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Mobile Mine Equipment Maintenance Safety: A Review of U.S. Bureau of Mines Research

By Joan K. Kuenzi and Bruce C. Nelson

UNITED STATES DEPARTMENT OF THE INTERIOR

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MOBILE MINE EQUIPMENT MAINTENANCE SAFETY: A REVIEW OF U.S. BUREAU OF MINES RESEARCH

By Joan K. Kuenzi[1] and Bruce C. Nelson[2]

ABSTRACT

This Information Circular brings together for consideration recommendations from U.S. Bureau of Mines safety research in the area of surface mine mobile equipment maintenance for the period 1982 through 1991. It updates the 1982 contract report by Baker and Alves that formed the basis for much of the work described in the present report. Recommendations for hazard abatement during work on mobile mine equipment are presented and stem from the results and recommendations of the research in two areas: (1) equipment and workplace hazard reduction, and (2) management of maintenance information. Recommendations included in this report apply to both the operators and maintainers of mobile mining equipment as well as to the manufacturers of that equipment.

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INTRODUCTION

Improving both the safety and efficiency with which maintenance is performed represents a large potential savings to the mining industry. Efficient mines invariably place a good deal of effort into properly managing equipment service and repair work.

Many points of this report, and many of the references cited herein, are addressed in a contract report conducted by Baker and Alves.[3]

Controlling equipment maintenance costs is one key to the future competitiveness of surface mining operations. A recent survey of maintenance costs at U.S. industrial plants found that the costs and staffing for maintenance were increasing faster than for most other functions at these plants, and that automated machines and electronic controls were placing many new and different demands on maintenance systems and personnel (*1*).[4] Maintenance costs average 96 pct of new capital investment value at some U.S. plants and estimates of equipment maintenance costs at U.S. mines vary from 30 to 60 pct of total operating costs (*1*).

The *safety hazards* related to maintenance work and the associated costs and lost-work time from *accidents* and *injuries* occurring during equipment maintenance cause frustration and concern for mine operators. Workers primarily assigned to equipment maintenance, or having some equipment maintenance tasks included in their duties, make up a large proportion of the total U.S. mining work force today. The maintenance jobs required by sophisticated, modern mining equipment can be more complex and diverse than most other mining work. In some equipment for instance, several components that are in themselves large and cumbersome, need to be removed to access parts that break down. Technical and cost data are essential to maintenance managers. Information on safety precautions and proper procedures are essential to the mechanics and workers.

U.S. Bureau of Mines (USBM) research indicates that over one-third of all surface mining accidents occur during maintenance of equipment, and that overexertion and slip-and-fall injuries occurring during maintenance of mining equipment are responsible for 64 pct of all the lost-time maintenance injuries. This research also suggests that improving the management of information necessary to perform mining maintenance might improve both the safety and the productivity of this work.

To close out the Mobile Mine Equipment Maintenance Safety project at the USBM Twin Cities Research Center, this report presents a review of recommendations for hazard abatement stemming from USBM research in the area. As previously noted, the 1982 contract report by Baker and Alves formed the basis for much of the work described in this report. First, a comparison of data from 1978, the first year analyzed by the researchers on this project, and 1990, the year the project ended, will be presented. Next, hazards and recommendations for hazard reductions brought forth in past research under this project will be discussed under these subheadings: training, tools, mobile equipment design, tire problems, and work environment. There were two main areas of interest within this project: physical hazards and information support and management. These two areas will be discussed separately.

SURFACE MOBILE MINING EQUIPMENT MAINTENANCE HAZARDS

Tasks required to service or repair mobile mining equipment differ significantly from those required for most other surface mining work, especially in the technical complexity involved and the degree of variety encountered. For example, whereas the *operation* of mobile mining equipment tends to be repetitive and routine, the *maintenance* of that equipment entails a wide range of complex tasks, subtasks, tools, and motions. Furthermore, repair tasks on mining equipment are often urgently needed in order to minimize costly production delays and often require workers to perform in cold, wet, dark, or cramped conditions.

MINE MAINTENANCE COMPARISONS, 1978 VERSUS 1990

Who performs maintenance on mobile mining equipment? The answer seems quite easy: mechanics, welders, electricians, oilers and greasemen, and shopmen. However, a review of accidents that happen to workers during maintenance in these occupations tells only part of the story. The report by Baker and Alves reviewed maintenance accidents involving haulage trucks for the years 1978-79. It covered metal/nonmetal as well as coal accidents for those years, and defined maintenance accidents as "...involving any personnel (regardless of job title) performing maintenance on mine haulage trucks."

The definition above broadens the pool of "maintenance workers" to include: (1) laborers and helpers who may usually be responsible for cleanup but are doing maintenance

[3]Baker, R. M., and H. G. Alves. Improved Equipment Design to Reduce Haulage Truck Maintenance Injuries. Final Report on Contract No. J0215007, 16 August, 1982, 96 pp.

[4]Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

on a piece of equipment; (2) foremen; and (3) mobile equipment operators who, even though they may have had no formal maintenance training, may be required to inspect and service their trucks and even repair breakdowns in the absence of the mechanic.

To examine how the injury patterns of mobile mine equipment maintenance have changed over a period of 12 years, an accident analysis was done using the U.S. Department of Labor, Mine Safety and Health Administration (MSHA) mine accident-injury database for 1978 and 1990.[5] The year 1978 was chosen because it was the first year of data used in the Baker and Alves analysis. The year 1990 was the most recently completed and verified in the MSHA database as of the writing of this report. The database was queried using the maintenance accidents definition given above.

DATA ANALYSIS METHODS

All haulage accident descriptions for surface mine mobile equipment filed in the MSHA database for 1978 and 1990 were accessed. The mobile equipment haulage-accident totals and information were retrieved using the following series of descriptor variables:

Mine type: Surface mining (both metal/nonmetal and coal).

Machine: Examples; haulage truck, front-end loader, dozer, etc.

Accident/Injury Code: Powered haulage.

Data were further broken down by: Occupation, Activity at the Time of the Accident, Source, Accident Type, and Part of Body Injured.

Maintenance occupations include mechanics, welders, repairmen, mechanic helpers, greasemen, oilers, electricians, tiremen, electrician helpers, carpenters, wiremen, communications repairmen, shopmen, machinists, electrical engineers, and maintenance foremen.

These job categories were evaluated in relation to the following list of activities that maintenance occupations were involved in during haulage accidents: getting on and off equipment, hand loading, handling materials and supplies, using hand tools, using impact wrenches, inspecting machinery, machine maintenance, and moving power cables. Other accidents that occurred during maintenance activities such as machinery maintenance and machine inspection, but which were attributed to occupations other than those defined above, were also included in the accident tally.

[5]Mine Safety and Health Administration (MSHA) Accident Injury Database, Years 1978-1990.

