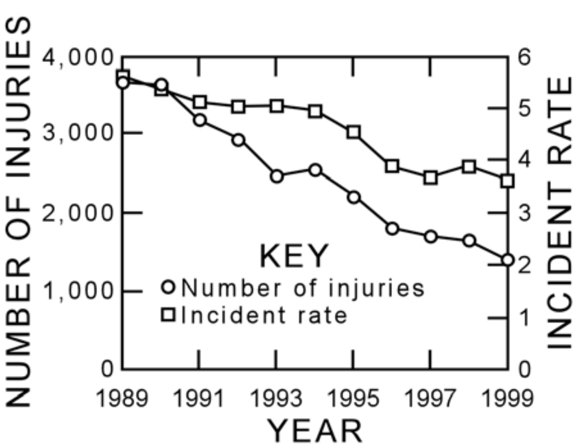

Figure 3.– Underground coal materials-handling injuries and incident rates, 1989-1999.

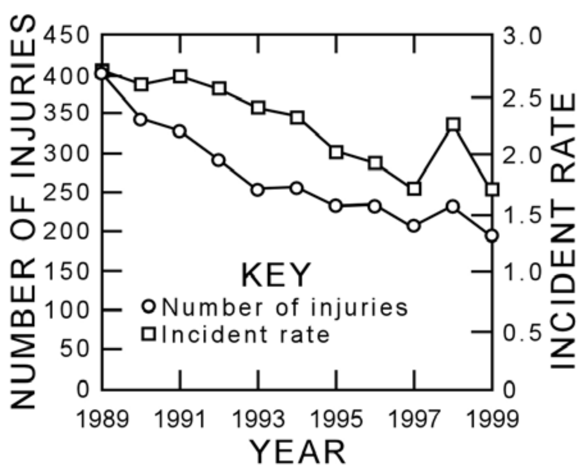

Figure 4.– Underground metal/nonmetal materials-handling injuries and incident rates, 1989-1999.

OBSERVATIONS OF MATERIALS-HANDLING ACTIVITIES DURING MINE VISITS

Several innovative designs, procedures, and equipment for reducing materials handling injuries were observed during mine visits. Many of these involved the use of mechanized equipment to aid in lifting.

Can Cribs

General improvements in materials handling in underground ore deposits in the western United States include replacing wood cribs with can cribs for roof control. The can is a few inches shorter than seam height and consists of a metal jacket approximately 76 cm in diameter with a wall thickness of 1 cm filled with lightweight grout (Figure 5). The can is fabricated off-site and shipped to the mine in predetermined lengths so it can be transported horizontally. It is rotated upright in place, capped with wood, and wedged against the roof. The use of cans reduces lifting and pinch-point exposures. Cans allow stress release, as do wood cribs. An attachment adapted to existing equipment is used to grip and lift the can off the floor or a trailer and rotate it into position (Figure 6). Much less manual labor is required to set a can crib support than is required to set a wood crib support, resulting in fewer materials-handling injuries.

