SAFETY ANALYSIS OF SURFACE HAULAGE ACCIDENTS

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ABSTRACT

Research on improving haulage truck safety, started by the U.S. Bureau of Mines, is being continued by its successors. This paper reports the orientation of the renewed research efforts, beginning with an update on accident data analysis, the role of multiple causes in these accidents, and the search for practical methods for addressing the most important causes. Fatal haulage accidents most often involve loss of control or collisions caused by a variety of factors. Lost-time injuries most often involve sprains or strains to the back or multiple body areas, which can often be attributed to rough roads and the shocks of loading and unloading. Research to reduce these accidents includes improved warning systems, shock isolation for drivers, encouraging seatbelt usage, and general improvements to system and task design.

INTRODUCTION

Although surface mining has always experienced lower accident rates than underground mining, and these rates have been generally improving, recent increases, particularly in the number of powered haulage accidents, have caused concern in the mining industry. As the most common type of machinery involved in surface accidents, haulage trucks have become the primary target for improving safety performance. This paper discusses the ongoing efforts by the successors to the U.S. Bureau of Mines (USBM) to analyze and solve haulage truck safety issues.

Ideally, accidents would not happen. Operating procedures would eliminate all possible hazards, and these procedures would always be followed. Equipment would be perfectly designed, flawlessly maintained, and never operated outside of design parameters. The worksite would be constant and predictable, introducing no hazards of its own. Unfortunately, this is an unattainable ideal -- the realities of people, machinery, and the mining worksite are constantly pushing one or more of these conditions outside of the ideal. Understanding and controlling the causal factors in haulage accidents is essential to reducing their probability of occurring.

Accident Causes and Solutions

Most accident research now recognizes the role of multiple causes in accidents, including a significant human performance component. In the most detailed study of accident causes in mining, Sanders and Shaw (1988) studied underground mining accidents through an expert-panel investigative procedure. Their research showed that 88% of accidents had at least two major causes. This study also showed that "perceptual-cognitive-motor" errors (related to the more common term, "human error") were a causal factor in 93% of the accidents. While the effort and expense entailed in this type of analysis have so far precluded its use in surface mining, the general principles should be applicable. That is, attempting to identify a single cause for every accident is usually an oversimplification. Also, human performance and limitations will often come into play, even if other factors (poor design, dangerous conditions, etc.) essentially "forced" an error.

In surface haulage, human performance becomes a critical issue because of the unusual demands the vehicles place on their human operators:

- Roadways and work areas change frequently.
- The sheer mass of the trucks sometimes requires control inputs (e.g., braking) far in advance of the desired action.
- In large operations, the drive into and out of the pit is long and tedious.
- Rough roads and loading impacts can subject the driver to dangerous shocks and vibration.
- Visibility is sharply curtailed by the bulk of the vehicle.

Because of these demands, solutions to haulage truck safety problems must consider the human factors aspects of the task, even when engineering solutions seem most appropriate. The specific problems that need to be solved can be determined by studying the accidents involving haulage trucks.

ANALYTICAL APPROACHES

Accident data analysis is an indispensable tool for understanding the causes of accidents. Systematic analysis of large numbers of accidents can reveal patterns and commonalities that might be not be evident when looking at a single incident. The analysis can be based on industry-wide databases of accidents, in-depth analysis of official written accident reports, or data collected especially for the analysis. Each of these approaches has characteristic strengths and weaknesses.

Industry-wide Databases

The most widely used source of U.S. mining accident information is the Mine Safety and Health Administration (MSHA) database collected from the quarterly 7000-1 and 7000-2 forms. In addition to reports published by the agency, the raw data is available from their Internet Web site (http://www.msha.gov). This data is essentially a census of injuries in the U.S. mining industry, although it is conceivable that some accidents are not reported. The current study reports updated statistics from the MSHA database, bolstered by cost estimates from the USBM-developed Accident Cost Indicator model (ACIM) described in more detail below.