RESULTS

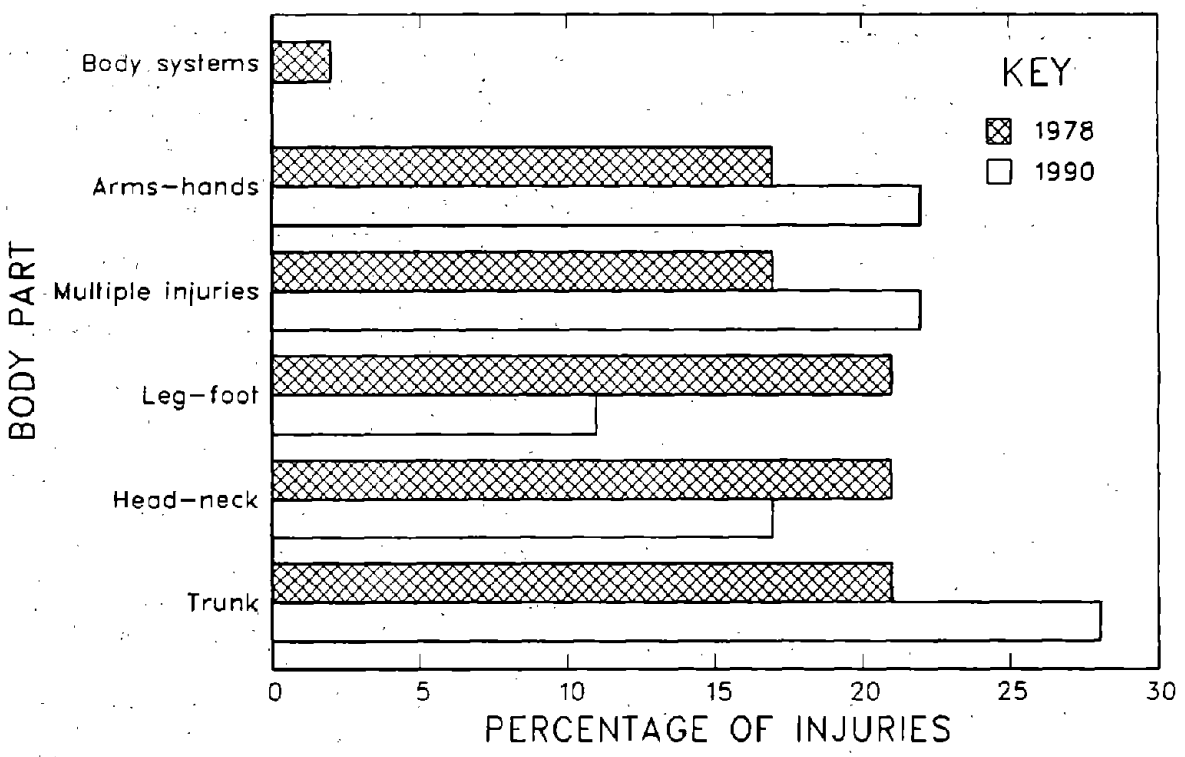
The resulting data set contained 441 total surface mine mobile equipment haulage accidents for 1978. Of those accidents, 52 (12 pct) could be attributed to occupations and activities specific to maintenance. For 1990, there was a 26-pct reduction in mobile equipment haulage accidents in surface operations. Of the 326 accidents for that year, 36 (11 pct) involved maintenance activities and occupations by this analysis. This suggests that maintenance activities are becoming less hazardous at the same rate as overall surface haulage activities. However, this apparent reduction in injuries could be misleading for several reasons: First, how data from contractor work were kept in the database. According to USBM researchers, in 1978, contractor data were included in the overall data, and in later years they were kept in separate files. Second, data only include accidents on site. Components may be shipped off site for contract repair, and if any injuries occur, they would not show up in the MSHA database.

Figure 1 indicates that the percentage of trunk, upper-extremity, and multiple-injury accidents increased even though the number of injuries decreased overall. Of the injuries attributed to maintenance activities and/or occupations, the greatest percentage in 1978 involved the trunk, head-neck, and leg-foot injuries (n=11 in each category), followed by multiple injuries and injuries to the upper extremities (n=9 in each category), and then body systems (n=1). In 1990, the greatest percentage of haulage maintenance injuries involved the trunk (n=10), followed by multiple injuries and upper extremities (n=8 in each category), then head-neck (n=6), and lastly, leg-foot (n=4). Looking at trunk injuries specifically, the number of back injuries within the trunk injury category changed from 6 out of the 11 in 1978 to 8 of the 10 in 1990.

Figure 2 compares the percentages of each "type of injury" for 1978 and 1990. The types of injuries recorded for haulage maintenance activities and occupations remained basically the same from 1978 to 1990. "Struck Against" was the category that was involved in the most injuries for both years (n=22 in 1978 and n=15 in 1990). The greatest percentage of those specifically involved being "Struck Against Moving Object" (80 pct in 1978 and 100 pct in 1990). The next two most frequently occurring types of injuries for both years studied were "Struck By" and "Caught." "Overexertion" accounted for a lower percentage than might be expected. The maintenance work done "in house" in 1990 may have involved a greater proportion of routine service, lubrication, and installing and tightening easily accessible parts. This routine service work involves more static working postures than the lifting, pushing or pulling required by heavier repair work, which more commonly results in "overexertion" injuries.

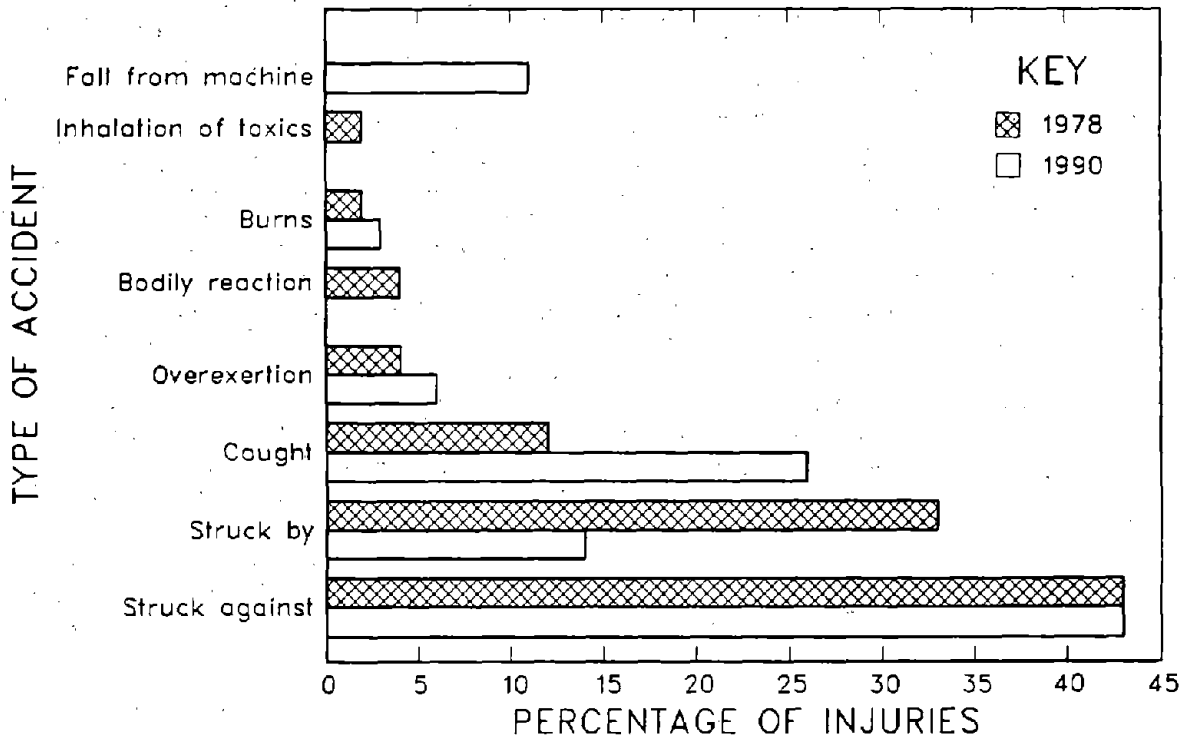
Figure 3 summarizes the range of occupations involved in maintenance accidents for the 2 years studied. Besides