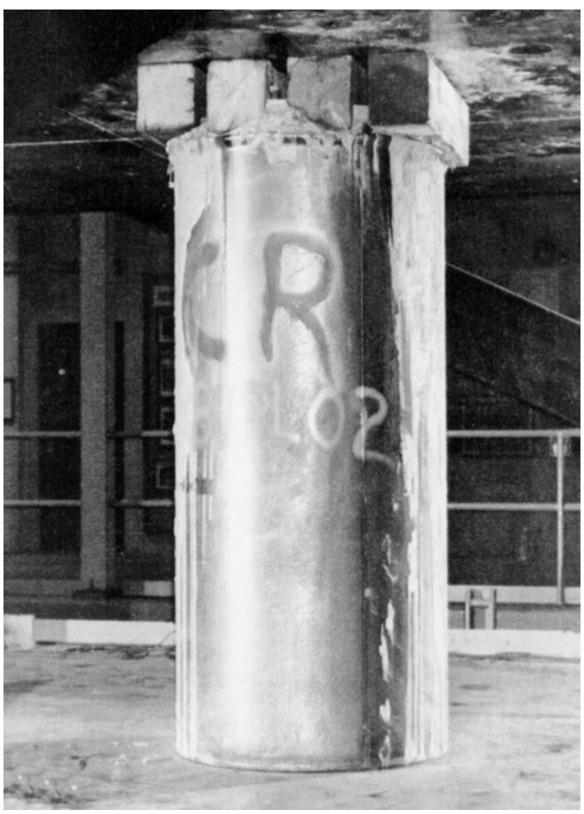

Figure 5.—Can crib used to replace wood crib in underground coal mines.

Figure 6.—Attachment used to pick up and maneuver can cribs.

Conveyor belts

Labor-intensive handling of belt-support structures has become commonplace. The weight of materials handled by workers has doubled over the past few years as a result of using wider belts, which has increased the number of back injuries incurred during this activity. Belt suppliers and mine personnel are coping with the demands of increased weight in several ways.

Increasing space. Mechanizing belt installation underground is an engineering challenge. The working space is narrow and uneven. A wider working space beside the belt in the same entry as the belt would greatly enhance materials handling for installation, removal, and maintenance of the belt line. However, in most cases, belt entries cannot be widened without jeopardizing roof control.

There are two approaches to creating more working space without widening total entry width. One is better utilization of the present working space by using smaller equipment. Underground mines are using small loaders to meet this demand. Manufacturers have an assortment of attachments that have worked very satisfactorily with few modifications for underground settings. A second approach is to eliminate space on the nonworking side (off side) of the belt by installing the belt closer to the off-side rib (Figure 7). Moving the belt closer to the off-side rib and using smaller equipment has resulted in keeping entry widths under 6 m, and, in some cases, under 5.5 m. These roadways are not main roadway widths, but with smaller equipment designed for belt work, the roadways are adequate.

Having a roadway beside the belt in the same entry has several materials handling accessibility advantages. These include—

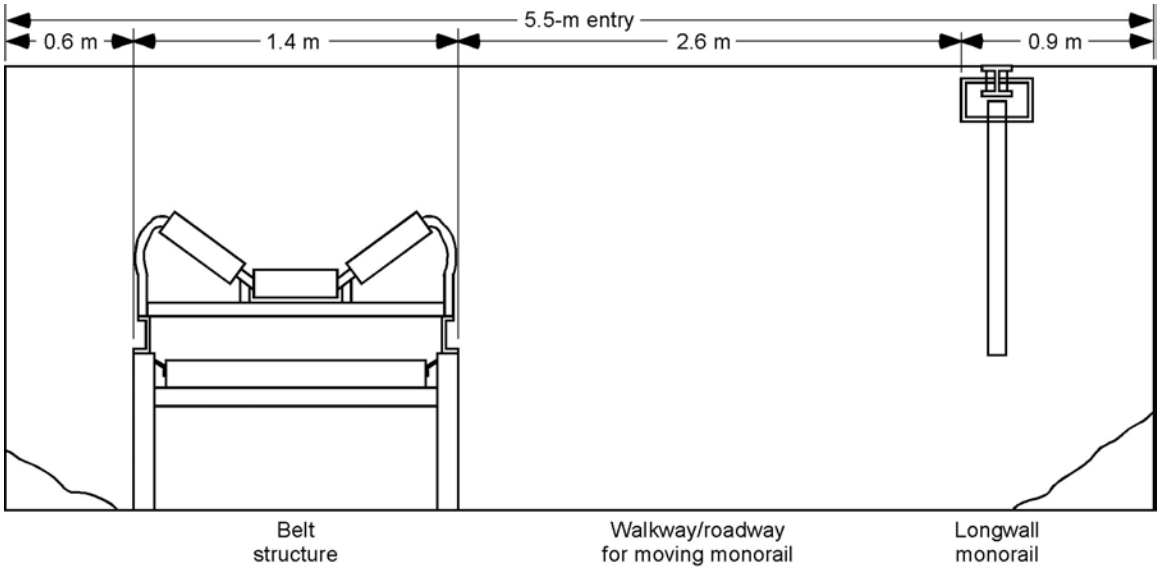

Figure 7.—Layout for belt entry to accommodate materials-handling equipment.