Textual Analysis of Official Reports

In addition to the coded information about accidents, there is sometimes a written description available. For instance, accidents reported to MSHA on the 7000-1 form also have a brief description provided by the mining operation. Fatalities have a more detailed textual record in the form of an official accident investigation report. This textual information, because it is free of the constraints of the coding system, can incorporate details about the accident that might be missed otherwise. The fatality reports are particularly informative, containing details about the work procedures, equipment, victims, and even diagrams of the accident site. Unfortunately, this approach is not without its limitations. It is very time-consuming to convert the textual descriptions into a form useful for tabulating and comparing

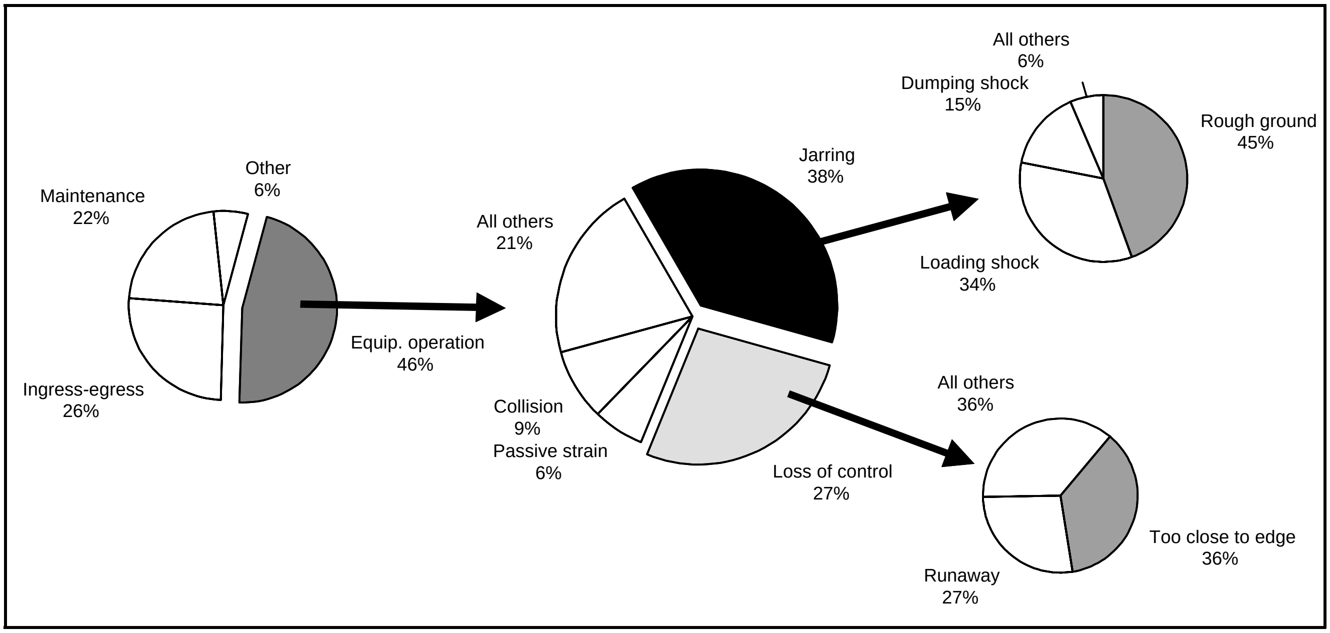

Figure 1. Surface coal haulage truck accident categories in successively higher detail. Based on analysis of written accident descriptions for 1989-91 (Aldinger, Kenney, and Keran, 1995).

large numbers of accidents. Key information can be omitted unless the report writer is following a specified format. This process also requires subjective judgements that may be difficult to duplicate or validate.