Figure 1



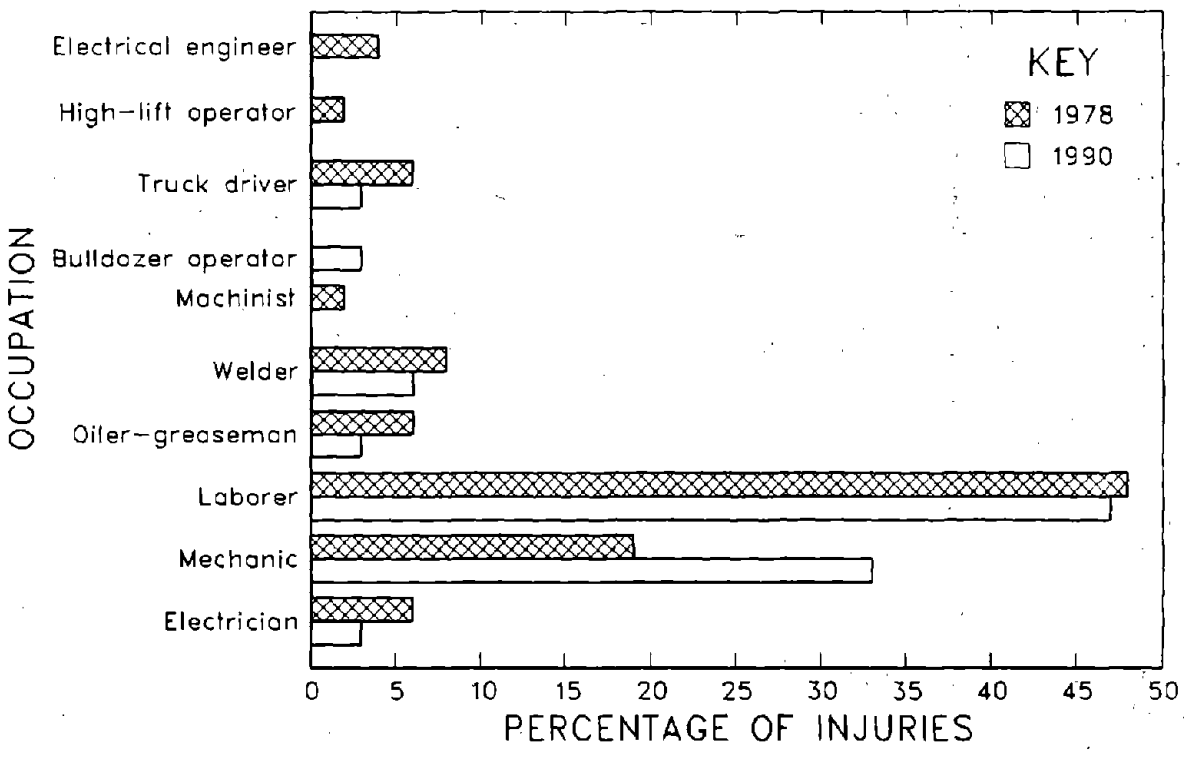
Percentage of haulage maintenance injuries by body part: 1978 versus 1990.

Figure 2



Percentage of haulage maintenance injuries by type of injury: 1978 versus 1990.

Figure 3



Percentage of haulage maintenance injuries by occupation: 1978 versus 1990.

traditional maintenance personnel, mobile equipment operators and managers also suffered accidents during both years. Information on worker hours of maintenance for each year, each occupation, and each activity would have been valuable to normalize the data and to make more informed comparisons. However, these data were not available, due to the difficulty of determining who performs the maintenance.

While there has been a reduction in the overall number of haulage-related injuries, the percentage of these injuries accounted for by maintenance activities and occupations has remained roughly the same for 1978 and 1990. The persistence of maintenance safety problems points to the need to review and update information regarding maintenance hazards and recommendations for their abatement.

REVIEW OF USBM RESEARCH ON MOBILE MINING EQUIPMENT MAINTENANCE HAZARDS

In this section, hazards will be discussed in five categories: training, tools, mobile equipment design, tire problems, and work environment. These categories overlap in some cases due to the fact that multiple factors can contribute to a maintenance accident.

In dealing with maintenance hazards, the best approach would be to look at different hazard categories, and to decide which recommendations would be feasible for a particular situation and how each guideline could be generalized from one area to another.

TRAINING

Who performs maintenance on mobile mining equipment and what kind of training is needed? What about the maintenance workers who are injured transporting mobile equipment to the shop areas? Are they trained on the vehicles they drive? The following is a list of the training deficiencies revealed in the literature reported under this project (*2-10*):

1. Lack of appropriate training in proper procedures (e.g., maintenance workers driving equipment back to the shop or equipment operators maintaining their own equipment without formal training) (*2, 4*).

2. Lack of effective training programs and work procedures for manual materials handling (*2, 4, 6*).

3. Lack of adherence to proper equipment maintenance and/or manual materials-handling procedures (*2, 4*).

4. Improper tool use such as improvising when correct tools are not available (*2, 4*).

5. Lack of awareness to known hazards in the area (*7*).

6. Inadequate use of personal protective equipment (*4*).

7. Lifting components that are heavier than anticipated (*4*).

8. Improper design and use of maintenance manuals. This will be discussed in more detail later.

TOOLS

It is important to define the tools used in mine maintenance in order to be aware of their size, weight, and overall dimensions. Besides hand tools and powered assist devices (such as torque wrenches), work stands and other access aids, as well as personal protective equipment, could and should be considered by the workers as tools since they are necessary to accomplish the job in a safe and efficient manner. As defined in the American Heritage Dictionary, a "tool" is "Anything regarded as necessary to the carrying out of one's occupation or profession" (*11*). The studies considered in this review often cite inappropriate tools as a major hazard to surface mine mobile equipment maintenance (*2-4, 6, 12-15*). The following is a list of the tool-related deficiencies revealed in the literature:

1. The inadequacy and availability of tools used in the field versus the shop (*4*).

2. The general inadequacy and availability of tools (i.e., not choosing or having access to the correct tool, chains failing under too great a load, and tool hand grips that do not give adequate slip resistance) (*2, 3, 6, 13*).

3. The poor maintenance of tools (*4, 12*).

4. The shortcomings of work stands used for maintenance access on specific pieces of equipment (*9, 12, 13, 15*).

5. The excessive physical force needed to use certain hand tools (*4, 14*).

6. The lack of personal protective equipment.

7. The frequency of injuries associated with welding and cutting equipment (*14*).

8. Poor location of tools in the shop (e.g., tools stored anywhere space permitted; not convenient to the users) (*1, 4*).

9. The lack of provision for work aids to support heavy components while they are being maintained (*4, 6, 13*).

MOBILE EQUIPMENT DESIGN

Baker and Alves listed the following as areas on haulage vehicles that were particularly hazardous: suspension, tires, engines, and truck bodies and cooling systems. Work by Albin and Long in 1987 and Albin in 1990 validated those findings for haulage trucks and added hazards involving the hoist and hoist cable, and swing systems on power shovels (*6, 13*). Work by researchers in the area of mobile equipment subsystem hazards indicated the following:

1. Burns from pressure releases on the radiator (*6, 13*).

2. Persons being caught in moving fans and belts (*6*).

3. The complexity of access for components requiring routine maintenance (e.g., the cooling and suspension systems) (*2, 15*).

4. Flying chips from pins being driven with hammers on power shovels, as well as other flying objects (*6, 13*).

5. Slips and falls (*13*).

6. Being caught in cables or moving parts (*13*).

7. Poor access to the part to be worked on (both in finding adequate footing in the area of the part and getting to the actual part) (*2, 3, 6, 7, 9, 10, 13, 16*).

A study by Albin and Adams in 1989 commented that "...maintenance workers climbed on and over machinery where no access systems were provided an estimated 7 pct of their total work time in order to perform routine maintenance and servicing tasks" (*7*).