- Allowing a piece of equipment to be available for lifting materials during installation.
- Eliminating the need to carry materials between crosscuts during maintenance.
- Allowing better inspection of the belt for maintenance and during a belt shutdown.
- Allowing better access for cleaning underneath the belt with mechanized equipment.
- Allowing more thorough rock dusting.

Placing and removing belt rollers. The manual process of placing and removing rollers in belt extensions on continuous miner advance, longwall retreat, and roller maintenance change-out involves bending and lifting the heavy rollers. Innovative methods have been developed to separate the belt for removing rollers on the longwall. In one mine, the last top belt roller is mounted to one end of two H-beams, and two hydraulic jacks are mounted to the other end. The H-beams are pinned to the tailpiece near the middle of the beam. Through a lever-type arrangement, when the two hydraulic jacks push one end of the beam down, the top roller and belt are lifted. When the belt roller is lifted, the distance between the belts is increased, and the belt is completely lifted up from the second roller from the tailpiece. Lifting the top belt makes the second roller accessible for removal and eliminates the need to lift the belt manually. The tailpiece uses hydraulic power during normal operation. This method could be used on any tailpiece and reduces the potential for accidents when removing the roller.

Another technique is to use an air bag to separate the belt to facilitate adding rollers in the belt advance process. Access to compressed air is necessary to using an air bag, but a mine may be able to utilize this technique in combination with other techniques.

A very successful approach for lifting the top belt for adding the roller has been to use small loaders with an attachment bar (a standard hard-roll steel bar bolted horizontally to the bucket). The advantage of the loader is that it can be employed to carry the roller and lift the belt. The loader is faster and eliminates the process of a worker lifting and bending while holding a come-along and chains or manually placing an air bag prior to inflation.

On super-wide (1800 mm) belt structures, the weight of a single top idler is approximately 127 kg, and the return idler weighs 118 kg. To reduce the weight of any one unit, mine engineers and conveyor belt manufacturers redesigned the structure by breaking it into several individual components. This not only made individual components lighter, but also provided a more compact assembly for transporting the structure into and out of the mine.

Conveyor belt cleaning. When transporting coal with belt conveyors from the working face to the portal, fine coal particles stick to the belt beyond the discharge point. Residual materials (carryback) stick to the bottom belt. Belt cleaners are installed at the head roller area to remove the sticky materials. If in good mechanical condition, the cleaners clean off approximately 95% of the carryback. The remainder is jarred and scraped off as the belt returns to the tail roller. In a three-shift-per-day operation, it is not uncommon for 2 tons or more of carryback to be deposited on the mine floor per week of belt operation. The carryback is usually wet when deposited, but dries over time. This becomes very dangerous. Coal dust particles are very small and, if ignited, burn very quickly, to the point of exploding. U.S. regulations require cleaning belt lines to remove the danger from carryback exploding.

The standard method of cleaning the carryback is to use a long-handled, flat shovel to pick up coal dust and place it back on the belt. However, the coal dust is sticky and clings to the shovel blade. Cleaning is time consuming, and workers are prone to injuries while twisting and dumping. To reduce costs and accidents, one mine operation has purchased specialty scoops to clean under the belts. The scoops must be small to operate in narrow spaces and should have an extended flat bucket to reach under the belt line. A roadway along the belt lines must also be present to operate the scoops.

Industrial vacuums can also be used to clean the area around conveyor belts. In most cases, the vacuums are used to clean high-spillage areas, such as dumping points and the bottom of declines. The vacuum system has been proven in many other industrial situations. Vacuum suppliers and underground mines are working to develop a lower-profile, mobile version for belt lines.