This analytical approach was successfully applied to surface equipment accidents by Aldinger and Keran (1994) in an overview of the entire mining industry, and by Aldinger, Kenney, and Keran (1995) in a more detailed study of the coal segment of the industry. They employed a panel to categorize accidents based on the written narratives in the MSHA database. By using the narratives, they were free to develop categories of accidents that were more descriptive than the traditional categories. In their study of surface coal mining, Equipment Operation was the most common category of accident for haulage trucks (46.3%) followed by Ingress-egress (25.8%) and Maintenance (22.1%). Within the Equipment Operation accidents, the most common types were Jarring (37.7%) and Loss of Control (26.8%). The main Jarring categories were Rough Ground (44.5%), Loading Shock (33.5%), and Dumping Shock (15.5%). Loss of Control categories included Too Close to Edge (36.4%) and Runaway (27.3%). Figure 1 shows how these categories and subcategories are related.

Seatbelt usage is another area where the textual information reveals new accident details. While only 163 of the 2,720 accident reports studied by Aldinger and Keran (1994) reported whether or not seatbelts were worn, these cases at least suggest some trends. For instance, none of the fatalities in their study involved a victim wearing a seatbelt. Also, injuries tended to be less severe (involving less time off of work) when seatbelts were worn.

Special-purpose Data Collection

The most expensive, but potentially most rewarding, method of analyzing accident causes is to perform an independent scientific study. Sanders and Shaw (1988) used this method to investigate causal factors in underground mining. They conducted independent investigations of 338 accidents at 20 mines. The investigations resulted in detailed descriptions of each accident, including interviews with employees and a study of the worksite and equipment. The methodology was based on a systems theory of accidents -- that is, accidents result from a system of interrelated factors in workplaces, machinery, people, and social structures.

Although this process yielded unprecedented detail about the accidents it studied, it does have some limitations. The 20 mines studied may not be representative of the industry as a whole, especially since the sample consisted mostly of medium-to-large underground coal mines. This type of study also tends to be quite expensive, costing hundreds or thousands of dollars per investigated accident.

Each of these studies has some merits. The strengths of one approach can be used to complement the weaknesses of others and add missing pieces to the overall puzzle of true accident causes.

ACCIDENT ANALYSIS

The accident trends and breakdowns reported here cover accidents in the MSHA database under the category "Ore haulage trucks, off highway and underground." Accidents classified as occurring underground or to officeworkers were eliminated so that the reported data would reflect surface operations only. The reported data include independent contractors, and, unless otherwise noted, cover the years 1986 through 1995. The 1995 data are currently considered "preliminary" by MSHA.

1986-95 Trends

Surface mining fatalities, including haulage truck fatalities, have been generally declining since 1986. However, although the industry attained a historic low of 54 fatalities in 1994, there was a sharp upswing to 70 fatalities in the preliminary 1995 data. A significant component of this upswing was the rise in haulage truck fatalities from 10 to 17. This increase has been a source of concern in the mining community. It would be even more troubling if there were a similar rise in injuries. Fortunately, lost-time haulage truck injuries declined from 579 in 1994 to 460 in 1995, mirroring an overall surface accident reduction from 9,040 to 7,883 (figure 2). The overall trend since 1989 has been a consistent drop in the number of lost time injuries, with the exception of a slight rise in 1994. The increases prior to 1990 can be attributed to changes and clarifications in reporting practices, rather than an actual rise in accidents (Randolph, 1992; Weaver and Llewellyn, 1986).

Estimated Cost

The Accident Cost Indicator Model (ACIM) (DiCanio and Nakata, 1976) was used to estimate the total cost of haulage truck accidents during 1994, the most recent year for which data are available. The ACIM provides cost estimates based on publicly available data on wages, workers' compensation, medical payments, investigation costs, and other direct and indirect costs. Although it has some limitations, including the omission of data on