8. The complexity of the equipment to be maintained by relatively unskilled personnel (*2, 15*).

9. Manual materials-handling requirements for very large components in tight spaces with poor tools, clearance, or support systems (*2, 15*).

10. Problems with securing large components during installation and removal (*2, 6, 7, 9, 10, 13, 15*).

11. Deficient guardrail and handrail designs (*9, 15*).

12. Overly flexible lower rungs on access ladders (*9, 15*).

13. Excessively high first-step distances (*9, 15*).

14. Bad step designs (*9, 15*).

15. Access systems that used nonaccess specific components such as the tracks on dozers for mounting and dismounting the piece of equipment (*2, 6, 7, 9, 10, 12, 15*).

TIRES

Five of the papers reviewed discussed the hazards involved in tire repair (*2, 4, 6, 13*). Long's work in 1987

cited tire work as one of the most hazardous maintenance tasks (*2, 4*). Baker and Alves cited seven specific hazards:

1. Protection for workers working on or around large tires was not adequate (*4*).
2. The tools used were poorly designed; required too much force (*4, 6*).
3. The devices used to lift tires and wheels were not appropriate (*4, 6*).
4. Workers often improvised on tool choices due to inadequate supply of correct tools.
5. The lack of an effective tire wear and damage guide so that workers could perform maintenance before the tire was too worn (*4*).
6. The inappropriateness of work procedures that were very hazardous for working on tires (*4*).
7. Little or no training (*4*).

WORK ENVIRONMENT AND AREA

The interaction between the worker and the work area is discussed in several studies (*7, 10, 12*). A study by Albin in 1988 found that the interaction between workplace design and worker behavior was responsible for 49 pct of slip-and-fall accidents, design alone accounted for 39 pct, and behavior for only 11 pct of accidents studied over the years 1985, 1986, and the first half of 1987 (*12*). This is important in showing that in order to fully benefit workers in a given situation, more than just the physical design and layout of the work areas must be taken into account. The physical aspects of the work could be excellent, however, if there is pressure to get the work done or no enforcement of safety procedures, unsafe behavior is likely to occur. Conversely, given an excellent safety program and poorly designed and equipped work areas, it is also likely that workers will adopt unsafe behaviors to adapt to the environment. Work by researchers indicated the following:

1. Service bays were too crowded (*2*).
2. Ventilation and lighting systems were not sufficient for the work being done (*2*).
3. Noise levels were excessive (*2*).
4. Lack of proper work stands for work being performed on mobile equipment (*2*).
5. Poor communication between workers working on the same vehicle (*2, 4, 12*).
6. Inadequate work room between vehicles in the shop to use tire grabbers and forklifts to handle the heavy parts (*2*).
7. Poor housekeeping (e.g., cable management and grease- and oil-covered floors or truck decks) (*6*).
8. Tools not conveniently located.

Field versus shop hazards were discussed in several papers (*4, 6*). In the Baker and Alves study, 30 pct of all accidents occurred outside the shop.

9. Improvisation of tools needed for repair in the field when the resources needed were back at the shop (*4*).
10. Steam burns from opening the hot radiator caps (*6*).
11. Environmental conditions in the field.
12. Lack of appropriate lighting in the field.
13. Slips and falls due to uneven footing (*6*).

RECOMMENDATIONS FOR THE REDUCTION OF HAZARDS IN MOBILE EQUIPMENT MAINTENANCE

There are two ways of thinking about where fault lies in accidents. Heinrich wrote in 1931 that 88 pct of the accidents he studied were due to inattentive, unsafe behaviors (*16*). Other findings suggest that the fault lies more with the design of work and equipment, which should be "foolproof" (*3*). Results presented in work by Albin showed that the interaction of workplace design and worker behavior was responsible for 49 pct of all slip-and-fall accidents, while design factors alone accounted for another 39 pct and behavioral factors 11 pct (*12*).

In their report, Baker and Alves offered what is perhaps the most comprehensive and most organized list of recommendations for the reduction of hazards involved with equipment maintenance. One of the recommendations listed did not fall into any one category; it is more global and therefore should be mentioned first.

The primary recommendation was "...to maintain a positive attitude about safety at all levels of a mine's maintenance department."

The following subsections review recommendations for mobile mining equipment maintenance using the hazard categories cited above. Recommendations included in this report apply to both the users and maintainers of mobile mining equipment as well as to the manufacturers of that equipment.

TRAINING AND MANUAL DESIGN RECOMMENDATIONS

Further information on the following recommendations can be found in references 2-4, 6-8, 10, 13, and 17, as well as a contract report by Ferguson and others.[6]

[6]Ferguson, C. A., S. Mason, S. G. Collier, D. Golding, R. A. Gravelling, L. A. Morris, A. J. Pethick, and G. C. Simpson. The Ergonomics of the Maintenance of Mining Equipment (including Ergonomic Principles in Designing for Maintainability). Final report on CEC Contract No. 7247/12/008, Institute of Occupational Medicine, Roxborough Place, Edinburgh EH8 9SU, 108 pp.

1. Improve supervisor and employee awareness of all hazards and the weights to be lifted by the crew before starting a job (*3, 4, 6, 7*).

2. Train employees in the necessary lifting aids and manual materials-handling procedures for heavy and/or awkward components (*2, 4, 6, 7*).

3. Improve employee skills training; emphasize the importance of using and following prescribed safety procedures using the proper tools (*2*).

4. Provide periodic refresher courses (*13*).

5. Stamp each component with its exact weight.

6. If equipment maintenance workers are to be required to operate the equipment they maintain, make sure they are trained on the operation of such equipment (*2*).

7. Require work planners to add more workers to jobs requiring heavy lifting and excessive physical demands (*4*).

8. Assign only qualified personnel to maintenance tasks (*2*).

9. Include safe manual materials-handling procedures in all manuals.

The National Institute for Occupational Safety and Health (NIOSH) Work Practices Guide for Manual Lifting is a good starting point for determining manual materials-handling aid needs (*17, 18*). This guide was developed to aid in the analysis of lifting. Also, for a study that looked at recommended lifting procedures for the maintenance of underground mining equipment, see the contract report by Ferguson and others.[7]

10. Develop and implement task training programs for haulage maintenance personnel. This training should emphasize hazard recognition, knowing proper job procedures for the various models of the equipment, and the correct tools and equipment for each job.

11. Cross-reference and index systems are important to the usability of manuals (*4, 8*).

12. Include a trouble shooting guide in manuals as a job performance aid (*4*).

13. Provide for the manuals to be easily updated so that technical corrections, improved maintenance procedures, and safety warnings can be passed on to the users (*4*).

14. Make the manual compact and easily portable for use in working sections (*4*).

15. Make manuals complete, up-to-date, and specific to the piece of equipment (*2, 4*).

16. Emphasize hazards involved in specific maintenance tasks in the manuals (*4*).

17. Revise manuals to include procedure charts (i.e., a step-by-step list), special hazards, tools, and recommended safety procedures (*13*).

[7]Work cited in footnote 6.

TOOL RECOMMENDATIONS

For additional information on these recommendations, consult references 2, 4, 6, and 14.

1. Choose the right tools. Improve workplace knowledge about tools that may be more effective in certain jobs (*2*).

Periodic research into tool manufacturing can reveal innovative tools for old uses, as can input from employees. These are the experts, and asking them for input can not only yield good ideas for improvements, but can also improve employee morale and motivation to improve their situation thus improving the safety attitude of the department.