Roof bolt supplies

Innovative approaches to reducing manual materials-handling tasks include loading skids and specialty trailers on the surface and using face equipment to take the loaded skids and trailers directly to an underground worksite, and designing attachments for existing pieces of equipment so that materials can be lifted without manual labor. Such attachments include removable pods and trays on roof bolters for carrying roof bolt supplies for a shift or entire day of operation. These pods can be loaded either underground or at the surface with a forklift and can be positioned for easy access by the operator. Bolters with removable pods and trays can significantly reduce manual handling of the hundreds of roof bolting supplies needed daily in underground mines.

Construction activities

One mine has a good method to reduce lifting weights when sealing areas of abandoned mines. After the sealing form is built, a stack of two or more pallets of dry sealant in 50-lb bags is brought in with a forklift and placed next to the roller conveyor. The first pallet is kept in place to form the base of an elevated storage platform. After the bags of sealant have been emptied on the conveyor, the forklift stacks the second pallet on top of the first one so the bags do not have to be lifted and emptied from near the ground. From the top pallet, one miner places the bags on the conveyor. Another miner cuts the bags and empties them into a hopper. One miner operates the forklift, and another picks up the empty bags. The positions are rotated so no miner is constantly doing the same job. The area is well lighted and ventilated, and each miner is given instructions on proper lifting techniques and is allowed time for stretching exercises prior to beginning the job.

Other techniques

Other attachments include a retractable pin on a longwall shearer for moving small parts down the longwall face and small, revolving chain hoists fitted on a stageloader for moving parts over the stageloader and down the longwall face. Other equipment includes special racks for hauling 19-L water jugs and hydraulic hoses and specially designed skids for moving conveyor belt parts. Special metacarpal gloves for hand protection are also being required by some mines, and mine standards sometimes exceed federal and state requirements for protecting workers.

Using lightweight materials is another means of reducing the amount of exertion required. Examples include the use of aluminum instead of steel bars for monorail systems on which high-voltage cable is transported in longwall mines, lightweight blocks with gripping grooves for ventilation stoppings, and lightweight rollers with handles for conveyor components. To prepare workers for physical tasks, mines are allowing time for stretching exercises before starting work and after long breaks.

MECHANIZATION OF MANUAL TASKS

Some activities are very difficult if not impossible to mechanize. Other alternatives have to be considered for these tasks. However, many of the priority tasks in Table 1, as well as other tasks not listed, can be mechanized.

Past U. S. Bureau of Mines materials-handling research

In the 1980's, several inexpensive, easy-to-construct, materials-handling devices were developed and tested at the USBM's Pittsburgh Research Center (Conway and Unger 1989). These devices, primarily for use in underground coal mines, included a lift transport for lifting tires and heavy (up to 450 kg) machine parts, a scoop-mounted lift boom for transporting and maneuvering heavy machine components up to 1,350 kg, a lightweight swing arm boom to lift objects up to 227 kg on and off transport vehicles, a mine mud car to aid in moving supplies from storage areas to the point of use, a container workstation vehicle to transport tools and supplies on a daily basis, and a timber car with a 227-kg lift capacity for installing crossbeams for roof support. Research to reduce injuries from specific materials-handling tasks, such as hanging cables, building stoppings, and handling bags of rock dust, was also conducted (Unger and Bobeck 1986). All of these devices were designed to reduce materials-handling injuries by using mechanical aids to perform specific tasks. These devices are still useful and are still used at some of the mines visited during the course of the current research (Figure 8). Unfortunately, workers at many mines continue to do manually the tasks this equipment was designed for.

Figure 8.—Swing boom arm attached to mine vehicle.

Figure 9.—Laboratory tests on Coleman manipulator as received from factory

Figure 10.—Artist's concept of mobile manipulator after modifications.