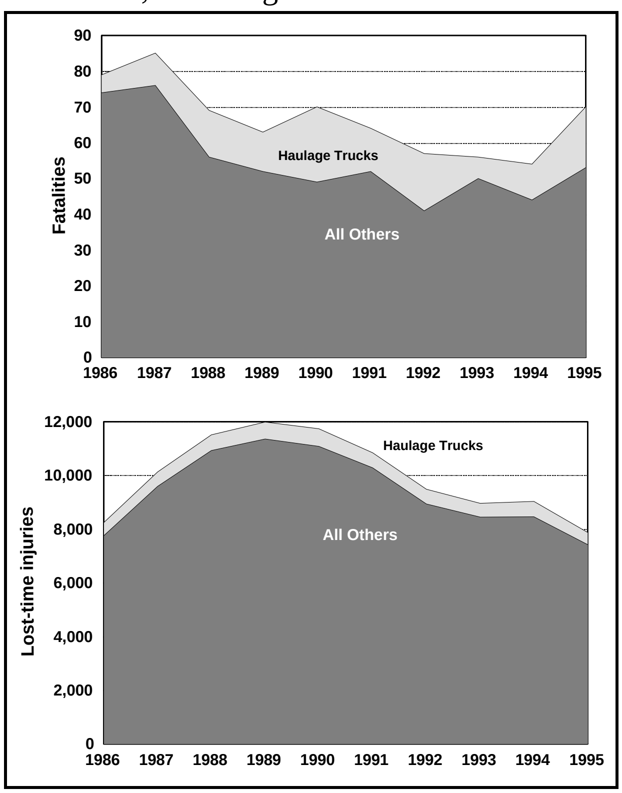

Figure 2. Surface fatalities and lost-time injuries, 1986-95.

independent contractors, it provides a useful guideline on the magnitude of costs suffered by individuals, industry, and society. According to the ACIM, the six haulage truck fatalities in 1994 cost an estimated $2.58 million while the 519 lost-time injuries cost $3.27 million. The total estimated cost for haulage truck fatalities and lost-time injuries in 1994 was more than $5.8 million.

Independent Contractors

The use of independent contractors in the mining workforce is rising. They account for 18% to 67% of the haulage truck fatalities each year (figure 3) and from 4% to 13% of the lost-time injuries. The haulage truck accident fatality rate for contractors has been consistently higher than the rate for mine operator employees, although their lost-time rate has been similar (figure 4). Making conclusions about these accident rate differences is hampered by a lack of information about how many hours are worked by truck drivers. We only know the hours reported by general work location, not by task, job title, equipment operated, or any other more specific characteristics of exposure.

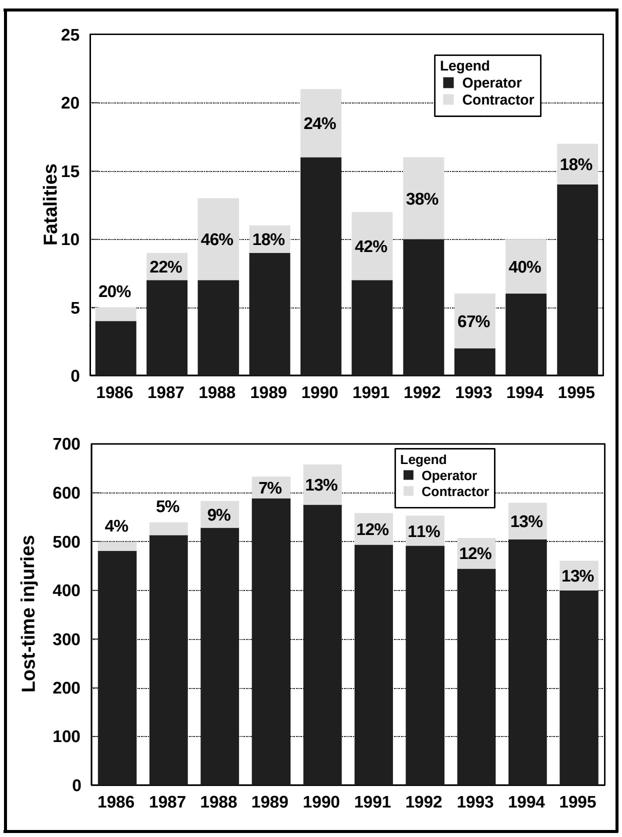

Figure 3. Contractor and operator haulage truck fatalities and lost-time injuries, 1986-95.