2. Fabricate or provide mobile tool racks for special tools (*4*).

3. Have specialized tool sets ready with all anticipated parts and tools included (*4*).

4. Stock enough of the proper tools so that workers will not improvise with insufficient tools (*4*).

5. Use portable stands correct for the repair (i.e., the height of the worker is such that the repair can be made close to the worker's body, and preferably at waist height) (*4*).

6. Provide or develop a towing vehicle to tow mobile mine equipment back to the shop for repair (*2*).

This last recommendation may be a bit farfetched for some of the largest capacity haulage vehicles and power shovels. Using recommendations 2 and 3, the maintenance shop could devise vehicles with specialized tool sets, ground cover (e.g., "tarps"), and lighting and power generating capabilities that could be dispatched to the larger pieces. These specialized tool vehicles could be responsible for repairing the vehicle or getting it repaired to a point that it could be driven to the shop area under its own power. However, the authors feel that a vehicle capable of towing some of these immense vehicles would pose operational and maintenance hazards of its own.

7. Improve tool design (*2*).

Again, employees are a great resource for this information. They have insight into how they want the tool to be designed in order for it to accomplish the job as easily and painlessly as possible. Ask for their input before spending the money to hire tool designers; they must ask the employees anyway if the ensuing design is going to be accepted and used. Using the employees first helps to strengthen their feelings of control over their situation and helps in the design process.

8. Train mechanics, and anyone else required to repair or maintain their equipment, in how to choose the correct tool for the job (*2*).

9. Management should enforce the use of proper tools (*2, 6*).

In addition to enforcement, managers should practice what they preach. If required to requisition new tools and

supplies, they should take into account what the tool should be used for and how often it is used. It should be reiterated here that "tools" include work stands, hand and power tools, and personal protective equipment. The recommendations listed above, as well as those listed in the remainder of this section, should be generalized to all of these "tools," and, especially in the case of personal protective equipment, management should not only enforce but apply these recommendations to their own work practices. For example, if managers ignore the wearing of personal protective equipment while working in the same areas as employees, why should anyone wear them?

10. Use powered hand tools wherever possible, thereby reducing the amount of force involved (*6, 14*).

11. Fabricate or provide work stands that have adequate railings and toe boards that could be used within the confines of haul trucks (*6*).

12. Provide safety belts, gloves, and lines for maintenance workers involved in manual materials handling requiring postures that put them at risk (*6*).

Postures that could be considered risky include: reaching beyond one's physical limits, bending and twisting while lifting, pushing and pulling heavy components, and working above the shoulders and below the belt for extended periods of time.

13. Develop equipment to be mounted on a forklift for securing and moving components, such as personnel cages (*6*).

14. Develop fixtures to support and move components in areas where forklifts cannot be used (*6*).

15. Adjustable work stands allow workers to access different heights on mobile equipment; these could be modeled after the hydraulic rigs used in drive train removal (*6*).

16. Use grip-strut grating, nonskid paint, or antiskid strips on ladder steps and work platforms (*6*).

17. Use a soft metal hammer (i.e., not steel) for hammering retainer pins when changing buckets, wear parts, and hoist cable systems on power shovels and loaders (*6*).

This recommendation may be a result of hazards caused by choosing pins of inferior quality rather than the hammer material being "too hard." Perhaps, as an addendum to this recommendation, the quality of all tools and components used should be carefully checked.

18. Establish tool cribs or central locations where tools are kept for distribution.

19. Provide effective tool maintenance (*1*). Always make sure that any tool to be used on a job is itself properly maintained (i.e., balanced, clean, the right size, and in working order). Give the employees who use the tools the responsibility as well as the time to care for them.

20. Shape code any tool storage racks to ensure replacement of tools when the job is finished.

21. Ensure safe and secure positioning of heavy components (e.g., use a nylon sling that supports the component, conforms to its shape, and reduces the possibility of slipping due to inadequate friction between the component and the work aid).

22. Ensure adequate protection for workers from falling objects (e.g., small parts) (*6*).

23. Develop cable trees from standard pipe and flange on which to attach air or water hoses and cables, thus providing clear walkways.

24. Install maintenance-free batteries and Society of Automotive Engineers (SAE) J1283 plugs that eliminate guesswork as to the order or location of jumper cable connections.

MOBILE EQUIPMENT DESIGN RECOMMENDATIONS

Refer to references 6, 7, 9, 10, 12, and 15 for more details on mobile equipment design.

1. Manufacturers should always take maintainability into account when designing mobile equipment, or any equipment for that matter. Operator comfort is only half of the ergonomic picture! As Albin and Long found, among others, access constraints force workers into unsafe postures both from the standpoint of sustained static postures and from pinch points and moving parts in close proximity (*7, 13*).

2. Use a pressure-release radiator cap or any method that controls steam release so that it is away from the worker's hand and that also alerts workers to pressure buildups.

3. Develop a sight glass appropriate to field conditions (e.g., a transparent overflow reservoir similar to those installed in automobiles) that could be added to the cooling system to show coolant levels while the system is still closed (*6*).

4. Install a remote opening system on the coolant system to blow off the pressure while the worker is at a safer distance from the piece of equipment (*6*).

5. Provide locking radiator caps, with limited key distribution. Albin admits to a problem with down time in this case (*6*).

6. Install engine oil sight gauges and/or extended dipsticks.

7. Install automatic lube systems and/or extended grease lines.

8. Install emergency kill switches on the front grill where it can be reached from ground level (it should have a lockout feature).

9. Provide safe positioning and footing for mobile equipment maintenance workers (provide support and reduce the potential for overreaching or slips and falls) (*6*).

10. Use nonskid paint or antiskid strips on mobile equipment decks and other flat surfaces that may serve as access system components.

11. Improve secure access to, and visibility of, service and inspection points.

12. Install antiwhip devices or automatic shut-offs on all air lines.

13. Improve access to, and the removal of, engine and suspension parts by designing access areas with the user in mind. Install permanent access doors in truck hoods and suppress noise from new openings with insulation. Install lifting eyes-hooks in the engine compartment over the most frequently removed heavy parts and rear access openings, or the open hood area and over suspensions to aid in slinging and stabilization during removal.

14. Employ alternate means of fitting and removing close tolerance parts. Baker and Alves recommend hydraulic presses, pullers, and impacts, or cryogenically freezing parts using liquid nitrogen.

15. Develop standard operator controls on vehicles of the same type (e.g., all haulage trucks).

16. Fabricate or provide access ladders that have adequate ground-to-first-step clearances (greater than 30 inches), have step designs that permit material to flow freely and not accumulate, and provide adequate handrail and guardrail designs (*9, 15*) that can be retracted when not in use. Do not mount them to the bumper as this may result in large shear forces at the highest point of the ladder, do not install them on the side of the truck unless the truck moves sideways, keep the weight as low as possible, and maintain step width over the length of the access system (*10*).

17. Install handholds where workers need to access vehicles.

TIRE RECOMMENDATIONS

Recommendations in this section could have fit under either the tool or work station subheadings, however, as the injuries associated with tires are severe and sometimes fatal, it was deemed important to separate them. References 4 and 6 address these recommendations.

1. Fabricate or provide tire cages for tire changing.

2. Use only specially-designed (and well-maintained) mounting tools for tire work.

3. Mount damaged or worn tires on the inside of the vehicle so that when and if it blows in transit, the possibility for injury is lessened.

4. Set aside special areas for tire work. These special areas should be equipped with protective screens.

5. Use fork-lift-adapted tire grabbers.

6. Deflate tires before changing them (both tires on dual mounts) (*6*).

7. Fabricate or provide adequate support for tires while removing and working on them (*6*).

8. Train tire changers in manual material handling procedures (*6*).

9. Contract out for tire work.

WORK ENVIRONMENT AND AREA RECOMMENDATIONS

See references 2, 12, and 18 for more information on these recommendations.