Current materials-handling mechanization research at NIOSH's Spokane Research Laboratory

Mobile manipulator system. Assisted lift devices (manipulators) are currently used in many manufacturing sectors to reduce injuries associated with manual equipment and materials handling. Manipulators allow workers to lift and maneuver heavy objects throughout a work envelope, yet require that the operator exert only a few pounds of force. After purchasing a standard Coleman manipulator (figure 9), SRL personnel conducted a series of typical lifting activities to determine baseline performance. The device operated as intended with regard to lifting; however, several functional limitations and operational capabilities were identified as needing improvement before the device would be practical for mine use. The most significant limitation was lack of mobility. With a weighted pallet jack base of 680 kg, the manipulator was too heavy for one person to move and position. A second limitation was lack of stability and leveling capability; that is, the device would rock on two of its four contact pads if the floor had any uneven or low spots. The manipulator arm would also list to the low side of a flat, but inclined, floor. A third limitation was the height and length of the unit, which made it difficult to move from one work area to another. Doorways were difficult to pass through because of the height, and corners were hard to navigate around because of the length.

Thus, researchers decided to modify the manipulator to improve its basic function. For the device to be practical, it would have to be self-propelled, compact enough to fit through openings and around corners, and stable and level once positioned. Also, the device would need to be self-contained with regard to the air and electrical supply for the lifting/driving/leveling system. An integrated design incorporating the manipulator was designed and named the mobile manipulator system (MMS).

Engineering design for the manipulator component of the MMS involved modifications to the manipulator arm and the development of several subsystems. The MMS will be mounted on a mobile base equipped with telescoping outrigger stabilizers and independently controlled leveling legs. An air compressor, inverter, and battery system will also be mounted on the mobile unit.

These individual components will form the basis of an integrated lifting system. The resulting MMS will be trammed to the location needed, outriggers deployed, the base unit leveled, then operated via the self-contained air-hydraulic system, all in a timely manner and requiring only a single user/operator. An artist's concept of the MMS is shown in Figure 10. If the performance of the baseline unit is satisfactory, then the device will undergo a series of tests designed to approximate the manual materials handling and maintenance activities in mining environments.

Underground shop areas where a variety of lifting activities occur in the course of performing maintenance activities are particularly good candidates for assisted lifting devices. Handling large pneumatic wheel-lug wrenches and changin-out hydraulic motors are examples of maintenance-related activities that involve lifting, positioning, and sometimes holding heavy objects.

The handling of materials being dispersed from laydown areas to work areas is a good candidate for an assisted lift device. In most underground mines, getting needed materials from the surface to underground laydown areas is done with forklifts or other mechanized devices. The materials are generally placed on a pallet and tied together. Once in the laydown area, however, materials are separated and often manually loaded into a scoop or supply car and taken to the work area.

Other possible applications for assisted lifting devices involve maintenance of heavy equipment where no overhead lifting system is in place, such as conveyor belt systems in underground mines, which are often manually disassembled, moved, and reassembled. Use of manipulators for bulk-heads, overcasts, and stopping construction and for hanging supplies (waterlines, ventilation tubes, etc.) from the mine roof is another possibility.

Figure 11.—Track-guided pincher arm attached to hydraulic impact hammer head.

Track-guided pincher arm (TGPA). The TGPA (Figure 11) was developed and tested by NIOSH researchers in cooperation with Gonzaga University, Spokane, WA. The original purpose of the device was as an attachment to a hydraulic impact hammer head mounted on a backhoe-type arm. The device was designed and built to pick up and remove timbers, mesh, bolts, etc., from recessed ore pass grizzlies in hard-rock mines without interfering with the impact hammer operation (Figure 12). It employs two arms that come together at the end of their travel to create a clamp. The TGPA is designed so that the arms can extend into the clamping position, pick up debris, and retract out of the way. The arms can open wide to accommodate large objects. The device was tested successfully at an under-ground mine in Idaho. It is capable of withstanding the daily pounding of the impact hammer and is fully functional in a mine environment.

Although originally designed for use in underground hard-rock mines, the TGPA could be mounted directly to any backhoe-type mobile equipment and be used at any mine for lifting, pulling, or hanging tasks currently done manually. The TGPA is low cost and can be designed and built on-site at most mines.