Accident Categories

A more detailed picture of haulage truck accidents emerges by looking at the MSHA categories into which they fall (figure 5).

Nature of injury. The "nature of injury" reported for haulage truck fatalities was predominantly "multiple injuries" (64 fatalities) or "crushing" (34) (Figure 5, top left). The nature of lost-time injuries was somewhat different (figure 5, top right). Sprains and strains were the largest category (2,437 injuries), consistent with Aldinger, Kenney, and Keran's reports of jarring as the main accident type.

Body part injured. Haulage truck fatalities tend to be catastrophic, involving serious damage to multiple body parts (figure 5, center left). Lost-time injuries (figure 5, center right)

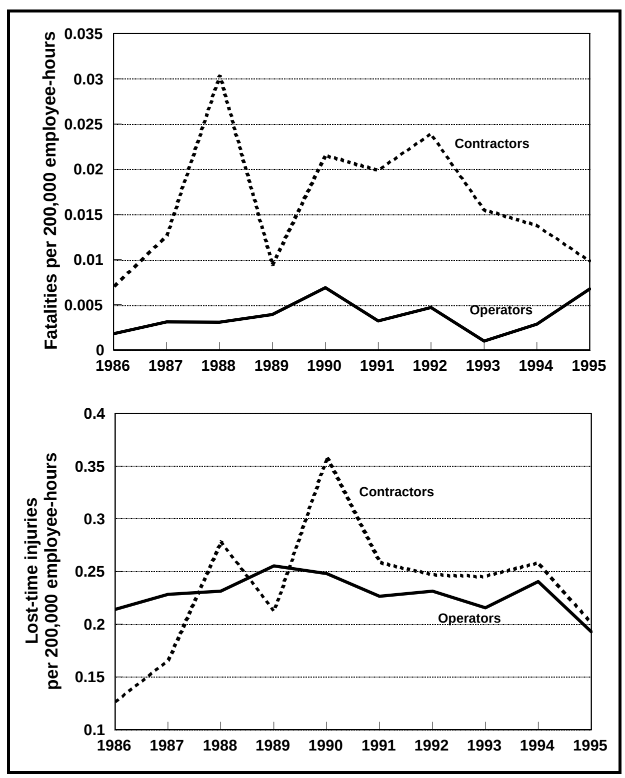

Figure 4. Contractor and operator haulage truck fatality and lost-time injury rates, 1986-95.