1. Light any maintenance work area well using automotive hang lights or other means (*2*).

2. Improve the organization of the work area by improving work area housekeeping and cable management (*12*).

3. Improve the physical design of maintenance bays to reduce crowding; maintain good housekeeping and cable management (*12*).

4. Give workers who are working on the same piece of equipment a way to communicate with one another via lockout/tagout or headsets.

5. Improve the exhaust systems in welding areas as well as the maintenance shop in general (*2, 12*).

6. Take steps to dampen the noise associated with metal components and power tools (*2*).

7. For field work, make sure all tools, parts, and portable power generators are included in a vehicle designed for a mobile work area.

This vehicle should be able to provide adequate lighting over a broad variety of weather conditions, adequate power to run necessary equipment from the battery capability of the repair vehicle, and storage capability to haul used components back to the shop. Communication is still important in the field, so communication apparatus and lockout/tagout equipment should be part of the vehicle stock. There should also be a means of accessing components (e.g., an adjustable work stand as part of the vehicle as in a line truck for the telephone company).

REVIEW OF USBM RESEARCH ON MAINTENANCE INFORMATION SUPPORT AND MANAGEMENT

As previously discussed, USBM research on maintenance accidents shows that "failure to follow proper procedures" represents a prominent risk factor associated with such accidents (*2, 4*). Work safety and efficiency can be seriously compromised whenever repairs on "off-road mine equipment" are performed in any manner other than the specific manufacturer's recommended work practices, whether unknowingly or deliberate (*5*). These findings suggest that any improvements in the information necessary to manage and perform mining maintenance might

improve both safety and productivity, because productivity declines rapidly whenever improperly maintained equipment fails during production.

The communication and management of vast amounts of maintenance information is crucial to the safe, efficient performance of mine maintenance work. To safely perform their work, maintenance workers must be aware of the dangers associated with mine equipment maintenance work such as charged capacitors, pressurized lines or vessels, hot parts or fluids, or heavy parts that will have to be handled, etc., as well as the correct procedures and the proper order to conduct the work. Previous project work has identified several areas in which technical documentation of service and repair procedures might be improved, particularly in the areas of locating and reading the information, graphics presentation, currentness of the information, and the time needed to acquire the needed information (*5*).

The amount of information that must be incorporated to effectively manage a maintenance program represents a significant human factors problem in its own right. Technical information, specifications, and procedures for each machine must be incorporated with operator reports, inspection reports, diagnostic readouts, service and repair histories, parts inventories, parts and labor costs and availability, preventive maintenance schedules, and so forth. This section will review three USBM studies related to maintenance information support and management in mining. The general topic area of these three studies are: (1) maintenance manual design, (2) automation of maintenance information management, and (3) hard-copy versus computer-based maintenance manuals.

MAINTENANCE MANUAL DESIGN

The first of the 3 USBM studies involved conducting interviews with 36 maintenance workers. The purpose of these interviews was to evaluate 16 mining equipment service and repair manuals, not for technical content, but for several variables important to the human factors design of the manual: readability, legibility, organization, and indexing. These design factors were specified in accordance with SAE Recommended Practice J920 (*19*), Military Specification Mil-M-38784B (*20*), and other significant research findings on the design of technical manuals (*5*).

Major findings from this research include: (1) deficiencies in manuals do exist (as perceived by workers, and as measured against standards); (2) these deficiencies contribute to a lack of use by workers, probably contribute to increasing costs and accidents in maintenance work, and increase the risk of liability suits against manufacturers; (3) the equipment industry has demonstrated a desire and some activity to improve manuals; and (4) human performance tests confirm that specific improvements to manuals do improve worker access, understanding, and acceptance.

It is anticipated that specific conclusions and recommendations from this research will help guide improvements in equipment repair manuals and the industry standards that have been established to direct them, thereby improving the safety of mining equipment maintenance work.

HARD-COPY VERSUS COMPUTER-BASED MAINTENANCE MANUALS

The second study was a comparison of hard-copy manuals versus an information access program for computer-based maintenance. Four different formats of an existing mining equipment repair manual were prepared: (1) original printed text, (2) printed text improved according to design guidelines cited above, (3) computerized version of original text, and (4) computerized version of improved text with additional help features. Students in a diesel mechanics class were tested for proficiency in accessing and understanding information presented in these different manual formats (*8*).

Results of this study indicated that: (1) although the users accessed the information less quickly using the computer than with hard copy, they positively endorsed the computerized hypertext presentation of maintenance information; and (2) enhanced text readability and indexing improved access to, and understanding of, maintenance information, but this improvement was not subjectively appreciated by the users relative to other manuals they had used. Difficulty in finding material with the hypermedia format and in reading text from the computer screen were observed to be factors in degrading performance of the computer subjects. Insufficient training time was probably also a factor, but because everyone received the same training, this cannot be confirmed. Since computerized storage and display of maintenance information represents an inevitable technology advance, more research is needed to understand the human-factors aspects of this technology before electronic display of maintenance information replaces hard copy. This research should investigate training needs for maintenance workers to help them develop the proficiency needed to use computerized hypermedia manuals, the minimum computer screen resolution needed, and whether providing a hard-copy printout of the electronically-stored information can improve the performance of the overall system. More study should also be done to confirm whether minimum readability indices should be specified as a goal for all mine equipment maintenance manuals, and if so, what level should be specified (*8*).

AUTOMATION OF MAINTENANCE INFORMATION MANAGEMENT

The last of the three studies involved maintenance management software. This software logs and tracks information crucial to the efficient management of the equipment

maintenance function. It is used to track work completed, work that needs to be completed, and expected planning requirements for the work. Maintenance management software appears to offer improved safety and up to 30-pct improvement in the efficiency and overall operating costs for some mechanized operations. Furthermore, in some cases, a complete desktop computer system with the maintenance management software included can be purchased for under $10,000. However, implementing these programs within a mining operation often results in human-factors difficulties that can be very frustrating and that result in costly mistakes and wasted time. Therefore, to avoid these mistakes and difficulties in the future, and to ensure success in implementing these powerful new cost-saving programs, it is essential to conduct careful evaluation, planning, training, and ongoing support (with special consideration for the human factors of using such software) (*21*).

A recent report outlines the characteristics and problems of implementing a program using this software and reviews several human factors principles and plans that can help mine operators overcome the mistakes and difficulties mentioned earlier and help guide the implementation of these programs to a greater probability of success in the future (*21*).

Ten mistakes cited by mining operations that have encountered difficulty implementing these programs are (*22*):

1. Too few people in the organization understood the vast amount of information involved in coordinating equipment maintenance; or they miscalculated the human logistics of entering all the pertinent background data into the computer; or maintaining all these records from day to day.

2. Some people in the organization did not understand the need or the benefit for sophisticated (computerized) management of this information.

3. Those managers, who could really make productive use of this data for day-to-day decisions, did not understand what specific questions could be answered within the system; did not understand how to access such an answer from the on-line computer; or did not have the time or the technical confidence to explore it.

4. Some of the systems, especially the mainframe systems, have been quite inflexible or very difficult to access in a flexible way, making it even harder for these managers to learn.

5. The workers assigned to interface with the system did not feel comfortable or confident with the computer operation, the disk operating system, or the database command language.

6. The people assigned to interface with the system did not feel comfortable with the large data-entry requirements, especially during the beginning phase when the system had to be loaded with large amounts of background information to get started.

7. The organization tried to get by with less training and support than was suggested or needed as a means to save money.