Figure 12.—Track-guided pincher arm picking up pipe debris from recessed grizzly

Conveyance monitoring system. When hoisting ore, equipment, or other heavy materials in and out of under-ground mines, excessive dynamic loads may cause allowable safety factors in the hoist rope to be exceeded. Loads may shift or hang up. Measurements of end loads have been successfully obtained using the recently developed NIOSH flexbeam load sensor. The flexbeam load sensor is attached to the hoist rope and transmits tension data to the surface using a wireless data link. In addition, a conveyance position encoder is being designed and fabricated to determine accurately dynamic variables, such as loads caused by ventilation winds during transit, acceleration/deceleration loads, and other extraneous forces on a hoist rope.

Portable in-mine hoisting device. Because of space constraints, location, or unavailability of equipment, miners are often required to hand-carry supplies and materials from one location to another. The material is often heavy and awkward, and a miner has to carry the material hundreds of feet over uneven ground. A new project task this year is to develop a portable, lightweight hoisting and trolley system capable of lifting 136 kg a distance of 75 m. The system will be easily set up and taken down and be able to turn 90°. It will also have a braking system for going downgrade.

CONCLUSIONS

Hundreds of materials-handling tasks are performed in underground mines each day. It would be hard to find one of these tasks that has not resulted in an injury at least once. For years, underground miners, mine foreman, safety engineers, researchers, and others have been designing, developing, and testing innovative equipment and tools that can be used to make jobs easier and reduce injuries. These efforts have paid off considering that the number of materials-handling injuries has been reduced by over 60% in the last 10 years. However, materials handling continues to be the MSHA category with the highest percentage of accidents and injuries in underground mines, and these efforts have to continue. Some solutions are simple, such as reducing "package" weight. Other solutions are not so simple, such as hanging objects overhead and moving trailing cables. Because of the diversity of materials-handling tasks, no single solution exists that will eliminate materials-handling injuries.

Mechanization

Research and development of mechanized materials-handling tools and equipment need to continue with an emphasis on those tasks that currently result in numerous materials-handling injuries, such as moving roof bolt supplies, hanging waterlines and ventilation tubes, and moving cables and conveyor belt parts. One of the best sources of information about materials-handling mechanization needs is the miners who daily handle supplies and materials. Managers need to listen to their needs and then supply the resources to make their materials-handling job safer.

Two good sources of aid in developing and testing materials-handling devices are government mine health and safety agencies, such as NIOSH's Office for Mine Safety and Health Research and MSHA's Technical Support Division, and departments of engineering at universities having graduate studies and/or senior design programs. These programs usually consist of three or four senior engineer students (mechanical, civil, electrical, etc.) who spend their final year working and completing a sponsored project as part of their degree requirements.

Materials-handling safety criteria

It is neither technically nor economically feasible to mechanize all underground materials-handling tasks. Some tasks need to be done manually. Injuries can be minimized if mandatory site materials-handling safety criteria are established. The criteria would be established by the safety manager as per the manual task injury records, task location, type of task, and other factors. However, mandatory materials-handling criteria are useless unless the individual performing the task follows them. It is up to the individual to think about every lifting action prior to doing it. Unfortunately, many people have to experience a " back-knee" injury (an injury while lifting an object that causes so much pain in your back that it instantly puts you on your knees) before they learn this. There is always a better, easier, less injurious way to handle material. Even if the lifting job is delayed waiting for proper help or equipment, it is better for the individual and the company than a long-term back injury. Management at all levels should mandate smart, risk-free materials handling with "take time to do it right" criteria.

Training

Materials handling should be an integral part of *every* safety and job training meeting for mine workers. Any increase in materials-handling incident rates is a warning sign. Mine safety officers should identify those tasks that cause frequent injuries at their mines and conduct specialized materials handling safety training to individuals performing these tasks. This would be valuable for new miners because they frequently get jobs involving supplies and materials. Constant (daily) safe materials-handling reminders from safety managers and shift foremen will aid in getting miners into the habit of not only "thinking before they lift," but also thinking before they carry, pull, hang, or push supplies and materials.

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