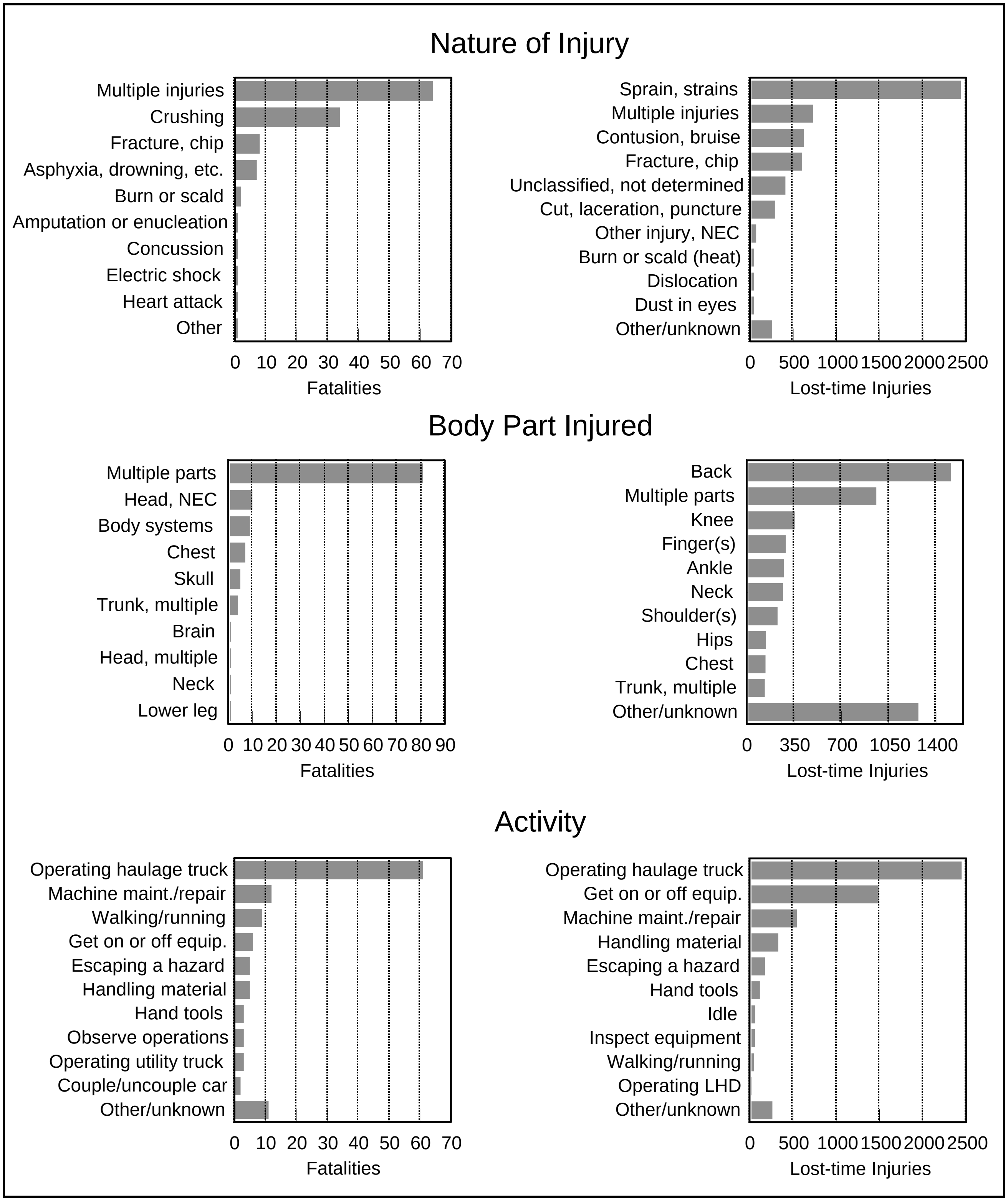

Figure 5. Haulage truck fatality and lost-time injury categories: Nature of injury, body part injured, and victim's activity, 1986-95.

most often involve the back (1,511) or multiple parts (959), which is again consistent with the jarring scenario.

Victim's activity. The most common activity recorded for victims of fatal haulage truck accidents was operating the truck (61) followed by maintenance (12), walking or running (9) and getting on or off the machine

(6) (figure 5, bottom left). Operating the truck was also the largest lost-time category (2,447 injuries) followed by "get on or off equipment" (1,489), maintenance (547), and handling supplies or material (331) (figure 5, bottom right). These categories are roughly consistent with the findings of Aldinger, Kenney, and Keran (1995) despite differences in methods and data.

Mine Size

Small mines differ from large mines in important ways, including different geology, fewer resources, and the special problems confronted by all small businesses. A common perception in the mining community is that small mines, at least partially because of the factors listed above, are less safe than larger operations. Recent analyses of accident rates at different sizes of underground coal mining operations (Peters and Fotta, 1994) showed that small mines had a higher fatality rate than large mines. However, there was no consistent pattern of higher nonfatal injury rates at smaller mines. Less has been reported about the relationship between mine size and safety at surface mines.