8. The day-to-day data entry was not kept current, and/or the system was used only as a routine monthly or quarterly report generator, which takes away many of the advantages of storing the data on an on-line computer (i.e., if the information is not current, it is useless for guiding day-to-day decisions and generating daily work orders or inventory reorders).

9. The system was run in isolation from the production people, thereby losing their commitment to the program, which is vital for a tightly scheduled program like this to work. Input from production people can also provide observations of the operating conditions and machine response that are essential to tracking the underlying causes to any machine maintenance needs, especially in a rugged mine environment.

10. The system was given up on to some degree before it was fully implemented or its impact fully realized.

SUMMARY AND RECOMMENDATIONS FOR COMPUTERIZED MAINTENANCE MANUALS OR MAINTENANCE MANAGEMENT INFORMATION SYSTEMS (MMIS)

Studies of human-computer interaction have found that individual performance differences can be enormous compared with those found in most work settings. Four recent approaches to these user differences that mix specialized interface design and specialized user training in different proportions have been fairly successful (*9*). These are:

1. Robust interfaces that have been altered, based on user testing, to improve performance on those features where performance differences were greatest. Some of these interface improvements have merely reduced or simplified some of the commands, while others have developed into very novel improvements to interface design such as menu driven interfaces, natural language interfaces, on-line aiding <HELP> interfaces, input devices (i.e., joysticks, mice, light pens, and touch screens), graphic-oriented interfaces, windowing systems, and speech output and recognition systems.

2. User prototypes that are programmed to interface with specific user groups have proven helpful where the existence of strongly defined groups mandates that each group be treated separately.

3. Adaptive training systems that deal with errors during practice by blocking certain errors, prompting correct responses, and/or giving feedback following errors. This help can be provided in a separate training system for practice only, but it has also achieved success when incorporated into the working system and made appropriate to aid even the skilled user.

4. Mastery learning approaches allow each student as much time and instruction as needed to master a program by separating the operation into small units and objectives, and providing testing and follow-up until each part is mastered.

Carroll and Olson (*22*) showed that modeling or giving a flow diagram of complex computer-software interaction can help, especially for novice users. Sheridan (*23*) showed that for systems that take over some of the previous human tasks and control, making the system "human trustable" is as important as making it "human usable."

Obstacles that have precluded acceptance or success of technology for computer manuals or MMIS in the past can be largely summed up with the following five factors: (1) acceptance of technology, (2) unfamiliarity or lack of data-entry skills, (3) interfacing and control of computer hardware and software, (4) difficult computer hardware and software interfaces, and (5) training (*21*). The following evaluation discusses possible solutions or approaches to overcome these obstacles.

ACCEPTANCE OF TECHNOLOGY

The lack of managerial confidence, or commitment to MMIS technology is a common problem when implementing this technology. The lack of adequate understanding of the needs for, and the benefits of, this technology is the cause.

Recommendations:

1. Provide basic orientation and training about the system for managers (MMIS, finance, maintenance, and a production executive).
2. Conduct an accurate economic evaluation and estimate of benefits to be gained at the operation.
3. Establish early involvement, by the managers mentioned earlier, in decisions about how the system will be implemented and maintained.
4. Establish clear lines of responsibility for implementing and maintaining the system.
5. Organize responsibility for the maintenance function to be shared with operations, giving a better environment for maintenance success.

UNFAMILIARITY OR LACK OF DATA-ENTRY SKILLS

Unfamiliarity and lack of skills or comfort for data entry among maintenance workers given the large data-entry requirements of these systems is a common problem. This problem is especially evident during the beginning phase, when the system has to be loaded with all the back-dated information to get started.

Recommendations:

1. Increase training and practice.
2. Upgrade to hardware that allows bar code readers to automatically do some of the data entry.
3. Provide graphical-based, menu-driven software.

INTERFACING AND CONTROL OF COMPUTER HARDWARE AND SOFTWARE

Unfamiliarity and lack of skills among maintenance workers for interfacing and controlling computer hardware and software can be a serious problem when implementing these systems.

Recommendations:

1. Increase training and practice.
2. Upgrade to hardware that allows bar code readers to automatically do some of the data entry.
3. Provide graphical-based, menu-driven software.
4. Assign someone in the organization who is already familiar with the interface and operating system to help get the system going.

DIFFICULT COMPUTER HARDWARE AND SOFTWARE INTERFACES

Recommendations:

1. Provide menu-driven software and interface.
2. Upgrade to hardware that allows bar code readers to automatically do some of the data entry.
3. Provide graphics-based software and hardware interface.
4. Assign someone in the organization who is already familiar with the interface and operating system to help get the system going.

TRAINING

Poorly formulated or implemented training approaches for introducing these systems among maintenance workers is common.

Recommendations:

1. Provide more and better training.
2. Establish clear lines of responsibility for implementing and maintaining the system.
3. Provide support from one or several facilitators and technical experts on the system.

DISCUSSION

The recommendations presented in this report come from almost a decade of research under the Mobile Mine Equipment Maintenance Safety project at the USBM. They cover a variety of areas from manual design to the design of tools used. This report should be used as an overview from which the reader can obtain resources for more information.

It is important to think of work safety as a dynamic system: change one thing and a chain reaction could be started. Careless and hasty implementation can have disastrous results. In any given mine maintenance situation, there are aspects of the work that cannot be changed. New equipment that complies with all the above equipment design recommendations will not be instantly available, nor will it be cost effective for all mine sites to immediately purchase them. Rather than scrapping an ergonomic approach to safety, analyze the present situation to discover what can be changed and what will be cost effective. These recommendations are meant to be used as they fit the situation; not all at once.

The best guideline to start with is TO CREATE A POSITIVE ATTITUDE TOWARDS SAFETY THROUGHOUT A MINE'S MAINTENANCE DEPARTMENT. The following is a quote from Baker and Alves: "While the chance for these errors can be significantly reduced through the improved design of the work environment, including the procedures followed on the job, hardware improvements do not, alone, guarantee success in reducing accidents. Attitudes towards safety must originate with a commitment from top management and filter down to the newest hire. Organizations with a positive attitude towards safety as a means to higher productivity most often enjoy excellent safety records."

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APPENDIX A.—ACCIDENT-TYPE DESCRIPTOR VARIABLES

1—STRUCK AGAINST STATIONARY OBJECT
2—STRUCK AGAINST MOVING OBJECT
3—STRUCK BY CONCUSSION
4—STRUCK BY FALLING OBJECT
5—STRUCK BY FLYING OBJECT
6—STRUCK BY SLIDING OBJECT
7—STRUCK BY POWERED OBJECT
8—STRUCK BY NEC*
9—FALL DOWN RAISE, SHAFT
10—FALL FROM WALKWAY
11—FALL FROM HEADFRAME
12—FALL FROM MACHINE
13—FALL FROM PILED MATERIAL
14—FALL FROM LADDER
15—FALL FROM STAIRS
16—FALL NEC
17—FALL TO WORKING SURFACE
18—FALL AGAINST OBJECT
19—FALL ON SAME LEVEL, NEC
20—CAUGHT IN MESHING OBJECTS
21—CAUGHT IN MOVING, STATIONARY OBJECT
22—CAUGHT IN TWO MOVING OBJECTS
23—CAUGHT IN COLLAPSING MATERIALS
24—CAUGHT IN NEC
25—RUBBED OR ABRADED
26—BODILY REACTION
27—OVER-EXERTION, LIFTING
28—OVER-EXERTION, PUSHING-PULLING
29—OVER-EXERTION, WIELDING, THROWING
30—OVER-EXERTION, NEC
31—ELECTRIC CURRENT
32—CONTACT WITH HEAT
33—CONTACT WITH HOT SUBSTANCE
34—CONTACT WITH COLD
35—CONTACT WITH COLD SUBSTANCE
36—INHALATION OF TOXICS
37—INGESTION OF TOXICS
38—ABSORPTION OF TOXICS
39—FLASH BURNS, ELECTRIC
40—FLASH BURNS, WELDING
41—DROWNING
42—NEC
43—INSUFFICIENT DATA
44—ACCIDENT, NO INJURIES