This analysis differs from the preceding breakdowns of surface truck accidents in several key ways. Because it examines the characteristics of mining operations as a possible factor in haulage safety, the analysis had to be restricted to surface mines only, excluding the surface operations of underground mines as well as preparation plants and mills. It also excludes independent contractors because the hours worked by these employees are reported by the contract company and cannot be attributed to any particular size of mining operation. This analysis used data from just a 3-year period to minimize the problems of a constantly changing population of mining operations. The accidents were broken down into five mine-size groupings: 1-10 employees, 11-20, 21-50, 51-100, and over 100. There are very many small surface mining operations -- the median mine size is just four employees.

Figure 6 shows the normalized rates (per 200,000 employee-hours) for surface mine fatalities and lost time injuries. The graphs show both the overall rates as well as the rates for haulage trucks alone. The rates are not clearly higher for the smallest mines. The overall fatality rate for 1-10 employee mines (0.0357) was almost the same as that for 51-100 employee mines (0.0349). For haulage trucks only, the rate for 11-20 employee mines (0.0083) was the highest by a very small margin over the over-100 employee mines (0.0081). The numbers of fatalities upon which these rates are based were very small, ranging from just one haulage truck death for 21-50 employee mines during 1993-95 to eight fatalities at mines with over 100 employees. Because lost-time injuries occur in much higher numbers, they can be more useful than fatalities for identifying stable overall trends.

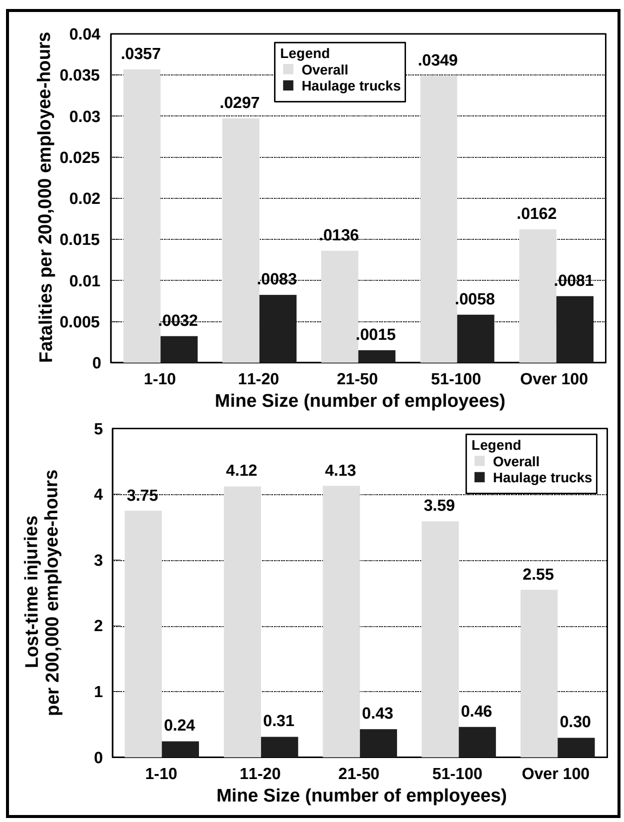

Figure 6. Fatality and lost-time injury rates for different surface mine sizes, 1993-95.

The lost-time rates shown in figure 6 reveal that the highest rates are for the middle-sized mines. The 11-20 employee and 21-50 employee mines have the highest overall rates of 4.12 and 4.13. The peak for haulage truck lost-time injuries is also in the mid-range, but farther along the mine size continuum at 51-100 employees (rate: 0.46). Again, there is no clear trend toward higher rates as mine size decreases.

CONTINUING RESEARCH

In 1995, the USBM laid out new initiatives for improving surface haulage safety based on a history of research (May and Aldinger, 1995). Although the USBM was abolished by Congress in 1996, the health and safety research functions in Pittsburgh, Pennsylvania and Spokane, Washington were continued. The surface mining hazard reduction project, formerly conducted out of the USBM's Minneapolis, Minnesota center, is continuing in Spokane. The project, "Hazard Reduction for Surface Mining", is continuing to build on past accomplishments while re-focusing future goals to meet the needs of the newly formed health and safety research centers. The objective for the project is to reduce accidents and injuries associated with coal and metal/nonmetal surface mining. Several strategies are being investigated, including improved operating practices, hazard recognition, and safety and warning devices.

Equipment manufacturers are working to incorporate alarms, improve vision, and improve ergonomics on large equipment. Other approaches involve the development of remote-controlled or autonomous vehicles for specific extremely hazardous or repetitive, simple tasks. Improvements in sensing technology such as GPS, radar, laser, and infrared offer an opportunity to introduce these technological improvements as an aid to vehicle operation and/or control.

Currently the efforts for the Hazard Reduction for Surface Mining project are aimed at:

- *Safety Analyses*. This will review MSHA accident data to determine root causes of recorded accidents. For example, slips and falls from powered equipment are a major cause of injuries. But in evaluating the accident narratives, nearly half the slips and falls are affiliated with jumping from a vehicle or conveyor. Of those jumping, over half were from vehicles which had lost power or brakes. This analysis will help identify operating practices that should be modified or avoided to improve safety.
- *Early Warning.* Existing and developing sensing technology will be reviewed to determine what systems might be easily incorporated onto existing equipment or into current operations to provide warning to operators and others in the immediate proximity. Currently, engine performance (rpm, oil pressure) and machine operating conditions (speed, tilt, load) will be reviewed as possible parameters that could be used or recorded to define machine operating safety. In addition, geotechnical sensing devices, laser surveying, slope monitoring, proximity warning and optical sensing devices will be investigated to determine the potential of short- and long-term applications that might be used to improve equipment operating safety.
- *Operator Safety.* Methods to minimize injury to operators during accidents will be investigated. Previous research on vibration testing done by TCRC will be continued to define and isolate elements that could lessen shock loads to the operator. Methods to promote seatbelt use will also be investigated.

- *Human Factors.* Work will continue to be coordinated with the Human Factors section at PRC to develop effective training and ergonomic support designs for small- to medium-sized coal and metal/nonmetal surface mining operations. In addition, this task will involve investigations of the psychological and physiological factors of reducing operator-induced accidents.

CONCLUSIONS

There is sufficient evidence from a variety of studies, including the data presented here, to identify several key problem areas in surface haulage truck usage. These include:

- *Driver fatalities involving loss of vehicle control.* These accidents can be addressed though a combination of solutions, including haulage roads with less-steep grades, better signs, and longer sight lines. Also, driver visibility can be improved through mirrors, video cameras, and cab design. Drivers can be educated about keeping their equipment within controllable limits. Finally, seatbelt usage should be promoted for those times when loss of control cannot be averted.
- *Strains and sprains from rough roads, and the shocks of loading or unloading.* Road maintenance can smooth out washboarding and other types of bumps. Loading and unloading techniques, such as lining the truck bed with small material before loading large boulders, can reduce shocks. Also, suspensions can be used to dampen the transmitted shocks.
- *Strains and sprains resulting from a slip or fall while mounting or dismounting the truck.* Improved railings, non-skid surfaces, and damage-resistant ladders are some of the ways of helping drivers to mount and dismount their vehicles safely.

Despite the range of data presented here, there are still many unanswered questions to pursue:

- How often are seatbelts used, and how can usage be increased?
- How many truck drivers are in the mining workforce, and how many of them are contractors? Do any of these groups have a disproportionate number of accidents?
- What range of truck sizes are in use. Are some types of accidents more likely for different-sized trucks?
- What haulage safety problems will be solved by automation? What new hazards will be created?
- How can the existing information on improving haulage safety be communicated more effectively?

These issues, and others that will emerge from more detailed analysis planned during the next year, will guide the development of tools and strategies for improving haulage truck safety.

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