*Not Elsewhere Classified

APPENDIX B.—PART OF BODY DESCRIPTOR VARIABLES

100—HEAD, NEC*
110—BRAIN
120—EAR
121—EXTERNAL EAR
122—INTERNAL EAR
130—EYES
141—JAW, CHIN
142—MOUTH
143—NOSE
144—FACE
150—SCALP
160—SKULL
170—HEAD, MULTIPLE PTS.
200—NECK
300—UPPER EXTREMITIES, NEC
311—UPPER ARM
312—ELBOW
313—FOREARM
314—ARM, MULTIPLE INJURIES
310—ARM NEC
320—WRIST
330—HAND
340—FINGERS
350—UPPER EXTREMITIES, MULTIPLE
400—TRUNK, NEC
410—ABDOMEN (INTERNAL ORGANS)
420—BACK
430—CHEST
440—HIPS
450—SHOULDERS
460—TRUNK, MULTIPLE INJURIES
500—LOWER EXTREMITIES, NEC
510—LEG NEC
511—THIGH
512—KNEE
513—LOWER LEG
514—LEG, MULTIPLE INJURIES
520—ANKLE
530—FOOT
540—TOES
550—LOWER EXTREMITIES
600—BODY SYSTEMS
700—MULTIPLE INJURIES
800—BODY PARTS, NEC
900—UNCLASSIFIED

*Not Elsewhere Classified

APPENDIX C.—OCCUPATION OR JOB TITLE DESCRIPTOR VARIABLES

1—BELTMAN
2—ELECTRICIAN
3—ELECTRICIAN HELPER
4—MECHANIC, REPAIRMAN
5—MECHANIC HELPER
6—ROCK DUSTER
7—BLASTER
8—MASON, VENTLINE
9—SUPPLYMAN
10—TIMBERMAN
11—WIREMAN, COMM REPAIR
15—FAN ATTENDANT
16—LABORER, PROPMAN
19—CEMENT MAN
24—TRAINEE
25—BOBCAT DRIVER
26—GRIZZLY MAN
28—SCOOP, TRAM OPERATOR
29—MUCKING MACHINE OPERATOR
30—SLUSHER OPERATOR
31—BEATER, SHOTFIRE HELP
32—BRATTICE MAN
33—DRILL HELPER
34—DRILL OPERATOR
35—CONT MINER HELPER
36—CONT MINER OPERATOR
37—CUTTING MACHINE HELPER
38—CUTTING MACHINE OPERATOR
39—HAND LOADER
40—HEADGATE OPERATOR
41—JACK SETTER
42—LOADING MACHINE HELPER
43—LOADING MACHINE OPERATOR
44—LONGWALL SHEAR OPERATOR
45—ROCKMAN, CHUTE
46—ROOF BOLTER
47—ROOF BOLTER HELPER
48—ROOF BOLTER MOUNTED
49—SECTION FOREMAN
50—SHUTTLE CAR OPERATOR
51—STALL DRIVER
52—TAILGATE OPERATOR
53—UTILITY MAN
54—SCOOP CAR OPERATOR
57—STOPE MINER
58—DRIFT MINER
59—RAISE MINER
63—MINER NEC
64—CONTRACT MINER
67—POWER SHOVER OPERATOR
68—BULLDOZER OPERATOR
75—GRADER OPERATOR
76—TRUCK DRIVER
78—CRANE OPERATOR
82—FRONTEND LOADER OPERATOR
101—CONVEYOR MAN
102—ELECTRICIAN
103—ELECTRICIAN HELPER
104—MECHANIC
105—MECHANIC HELPER
106—ROCKDUSTER
108—STOPPING BUILDER
109—SUPPLYMAN
110—JACKSTER
111—WIREMAN
112—BELT VULCANIZER
113—CLEANUP MAN
114—COAL-MN SAMPLER
115—FAN ATTENDANT
116—LABORER, MUCK MACH OP
117—RODMAN
118—OILER, GREASEMAN
119—WELDER, CEMENT MAN
122—DUMP OPERATOR
123—TRANSIT MAN
124—TRAINEE
126—GRIZZLY MAN
128—GIZMO OP
149—LABOR FOREMAN
154—BELT CLEANER
155—CHAINMAN
156—ROCKDRILLER
157—PUMPER
158—ROCK MACHINE OP
159—WATERLINE MAN
160—SHOPMAN, MACHINIST
163—MINER, NEC
167—POWER SHOVER OPERATOR
168—BULLDOZER OPERATOR
175—GRADER OPERATOR
176—TRUCK DRIVER
178—CRANE OPERATOR
182—FRONTEND LOADER OPERATOR
201—BELTMAN
216—TRACKMAN
220—CAGER
221—HOISTMAN
224—TRANSPORTATION TRAINEE
230—SKIP TENDER
240—LOADER, HEADER OPERATOR
255—CHAINMAN
261—BATTERY STATION OPERATOR

262—BRAKEMAN, ROPE RIDER
265—DISPATCHER
269—MOTORMAN
276—TRACTOR OPERATOR
277—BUGGY PUSHER
301—BELT MAN
302—ELECTRICIAN
303—ELECTRICIAN HELPER
304—MECHANIC
305—MECHANIC HELPER
307—BLASTER
308—MASON
309—SUPPLYMAN
311—COMMUNICATIONS REPAIR
312—BELT VULCANIZER
313—CLEANUP MAN
314—COAL, MN SMPLER
315—FAN ATTENDANT
316—LABORER
317—RODMAN
318—OILER, GREASER
319—WELDER
320—CAGER
321—HOISTMAN
322—DUMP OPERATOR
323—TRANSIT MAN
324—TRAINEE
325—BOBCAT OPERATOR
327—SURFACE MINER
330—SKIP TENDER
331—CLAW OPERATOR
333—DRILL OPERATOR
334—DRILL HELPER
340—BOOM OPERATOR
347—CLEANING PLANT OPERATOR
350—SHUTTLE CAR OPERATOR
355—CHAINMAN
356—ROCK DRILLER
360—MACHINIST
362—BRAKEMAN
363—QUARRY WORKER
365—DISPATCHER
366—WATERBOY
367—POWER SHOVEL OPERATOR
368—BULLDOZER OPERATOR
369—MOTORMAN
370—AUGER OPERATOR
371—AUGER HELPER
372—BARGE ATTENDANT
373—CAR DROPPER
374—BONEY OPERATOR
375—GRADER OPERATOR
376—TRUCK DRIVER
378—DRAGLINE OPERATOR
379—KILN OPERATOR
380—FINE COAL PLANT OPERATOR
381—HOIST OP HELPER
382—HIGHLIFT OPERATOR
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593—SAFETY REPRESENTATIVE
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599—UNKNOWN OR NEC

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This IC brings together for consideration recommendations from U.S. Bureau of Mines (USBM) safety research in the area of surface mine mobile equipment maintenance for the period 1982 through 1991. It updates the 1982 contract report by Baker and Alves which formed the basis for much of the work described in the present report. Recommendations for hazard abatement during work on mobile mine equipment are presented stemming from the results and recommendations of the research in two areas: (1) equipment and workplace hazard reduction, and (2) management of maintenance information. Recommendations included in this report apply to both the operators and maintainers of mobile mining equipment as well as to the manufacturers of that equipment.

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